

Technical Volume



37<sup>th</sup>

# Indian Engineering Congress

December 16-18, 2022

Venue: Hotel Le Royal Meridian, Chennai

## Theme

# Role of Engineers for Creating A Sustainable & Self-Reliant India

Organised by



**The Institution of Engineers (India)**

8 Gokhale Road, Kolkata

Hosted by

Tamilnadu State Centre



# The Institution of Engineers (India)

## Notification for R&D Grant-in-Aid

To promote appropriate technology, assist in building up design & research talents and, most importantly, to help in nurturing potential R&D venture amongst engineering students pursuing Diploma/UG/PG/PhD courses, The Institution of Engineers (India) had instituted the R&D Grant-in-Aid program way back in 2001.

Every year, the Institution invites applications for funding industry-oriented R&D projects and research initiatives aimed at improving the life-style of common people from engineering students pursuing full time Diploma/UG/PG/PhD engineering program in AICTE/UGC/NAAC approved Institutions/Colleges/Universities. The application form and guidelines are available in our website <https://www.ieindia.org>. The projects should be carried out under the guidance of faculty members who are Corporate Members of IEI. Membership criteria for student(s), guide(s) and Institution(s) are as follows:

Project Category	Student/Applicant Membership	Guide(s) Membership	Institutional Membership
1. Diploma	Exempted [Membership of Student Chapter is desirable]	AMIE/MIE/FIE	Not Mandatory
2. UG (BE/BTech/AMIE/Equivalent)	'Student Member' (SMIE)	AMIE/MIE/FIE	Applicant's Institute should preferably be an Institutional Member with NBA / NAAC Accreditation or valid NIRF Rank
3. PG (ME/MTech/Equivalent)	AMIE/MIE/FIE	MIE/FIE	Applicant's Institute should preferably be an Institutional Member with NBA / NAAC Accreditation or valid NIRF Rank
4. PhD	AMIE/MIE/FIE	MIE/FIE	Applicant's Institute should preferably be an Institutional Member with NBA / NAAC Accreditation or valid NIRF Rank

The soft copy of the duly filled-up applications (in editable format), as per the pro-forma available in our website [www.ieindia.org](http://www.ieindia.org), should be sent through email to [research@ieindia.org](mailto:research@ieindia.org) and one printed copy of the same should reach the following address:

**Director (Technical)**

**The Institution of Engineers (India), 8 Gokhale Road, Kolkata 700 020**

Kindly go through the guidelines (visit link <https://www.ieindia.org/webui/IEI-Activities.aspx#RnD-Initiative>) before filling up the application.

# TECHNICAL VOLUME

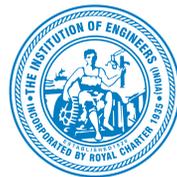
37<sup>th</sup> Indian Engineering Congress

16-18 December 2022

Chennai

*theme*

**Role of Engineers for Creating  
a Sustainable & Self-Reliant India**



**The Institution of Engineers (India)**

8 Gokhale Road, Kolkata 700020





# The Institution of Engineers (India)

AN ISO 9001 : 2015 CERTIFIED ORGANISATION  
(ESTABLISHED 1920, INCORPORATED BY ROYAL CHARTER 1935)  
8 Gokhale Road, Kolkata 700 020

*A Century of Service to the Nation*

**Dr H O Thakare**

President  
The Institution of Engineers (India)



## Message

It is a matter of immense pleasure to note that Tamilnadu State Centre of The Institution of Engineers (India) is organizing the 37<sup>th</sup> Indian Engineering Congress, the premier annual event of the Institution during December 16-18, 2022 at Chennai. The theme for the Congress this year is '**Role of Engineers for Creating a Sustainable & Self Reliant India**'.

GOI has taken several initiatives towards 'Atmanirbhar Bharat'. It has announced several schemes like Make in India, Pradhan Mantri Kaushal Vikas Yojana (PMKVY), Stand Up India, Pradhan Mantri Mudra Yojana, Start-up India, Ayushman, Digital India Mission, Smart Cities Mission, etc. towards making India self-reliant and Economic Super Power. The rapid industrial transformation of India after post Covid that leads to the road of prosperity has to take into consideration the sustainability factor. Only a sustainable development and self-reliance will lead the present young generation towards secured future. To meet the climate goals, our country has taken remarkable initiatives to improve energy efficiency in industry sector. India has also embarked on accelerating its digital infrastructure development and leveraged the potential of smart factories to connect people, processes and machines to achieve better energy efficiency and output.

Based on the theme of the Congress and associated sub-theme, the contributions received from the professionals, academicians and scholars in different fields, are compiled and placed in the Technical Volume, which contains an extremely enriched and comprehensive contents,

I extend my sincere thanks to the members of the Technical Committee and the Technical Department of IEI HQ for their relentless effort to publish this Technical volume.

I wish the Engineering Congress All Success.

(H O Thakare)





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*A Century of Service to the Nation*

## Dr G Ranganath

Chairman  
Committee for Advancement of Technology and Engineering  
The Institution of Engineers (India)



## Message

I am happy to learn that Tamilnadu State Centre of The Institution of Engineers (India) is organising the 37<sup>th</sup> Indian Engineering Congress on the theme '**Role of Engineers for creating a Sustainable & Self Reliant India**' during 16-18 December 2022 at Chennai.

The objective of the apex activity of IEI is to bring to the forefront the best innovative practices in science and technology from the engineering professionals, technologists, academicians etc, which in turn leads to the benefits for the society at large.

Covid-19 has resulted in significant vulnerabilities and thus pushed millions of people into extreme poverty across the world. When countries across the world are struggling to find equitable pathways within the complex ambit of resilience and recovery, India, with a legacy of courage and direction deeply ingrained in its' spirit of self-reliance has inspired implementation of the model of self-sufficiency in the Indian economy. With the economic development to achieve the social, economic and environmental goals, the scope of sustainable development is also widened.

I sincerely thank the Organising Committee, Technical Committee and IEI Secretariat for their tireless effort to bring out the Technical Volume during the 37<sup>th</sup> Indian Engineering Congress. I am confident that the publication will be a valuable reference for the professionals at their respective domains.

I wish the Congress a Grand Success.

(G Ranganath)





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*A Century of Service to the Nation*

**Er R Ramdoss, FIE**

Organising Secretary  
Organising Committee  
37<sup>th</sup> Indian Engineering Congress  
The Institution of Engineers (India)



## Message

I am indeed very happy to greet all of you for the 37<sup>th</sup> Indian Engineering Congress on the theme “**Role of Engineers for Creating a Sustainable & Self-Reliant India**” by the Institution of Engineers (India) Tamil Nadu State Centre at Chennai.

This Technical Volume consists of articles from various engineering divisions, and it will be deliberated during the congress. The experience and observations of professional engineers in the country are expected to be covered in these articles, with a view to share knowledge with a wider cross – section of professionals.

I convey my best wishes to the Chairman and Members of the Technical Committee of 37<sup>th</sup> Indian Engineering Congress.

( Ramdoss)

Immediate Past Chairman, IE(I) TNSC  
&  
Chairman, ETASmart Private Ltd





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VICE CHANCELLOR

05.12.2022

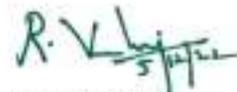
**MESSAGE**



It gives me great privilege to congratulate the 37th Indian Engineering congress on "**Role of Engineers for creating sustainable and self-reliant India**" organized by Tamil Nadu State Centre of the Institution of Engineers (India). India is gaining momentum and respect in recent days upon assuming G20 presidency. The 37th Indian Engineering congress is in line with the vision of Honorable Prime Minister of India's Atmanirbhar Bharat Abhiyaan with longstanding commitment to sustainable development.

India has the largest numbers of engineers as well as the largest number of engineering education institutes and infrastructure in the world. As of 2021, India annually produces fifteen lakh engineering graduates. The world requires skilled hands and India has the talent to cater to these global needs. Engineers play a vital role in addressing basic human needs, alleviating poverty, promoting secure and sustainable development, responding to emergencies, reconstructing infrastructure, bridging the knowledge divide and promoting intercultural cooperation to achieve the Sustainable Development Goals of United Nations.

I extend my greetings and congratulations to all delegates, participants and those associated with the 37th Indian Engineering congress on "**Role of Engineers for creating sustainable and self-reliant India**" and wish the congress all success with the anticipation of indigenous local hub of smart manufacturing in our country in the near future to attain self - reliant India.

  
(R. VELRAJ)

Chairman  
Technical Committee  
37<sup>th</sup> Indian Engineering Congress  
The Institution of Engineers (India)



**Technical Volume**  
of  
37<sup>th</sup> Indian Engineering Congress, 2022

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**CHEMICAL  
ENGINEERING  
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# Overview of Low-Salinity Seawater Injection as an Enhanced Oil Recovery Method for a Sustainable Energy Supply in India

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**Abstract:** Oil production is declining due to the increasing rate of production of mature reservoirs. In India, crude oil production is not adequate to meet the energy demand. This leads to more importing of crude oil from other countries. Enhanced oil recovery (EOR) has the potential to help and meet the sustainable energy demand for a self-reliant economy. Easy oil is no longer achievable nowadays.

This article will explain the process and importance of low-salinity seawater injection (LSWI) as an EOR method. LSWI, which involves injecting low-salinity seawater into reservoirs for extracting oil, is environmentally friendly and cost effective. It improves the water flood performance to a degree that depends on the formation of rock type, porosity, and saturation of reservoir fluid. LSWI reduces the interfacial tension and alters the wettability of the reservoir rock, thus leading to increased oil recovery. LSWI avoids the blocking of reservoir pores with solids, corrosion of down hole piping, souring of the reservoir, and scaling of the reservoir.

LSWI bolsters the commitment to sustainability with reduced emissions, reduced energy consumption, and improved quality of the discharge water, which minimizes pollution.

**Keywords:** Energy; Seawater Injection; Oil Recovery; Low Salinity; EOR

## INTRODUCTION

Engineering and operations teams in topsides operations (upstream oil and gas) have been continually challenged to deploy efficient solutions for improving oil recovery. The varying requirements of the oil and gas industry are dictating the expansion of new technologies and the application of proven technology in novel ways to meet the industry demand.

Crude oil production in India averaged ~630,000 barrels per day (June 2022 data[1]) whereas the oil import bill doubled to USD 119 billion in the 2022 current financial year. Technological interventions have significant potential in stimulating the recovery of hydrocarbon reserves from the matured/aging fields. An increase by 5% in recovery rate of original in-place volume in oil production is envisaged producing 120 MMT additional oil in next 20 years [The Government of India approved the 2018 policy framework 2018 to promote and incentivize enhanced oil recovery (EOR) methods].

EOR is usually employed when the oil left in the reservoir is trapped in hard-to-reach (low-permeability) sections with poor oil-water contact or irregular fault lines. In oil and gas production (**Figure 1**), seawater, produced water, or fresh water is often injected into the oil-bearing formation for pressure maintenance. Treated seawater injection (SWI) is commonly used as a means of EOR in the oil and gas industry.

Over the last few years, there has been substantial growth supporting the use of low-salinity SWI (LSWI) as a feasible EOR process. Conventional SWI only has particle and Dissolved Oxygen (DO) removal for injection (low sulphate (<100 ppm) water only used in certain reservoirs where sulphate reduction required to reduce scaling or souring potential) whereas the LSWI process uses total dissolved solids (TDS) content of less than 5000 ppm (typical value as varies with the fluid characteristics of the individual reservoir). Typically, reverse osmosis membranes used to remove dissolved minerals to meet the desired TDS level for LSWI process.

Multiple combination of reverse osmosis (RO) membranes is used to create blended quality with lower salinity than sea water but higher salinity than drinking water that is required for the LSWI process. LSWI improves waterflood performance by 5 to 10% depending on the formation rock type, porosity, permeability, saturation and distribution of reservoir fluids, and optimum time of water injection.

Based on the study of the oil displacement mechanism, factors that influence oil recovery by low-salinity waterflooding include but are not limited to wettability, temperature, porosity and permeability correlation, and reservoir fluid

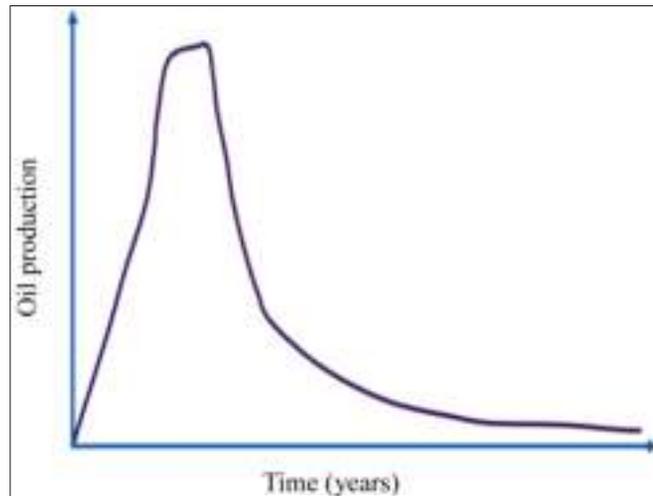


Figure 1 Oil production profile

properties.

### EOR SCREENING

Screening of the mature oil fields for implementing the EOR operation commences with the identification of the target fields, which are referred to as brownfields. These fields are those where hydrocarbon reserves have advanced towards the declining stage of recovery. Such fields are the most suitable ones for implementing EOR methods in the Indian oil and gas industry. With steady declining reserves and marginal discoveries of new oil fields, it is time for the major operating companies in India to carry out full-scale screening of the existing brownfields.

### WHY LSWI?

The objective of LSWI is to alter wettability in reservoir to produce initially non movable oil.

### Theory on the Requirement to Treat Seawater before Injection

The main reasons to treat seawater (SW) before injection is to avoid reservoir pores blocked with solids, corrosion of downhole piping, biological contamination of reservoir, and souring of reservoir (only applicable where low sulphate water required) due to activity of thermophilic sulfate reducing bacteria and scaling of reservoir [Equation (1)].



To design an LSWI system, typical data to be known and analyzed are oceanography (depth of water, prevailing currents, land-based runoff), water chemistry (dissolved inorganic salts that induce scaling, dissolved gases like oxygen and carbon dioxide that induce corrosion, bacteria and other living organisms that increase biofouling, and size and quantity of suspended solids that tends to increase fouling rate) and temperature profile (seasonal temperature range and viscosity).

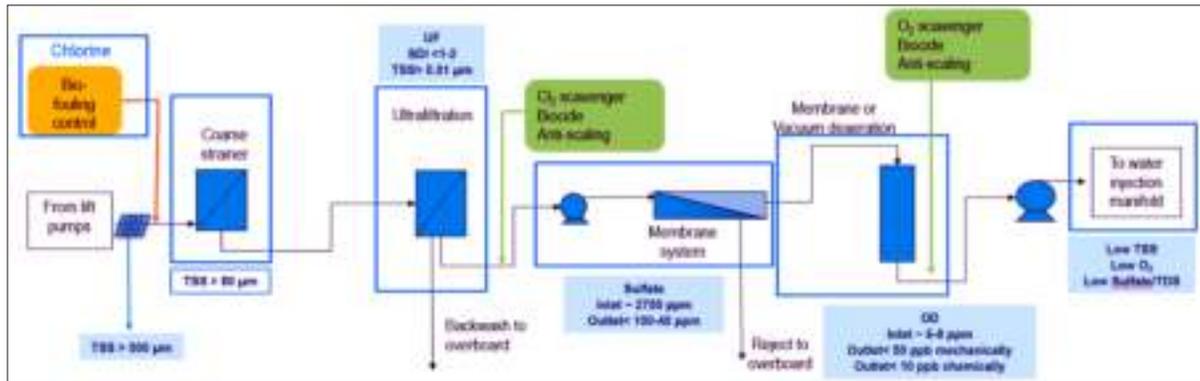
Typical seawater salinity is ~35,000 mg/l and sulphate content is < 3000 mg/l (low sulphate water injection only specified if interaction between reservoir and seawater sulphate content is expected as it depends on the reservoir as all have different water analysis), whereas reservoir water has 200 ppm barium. Calcium/barium/strontium sulphate may precipitate during the injection of seawater with high sulphate content into formation brine with high calcium/barium content.

### OVERVIEW OF SEAWATER INJECTION PROCESS

#### Treatment Process

The main treatment steps for normal seawater injection involve biofouling control, removal of suspended solids and dissolved oxygen content against reduction of majority total dissolved solids (LSWI), and removal of dissolved oxygen content from seawater. Requirement of reduction of sulphates is applicable for low sulphate water injection.

The schematic in **Figure 2** illustrates the described SWI/LSWI and the way in which it can be integrated into what is



**Figure 2** Overview of waterflood injection

otherwise a conventional topsides water injection system design.

*Primary Treatment*

Primary treatment comprises coarse filtration (an automatic back washing design with straining elements rated at 80 micron) and ultra filtration or combination of multi-media filtration (MMF) and cartridge filtration (designed to remove suspended particles, bacteria, viruses, and other elements to the specified filtration level) as deemed necessary for secondary treatment (silt density index < 3).

*Secondary Treatment*

Injection water qualities are typically classified as: (a) low salinity, sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP); (b) medium salinity, SAR, and ESP; and (c) high salinity, SAR and ESP.

Final TDS specification would be met using Reverse Osmosis (RO) or a combination of sulphate removal (SR) and partial RO membrane train operating in parallel. Each SR and RO membrane train is equipped with two main flow



**Figure 3** Photograph of waterflood injection module

control loops. The first ensures that the feed-water flow rate to each of the trains is controlled. The second controls the recovery ratio (treated/feed-water flow ratio). Blending of SR and RO treated streams to the set point treated water total dissolved solids is automatic under conductivity control.

The block diagram in **Figure 4** illustrates the LSWI process and blend control (one of the combinations).

#### *Tertiary Treatment*

In vacuum deaeration, packed towers are continuously evacuated by vacuum systems, reducing the oxygen partial pressure to create a driving force for mass transfer from the liquid to the gas phase. Desired oxygen concentration by mechanical means is up to 50 ppb and by chemical means <20 ppb is with addition of oxygen scavenger.

Another option involves membrane-based deaeration which is mature technology for onshore applications and now undergoing technology transfer for offshore applications.

#### *Chemicals used in the LSWI Treatment Process*

Residual chlorine levels are kept as low as necessary while still preventing bio-growth. Chlorine is added as hypochlorite into the seawater lift pump system and levels are typically, maintained at 0.5 ppm residual chlorine (since higher levels of chlorine are corrosive to the system).

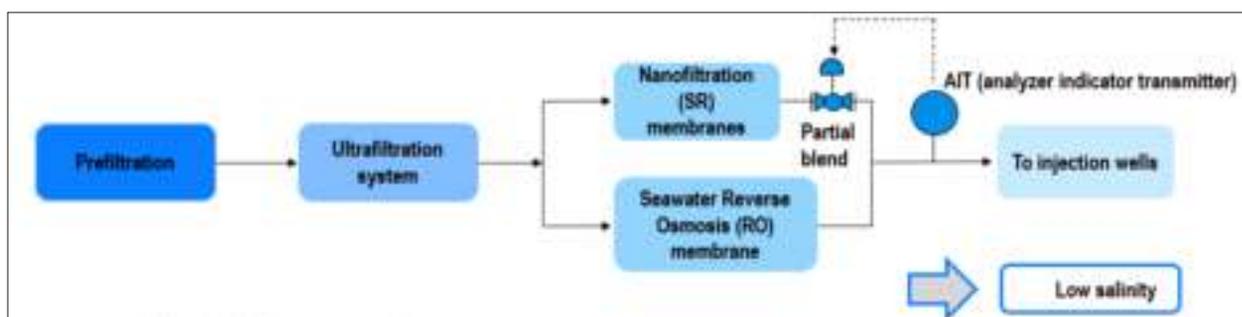
Solids in the seawater should be removed or reduced to a minimum to reduce corrosion in the injection system. Filtration agents such as ferric chloride and/or polyelectrolytes are often added to the seawater to aid filtration (on conventional systems where media filtration is used).

Chemical dosing (scale inhibitors, biocides, and chlorine scavengers) is used for SR/RO membrane protection:

- (a) Scale inhibitor is added to inhibit deposition of scale on membranes.
- (b) Microbially induced corrosion (MIC) is a potential risk because both aerobic and anaerobic bacteria are normally present in seawater and can become active in different parts of the injection system. Biocides added for SR/RO membrane protection.
- (c) Chlorine scavenger (such as ammonium bisulphite or sodium bisulphite) is used to reduce the chlorine content in sea water since chlorine content presence damages the membranes.

Chemical dosing (scale inhibitors, biocides, and chlorine scavengers) is also used for reservoir injection system protection (downstream of deaeration):

- (a) Oxygen scavenger (such as ammonium bisulphite or sodium bisulphite) is used to reduce the oxygen content in sea water since mechanical / membrane-based deaeration alone may not be efficient enough to reduce the oxygen concentration to a level at which the corrosiveness of the seawater is acceptable.
- (b) Water injection scale inhibitor is added to inhibit deposition of scale on water injection system/pipelines.
- (c) Water injection biocides used to inhibit the growth of algae, bacteria, and fungi. It is especially effective against sulphate-reducing bacteria (SRB), which are particularly troublesome in EOR operations, such as injection water treatment.



**Figure 4** LSWI process control



**Figure 5** Module with conventional deaeration tower

#### WEIGHTS AND DIMENSIONS ANALYSIS

The estimated weights and dimensions for SWI and LSWI operations with a typical injection module are listed in **Table 1** for comparison.

Installation of LSWI has a higher capital expenditure (CAPEX) compared to conventional or low sulphate water injection system, however, the key benefit is that LSWI increases oil recovery in place (OIP) compared to conventional or low sulphate water injection, there is a direct payback in oil revenue. It can be implemented in ongoing and new waterflood projects onshore and offshore and has shown potential for sandstone and carbonate reservoirs. It also can alleviate problems associated with conventional waterflooding, such as scale formation and souring.

#### MATERIAL SELECTION AGAINST CORROSION

The seawater lines upstream of the deaeration system should be composed of seawater-resistant material (depends on operating pressure, say glass reinforced plastic (GRP) is used up to 150 pound pipe class pressure rating or super-duplex stainless steel (SDSS) with pitting resistance equivalent number of 40 or higher is used either for lower or higher pipe class pressure rating. Downstream of deaeration system, the oxygen content should be < 20 parts per billion (ppb). The water should be verified as not corrosive to carbon steel with an adequate corrosion allowance; otherwise, superduplex should be considered.

Corrosion in seawater injection systems should be monitored using probes such as linear polarization resistance (LPR), electrical resistance (ER), or galvanic probes, and corrosion coupons installed on the common discharge header between the water injection pumps and the injection wells.

**Table 1** SWI vs LSWI

Option	Injection Flow Rate (m <sup>3</sup> /h)	Installed Dimensions (ft)	Dry Weight (kg.)	Operating Weight (lb.)
		L × W × H		
Conventional SWI	~ 925	24 × 20.4 × 16.5	590,200	862,600
LSWI	~ 925	24 × 20.4 × 16.5	726,400	1,044,200
Conventional SWI	~ 660	21 × 20.4 × 16.5	454,000	681,000
LSWI	~ 660	21 × 20.4 × 16.5	590,200	817,200



## CONCLUSION

Increased oil revenue due to increased oil recovery is the driver for a step change in technology selection (LSWI). This increases the potential for implementing EOR schemes in the oil and gas fields of India by addressing changes in the influent stream quality, minimal weight, and footprint requirements.

## ACKNOWLEDGMENT

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## REFERENCES

1. Crude Oil Production Stats. <https://tradingeconomics.com/india/crude-oil-production>
2. Manikandan Sakthivel, Combinational Membrane Technique to Support Low Salinity Water Flooding (LSWF), International Petroleum Technology Conference, IPTC-22612-EA

# Low Cost Process for the Production of Graphene from Natural Graphite

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**Abstract:** Graphene, the “material of the future”, a Nobel prize-winning discovery by Geim and Novoselov in 2004, has globally impacted the world of 2D materials. Ever since then, it has garnered interest from the scientific community. Graphene has a high degree of mechanical strength, optical transparency, electron mobility, thermal stability, and chemical stability. Owing to these extraordinary properties make, it a suitable candidate for the electronic industry. Though there is significant growth in the application of graphene, the challenge arises in the scaling up of the same for commercialisation. The next phase is for massive, inexpensive graphene manufacturing to meet market demand which the ball milling technique can solve, which executes the shear exfoliation of the material. For the study, we have used graphite from two sources: industrial low pure flaky graphite with 96% purity and 99% high pure commercial graphite. The existing market price of flaky graphite is around Rs. 60-70 INR/kg and the preliminary studies on production of graphene by horizontal planetary ball mill and the price arrived at the cost of Rs. 500/100 g batch.

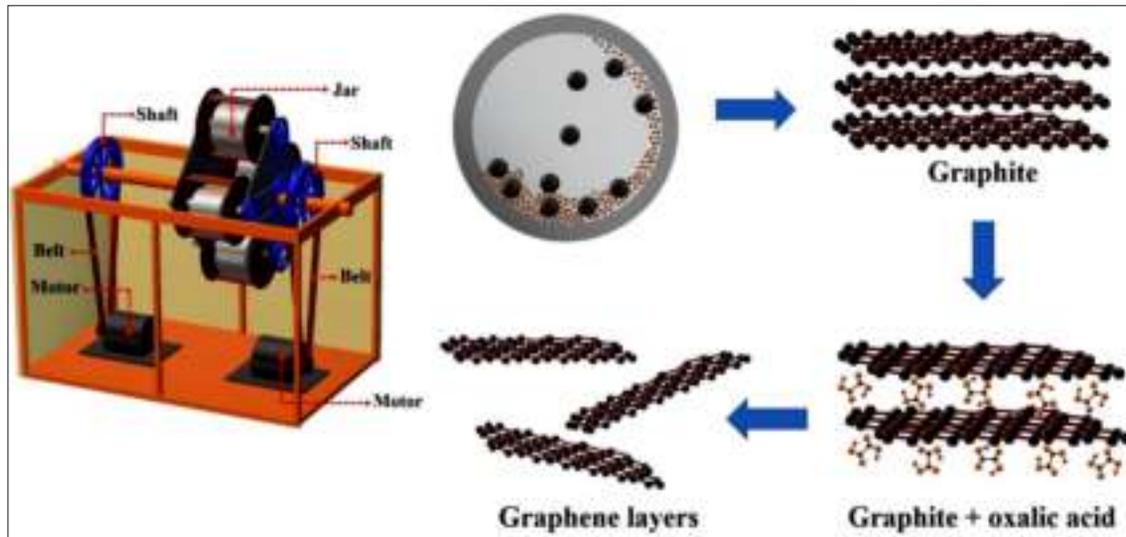
**Keywords :** Planetary Milling; Graphite; Exfoliation; Electronics; Beneficiation

## INTRODUCTION

Graphene research is still in its first phase and the researchers focused the preparation of good quality graphene. But the gap is aroused between synthesis and application part due to the issue of mass production. The prevailing synthesis routes includes: (1) Scotch-tape method, where individual graphene layers are peeled off using adhesive tape but this method is viable only in laboratory scale; (2) chemical vapour deposition, where high quality graphene can be produced in large scale but issue comes in being complexity of the procedure; (3) electrochemical exfoliation, where instead of pristine graphene, the resulting product resembles more like graphene oxide; (4) chemical reduction of graphene oxide[1]. The commercialisation of graphene is directly linked to the upscaling of production which focus on quality, uniformity, duplication, safety while keeping account of production cost. There are always room for challenges in the lab-scale to pilot scale conversion of such a material and right now the world market for graphene production is dominated by China, followed by the United States and Europe[2].

We present an easy but efficient and eco-friendly method to address the aforementioned limitations of the scaling up the graphene synthesis by incorporating the ball-milling method which execute the shear exfoliation of the material. While shear force results in the formation of massive graphite flakes, the collision or vertical impacts results in fragmentation[3]. The impact force overcomes the weak Vanderwaals interaction between the graphitic layers which was resisting the exfoliation. This mechanical exfoliation method makes use of the factors such as jar and gyrating speed, ball-to-powder ratio, milling time, type of grinding medium and size of the container for the maximum efficiency. The percentage of critical speed, which is dependent on the gyrating and jar speeds, is used to calculate the dynamics of shear force milling. In non-destructive graphene processing, shear force and mill assisting agents are critical. Due to the plate-like nature of graphite layers, exfoliating graphite using the dry ball milling method is difficult. The grinding jar and the balls used for the milling play an important role in the extent of exfoliation. Mostly its preferred to have both the jar and balls of the same material in order to avoid contamination. Some of the options include tungsten carbide[4], zirconia[5,6], agate[7], polytetrafluorethylene[5]. But the most preferred one is stainless steel[8,9–11] since it can prevent corrosion and hence contamination of the sample. To increase the impact and shear energy on the sample, low diameter balls are used resulting in low dimensional contact with the particles. To assist non-destructive exfoliation, milling assisting agents or process control agents play a vital role. Dry ice, sulphur trioxide, melamine, polystyrene[12], anionic surfactants[13], triazine derivative, oxalic acid[11] are commonly used reagents.

The main aim of this work is to produce high purity graphene from natural graphite obtained from ore, Jharkhand using



horizontal planetary ball mill having stainless steel jar and hardened steel balls. Oxalic acid and toluene are used as process control agents and milling medium. This is a comparative study as well, where the graphene obtained by milling both natural flaky graphite from ore as well as commercially available graphite powder are compared, to study the extent of exfoliation in both type of samples.

#### MATERIALS

Natural graphite flakes obtained from ore (Chota Nagpur Industries, Jharkhand), Commercial graphite powder (Himedia), Oxalic Acid [ $C_2H_2O_4$ ] (Himedia), Toluene [ $C_7H_8$ ] (Molychem), Hydrochloric acid [HCl] (Molychem).

#### PROCEDURE

Graphene was synthesised by means of shear mechanical exfoliation using horizontal planetary ball-mill. Mill is provided with two distinctly controlled driving system: one attached the jar and other to the disc which is in contact with the jar. Hence the RPM of both can be set individually. The jar used is made of stainless steel and the balls are of hardened steel of diameter 10 mm.

Two sets of samples were made. One jar is loaded with 50 g of natural flaky graphite obtained from ore and other is loaded with 50 g commercial graphite powder. 80 g of oxalic acid is added to both the jars. The ball-to-powder ratio was kept at 10:1 and toluene were used as the milling medium. The samples were milled for 5 h, 10 h and 20 h. The mill speed was 100 rpm and jar speed was 250 rpm. The ore sample in 5,10 and 20 h will hereafter be referred as O-5, O-10 and O-20, respectively and for the commercial graphite sample 5,10 and 20 h will hereafter be referred as H-5, H-10 and H-20, respectively. The samples were taken out during the specified time and was washed with distilled water and then leached with 1M Hydrochloric acid to remove any impurities which occurred during the milling.

#### RESULTS AND DISCUSSION

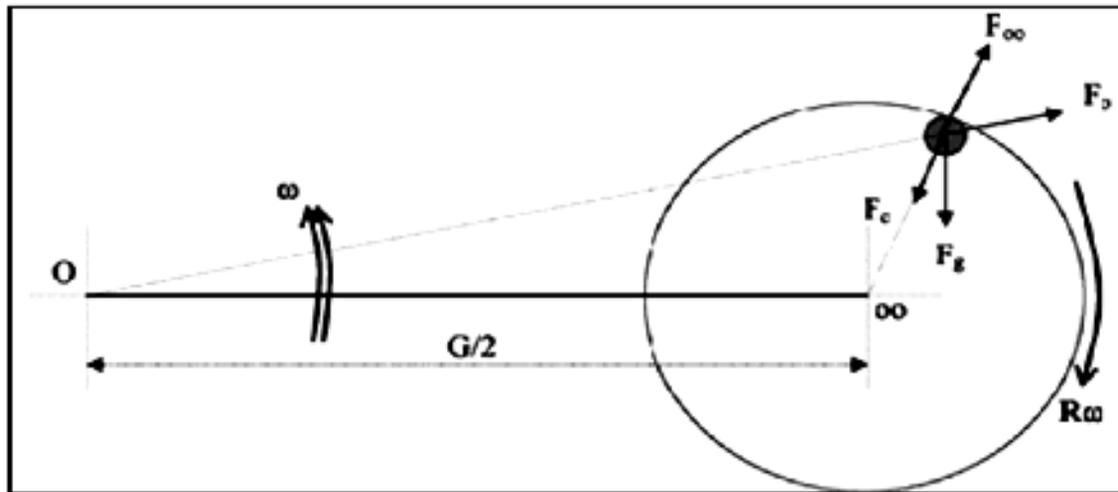
##### Mechanism in Horizontal Mill

The samples are quickly and effectively comminuted by impact, frictional and shear forces resulting from ball-to-wall and ball-to-ball collisions. The grinding result is influenced by a number of parameters, especially by the rotation speed of the mill, the grinding time, the ratio of the sample to the ball filling as well as the material of the grinding parts. Due to the planetary movement, the grinding bowl filling is not only subjected to the gravitational forces but also Coriolis and centrifugal forces further improve the kinetic energy of the grinding components up to 100 times the gravitational forces.

These forces produce a special acceleration field inside the mill which is difficult to visualize.

##### Schematic of the Acceleration Field in the Planetary Mill

Here  $G$  is the diameter of rotation of the axis of the jar and  $D$  is the diameter of the jar itself. Once these parameters are



fixed, it turns out, that the planetary mill could be simply characterized by the ratio of the diameter of rotation of the mill axis  $G$  to the diameter of the mill  $D$ . Let  $R$  be the ratio of speed of rotation of the mill axis to the speed of rotation of the mill about its center. Then, if the shaft rotates at an angular velocity of  $\omega$ , the mill rotates at  $R\omega$  on the shaft. A negative value of  $R$  indicates that the mill and the shaft rotate in opposite direction.

### X-ray Diffraction Technique

Structural analysis of both set (ore and commercial) of samples were done using X-ray diffraction analysis. The diffraction peaks of the raw, 5 h, 10 h and 20 h samples were carried out. A distinct strong single diffraction peak was obtained at  $2\theta = 26^\circ$ - $27^\circ$  which corresponds to the (002) lattice plane of the sample. As milling time increases, the (002) peak intensity decreases subsequently in both commercial and ore samples. At the same time the peak broadening was also observed with the increase in milling time. It could be due to the decrease in crystalline size, fluctuating strain and local correlated disorder[14].

The interlayer distance ( $d$ ) was calculated using the Bragg's equation,

$$d = \frac{\lambda}{2 \sin \theta} \quad (1)$$

where  $\lambda$  is the wavelength of the X-ray source and  $\theta$  is half the angle of the diffraction. The value obtained was about  $3.3 \text{ \AA}$ - $3.4 \text{ \AA}$  which satisfies the literature survey. While the peak position depends on the interlayer distance, the peak width depends on the size of the subject. As the crystalline size of the graphene decreases, broader the peak becomes. In

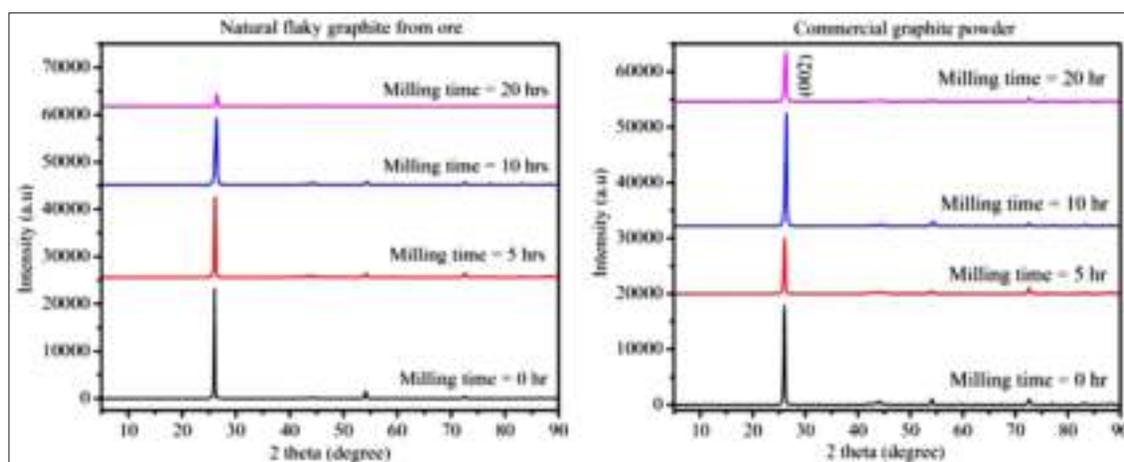
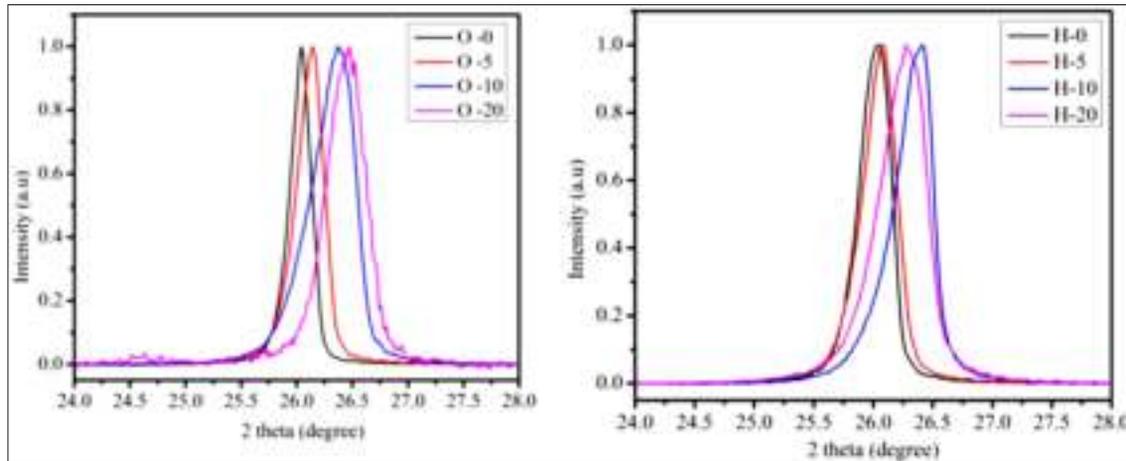


Figure 1 XRD of ore and commercial graphite



**Figure 2** Normalised XRD of ore and commercial graphite

other words, the peak width is inversely proportional to the crystalline size. Microstrains, crystal structure defects or even stacking faults could give rise to peak broadening[15].

Crystalline height of the sample was calculated using the Debye-Scherrer formula,

$$L_c = 0.9\lambda / B \cos\theta \quad (2)$$

where B is the full width half maxima of the sample.

It was found that as the milling time increases, the crystalline height (**Table 1**) (the perpendicular dimension of the graphitic ordering) ( $L_c$ ) decreases. This result was satisfactory with the peak broadening which occurred as milling time increases. Since graphite is having a layered structure and grinding for long periods of time may cause changes in some structural properties of graphite which results in the decrease in crystalline size[16].

### Raman Spectroscopy

The Raman spectra (**Figures 3 and 4**) of the initial samples and milled samples were carried out at different time intervals. It is characterised by the three main bands: D band, G band and 2D band was observed around  $1320 \text{ cm}^{-1}$ ,  $1560 \text{ cm}^{-1}$  and  $2660 \text{ cm}^{-1}$ , respectively. The G band which is common to all SP<sub>2</sub> carbon systems arises due to the stretching of C = C bonds; whereas, the D band is caused by the defects formed on to the graphene structure. The 2D band is mainly used to analyse the layers of the structure.

Regarding the intensities of these bands, while the D band intensity was low initially for ore graphite samples, it continued to rise throughout the milling. But in commercial graphite samples, it was high initially and later decreased during 5th h and 20th h of milling. When ore graphite showed minimum defect during initial hours and maximum during the end of the milling, this trend is not followed in the case of commercial graphite. The shear force which arises during the milling is executed on to the sample which results in size reduction and hence rise in defects. Since the change is comparatively less, it could be concluded that, though the defects are unavoidable, crystallinity of the sample is preserved during the milling process.

**Table 1** Crystalline size and D-spacing

	FWHM	2θ	Crystallite Size (Å)	d-spacing
O-0	0.235	26.030	359	3.42
O-5	0.245	26.140	344	3.40
O-10	0.393	26.350	212	3.37
O-20	0.398	26.450	209	3.36
H-0	0.294	26.010	285	3.42
H-5	0.319	26.060	262	3.41
H-10	0.315	26.390	266	3.37
H-20	0.409	26.260	203	3.36

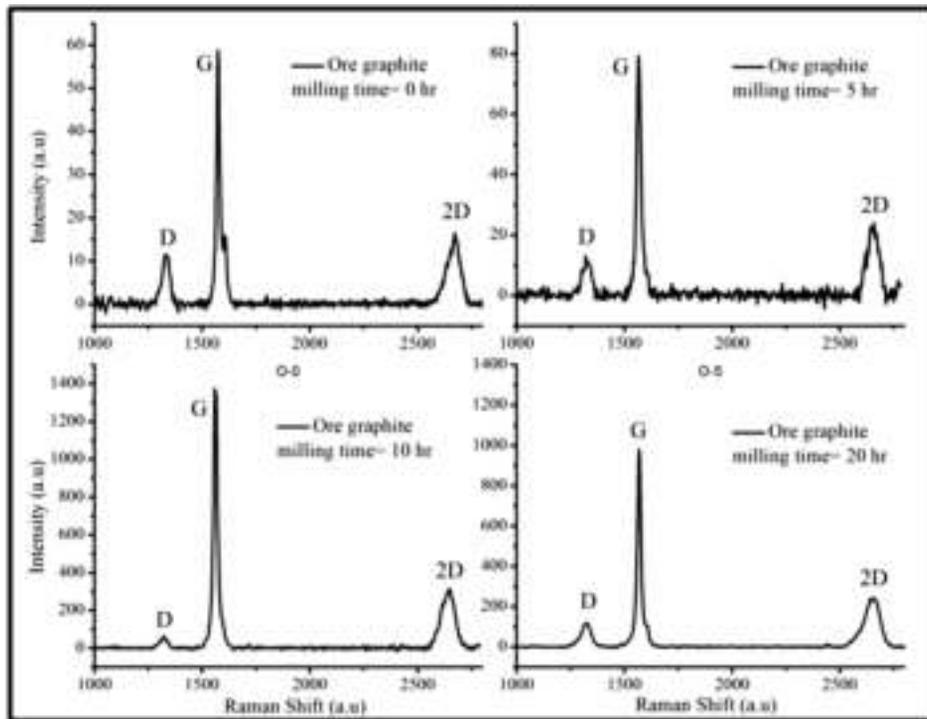


Figure 3 Raman spectrum of ore graphite

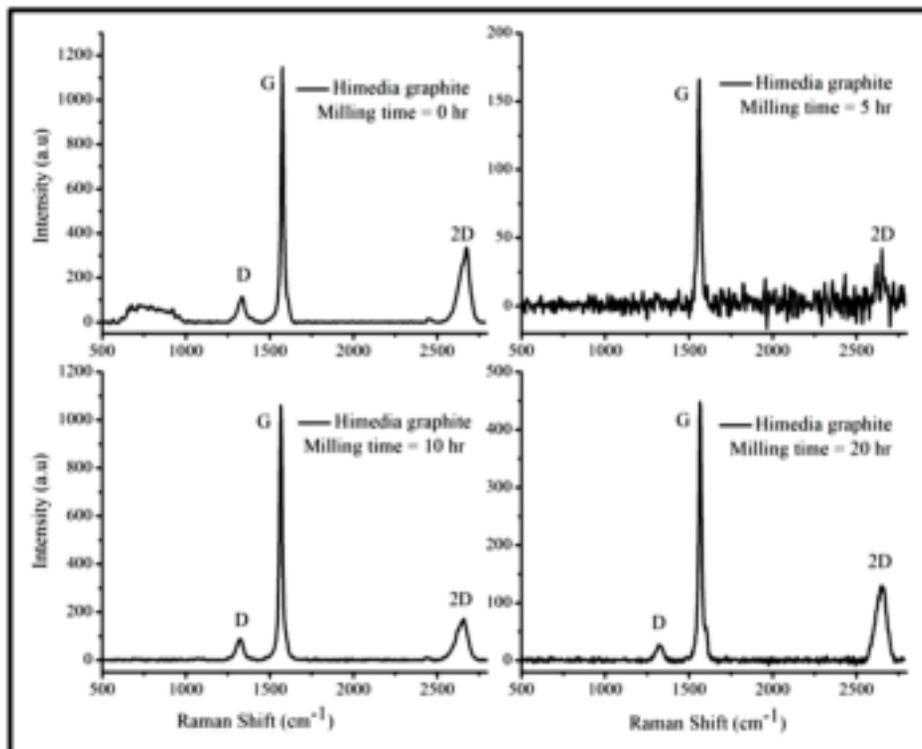


Figure 4 Raman spectrum of commercial graphite

The  $I_D/I_G$  and  $I_{2D}/I_G$  value of ore and commercial graphite (20 h) shows the presence of few-layer graphene. The  $SP^2$  crystallite diameter of the nano-graphitic samples were determined using the equation[17]:

$$L_a = (2.4 \times 10^{-10}) \lambda^4 I_{2D}/I_G^{-1} \quad (3)$$

In the case of crystalline width (diameter)  $L_a$ , there was tendency to increase and later decrease with respect to milling time (Table 3).

### Scanning Electron Microscopy and Transmission Electron Microscopy

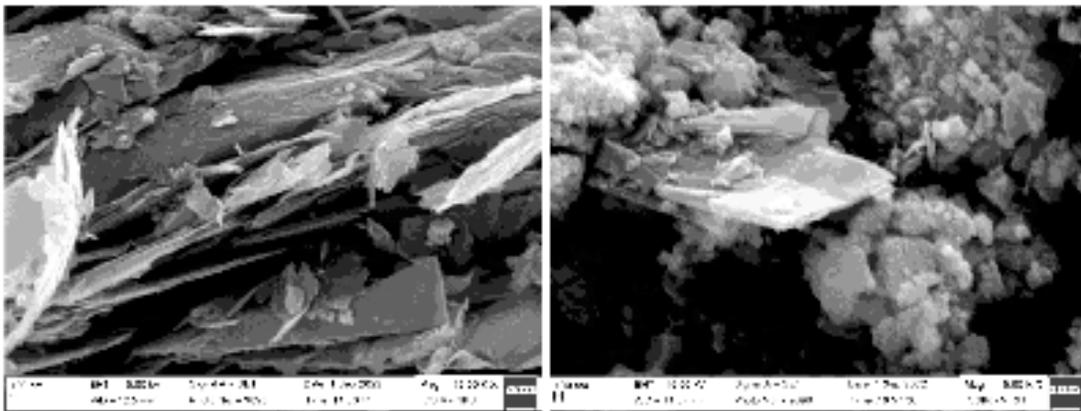
SEM and TEM investigations (Figures 5 and 6) were used to examine the morphology of the sample. It was discovered

**Table 2** Comparison of Raman spectrum data

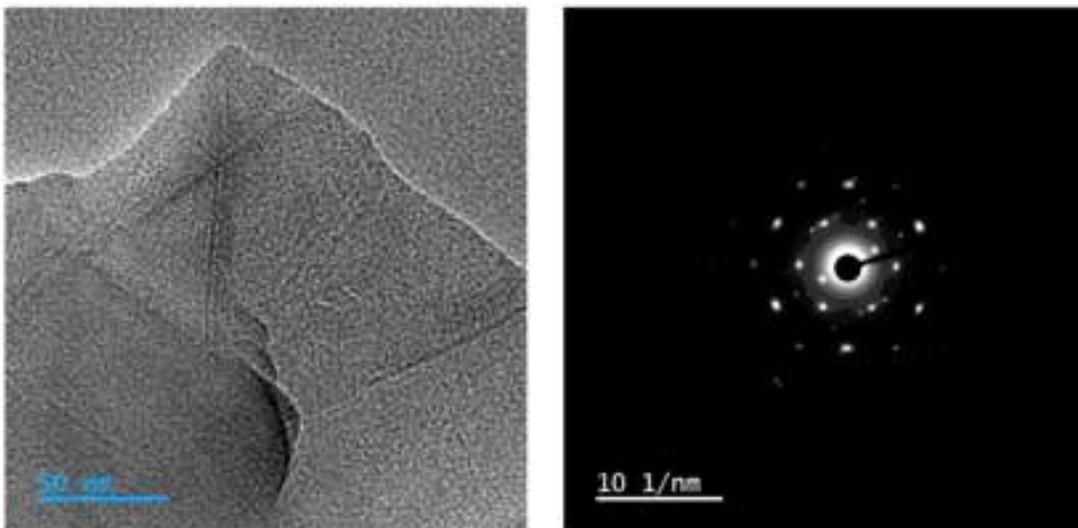
	0-0	0-10	0-20	H-0	H-10	H-20
$I_D/I_G$	0.19	0.043	0.12	0.1	0.083	0.062
$I_{2D}/I_G$	0.38	0.39	0.35	0.29	0.161	0.29

**Table 3**  $SP^2$  crystallite diameter of the samples

	0-0	0-10	0-20	H-0	H-10	H-20
$L_a$	203.80	856.7	331.1	385.52	464.25	621.49



**Figure 5** SEM images of ore and commercial graphite



**Figure 6** TEM image and SAED pattern of ore graphite



that the sample was crystalline, and the ore sample clearly displayed the flaky nature. The size of the sample was significantly reduced after mechanical milling. The SAED pattern showed the crystalline property. The appearance of thin sheet-like structures in SEM and TEM images demonstrated the efficient exfoliation occurred during the ball milling process[18].

#### ACKNOWLEDGMENT

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#### REFERENCES

1. D G Papageorgiou, I A Kinloch and R J Young, Mechanical Properties of Graphene and Graphene-Based Nanocomposites. *Prog. Mater. Sci.*, 90, 2017, 75–127.
2. L Lin, H Peng and Z Liu, Synthesis Challenges for Graphene Industry, *Nat. Mater*, 18 (6), 2019, pp 520–524.
3. M Yi and Z Shen, A Review on Mechanical Exfoliation for the Scalable Production of Graphene, *J Mater. Chem. A*, 3(22), 2015, pp11700–11715.
4. Y Chen, J Fitz Gerald, L T Chadderton and L Chaffron, Nanoporous Carbon Produced by Ball Milling. *Appl. Phys. Lett.*, 74 (19), 1999, pp 2782–2784.
5. W Zhao, M Fang, F Wu, H Wu, L Wang and G Chen, Preparation of Graphene by Exfoliation of Graphite Using Wet Ball Milling. *J. Mater. Chem.*, 20 (28), 2010, 5817.
6. W Zhao, F Wu, H Wu, G Chen, Preparation of Colloidal Dispersions of Graphene Sheets in Organic Solvents by Using Ball Milling. *J. Nanomater*, 2010, pp 1–5
7. Z Zhang, J Sun, C Lai, Q Wang and C Hu, High-Yield Ball-Milling Synthesis of Extremely Concentrated and Highly Conductive Graphene Nanoplatelet Inks for Rapid Surface Coating of Diverse Substrates, *Carbon*, 120, 2017, pp 411–418.
8. J Xu, X Zhao, F Liu, L Jin and G Chen, Preparation of Graphene via Wet Ball Milling and in Situ Reversible Modification with the Diels–Alder Reaction. *New J. Chem.*
9. T Lin, J Chen, H Bi, D Wan, F Huang, X Xie and M Jiang, Facile and Economical Exfoliation of Graphite for Mass Production of High-Quality Graphene Sheets. *J Mater Chem A*, 1 (3), 2013, pp 500–504.
10. V León, A M Rodriguez, P Prieto, M Prato and E Vázquez, Exfoliation of Graphite with Triazine Derivatives under Ball-Milling Conditions: Preparation of Few-Layer Graphene via Selective Noncovalent Interactions. *ACS Nano*, 8 (1), 2014, pp 563–571.
11. G R Kumar, K Jayasankar, S K Das, T Dash, A Dash, B K Jena and B K Mishra, Shear-Force-Dominated Dual-Drive Planetary Ball Milling for the Scalable Production of Graphene and its Electrocatalytic Application with Pd Nanostructures. *RSC Adv*, 6 (24), 2016.
12. X Fan, D W Chang, X Chen, J B Baek and L Dai, Functionalized Graphene Nanoplatelets from Ball Milling for Energy Applications. *Curr. Opin. Chem. Eng.*, 11, 2016.
13. R Nandhini, P A Mini, B Avinash, S V Nair and K R V Subramanian, Supercapacitor Electrodes using Nanoscale Activated Carbon from Graphite by Ball Milling. *Mater. Lett.*, 87, 2012, pp 165–168.
14. H Hermann, Th Schubert, W Gruner and N Mattern, Structure and Chemical Reactivity of Ball-Milled Graphite. *Nanostructured Mater*, 8 (2), 1997, pp 215–229.
15. R Sharma, N Chadha and P Saini, Determination of Defect Density, Crystallite Size and Number of Graphene Layers



- in Graphene Analogues Using X-Ray Diffraction and Raman Spectroscopy. *APPL PHYS*, 55, 5, 2017.
- 16 E Crespo, F J Luque, J F Barrenechea and M Rodas, Influence of Grinding on Graphite Crystallinity from Experimental and Natural Data: Implications for Graphite Thermometry and Sample Preparation. *Mineral. Mag.* 70 (6), 2006, pp 697–707.
17. L G Cançado, K Takai, T Enoki, M Endo, Y A Kim, H Mizusaki, A Jorio, L N Coelho, R Magalhães-Paniago and M A Pimenta, General Equation for the Determination of the Crystallite Size  $L_a$  of Nanographite by Raman Spectroscopy. *Appl. Phys. Lett.*, 88 (16), 2006, 163106.
18. A S Nair, V Nallusamy, K Jayasankar and S Ss, Scalable Preparation of Graphene from Graphite Ore via Mechano-Chemical Ball Milling. *Mater. Manuf. Process.* 37 (1), 2022, pp 113–122.

# Green Hydrogen and Electricity Way for Decarbonization of Chemical Processes and Plant Utilities

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**Abstract:** Renewable energy sources, such as solar and wind, have become increasingly prevalent and helped drive progress toward decarbonization of electricity. Renewable energy sources are often discussed in the context of the electrical grid, transportation, and household devices. However, the commodity chemical industry is a large consumer of energy and a major contributor to global greenhouse gas emissions.

Decarbonizing the chemical industry would have a significant impact on global carbon dioxide emissions, and electrification of the industry using renewable sources is a possible step toward reducing the carbon footprint of chemicals.

Globally we emit about 35 billion tons of CO<sub>2</sub> each year. Approximately 70% is generated by coal or oil combustion in transportation and in power generating plants. Around 25% is emitted by thermal appliances in a wide variety of applications in the manufacturing industry and in commercial heating. Most of these thermal appliances are natural gas fired (+/- 90%), only a small part is light oil fired.

The greenhouse gas emissions from various processes leads to temperature rise. The carbon dioxide emissions is major contributing factor. The major emissions are from thermal power plants and chemical process. The atmospheric gas has a limitation to accommodate carbon dioxide. The solution is to adopt the process which work on concept of decarbonization.

In order to decarbonize the chemical industry, we need to reduce carbon dioxide emissions by closing and moving beyond the current carbon cycle. In this context, decarbonization refers to the reduction of atmospheric carbon dioxide emissions.

One route to decarbonization could involve converting emitted carbon dioxide into valuable commodity chemicals. A second strategy toward decarbonization would involve avoiding the generation of carbon dioxide altogether; that is green hydrogen generation and utilisation.

Lastly going for Electrochemical methods for chemical formation or energy storage.

This paper deals with various methods for decarbonization using hydrogen and electrochemical process.

**Keyword:** Decarbonization; Blue Hydrogen; Green Hydrogen; Electrochemical Reactions

## INTRODUCTION

India's industry – chemical and refining, are the largest producer and consumer of hydrogen in India. The hydrogen, as chemical, either in its molecular form or in a form where it is bound within a molecule, fulfils multiple roles along the industrial value chain – both in case of organic and inorganic outputs (Ausfelder and Bazzanella 2016).

For example, hydrogen produced from feedstocks such as natural gas, naphtha and heavy oil forms the basis of production of nitrogen-based fertilizers, which is an integral part of the agricultural value chain in India and possibly one of the most important process, within the current setting, involving hydrogen. India produced 36 million tons of nitrogen-based fertilizers in 2018- 19 (Department of Chemicals and Petrochemicals 2020) and imported an additional 9 million tons to fulfil the demand gap.

Hydrogen is also a by-product in some industries. For example, Chlor-alkali units in India produced 2.9 million tons of caustic soda, along with which 83,000 tons of hydrogen was produced as a by-product in 2018-19 (BEE 2018) (Department of Chemicals and Petrochemicals 2020).



Due to a lack of trading infrastructure, however, hydrogen currently produced in chlor-alkali units is utilized for captive requirements such as process heat, with a portion of the gas also being flared. Molecular hydrogen, apart from its role in production of useful hydrocarbons, is also used as a reduction agent, both within the chemical industry and other industrial sectors, such as metallurgy, to reduce the precursor molecule, alloy or ore into the desired product. This reducing function also serves to remove undesired compounds from the mixtures, for example in the removal of sulphur containing compounds or in the cleaning of semi-conductor surfaces.

Within the chemical industry, hydrogen is also widely used for catalyst regeneration (Ausfelder and Bazzanella 2016). Currently limited by appropriate regulations and a lack of trading ecosystem, it is not uncommon to see the entire value chain of hydrogen from production to consumption, in the same industrial unit.

This makes it difficult to estimate the overall production numbers associated with hydrogen, as there is limited availability of data from industrial units which produce or consume the gas.

The details are indicated in **Table 1**.

### HYDROGEN GENERATION AND COLOUR

The element hydrogen, though abundant in nature is not readily available for consumption.

It is an extremely reactive atom and bonds with most other elements to form compounds such as water (H<sub>2</sub>O) or hydrocarbons such as methane (CH<sub>4</sub>), coal (C<sub>13</sub>H<sub>9</sub>7O<sub>9</sub>NS) etc

The hydrogen is produced by different principles. Depending on the principle and generation of byproduct like carbon dioxide and its method of its utilization, the hydrogen color is specified as under

To retrieve hydrogen and make it useful, it is derived from the aforementioned sources. The derivation of hydrogen from water is through electrolysis, while its derivation from hydrocarbons is through hydrocarbon reforming. Based on the production method deployed to isolate hydrogen and level of associated emissions, the gas has been categorized by the industry in to different colours – grey, blue, green and turquoise

#### Grey Hydrogen:

Grey hydrogen is based on the use of fossil hydrocarbons. Grey hydrogen is mainly produced via the steam reforming of natural gas.

#### Blue Hydrogen

Blue hydrogen is hydrogen which is produced using a carbon capture and storage (CCS) system. This means that the CO<sub>2</sub> produced in the process of making hydrogen does not enter the atmosphere, and so the hydrogen production can be regarded on balance as carbon-neutral.

**Table 1** Hydrogen consumption in India (in major sectors) in 2018-19

Industry Consumption (in thousand metric tons)	Production Method	Typology
Oil Refining 2600.00	Hydrocarbon reforming	Grey hydrogen
Ammonia 2850.21	Hydrocarbon reforming	Grey hydrogen
Ammonia 752.15 (Imported as fertiliser)	Hydrocarbon reforming	Grey hydrogen
Methanol 51.67 (Domestic)	Hydrocarbon reforming	Grey hydrogen
Methanol 361.00	Hydrocarbon reforming	Grey hydrogen
Chlor-alkali 34.37	Electrolysis	Green hydrogen*
Chemical 29.25	Electrolysis	Green hydrogen*
Industry		
Other industries 9.51 (glass, electronics etc.)	Electrolysis	Green hydrogen
Total consumption of hydrogen 6688.16 thousand metric tons (TMT)		

*Source: Status Quo mapping of hydrogen production and consumption in India based on (Department of Chemicals and Petrochemicals 2020) (B&E 2018)*



## Green Hydrogen

Green hydrogen is produced via the electrolysis of water; the electricity used for the electrolysis must derive from renewable sources. Irrespective of the electrolysis technology used, the production of the hydrogen is zero-carbon since all the electricity used derives from renewable sources and is thus zero-carbon.

## Turquoise Hydrogen

Turquoise hydrogen is hydrogen produced via the thermal splitting of methane (methane pyrolysis). This produces solid carbon rather than CO<sub>2</sub>. The preconditions for the carbon neutrality of the process are that the heat for the high-temperature reactor is produced from renewable or carbon-neutral energy sources, and the permanent binding of the carbon

## DIFFERENT METHODS

The hydrogen is produced from various process. The literature review suggest the various process are hydrocarbon reforming, gasification, steam reforming, partial oxidation, auto thermal reforming, waste and coupled stream. All these processes have the feed stock as carbon-based chemicals.

The second type of hydrogen generation processes are set of process is based on electrolytic process principles. These processes are alkaline electrolysis, PEM electrolysis, high temperature electrolysis,

The third principle is biological processes for production of hydrogen, and they are direct bio-photolysis, photo-fermentation, dark fermentation. Even the biomass become the source of hydrogen where the methane from biodigester is converted to hydrogen.

Cost associated with hydrogen production in India; the various hydrogen production methods along with their advantages, disadvantages, efficiencies. Currently, as also aforementioned, a lion share of the hydrogen production is from non-renewable fossil fuels, in particular, steam reforming of natural gas, naphtha or heavy oils. The usage of fossil fuel as a feedstock produces 'grey hydrogen' of low purity with a high concentration of greenhouse gases.

## Decarbonization

The release of carbon dioxide to the leads to carbonization of environment. The environment cannot accommodate large carbon dioxide loads; as it has limitation and there is sever impact on environment; which leads to climate change. Considering to the environmental impact productivity of agricultural sector along with issues of social security of human kind ; there is need to have the sustainable process for hydrogen production. There are various ways the electrolysis process can help to develop sustainable hydrogen generation and hydrogen-based chemicals. The details are explained as under

## Electrolysis

The electrolysis of water is known to scientist and technocrats form long time. The electrolysis is the simple process, but requires lot of electrical energy. However, due to cost competitive cost and availability of renewable energy; the producing green hydrogen will become competitive and also help in decarbonatization. The process details are explained as under.

The electrolysis is the splitting of water to hydrogen and oxygen. They are produces in electrolysis cell. The set of cells are arranged to produce desired capacity of hydrogen. In order to increase the efficiency of separation PEM based electrolyser are used. The Proton exchange membrane helps in increasing the efficiency and effectiveness of process. The principle of producing green hydrogen is indicated in **Figure 1**.

Renewable energy in particular the solar energy is source of power. To optimize the power requirements and to get reliable renewable energy the wind with solar can support as electrical energy, as reliable source.

**Figure 2** Elaborates the construction of fuel cell and system. The hydrogen is produced, may not be utilized at the same place. Hence, there is a need to have supply chain for storage and transportation which is to be followed by distribution. **Figure 3** elaborates the supply chain where as **Figure 4** indicates various methods of storage of hydrogen.

There are various methods of storage for hydrogen; which is primarily physical based and material based the details are elaborated in **Figure 4**.

The various Material base systems include absorbent, liquid organic, intestinal hybrid, complex hybrid.

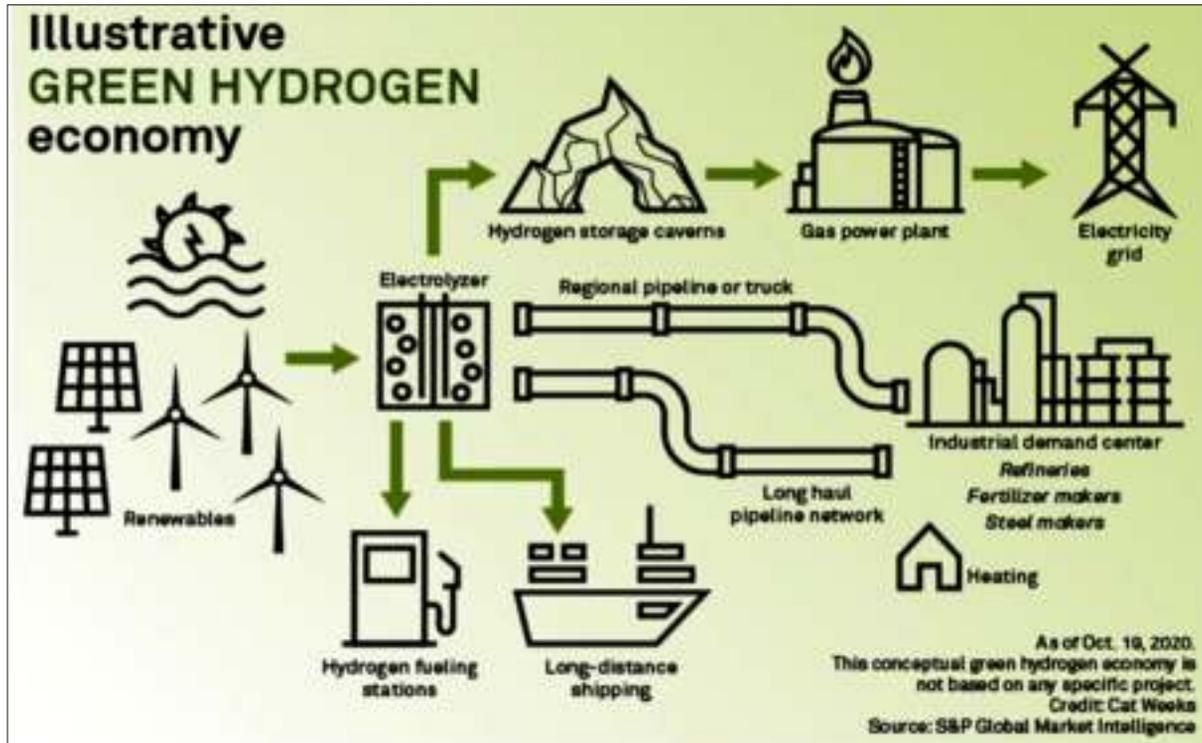


Figure 1 Principle of green hydrogen

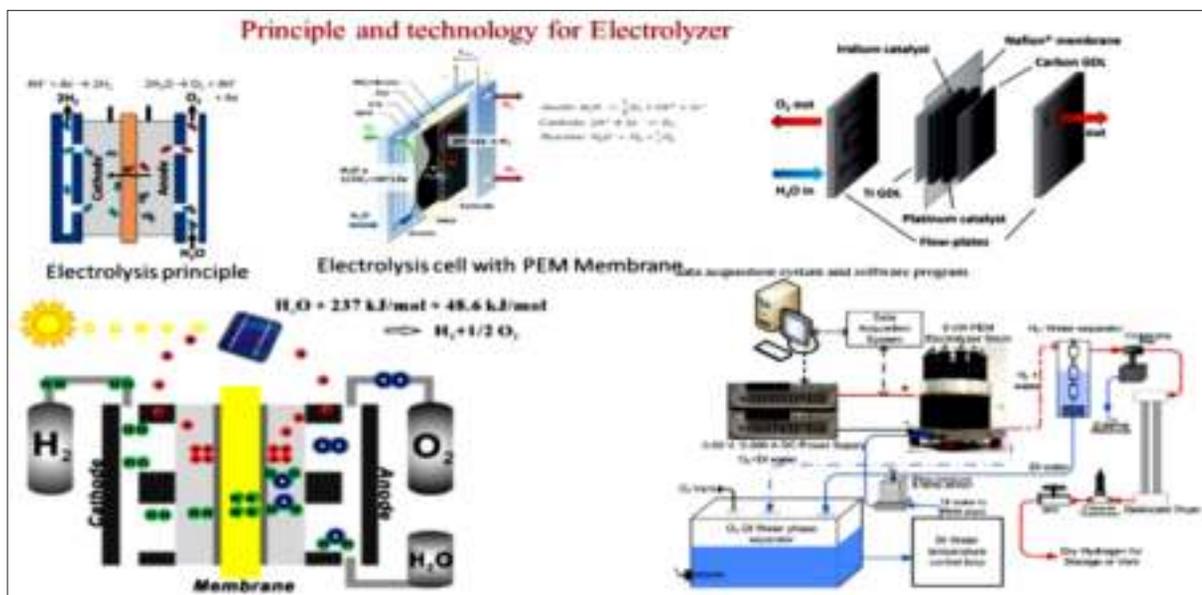


Figure 2 Details of cell and electrolysis based system

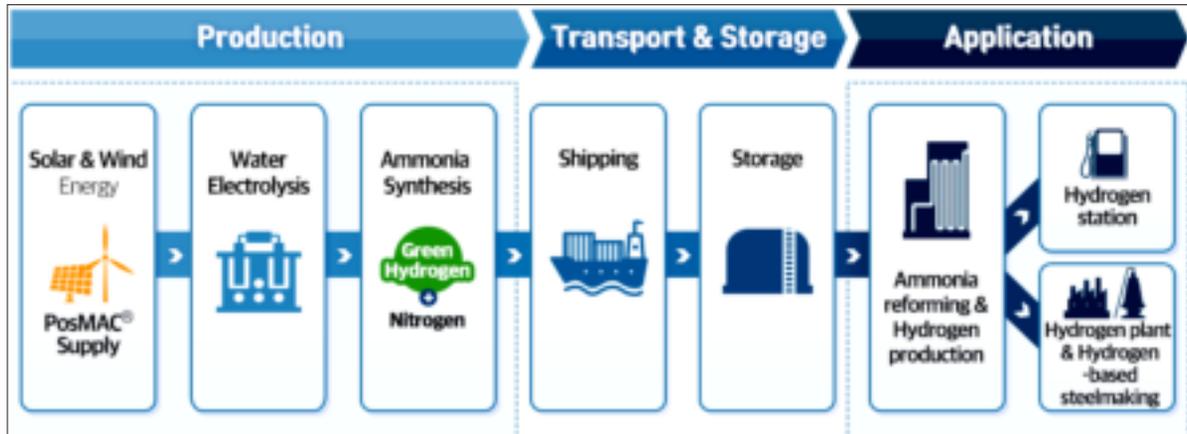


Figure 3 Supply chain for green hydrogen

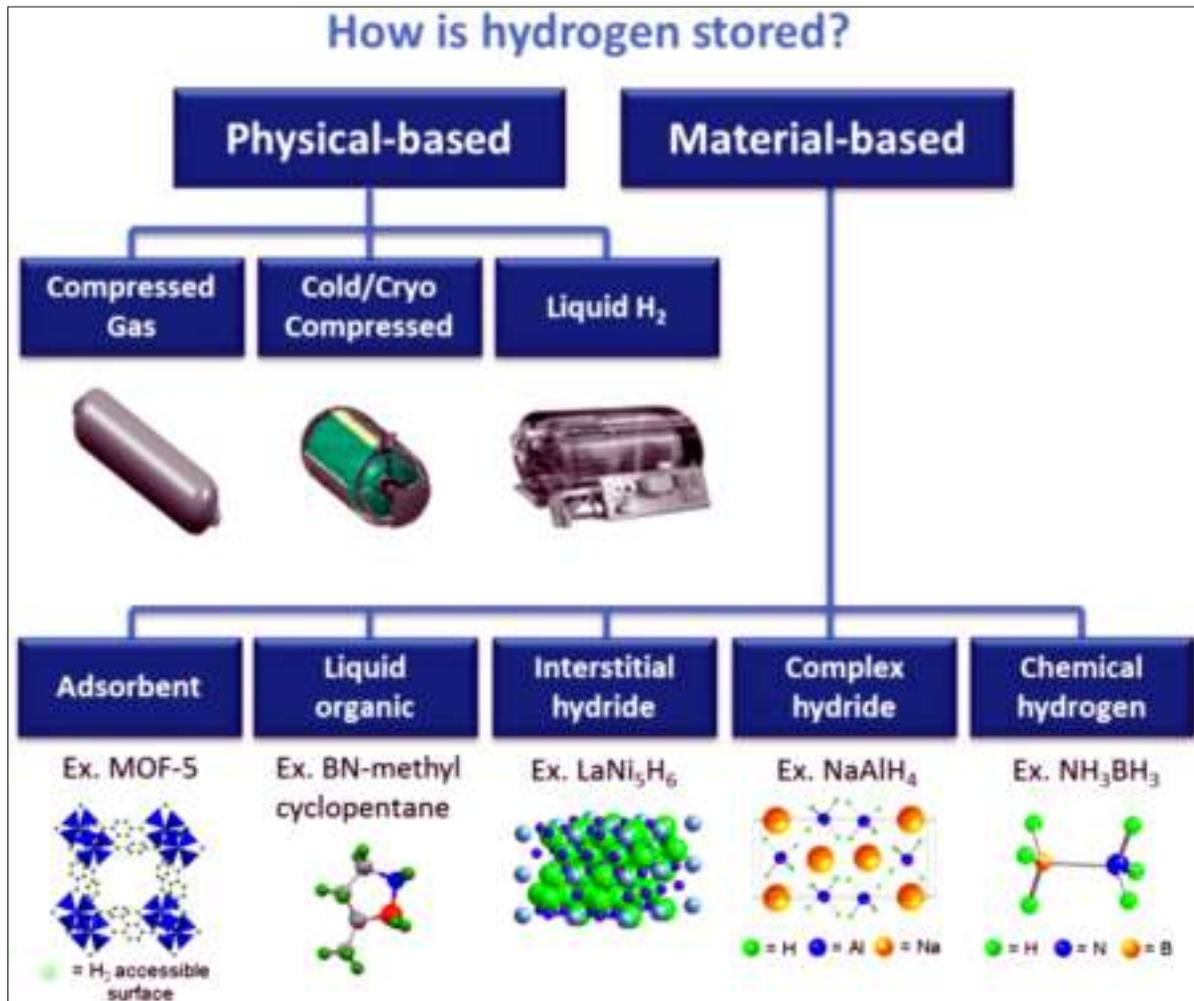


Figure 4 Various methods of storage of hydrogen



## OTHER DECARBONIZATION PROCESSES

### Steam Generation

The renewable energy can be used for steam generation using electrolytic principles, where the steam is produced by passing water over the electrode. The electrodes will be provided with high voltage to produce steam instantaneously. This leads to decarbonization in steam generation.

### Electrochemical Process

#### Electrification via Electrochemistry

There are many possible routes for electricity to drive a chemical reaction. For the direct transduction of electrical energy to chemical bonds, electrochemical methods are attractive and have some advantages over traditional thermochemical methods.

Electrochemical methods enable bond-formation steps using electricity, which offers an alternative driving force, voltage, that can enable operation at mild temperatures and pressures. In addition, electrochemical cells often result in natural product separation due to the use of a membrane that keeps products generated at the cathode and anode separate. We can understand the impact of electrochemical versus thermochemical routes using ammonia production as a case study. Here, we specifically look at the thermodynamics of two alternative routes by calculating the reaction conversion as a function of various operating conditions. The equilibrium constant and corresponding conversion are calculated using tabulated thermodynamic properties of the reactants and products, accounting for the electrical work contribution of the applied potential. Our system contains stoichiometric feeds, and we assume ideal liquids with unit activity and ideal gas mixtures. We first consider the case in which nitrogen and hydrogen react to form ammonia [Equation (1)]:



Running this reaction thermochemically is simply the commercially practiced Haber-Bosch process. Although equilibrium conversion can be much higher at low temperatures and ammonia is thermodynamically favoured at ambient conditions, the kinetics are only favourable at high temperatures, and high pressures are necessary to achieve reasonable conversions; at high temperatures. As a result, the standard operating conditions for the Haber-Bosch process are around 450°C and 200 bar. Replacing pressure with voltage in an electrochemical route to drive conversion to ammonia, the thermodynamics of the system become favourable without the use of elevated pressures. The voltage may also help to accelerate the kinetics with a suitably designed catalyst. To achieve low-carbon ammonia synthesis, the electrochemical route would need to use hydrogen gas sourced from splitting of water, perhaps also through an electrochemical route. Instead of first splitting water to generate hydrogen and then reacting this hydrogen with nitrogen in a separate electrochemical reactor, it is appealing to react nitrogen and water directly in a single reactor



### CONCLUSION

The review of the various processes indicates that it is feasible to adopt electrolysis routes for green hydrogen. Also, it is possible to implement electrochemical processes.

Though technical feasibility exists, there is a need to develop the technology and process to generate hydrogen and chemicals by this route cost competitively. For the suitability of the process, technical developments will take place.

### REFERENCES

1. Proceedings of Indo German Energy Forum, Federal Ministry for Economic Affairs and Energy (BMWi), Government of Germany.
2. Zachary J Schiffer and Karthik Manthiram, *Joule*, Electrification and Decarbonization of the Chemical Industry, September 6, 2017, pp 10–14.

# Bioethanol Production: Establishing the Potential of Brown Macroalgal Biomass of *Hydroclathrus clathratus* as Sustainable Feedstock

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**Abstract:** One of the most promising alternative fuels to address the current energy crisis is bioethanol. Algal biomass has been deemed more favourable for bioethanol production due to the existence of low lignin and hemicellulose concentration in contrast to lignocellulosic biomass. The present investigation focuses on establishing the suitability of brown macroalgae *Hydroclathrus clathratus* as carbon source to produce bioethanol through fermentation. The macroalgal biomass collected from Mandapam coastal waters was preprocessed using acid hydrolysis to obtain the hydrolysate rich in fermentable sugars. The amount of glucose in the fermentable sugars was estimated using DNS (3,5-Dinitrosalicylic acid) method and found to be 1.2 mg/ml. Further, the presence of major chemical groups in polysaccharides ( $1000\text{ cm}^{-1}$ ) was confirmed through Fourier Transform Infrared (FTIR) Spectroscopy. An anaerobic fermentation was carried out by the culture *Saccharomyces cerevisiae* using the hydrolysate as feedstock. The ethanol concentration from the distillate of the fermentation broth was determined using potassium dichromate method and found to be 0.4 g/ml. The ethanol production was also verified through Gas Chromatographic analysis and estimated that 16.65 g/L of bioethanol has been produced. Thus, the brown macroalgal biomass of *Hydroclathrus clathratus* was successfully established as potential feedstock for bioethanol production.

**Keywords:** *Hydroclathrus clathratus*; *Saccharomyces Cerevisiae*; Fermentation; Bioethanol

## INTRODUCTION

Biofuel is one of the most promising alternative fuels to resolve the present energy-related concerns. As a result, environmentally friendly, renewable, and sustainable energy has been discovered by the government, industrial, and energy sectors[1]. Around 40% of the total worldwide energy usage comprises of liquid biofuels, developed from renewable energy sources. It is a kind of fuel that derives its power from the biological processes that fix carbon[2]. The two main factors behind the current global energy crisis are uncontrollable population growth and the rise of industrialisation. It is inevitable for humans to rely on non-renewable energy sources, which causes the depletion of fossil fuels and the modification of the climate. Fuels produced from solid biomass, biomass conversion, various biogases, and liquid fuels make up biofuels[3]. The first-generation bioethanol process uses sugar and starch as carbon sources (from sources such as barley, corn, and potatoes). Worldwide, macroalgae is becoming more and more recognised as a significant source of third generation biofuels. The treatment of macroalgae can result in the production of a number of unusual sugars that can then be fermented to create a variety of bioproducts, including biofuels, biochemicals, biomaterials, and biofertilizers, depending on the macroalgae strain[4]. It has been acknowledged that seaweeds could be used to produce ethanol. A potential biochemical feedstock for the production of liquid biofuels like ethanol, butanol, and biogas is the polysaccharides present in macroalgae[5]. Although recently demonstrated *Saccharomyces cerevisiae* strains can also ferment monosaccharides into ethanol, engineered microorganisms are the most proficient at doing so. Brown algae have been considered a renewable biomass for the manufacture of bioethanol due to their quick growth rate and sugar content[6]. A prospective bioethanol feedstock, *Hydroclathrus clathratus* may be collected from the Ramanathapuram sea and has a dry weight cellulose content of 82.26 percent. Bioethanol is less toxic, easily degrades, and greatly reduces air pollutants than petroleum fuel. The use of bioethanol as a fuel for vehicles began with the development of the automobile[7]. Everything began with the use of ethanol in internal combustion engines. The utilisation of renewable sources of energy for the manufacture of biofuel is growing in popularity as a result of rising greenhouse gas (GHG) emissions, which are a significant contributor to global warming[8]. Biofuel development is being fuelled by factors including the need to boost energy security and price inflation as well as by piquing public and scientific interest. Identifying and producing energy that is environmentally friendly, renewable, and sustainable is the main objective[9,10]. The purpose of this study was to determine whether *Hydroclathrus clathratus* might be used as a

feedstock for bioethanol.

## MATERIALS AND METHODS

The overall methodology involved in the present work to establish the potential of biomass of *Hydroclathrus clathratus* as suitable feedstock for ethanol production is given in **Figure 1**.

### Collection of Macroalgal Biomass

The macroalgal biomass *Hydroclathrus clathratus* was collected from sea water of Mandapam region, Tamil Nadu, India.

### Preprocessing of Macroalgal Biomass

The biomass samples were properly cleaned with running water. The surplus water from the sample was drained using sunlight. The drained sample was dried at 100°C in an hot air oven. Mortar and pestle was used to grind the sample thoroughly. After sieving, the fine particles that remain were utilized for pre-treatment and further analysis.

### Composition of Macroalgal Biomass

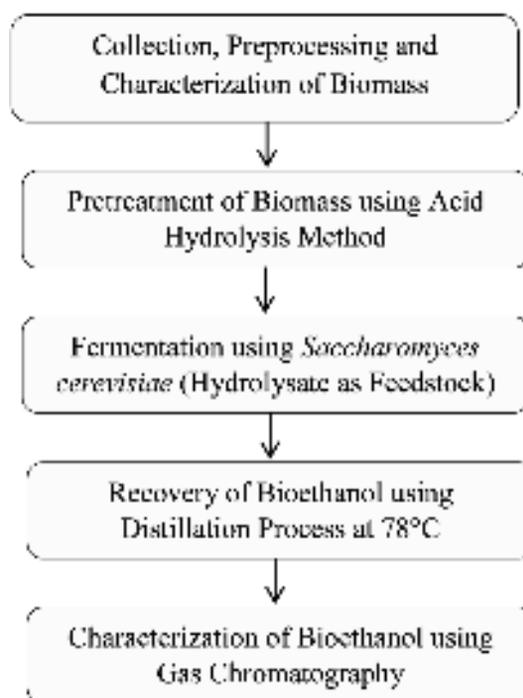
Moisture content was estimated using standard method. 3 g of powdered algal sample was taken and kept in the hot air oven at 105°C for 6 h. After 6 h, the weight of the sample was measured in the weighing machine. Ash content was determined by weighing samples before and after heating in a muffle furnace at 550°C for 12 h. Lipid content was determined using the Soxhlet method[11].

### Characterization of Macroalgal Biomass

The dried macroalgal biomass was characterized using Fourier Transform Infrared (FTIR) Spectrometer (Nicolet Nexus 670, USA).

### Pretreatment of Macroalgal Biomass

The dried macroalgal biomass was pretreated using acid hydrolysis method[12]. After hydrolysis, the hydrolysate was collected using centrifugation at 5000 rpm for 20 minutes and analysed for total reducing sugar concentration using 3,5-dinitrosalicylic acid (DNSA) method[13].



**Figure 1** Overall methodology

### Microorganisms used

Dry Baker's yeast (*Saccharomyces cerevisiae*) was purchased from local market and activated using warm water. The microbial culture was developed by inoculating activated yeast in Yeast Peptone Dextrose (YPD) Broth (Sisco Research Laboratories Pvt. Ltd. 66995) whose composition is given as: Yeast extract 10 g/L; Dextrose 20 g/L; Peptone 20g/L.

### Fermentation Conditions

The hydrolysate was subjected to fermentation using the above mentioned culture of *Saccharomyces cerevisiae*. In addition to the hydrolysate, yeast extract and peptone were added to the fermentation system at 10 g/L and 20 g/L respectively. Fermentation was carried out in the shaking incubator at 150 rpm for 72 h at 30°C.

### Ethanol Recovery and Estimation

Ethanol was recovered from fermentation broth by carrying out distillation process at 78°C and the distillate was collected. The distillate containing ethanol was estimated using potassium dichromate method[14]. The bio-ethanol production was further confirmed through Gas Chromatography – Flame Ionization Detector (GC-FID) at Tamil Nadu Test House Pvt. Ltd. Chennai, Tamil Nadu.

## RESULTS AND DISCUSSIONS

Preprocessing of macroalgal biomass makes acid hydrolysis process more effective. Thus, the collected macroalgal biomass were preprocessed as shown in **Figure 2**.

The composition of macroalgal biomass in terms of moisture, ash and lipids were measured and listed in **Table 1**.

The powdered sample of macroalgal biomass was given for the analysis of FTIR and obtained the results as shown in **Figure 3**. Based on the peak values, the functional groups were identified and listed in the **Table 2**.

**Figure 4** shows the acid hydrolysis of preprocessed macroalgal biomass and collection of hydrolysate. Here, sulfuric acid ( $H_2SO_4$ ) was utilised as the catalyst. In a 250 ml flask, three grams of dried macroalgal biomass were mixed with 30 ml of 0.2 M  $H_2SO_4$  and covered with a cotton and was then autoclaved for 15 minutes at 121°C. The residues were separated after hydrolysis by centrifugation at 5000 rpm for 25 minutes. This reaction hydrolyses cellulose which is a polysaccharide into reducing sugars such as glucose. Using DNSA method, a linear correlation between absorbance at 540 nm (y) and concentration of glucose in mg/ml (x) was obtained as  $y = 0.979x$  with  $R^2 = 0.9997$ . The amount of glucose in the hydrolysate was estimated to be 1.2 mg/ml.

**Figure 5** shows the distillation process which was carried out to separate bioethanol from fermentation broth. The distillation was collected and analysed for bioethanol concentration.

Using potassium dichromate method, a linear correlation between absorbance at 670 nm (y) and concentration of ethanol in mg/ml (x) was obtained as  $y = 0.044x$  with  $R^2 = 0.9693$ . The concentration of ethanol present in the distillate was found to be 0.4 g/ml.

About 10 ml of distillate obtained from the distillation process was given for the GC-FID analysis. The result obtained is shown in the **Figure 6**.

**Figure 6** shows a peak which represents the presence of ethanol in the given distillate sample whereas other residues were also present but in trace amount.



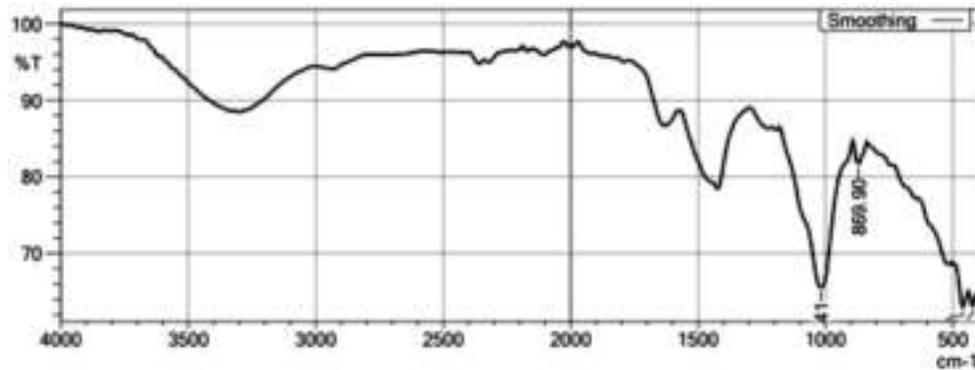
**Figure 2** Preprocessed macroalgal biomass

**Table 1** Composition of macroalgal biomass

S.No	Content	Percentage (%)
1	Moisture	9.63
2	Ash	6.47
3	Lipid	2.18

**Table 2** Functional groups of macroalgal biomass

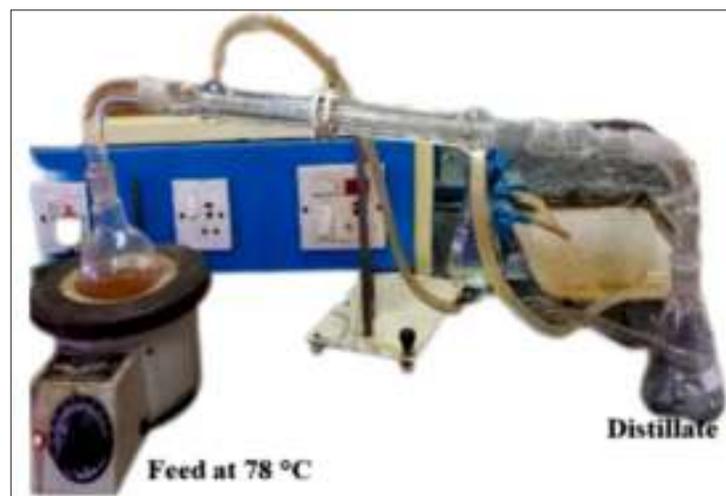
Peak (cm <sup>-1</sup> )	Group
3300-3400	N-H stretching
1450-1465	C-H bending
1040-1050	CO-O-CO stretching



**Figure 3** FTIR spectra of macroalgal biomass



**Figure 4** (a) Acid hydrolysis; (b) Separation of hydrolysate; (c) Hydrolysate



**Figure 5** Distillation process

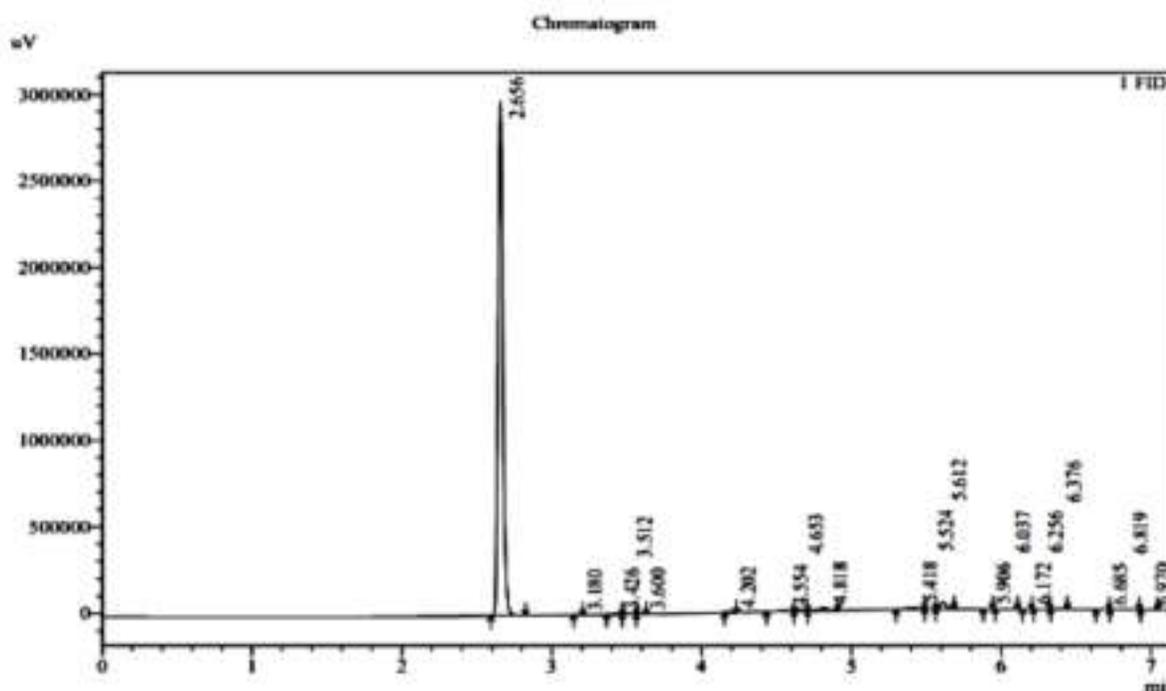


Figure 6 Gas chromatogram of distillate

## CONCLUSIONS

From the present study, the potential of macroalgal biomass of *Hydroclathrus clathratus* sustainable feedstock for ethanol production has been established. Though, the concentration of ethanol production is low, further improvement in pretreatment methods and microbial strain could achieve a significant increase in ethanol production.

## ACKNOWLEDGMENT

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## FUTURE SCOPE

With the present macroalgal system, further pretreatment, process optimization and alternate yeast strain could greatly affect ethanol production. An alternate yeast strain capable of ethanol production has been isolated from fermented idli batter and identified as *Candida tropicalis* JAV01 (Gen Bank Number: OP600490.1). The future work involves the optimization of process parameters for ethanol production using macroalgal biomass of *Hydroclathrus clathratus* by *Candida tropicalis* JAV01.

## REFERENCES

1. I. Dincer, Renewable Energy and Sustainable Development: A Crucial Review, *Renew. Sustain. energy Rev.*, vol 4, no 2, 2000, pp 157–175, doi: 10.1016/S1364-0321(99)00011-8.
2. G Sivakumar, et al, Bioethanol and Biodiesel: Alternative Liquid Fuels for Future Generations, *Eng. Life Sci*, vol 10, no 1, 2010, pp 8–18, doi: 10.1002/elsc.200900061.
3. E A, Biofuel: Sources, Extraction and Determination, *Liq. Gaseous Solid Biofuels - Convers. Tech.*, 2013, doi: 10.5772/51943.
4. S Behera, R Singh, R Arora, N K Sharma, M Shukla and S Kumar, Scope of Algae as Third Generation Biofuels, *Front. Bioeng. Biotechnol.*, vol 2, February 2015, pp 1–13, doi: 10.3389/fbioe.2014.00090.
5. K Kumar, et al., Recent Developments on Biofuels Production from Microalgae and Macroalgae, *Renew. Sustain. Energy Rev*, vol 65, 2016, pp 235–249, doi: 10.1016/j.rser.2016.06.055.



6. K B Möllers, D Cannella, H Jørgensen and N U Frigaard, Cyanobacterial Biomass as Carbohydrate and Nutrient Feedstock for Bioethanol Production by Yeast Fermentation, *Biotechnol. Biofuels*, vol 7, no 1, 2014, pp 1–11, doi: 10.1186/1754-6834-7-64.
7. M. Balat, H. Balat, and C Öz, Progress in Bioethanol Processing, *Prog. Energy Combust. Sci.*, vol 34, no 5, 2008, pp 551–573, doi: 10.1016/j.peccs.2007.11.001.
8. S Nanda, R Azargohar, A K Dalai and J A Kozinski, An Assessment on the Sustainability of Lignocellulosic Biomass for Biorefining, *Renew. Sustain. Energy Rev.*, vol 50, 2015, pp 925–941, doi: 10.1016/j.rser.2015.05.058.
9. E L La Rovere, A S Pereira and A F Simões, Biofuels and Sustainable Energy Development in Brazil, *World Dev.*, vol 39, no 6, 2011, pp 1026–1036, doi: 10.1016/j.worlddev.2010.01.004.
10. L Yang, M Takase, M Zhang, T Zhao and X Wu, Potential Non-edible Oil Feedstock for Biodiesel Production in Africa: A Survey, *Renew. Sustain. Energy Rev.*, vol 38, 2014, pp 461–477, doi: 10.1016/j.rser.2014.06.002.
11. N Kim, H Li, K Jung, H Nam, and P. Cheon, Bioresource Technology Ethanol Production from Marine Algal Hydrolysates using *Escherichia Coli* K011, *Bioresour. Technol.*, vol 102, no 16, 2011, pp 7466–7469, doi: 10.1016/j.biortech.2011.04.071.
12. V Alfonsín, R Maceiras and C Gutiérrez, Bioethanol Production from Industrial Algae Waste, vol 87, 2019, pp 791–797, doi: 10.1016/j.wasman.2019.03.019.
13. G L Miller, Use of Dinitrosalicylic Acid Reagent for Determination of Reducing Sugar, *Anal. Chem.*, vol 31, no 3, March 1959, pp 426–428, doi: 10.1021/ac60147a030.
14. M B Williams and H D Reese, Colorimetric Determination of Ethyl Alcohol, *Anal. Chem.*, vol 22, no 12, December 1950, pp 1556–1561, doi: 10.1021/ac60048a025.

# Role of Chemical Engineering Fraternity in Creating — A Sustainable and Self Reliant India

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**Abstract:** India is on rise, as world's great democracy as well as the hub of engineering excellence in terms of manufacturing capacity and engineering intellect. The basic needs of development of humankind being food, clothing and shelter the self-sufficiency and growth of chemical engineering industries is spearheading the nation's growth and so, the chemical engineering fraternity has a great role in creating a sustainable and self-reliant India. The challenge of the manufacturing industry is to develop the future needs with optimized use of raw materials, at minimum energy and ensuring that green products that don't harm the ecology is produced with green energy. These challenging areas are where, the chemical engineering fraternity is having the maximum opportunity to contribute than the other engineering branches. The offshoots from chemical engineering like biotechnology, bioengineering are also making the chemical engineering fraternity more intrusive into human body's chemical needs and well being in fields of human survival and increased lifespan.

**Keywords:** Chemical Engineering; Sustainable Development; Role; Self-reliant

## THE INDIAN MANUFACTURING GROWTH SAGA

The Indian growth story from Independence to present and the promises of future it holds, is in itself a remarkable growth story of sustainability, engineering, science, technology, and intellect development. Innovative growth, in manufacturing in terms of quantity and quality within affordable proportions for its masses and growth in exports, has made India a significant player in the world manufacturing and engineering scenario. The demographic growth of India, which was seen once with suspicion as a hindrance to development, was leveraged by improvement in education, science and technical knowledge growth, to catalyse the growth of Indian engineering and manufacturing sector in all spheres.

Indian aspirations are on rise as it finds itself in the confluence of a great pool of engineering talent resource and intellect spread not only in India but all over the world diaspora. And the government is dedicated to use all the advantages to change India to the manufacturing hub of the world and to focus on self-reliance for sustainable growth.

Sustainable development means the process of enabling development of social and economic progress of human activities to a pattern that can be sustained in perpetuity. In sustainable approach, the development has to address sustainment and replenishing of environmental needs within limits, so that the capacity of the nature to replenish its resources and coping with the consequences of human industrial activities is balanced. Social, environmental and economic accountability highlighted as Triple Bottom Line concept themes (Elkington, 1994) is the foundation stone of Sustainable development. Community or society which enhance growth, improves standards of development and also maintains harmony and balance between its social cultural, economic, environmental resources in a way that the members lead a happy healthy productive lives can be termed as a sustainable community.

To ensure sustainable growth of a nation, self-reliance in manufacturing matters, after the growth of a nation from developing to developed nation phase, or else the sustainability of growth will be choked by the interests of other stakeholder nations. Self Sufficiency and Self Reliance are virtues in isolation for nations in today's world where the needs demands and growth challenges are embedded in a varied hue of complex networks. For any nation to challenge its place into the top order in the competing world order on a firm basis the key objective is to be the technology leader in aspects of technical skills, along with a development of a skilled workforce with minimum unemployment amongst its technical fraternity. For improvement on national wealth utilisation and resource building up in sectors like manufacturing is also in a way developing forth a population mass which is surviving above poverty line. Self-sustainable self-reliance in a nation like India can be developed only with, skills, competitiveness of skills at world-class



levels, productivity of skills, infrastructure availability for skilled personnel and technological leadership in critical areas.

In a nation's context the apex objective should be a road map for: being a technology Leader, making all people move up the skill ladder; be competitive so that world is after you to get your goods; create enough job opportunities for all; all people to be much above poverty line (per capita income). The mantra to achieve this is — Skills, Productivity, Competitiveness and Technology Leadership.

For India, Self-Reliance or Self Sufficiency is not a conceptual new ideology even though India started its industrial growth journey during independence era. Pre independence relied and related history clearly states that the Indian name and fame in ancient science and technology is since time immemorial based on Vedic thoughts knowledge science etc. The colonial rulers left India in a shattered state with no manufacturing industries, the challenge of the governments in power was to develop and integrate India with huge investment in Power Plants, Steel Plants, Fertilizer Plants, and Refineries. India along with baggage of pre-independence economic thought and post independent economic strategy was to make and manufacture, everything as possible so that the populations basic needs are met with resources in our hand and since then India in 75 years have come a long way. From Import substitution to liberalisation reforms in 1991 growth was there but competitive edge was doubtful as being not challenged by demands of market economy. But after liberalisation Indian growth was spectacular with foreign investments, technologies coming in assimilating into India situations, making our people more skilled, our manufacturing competitive to world, and now India has integrated into the World Manufacturing segment. This integration of Indian capabilities to world class order was based on the skill set of the generations churned out in engineering and technological abilities. Improvements in research and development along with availability of a workforce technical engineering skillset was one of the reasons for the spectacular growth chain of India.

Clearly having a massive skilled talented manpower pool is an advantage for a nation like India but over the years of massive growth of engineering graduates without induction of practical skills has raised some question marks on quality of the engineering fraternity churned out. Without the required practical exposure and hands-on experience and original thought process skilled engineering fraternity to meet the challenges of industry and the nation to spearhead to the top of the order is an arduous task. Engineers above the mere levels of memorised theoretical concepts are required for the industry. Engineering fraternity with skills, dexterity, capabilities, having scientific temper, inquisitiveness, with skill sets to provide solutions to new challenges are required. Engineers need not only have technical abilities in these times but are to also have leadership roles in enabling concepts of sustainable development, challenges of climate change, depletion of resources, environmental pollution, rapid population growth and damage to ecosystems etc. Achievements in engineering has to be balanced and weighed with their impact on social, economic, and environmental natural systems in this century. The need of chemical engineering fraternity in taking lead role in development of self-reliant and sustainable growth is imperative as most of the environmental impacts of industry come in their domain of expertise.

### **CHEMICAL ENGINEERING FRATERNITY ROLE IN GROWTH**

The challenge of chemical engineering is to develop a balance between development and sustainability of various chemical products and processes. The nature's capacity to recoup and its capacity of sustenance is bearing the brunt of the growth, and hence the reason of the chemical engineering's sudden spurt across boundaries of space, spheres, time, flows, disciplines, goods and services. Engineers especially in the chemical sector's net positive contributions with adherence to ideals of achieving self-reliance and self-sufficiency in fertilisers, oil, textiles etc, has enabled the nation from the state of having nothing to the future promised land of everything now. Questionnaire Studies on steps needed to increase the sustainable growth of manufacturing in India also point out the need of advancements of chemical engineering being more innovative, energy efficient and with less carbon foot print is the key to sustainable development of nation.

The resurgence of Indian engineering and technology from participative contribution to leadership is one of the positive outcomes over the decades of country's investment of resources in the engineering mind-set and institutions. With the seamless engineering and technology attitude and capabilities that the Indian engineering community has, Indian engineers can be the harbinger to the sustainable development of our economy with correct embodiment of a nurturing, reformist social and political systems. The future of mankind will be decided by the future of India and hence the vibrancy, intellect equity of the new order world engineering wave in terms of innovation and production will be led by the connect and management of Indian engineering diaspora in technology.

Chemical engineering has been churning out various products that are needed for human well-being be it fertilisers,



medicines, food products but also are having a contribution in the degradation of ecosystem, environment, climate, resources that are essential for sustainable existence of human species. Many researches also have confirmed the need on chemical engineering's role in promotion of sustainable development, Batterham (2003) and need for chemical manufacturing companies to develop reliable indicators, indices, tools for effective review of sustainability Batterham (2006) for continuous growth of the engineering discipline. Notable among such yardsticks are the American Institute of Chemical Engineers (AIChE) much discussed and publicized Sustainability Index with well-defined metrics and practical benchmarks. But the vertical and horizontal growth of the chemical engineering in process intensification, multiscale control and structured product synthesis with aid of multi scale modelling and near life simulations Charpentier (2007) is creating tremendous and critical interest with ambitious net zero targets to mitigate carbon emissions, climate change impacts & sustainable processing.

Increased bioprocessing utilising the technologies in the toolbox traditionally along with new areas of artificial intelligence, big data, and cloud computing etc opportunities to improve processes, equipment design, fabrication and relevant applications. Improved real-time monitoring, point-of-issue sampling, detection techniques, process control abilities are expanding the horizon of improving and manufacturing, energy efficient, sustainable, reduced carbon print, specific products and prototypes. Atmanirbhar Bharat which translates to 'Self-Reliant India', is based on five defined vertical pillars of Economy, Infrastructure, System, Vibrant Demography and Demand is meant to cater to social, economic and environmental domain needs with sustainability as its core. Enabling skills, education, engineering and technological upgrading, entrepreneurship is going to enhance the accreditation of Sustainable and Self Reliant India's technological drive and the boom of Chemical Engineering profession is going to be the driver of the phase.

Survey conducted on ninety-five engineers from various segments of manufacturing and engineering academia also signifies the role of chemical engineering fraternity in the self-reliance and self-sufficiency of India. A survey was conducted on finding the relationship between factors of Sustainable Development, Self-reliance, Chemical Engineers Role, Contribution of Chemical Engineers to have an perception of the role relevance of chemical engineering fraternity. The mathematical analysis is attached as **Appendix I**.

## **CHEMICAL ENGINEERING — THE FUTURE PERSPECTIVES**

Chemical engineering if we analyse is focused on understanding interactions at the molecular level, which can be scaled up to the industrial level, with potential of research and development, last-mile delivery, manufacturing and inventing new products for mankind. Indian engineering and manufacturing industry is on the threshold of positive changes with the positive outcomes over the decades of country's investment of resources in the engineering mind-set and institutions. And with the seamless innovative, engineering and motivated technology attitude and capabilities that the Indian chemical engineering fraternity has, it can be the harbinger to the sustainable and self-reliant development of our economy. As Indians have made foray into many parts and positions in the engineering diaspora of the world with their vibrancy, & intellect equity the new world engineering wave in terms of innovation and production will be led by the connect and management of Indian engineering diaspora in technology. And in the new era of manufacturing the multidisciplinary nature and skill set of chemical engineering fraternity, they could indeed play a major role in promoting and enhancing sustainable development. In engineering all aspects of engineering handle the systems in static state but the chemical engineers have to respond to the dynamic state of interaction in their activities and hence need to have a bird's view of all engineering expertise for effective economic solutions to new challenges. Commitment to sustainability, innovation, environmental performance, safety, product stewardship, social responsibility, value-chain improvement, adds to challenges faced by chemical engineering as reducing carbon footprint of manufacturing is now preferred based on climate change challenges. The control of processes, unit operations, energy efficiency with green initiatives are going to be the design basis in chemical engineering in the future and the tools of big data, artificial intelligence, new developments in frontiers of nano technology etc. are going to be integrated for satisfaction of new design needs of human species.

## **RESEARCH METHODOLOGY**

The research design of this study involves a questionnaire survey administered to a sample of Engineers ,higher end Executives related to academia &, manufacturing sectors in major large scale industries. The objective of the study is to establish the influence of Chemical Engineers role in sustainable development and for making India as self-reliant

## **HYPOTHESIS TESTING**

A Hypothesis is an assumption about a population of the study. Hypothesis is predictions that involve variables and



statistical data followed by tests. They are tentative assumptions made in order to draw out and arrive conclusions based on hypothesis testing (Research Methodology, C R Kothari). The various hypotheses developed for this study are given here.

Hypothesis 1 (for Part A in Questionnaire)

- H01 = There is no significant relationship between the role of chemical engineers and sustainable development
- Ha1 = There is significant relationship between the role of chemical engineers and sustainable development

Hypothesis 2 (for Part B in Questionnaire)

- H01 = There is no significant relationship between the role of chemical engineers and making India as self-reliant
- H02 = There is significant relationship between the role of chemical engineers and making India as self-reliant

### **Data Analysis and Interpretation**

The results of the empirical analysis are being discussed in this section. By using SPSS, the statistical analysis of this research was carried out. Data analysis comprised of Reliability Tests, Test for Normality, Correlation Analysis and Paired samples T-Test.

Step 1: Reliability Analysis

By doing the reliability analysis of the variables, an overall picture of the study was got. From the reliability analysis Cronbach's Alpha obtained is greater than 0.9 ie., 0.972 and this indicates excellent accuracy of the measuring instrument.

Step 2: Normality Tests

Once the Reliability analysis is over, the next stage is to check whether this study follows a Normal Distribution or not, The Normality shows the study follows the Normal Distribution,

Further data analysis was done with the help of parametric testing like correlation analysis, paired T test and independent sample T test for which the results are tabulated below.

Step 3: Correlations

Correlation is a term that refers to the strength of relationship between two variables. It is used to show whether and how strongly pairs of variables are related.

A strong positive correlation is obtained in our study, which shows that the selected variables are highly relevant.

Step 4: T-Tests

A paired sample t- test is used to determine whether there is a significant difference between the average values of the same measurement made under two different methods. Both measurements are made on each unit in a sample, and the test is based on the paired difference between these two values. The usual hypothesis is that the difference in the mean values is zero.

Hypo: 1 and 2 Results

From the independent sample t-test conducted (refer table in **Appendix**), the p-value obtained is less than 0.01. Hence, the null hypothesis is rejected and alternate hypothesis is accepted. There exists a significant relationship between the groups of variables for the factors taken.

Detailed SPSS analysis sheet are attached as **Appendix I**.

### **CONCLUSION**

India is in a clear path to global leadership in engineering and technology and becoming self-reliant in many of these spheres as the country has the resources, the institutions and the mind-set too to innovate, sustain, develop and improve on a constant basis. The essential condition for India's path towards self-reliance and emergent role in global engineering and technology, are that the Indian chemical engineering fraternity has to assimilate the advantages of the Indian growth conditions, tempered by the social and political systems, to be the harbinger of development of Indian economy in self-



reliable and sustainable way. Definitely Indian chemical engineering fraternity has a great role-play in it as per the survey highlights.

With the help of statistical and empirical data, results have provided general support for the hypothesis. It is found that there is significant relationship exists between paradigms in role of Chemical Engineers and sustainable development to make India self-reliant.

Sustainability is going to be the amalgamation of social responsibility, environmental stewardship and economic growth with the resources available for development of the nation. As the Indian chemical fraternity is having new opportunities with the massive increased chemical industry growth, the role of chemical engineers is challenging to provide eco-friendly manufacturing solutions to human population needs.

## REFERENCES

1. B R Bakshi, Toward Sustainable Chemical Engineering: The Role of Process Systems Engineering, *Annu. Rev. Chem. Biomol. Eng.*, 10, 2019, pp 265–288.
2. R J Batterham, Sustainability – The Next Chapter. *Chem. Eng. Sci.*, 61, 2006, pp 4188–4193.
3. R J Batterham, Sustainability – The Next Chapter. *Chem. Eng. Sci.*, 61, 2006, pp 4188–4193.
4. R J Batterham, *The Chemical Engineer and the Community*, 2003.
5. J C Charpentier, Modern Chemical Engineering in the Framework of Globalization, Sustainability, and Technical Innovation. *Ind. Eng. Chem. Res.*, 46, 2007, pp 3465–3485.
6. H J Cruickshank and R A Fenner, The Evolving Role of Engineers: towards Sustainable Development of the Built Environment, *Journal of International Development*, 19 (1), 2007, pp 111–121.
7. Asit Das, *Key Contribution of Engineering Science in Sustainable Development of India*, 2020.
8. R Dodds and R Venebles, *Engineering for Sustainable Development: Guiding Principles*. The Royal Academy of Engineers, London, UK, 2005, p 52.
9. J Elkington, Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development, *California Management Review* 36, no. 2, 1994, pp 90–100.
10. J García-Serna, L Pérez-Barrigón, M J Cocero, New Trends for Design towards Sustainability in Chemical Engineering: Green Engineering. *Chem. Eng. J.*, 133, 2007, pp 7–30.
11. C R Kothari, *Research Methodology*.

## APPENDIX I

### Reliability Check of the Questionnaire using Cronbach's Alpha

Reliability

Case Processing Summary			
		N	%
Cases	Valid	24	100.0
	Excluded <sup>a</sup>	0	.0
	Total	24	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics	
Cronbach's Alpha	N of Items
0.972	4

Here the obtained value is 0.972, hence the questionnaire is valid.



### Finding Correlations

		Correlations			
		Sustainable Development	Chemical Engineers Role	Self-reliant	Contribution of Chemical Engineers
Sustainable Development	Pearson Correlation	1	0.939**	0.997**	0.716**
	Sig. (2-tailed)		0.000	0.000	0.000
Chemical Engineers Role	N	95	95	95	95
	Pearson Correlation	0.939**	1	0.994**	0.715**
Self-reliant	Sig. (2-tailed)	0.000		0.000	0.000
	N	95	95	95	95
Contribution of Chemical Engineers	Pearson Correlation	0.716**	0.715**	1	1
	Sig. (2-tailed)	0.000	0.000		0.000
	N	95	95	95	95

\*\* . Correlation is significant at the 0.01 level (2-tailed).

All values obtained are positive. Hence strong positive correlation exists between our selected variables and the study is significant.

### Hypothesis Testing

Methods used are Paired Sample T Test and Independent Sample T Tests

		Paired Samples Test					t	df	Sig. (2-tailed)
		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Sustainable Development - Chemical Engineers Role	-0.300	0.865	0.193	-0.705	0.105	-1.552	92	0.137
Pair 2	Sustainable Development - Self-reliant	-0.500	0.834	0.186	-0.590	0.190	-1.073	92	0.297
Pair 3	Sustainable Development - Contribution of Chemical Engineers	0.150	1.565	0.350	-0.583	0.883	0.429	92	0.673
Pair 4	Contribution of Chemical Engineers - Self-reliant	0.050	0.686	0.153	-0.271	0.371	0.326	92	0.748

		Independent Samples Test								
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Sustainable Development	Equal variances assumed	.	.	-1.794**	92	.078	3.000	0.000	3.000	3.000
	Equal variances not assumed						3.000			
Chemical Engineers Role	Equal variances assumed	.	.	-1.621**	92	.110	4.000	0.000	4.000	4.000
	Equal variances not assumed						4.000			
Self-reliant	Equal variances assumed	.	.	-1.629**	92	0.110	2.111	0.633	4.650	3.572
	Equal variances not assumed						2.111			
Contribution of Chemical Engineers	Equal variances assumed	.	.	-1.312**	92	.192	4.000	0.000	4.000	4.000
	Equal variances not assumed						4.000			

## Gas Liquid Absorption in Simulated Packed Column (Stephens-Morris Type Disc Column) with Pulsed Gas Phase

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**Abstract:** Providing pulsation technique, imparting agitation and causing vibration into the continuous phase in gas-liquid absorption process increases the rate of absorption and mass transfer coefficients in both liquid phase and gas phase. The enhancement of mass transfer processes, caused by pulsation in the continuous phase is due to (i) increased turbulence which they induce at the interface and hence enlarged contact surface in both phases and (ii) to accelerate the relative velocity between to phases.

Earlier the effect of pulsation has been investigated in many types of chemical engineering apparatus in presence of liquid phase pulsation. However, the effect due to gas phase pulsation has been virtually neglected or done by very limited researchers.

In order to study the effect of gas phase pulsation on mass transfer in packed columns, initially experimental investigations are carried out in a simulated packed column of Stephen-Morris type disc column with known interfacial area. This is fabricated with stainless steel discs arranged in regular fashion on a stainless steel wire, all in the same plane, forming the absorption surface. It developed a column in which the film of liquid is interrupted at short intervals during it's descent, thus simulating the conditions of flow over a packing and thus maintaining packed column characteristics.

The process of absorption of a gas of low solubility gas ( $\text{CO}_2$ ) in  $\text{CO}_2$ -water system and one of high solubility gas ( $\text{NH}_3$ ) in  $\text{NH}_3$ - $\text{H}_2\text{O}$  system both belongs to physical absorption, in which no chemical reaction takes place between the dissolved gas and liquid. Another fast, irreversible chemical reaction  $\text{CO}_2$ -NaOH system, the absorption accompanied by chemical reaction where the dissolved gas reacts with liquid or with a substance dissolved in the liquid column have been investigated in the simulated packed column providing pulsation in gas phase. And then extended to the regular packed column of different dimensions (diameter and height) with different types of packings-raschig ring, glass spheres and ceramic pall rings.

The varying operating conditions are — (i) liquid flow rate (0.24 – 0.6) litre per minute, (ii) gas flow rate (6 – 36) litre per minute, (iii) pulsation frequency (0 – 9.06 Hz), (iv) effect of pulsation amplitude (0 – 26 MM), (v) effect of sodium hydroxide concentration (normality 0 – 4 N), (vi) effect of solute gas concentration (0 – 100 %), (vii) effect of varying the number of disc to 15, 20, 25 and 33 (varying the length of the column and interfacial area).

(a) It was established that coefficient of absorption increases in (i) direct proportional to the amplitude of pulsation and the frequency of pulsation (ii) increases to the liquid flow rate to the power 0.36 in case of unpulsed case and to the power 0.48 in case of pulsed case. Beyond frequency of pulsation of 5.43 Hz it is found to be 0.433.

(b) For liquid film controlled system  $\text{CO}_2$ - $\text{H}_2\text{O}$  and  $\text{CO}_2$ -0.5 N NaOH, the change of gas flow rate has absolutely no effect on the mass transfer rate. However, in the gas film controlled system (air-ammonia-water) shows that the mass transfer coefficient is proportional to the power 1.07.

(c) Absorption of liquid phase increases with the frequency of pulsation passes through a peak at 4.5 Hz, then decreases and increases again. For all amplitudes curves are almost identically in shape but of different slope.

(d) The rate of absorption for all the three systems studied for both pulsed and unpulsed conditions in varying number of discs, varying the solute gas concentration and varying the NaOH concentration, it is observed that the mass transfer is enhanced about 3 times with pulsation than that in the unpulsed case. The increase of partial coefficient of absorption of liquid phase proves of that the pulsating gas phase dose affect the liquid phase mass transfer.

**Keywords:** Disc Column; Pulsation; Amplitude; Frequency; Rate of Absorption; Mass Transfer Coefficient; Enhancement of Mass Transfer



## NOTATIONS

A	= Pulsation amplitude, mm
c	= Constant coefficient
d	= Diameter of a disc,
cm	= Diffusivity, cm <sup>2</sup> /s
F	= Pulsation frequency, Hz
h	= Height of a disc, cm
K <sub>g</sub>	= Gas phase mass transfer coefficient, g-mole/(cm <sup>2</sup> )(s)(atm)
K <sub>l</sub>	= Liquid phase mass transfer coefficient, cm/sec
K <sub>l0</sub>	= Liquid phase mass transfer coefficient without pulsation cm/sec.
N <sub>A0</sub>	= Rate of absorption (unpulsed), gm.mole/(cm <sup>2</sup> )(sec)
N <sub>AP</sub>	= Rate of absorption (pulsed) gm.mole/(cm <sup>2</sup> )(sec)
V <sub>g</sub>	= Velocity of gas, cm/sec
V <sub>l</sub>	= Average velocity of liquid with disc, cm/sec
V <sub>p</sub>	= Average velocity of pulsating gas cm/sec
T	= Time, s
t <sub>p</sub>	= Time period of one complete cycle, s
Z	= Degree of undulation, dimension less
ρ	= Density of liquid, g/cc
μ	= Viscosity of liquid, g/(cm)(sec)
Γ	= Volumetric loading rate, ml/(cm)(sec)
σ	= Liquid surface tension, (dynes/cm)
ν	= Kinematic viscosity, stokes
Re	= $4T/\mu$ , Reynolds number, dimensionless
Sc	= Schmidt number, dimensionless
Sh	= Sherwood number, dimensionless

## INTRODUCTION

Gas absorption is the unit operation in which one or more soluble components gas or gas mixture are dissolved in a liquid. The absorption may be purely physical phenomenon or may involve solution of the material in the liquid followed by reaction with one or more constituents in the liquid solution.

Absorption, desorption (stripping) are usually carried out in vertical, cylindrical columns with packing elements, particularly, widely used one is the packed column. The gas and liquid normally flow counter-currently in this column and the device serve to provide the intimate contacting between the two phases gas and liquid and the development of interfacial surface through which mass transfer takes place. These mass transfer operations are based on transfer of one or more components between two or more fluid phases. The development of interfacial area is hence the key factor for enhancing the mass transfer. Pertinent to the above, it is very well known that the mass transfer between two fluid phases can be greatly improved by external agitation, mechanism of pulsation or vibration of the gas phase, pulsation of the liquid phase, the vibration of the equipment as a whole, or the eddies and current of the turbulent flow. Because, it causes to enhance the contact surface, interfacial area and velocity of the transport species and acceleration of the relative velocity between two phases. These factors, created during the process, plays a vital role to enhance the rate of absorption, mass transfer co-efficient both in gas phase as well as in liquid phase.

It is an established fact that two main factors are there which influences the interphases mass transfer process are (i) Hydro-dynamic factors, (ii) Concentration dependant factors. Hydro-dynamic factors include flow rate of the



process, geometry of the equipment, interfacial area, interfacial tension between phases, viscosity, density etc., whereas, the concentration gradient factors include solubility, equilibrium between phases, chemical reaction, time of contact, concentration, diffusivity, etc. For increasing the surface area, methods used are (i) Film method, (ii) Rupture of bulb fluid, (iii) Dispersion through sub-merged orifices, etc. Rupture of bulb fluid is simplest and most common some industrial applications are in the field of chemical processing, bio-chemical science and technology, refining and petrochemicals, pharmaceutical industries and environmental engineering etc.

The effect of pulsation has been successfully studied in packed column absorption and extended too many other mass transfer absorption processes like falling film, waited wall column and bubble column etc. The influence of pulsation on the course of other processes such as dissolution of a solid, absorption, sublimation, drying and boiling, heat transfer equipment has been studied. In all these cases the course of the process is dependent on the pulsating motion of the given medium in which the process occur.

The increase of mass transfer/heat transfer for such processes caused by pulsation of the continuous phase has many advantages. The attraction of reducing the size of the transfer equipment has dragged many workers in these field. The mass transfer co-efficient is highly influential in scale up and optimising the cost and size of the equipment. Though, the pulsation technique used now a days to intensify the mass transfer rate, this is still in laboratory scale. But the results obtained are quite encouraging, effective and found economical to use in optimising the design and scale of the equipment and hence quite beneficial to use in development of the process.

## LITERATURE REVIEW

The effect of Pulsation on absorption has been studied for many years both for liquid-liquid extraction column, bubble column and packed column.

### Liquid-liquid System

The efficiency of liquid-liquid contacts is primarily dependent on the degree of turbulent imparted to this system and the interfacial area available for mass transfer. The rate of transfer can be enhanced by pulsating motion imparted to these liquids.

Hussein (1988)[1] has reported that based on the result obtained by the investigation of Van Dijck, this column is being used in number of industries including Petrochemical, metallurgical and nuclear fuels.

Jahya et al (2000)[2] studied the hydrodynamic characteristics, especially the flood point and dispersed phase hold up of the extractor. Based on this they determined the cross section area required to accommodate the desired flows without flooding.

Jahya (2000)[2] is then considered the mass transfer co-efficient in estimating the column height.

Yadav and Patwardhan (2008)[4] tested the available correlations of mass transfer coefficient against a large set of experimental data gathered from different researchers over the past 60 years.

Leo, et al (1998) studied the hydrodynamics and mass transfer performance and assessed that the efficiency of extraction column is still far from satisfactory. He further stated that the efficiency of liquid-liquid Contactors is primarily dependent in the degree of turbulence imparted to the system and the interfacial area available for mass transfer.

Very little is known about the effect of agitation, super imposed on the flow of the two phases in an extraction column, on the enhancement of mass transfer coefficient (Torab -Mostaedi, et al 2008)[5].

The beneficial effect of pulsed flow on mass transfer in liquid-liquid extraction column has also been studied [6-10]. The effect of pulsation on fluid-solid system has been measured [11-13]. The fluid dynamics of the pulsatile flow in a circular tube has been studied by Kusama [14], Lambrosly [15] and Womarsley [16].

Studies has been carried out on the effect of pulsation in increasing mass transfer rates in extraction column [17-19], in solid-fluid transfer in packed towers [20] and in transfer from isolated objects [21]. Harris [22], et al (1967) studied the theory for the rate of mass transfer with oscillatory flow in the tube. They found the increase in transfer rate is due to the molecular diffusion alone as a function of three-dimension less groups Reynolds number, Amplitude parameters and Schmidt number.



## Bubble Columns

Several workers [23-28] have found that gas absorption rate from bubble dispersions can be increased by the application of vertical vibration. The largest effect have been found in the frequency range of 10–150 C/S with well-defined maximum values at certain frequencies[26]. Measurement of gas hold-up as a function gas frequency[24-29] also show peak values at certain frequencies[8]. At high vibration intensities, gas bubble may be prevented from rising altogether [26, 31-32] or entrained downwards from the liquid surface[33].

In case of bubble column, the movement of a single bubble caught in a vibration liquid column in wide range of frequencies, amplitudes, liquid viscosities and densities was predicted by Rubin[35] which was quite good in agreement with experiment.

Hellium, et al[36] studied diffusion in pulsating flow in which he tried to develop theoretically the effect of pulsation in the flow field on inter phase mass transfer.

Baird, et al[34] determined the power consumption and gas hold up in a pulsed column. A resonant air pulsed water column was developed and experiments were described with raschig rings and fitted with baffle plates for packed and unpacked cases. The observed power consumption and theoretical predictions were all in good agreement.

Kubo, et al[37] studied the operating characteristics of multistage pulsed gas bubble column. In their experiment an off and on pulsating motion was superimposed on the feed gas stress in order to improve the performance of perforated plate multistage gas bubble columns.

Gas absorption in a pulsed bubble column was studied by Baird, et al [38]. In his case the absorption of CO<sub>2</sub> from air into tap water was measured in a pulsed bubble column of 'H' type. Compressed air was used for pulsation at frequency of 1.09 -1.35 Hz end amplitude up to 3.7 inch. Gas hold up (€) and mass transfer product (K<sub>L</sub>a) increased as much as three fold by pulsating.

The dynamics of a packed gas absorber by the pulse responding technique was studied by Sakata, et al [39] in which the dynamics response of a packed gas absorber to inlet gas composition changes was investigated by pulse response technique, where absorption was accompanied by pseudo first order irreversible reaction.

Krenner, et al[40] examined two limiting cases of mass transfer in a bubbling column with sharp pr. drop analytically (I) for a low rate of bubble growth (bubble size) i.e. for a laminar hydrodynamic layer about the bubble and [11] for a high rate of bubble growth (pr. drop) that is with a turbulent Boundary layer. Formulas were developed as a function of pulse frequency.

Zielkowald, et al[41] studied the effect of pulsation on mass transfer with bubbling through a deep liquid layer.

## Pulsating the Gas Stream

Desorption of CO<sub>2</sub> by air from water and evaporation of water in a stream of heated air were studied by Vasin, et al[42] in single tray test columns 100 and 260 mm diameter containing a sieve or valve tray with 10% free area. Results showed that pulsating the gas stream and gas liquid layers on bubble trays increased the liquid phase mass transfer rates. The effect of the location of the pulse generator suggested that amplitude, as well as frequency of pulsation has an effect on mass transfer.

Mass transfer between drops and pulsating fluids were studied by Molinier, et al[43]. The problem was studied for the case where resistance to mass transfer lied in the continuous phase.

Lamb[44] observed the natural oscillation of drops. Tudose[45] applied external pulsations to the gas phase and subjected the drops to undergo oscillations. In another investigation with pulsating gas phase Tudose[45- 46] found that the volumetric flow rate of the liquid for the incipient entrainment considerably decreased at a certain resonance frequency. He reported the work of Richardson, who studied the velocity profile of air, pulsating at frequencies 5-25 Hz in a Square duct. Contrary to known profiles he observed a ring effect, whereby the flow velocity reaches to a maximum value in the vicinity of the wall and gradually drops to a low value at the centre of the tube. The solution for the simplest case of pulsating laminar flow in a rigid tube has been given by Sexl [47].

Pasiuk and co-workers[48] (1959) initiated the study of the influence of pulsating motion on mass diffusion in a gas-



liquid system. Minnaert[49] first analysed the sound of bubbles produced at jets under various liquids and conducted that most of the sound was produced by radial pulsation of the bubble. Shortly after-wards Smith[50] considered the reverse effect the vibration of bubbles produced by sound generated in the liquid. In view of the above work it seemed likely that bubble vibration phenomena could be used to improve mass and heat transfer operations. Harbaum[55] studied the effect of sonic vibration on the absorption of CO<sub>2</sub> and from bubble in water.

Tudose[45- 46] investigated the mechanism for intensification of the process of absorption in a falling film of liquid by pulsating the gaseous phase. Buchanan[51] studied the promotion of different gas absorption by cyclic bubble migration using the absorption of oxygen from air by sodium sulphite solution. Jameson[52-53] has provided a mathematical expression for measuring the bubble velocity in a pulsating liquid and has obtained conditions at which the bubbles would move upwards, remain station any or more downwards.

Experimental measurements of terminal velocities of solid spheres falling through a pulsating liquid were carried out by Tunstall and Houghton[54]. The theoretical investigations of Houghton[54-55] show that motion of a freely falling particle is retarded by oscillating the surrounding fluid, and the uncertain conditions the motion of particle can be completely arrested Vyarawalla[56] studied the effect of gas phase pulsation on mass transfer from drops.

Lemlich[57] found a maximum of 660% enhancement in the rate of sublimation from a sphere of naphthalene achieved by vibrating it at frequencies of 20-120 Hz. Enhancement of mass transfer coefficient was also found by Noorderji and Rotte [61] by vibrating nickel sphere in solutions of K<sub>4</sub>Fe(CN)<sub>6</sub> and NaOH.

The effect of Pulsation has been studied in many types of Chemical engineering apparatus: heat exchangers, boilers, burners, fluidised bed reactors and drivers. Liquid-Liquid extraction columns and bubbling absorption in presence of liquid phase pulsation has been investigated by many authors.

Bubbling absorption in the presence of liquid phase pulsation has been investigated both in Poland [48,73-74] and USA[75]. Pulsed gas phase packed column absorption, however, has been virtually neglected except by the Romanian school[76-81] should be noted, moreover, that these studies have been almost solely concerned with immediate practical aims.

The literature does not yet contain an exhaustive account of the influence of periodic hydrodynamic disturbances of the gas flow rate on packed absorption column efficiency. Very little Work has been done on the study of effect of pulsation on pulsed gas phase Packed Column absorption.

The enhancement in mass transfer rate due to pulsations has been gradually related to the two basic requirement of a pulsating flow – viz. amplitude and frequency of pulsation. The rate of mass transfer has been found to increase linearly with the amplitude by many workers[45-69] some however, obtained a peek rate of mass transfer at only one particular amplitude for a fixed frequency of pulsation.

Axial diffusion in a cylinder with pulsed flow was studied by Harris, et al[31] in which the theory of the rate of mass transfer through a long tube connecting two reservoirs of constant concentration with oscillatory flow of tube, is developed.

Tudose[45-46] found the mass transfer intensification peek only at one particular frequency where as Harbaum and Houghton[50] found as many as five peeks. Baird suggested that these peeks occurred transition points

between resonant which of vibration of gas-liquid dispersion. Baird[62] also suggested that lower frequencies the gas hold up in a pulsed bubble column tends to alter in such a way that the system is always in resonance with the frequency of applied vibration. A few workers, however, have found the rate of mass transfer increasing with the increase of frequency without encountering any intensification point. Theoretical study on diffusion is pulsating flow has been given by Alabastro and Hellium [63] where he obtained the solutions for dimensionless concentrating equations by the method of LightHill [64].

It has been reported by several authors[65-66] that the power requirement for creating pulsations in a column is generally quite low when the overall enhancement of the mass transfer is considered. Healous and Jhonso[67] made a mathematical analysis of the power requirement in pulsating a fluid, as a function of inertia, fluid friction and static head of the fluid.

The absorption of oxygen from air into tap water in a pulsed bubble column was investigated by Baird and Garstang[68].



They used compressed air for pulsation where the earlier workers used mechanical means for producing pulsations. He gives an excellent review of the previous investigations of several authors.

Packed column was never before tried for enhancement of mass transfer with sole concern with immediate practical aim. Gianetto and Sicardi[70] tried packed columns exhaustively. In note they[70] carried out a theoretical research of hydrodynamics to perform a systematic quantitative study of the influence of gas flow disturbances on the operating conditions of an absorption column. To those end, propagation, phase shift and attenuation of harmonic pressure oscillations on a gas moving in a column packed with Raschig rings on the absence or in the presence of a fluid counter-currently percolating were studied.

A mathematical model was proposed and verified experimentally for various operating conditions, by comparing an effective mean velocity value analytically calculated; with the value obtained by direct measurements of pressure drop and by comparing the law of theoretical attenuation values. Finally an electrical simulation of pressure oscillation propagation was suggested.

He further[71] examined the influence of gas-flow periodic disturbances on the efficiency of a counter-current packed column. Particular attention was given to the mass transfer interfacial area. The latter was determined by measuring absorption in the presence of variously fast chemical reactions in the liquid phase. Several types of packing were employed and a wide range of liquid and gas flow rates and of oscillation frequencies and amplitude were experiments.

Under certain conditions, the transfer area was three times greater on the presence of pulsations than in their absence. A general relationship was also proposed between the increase in surface areas due to pulsation and difference between the mean pressure drop values per unit column height with and without pulsation. This latter parameter was argued as proportional to the volumic power dissipated on maintaining pulsation.

Correlations were given for the forecasting of main pulse presence drop in function of column operative parameters and for the knowledge of conditions in which gas induced entrainment of liquid would occur.

He further tried two systems one liquid mass transfer controlled[72] and another gas mass transfer controlled. Absorption of  $\text{NH}_3$  into  $\text{Na}_2\text{SO}_4$  solution were carried out in steady and pulsed systems in which the gas side resistance is higher than the liquid phase resistance.

In liquid mass transfer; liquid mass transfer coefficients in counter current column with and without pulsed gas phase were measured by desorption of oxygen with air from NaOH solution.

The coefficient  $K_{L0}$  obtained in steady flow was on agreement with determined by other authors for different packing dimensions; a theoretical explanation of the behaviour of  $K_{L0}$  as a function of liquid superficial velocity was also proposed. The mass transfer coefficient  $K_L$  in presence of pulsation was higher than steady one. ( $K_L/K_{L0}$  values up to 3.5 were found). Thus enhancement was assumed the vibration of liquid films increased the renewal surface.

The ratio  $K_L/K_{L0}$  diminished when owing to high liquid hold up; the pulsation generated “foaming” which probably reduced the mobility of liquid. A correlation between increase of ratio  $K_{La}/(K_{La})_0$  as a function of ratio of pressure drop in case of pulsation to without pulsation was reported.

In gas-mass transfer absorption of  $\text{NH}_3$  into  $\text{Na}_2\text{SO}_4$  solution were carried out in steady and pulsed system. As regards the steady flow, the correlation of the ratio between the mass transfer coefficient with and without liquid feeding, for various operates conditions, as a function of the ratio of the corresponding pressure drop resulted rather satisfactory.

In pulsed flow the increase of gas mass transfer coefficients  $K_y$  due to disturbances was reported as a function of the pulsating parameters, and was correlated with the energy consumption due to pulsation.

They found  $K_y$  enhancement resulted lower than those observed for interfacial areas and liquid mass transfer coefficients.

### Theoretical Considerations

A pulsating flow is one that is continuously accelerated and retarded. This alternate movement can improve mass transfer.

In absorption process pulsations can also be appointed to gas phase. These pulsations can either create turbulence in the



gas or through the gas phase, they may act upon the liquid phase. In order to study the influence of pulsations on the increase in rate of absorption process, it is necessary to obtain first a thorough knowledge of the flow characteristics of the two phases as well as the interactions between them.

An increase in mass transfer can take place in the accelerating or retarding period. These periods can be considered as an incipient process in which the interface is not yet completely developed. Under these conditions of flow the interfacial layer is very thin, resistance to the process of mass transfer is reduced and the rate of the process is increased.

There is variation of mean values of absolute velocities with distance from the wall at different frequencies. Contrary to the known profiles for steady state flows, in a pulsating flow a wavy effect is observed; where the flow velocities reach a maximum in the velocity of the wall and then drops suddenly towards the wall. This phenomenon is due to the variability of the ratio between this focus of inertia and those of friction at certain distance of the wall.

If this ring effect coupled with the development of the interface layer — it seems that it could be of considerable interest in enhancing the mass transfer.

The variation of gas flow velocity during one oscillation is of great interest. If we consider the steady state velocity of gas flowing through a pipe to be designated by  $V_g$ , and the pulsation of amplitude  $a$ , and frequency  $f$ , are produced by a pump without valves, then current velocity,  $V_x$ , created by pulsation can be expressed as follows.  $V_x = V_m \sin \omega t$  or as total velocity  $V_t = V_o \pm V_x = V_o \pm V_m \sin \omega t$ .

The Ratio  $V_m / V_o$  is defined as the degree of undulation.

$$Z = V_m / V_o, V_t = V_o (1 \pm Z \sin \omega t);$$

$$Z = \pi a f / V_o$$

The value of  $Z$  indicates the direction of total velocity in the pipe.

Thus for  $Z < 1$  we have a sinusoidal Pulsating flow with +ve velocities and for  $Z > 1$  during the period of retardation, we get negative values for the velocities toward the walls of the pipes.

### Experimental Set-up and Technique

Experiments were carried out in laboratory scale apparatus employing Stephan's and Morris[10]. The general arrangement is shown schematically in **Figure A**.

An idea borrowed from Stephan's and Morris type[10].

The apparatus is roughly described as a glass absorption column incorporating additionally a pulsator into the system.

The main component of the absorption column comprises a stainless steel wire of diameter 3 mm provided with 33 equally spaced (pitch 400 mm) stainless discs of diameter 18 mm and thickness of 5 mm housed coaxially in a glass tube or 1.49 m long and I.D. of 33 mm. The external surface of the discs over which a liquid film was flowing constituted the absorbing surface.

The liquid was allowed to flow from Niveau 'B' at a controlled rate over discs to the glass tube 'D' (20 mm dia) which was connected to a lute vessel 'E' for liquid was taken out periodically by the outlet valve 'J'. The distance between the tip of the funnel and the top disc was kept at 70 mm so as to enable complete wetting of the discs.

The air from the compressor, after being routed through a filter and saturator, was mixed with the solute gas (carbon dioxide or ammonia) from the cylinder. The mixed gas then passed through the flow meter and a long duct before entering the column to ensure complete homogeneity of concentration. The pulsations were provided into the gas before its entry into the column. With pulsations provided into gas-phase the increase in rippling of the surface film was quite visible. The liquid was observed to flow in a pulsating manner on discs and the wire.

Liquid samples were taken out from the top of the lute vessel and concentrations of the solute were determined by the method of titration using phenolphthalein and methyl orange as indicators.

While performing experiment or apparatus fabrication following cares to be taken:-

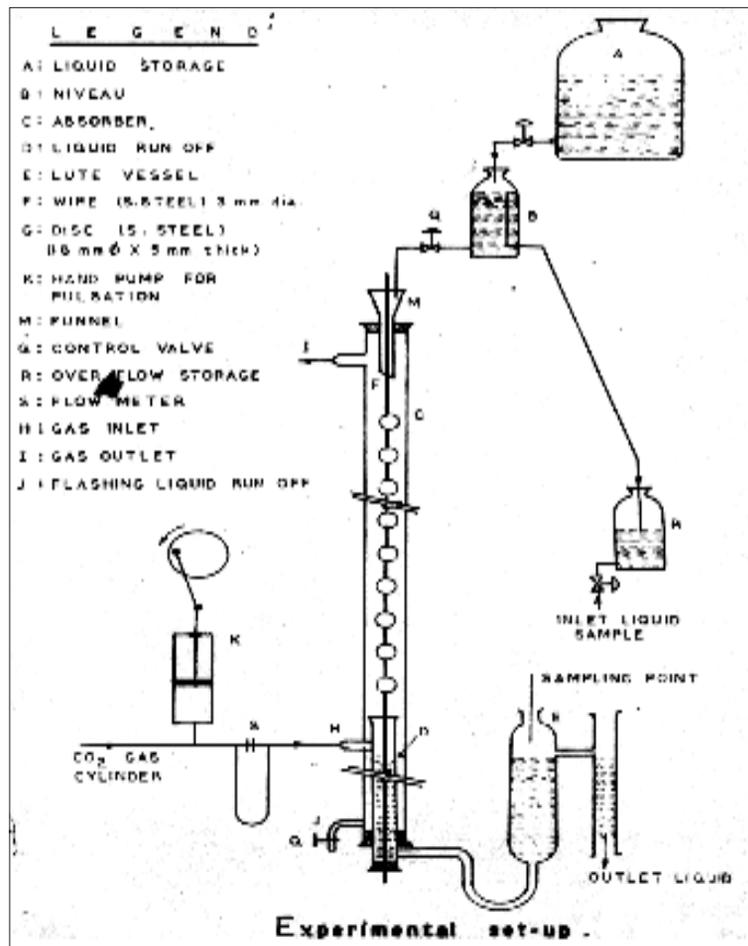


Figure A

- (I) The distance between the element and gas inlet should be as large as possible in order to provide a calming section for gas flow.
- (ii) It is ensured that:
- Liquid feed jet is located at 70 MM above the uppermost disc. Small distance gives low wetting and high distance gives more splashing.
  - Feed tube has to be wide enough to prevent air loss (15 MM dia).
  - The tube used for removal of liquid should be of large dia enough to avoid entrainment of gas (20 MM) and liquid surface has to be as high as possible in order to avoid additional absorption surface. In this case lute val was mounted on the stand whose position could be varied vertically and hence liquid level.

#### Dimensions

Column (glass): dia. internal = 33 mm  
 gas inlet and out let dia = 15 mm  
 total height = 1490 mm  
 distance between gas inlet and outlet = 1210 mm  
 height between gas outlet from top of column = 100 mm



in dia splashing liquid run off line = 4 mm  
dia of inner tube = 20 mm  
height of inner tube = 300 mm  
in dia of funnel = 5 mm

#### *Absorbing Element*

Disc : dia = 18 MM  
thickness = 5 mm  
distance between two discs = 40 mm  
dia of rod = 3 mm  
distance from tip of funnel to top disc = 70 mm  
distance from bottom disc to top of  
inner tube = 50 mm.

#### **Why Simulated Packed Column**

When a packed column has to be designed for a new process involving absorption or stripping, it is frequently impossible to calculate the mass transfer coefficient theoretically unless it is known that the rate of transfer is controlled by the gas film. If the liquid film resistance is important, prediction of the coefficient for physical solution may be prevented by lack of knowledge of the rate of diffusion in solution and if a chemical reaction occurs in solution, the process is more complicated and data to use in calculations are rarely available. It is necessary therefore in many cases to determine the absorption coefficient experimentally.

If the experiments are performed on a semi-technique scale with the actual packing, it is proposed to use the quantities of gas and liquid required will generally be large and in some circumstances may be prohibitive.

There is therefore a need for Laboratory Scale equipment which will give results which will give results that can be simply related to those obtained with full scale packing.

For the purpose of investigation a Stephen-Morris type glass column was fabricated with stainless discs arranged in a regular fashion on a single stainless steel vertical rod all in the same plane, forming the absorption surface.

Here, the liquid flows on the surface of discs being interrupted at regular intervals and thus making a Packed Bed Characteristics. It has the main advantage over Packed Bed that the gas and liquid consumption are quite low.

Simulation of the Packed Bed Characteristics can thus be achieved in a disc column where the interfacial area available is accurately known.

#### **Justification of Pulsating Gas Phase**

External agitation greatly improves mass transfer between two fluid phases. Contactors for Liquid-Liquid and gas-liquid systems, has been developed using the above principle. But very little work has been done on the study of the effect of Pulsation on gas absorption. Though, many workers have tried to standardise this, till now nobody has been able to come with a generalised theory on it application in the big scale plant has also not been possible so far. Because of the unlimited use of Packed Column in process industries, it is essentially required to find the technique to enhance the rate of absorption and mass transfer coefficient. This mass transfer coefficient is highly influential in scaling up the size of the equipment, reducing the cost of the equipment and reducing the size of the equipment as well scale up this size of mass transfer equipment in scale up, reducing the cost and size of the equipments.

It is therefore the present study has been taken up to study the effect of gas phase Pulsation in a Simulated Packed Column to enhance the rate of absorption and mass transfer coefficient for liquid phase and gas phase.

#### **RESULTS AND DISCUSSION**

The experimental investigation are carried out in simulated absorption column (Disc Column) to study the effect of



pulsation on absorption rate and mass transfer coefficients in various systems.

- (1) Absorption of carbon-dioxide in water;
- (2) Absorption of ammonia in water;
- (3) Absorption of carbon-dioxide in aqueous sodium hydroxide solution.

Among the parameters those are investigated in greater detail are the effect of (1) amplitude of pulsation, (2) frequency of pulsation, (3) liquid flow rate, (4) gas flow rate, (5) solute gas concentration in air, (6) normality of aqueous sodium hydroxide solution, (7) effect of varying the number of disc (length of the column, superficial area).

### Effect of Liquid Flow Rate

**Figures 19 to 34** show the influence of liquid flow rate on rate of absorption and mass transfer coefficient for both pulsed and unpulsed conditions, keeping other parameters remaining unchanged. For air carbon dioxide-water system (physical absorption) the absorption rate and mass transfer coefficient, seen in the figure (mentioned earlier), is proportional to the liquid flow rate to the power range from 0.54 to 0.78 in case of mass transfer and 0.5 to 0.8 in case of rate of absorption. But in the pulsed condition almost kept the same relationship with an upward shift for the pulsed condition. The value for the unpulsed system agree well with the value reported in the literature [15]. In case of pulsed case too much splashing occur high value is obtained due to increase of gas turbulence resulting from greater disturbances produced by liquid flooding over the junction between successive discs as the liquid rate is raised. The present observed power is 0.36 which agree quite remarkably. In case of pulsed case it tended to increase from an amplitude 3.5 and frequency 3.6 Hz and its value as 0.48 this is peak condition. Other none peak value at amplitude 11 MM and frequency 5.43 and above the power is to be 0.433. This can be concluded that mass transfer rate might have been increasing due to high repelling. The same slope relationship is maintained for the optimum pulsation condition but with higher magnitude of coefficient.

For the ammonia-water system (gas film controlled) process the mass transfer coefficient for both pulsed and unpulsed condition plotted against the liquid flow rate shown in **Figure 31**. It is seen that the coefficient varies with liquid flow rate with the power of 0.17. The same slope is achieved for pulsed system but with higher coefficient. This is comparable to the values reported in literature [15,17].

For carbon dioxide-aqueous sodium hydroxide solution **Figures 25 to 30** and **Figures 32 to 34**, The absorption coefficient varies with the liquid flow rate with the power of 0.6. The same slope relationship is maintained for the optimum condition but with higher magnitude of coefficient.

### Effect of Gas Flow Rate

In the present investigation, the gas flow rate has been varied from 6 to 36 litre per minute. Studies have been carried out for both pulsed and unpulsed conditions, changing frequency and amplitude of pulsation keeping other parameters constant. For liquid film controlled system studied i.e. CO<sub>2</sub>-water (**Figures 39 to 41**) and CO<sub>2</sub>-NaOH solution, the change of gas flow rate has absolutely no effect on mass transfer rate (**Figure 42**). However, the data/table obtained for gas film controlled system (air – ammonia - water) shows that the mass transfer coefficient is proportional to the gas flow rate to the power 1.07 (**Figures 35 to 38**). These results are quite in confirmative with the reported literature [15-17].

### Effect of Pulsation Frequency

**Figures 1 to 4** shows the effect of pulsation frequency on the absorption rate of carbon dioxide in water. In this figure, the absorption rate are plotted against pulsation frequency with solute gas concentration as parameter. The amplitude of pulsation is being kept constant at 2 MM the solute gas concentration has been varied from 0 to 1. It is observed from the figure that the absorption rate changes sinusoidally along with change of pulsation frequency. The attainment of the peak absorption rate is observed at pulsation frequencies of 3.63 Hz and 9.06 Hz, respectively within the range of the experimental conditions. The experimental runs could not be taken beyond the pulsation frequency of 9.06 Hz because of the limitation of the system. **Figures 1 to 25** present data for the same parameters but for different amplitude of pulsation, viz, 2.7, 4.5, 8 and 15 MM, respectively, similar trained is observed in all the figures. **Figures 7 and 8** corresponding to the amplitude of 21.3 and 26 MM, respectively, also show the same trained but the attainment of peak values are achieved earlier at frequencies of 1.81 and 7.25 Hz, respectively.

For air-carbon dioxide / 0.5 N aqueous sodium hydroxide solution, the absorption rate of carbon dioxide is shown against

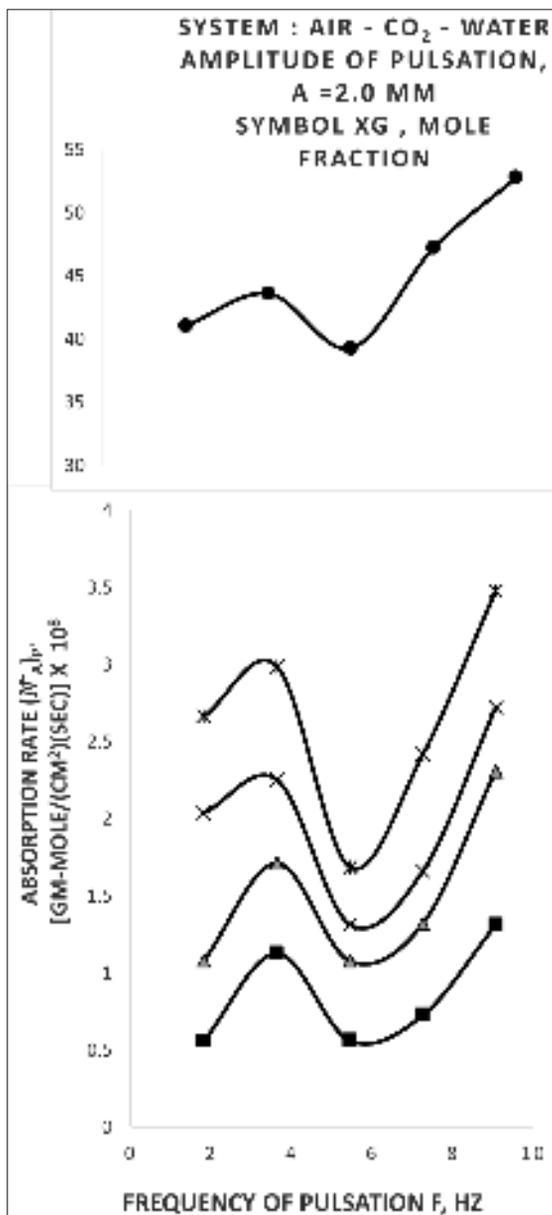


Figure 1

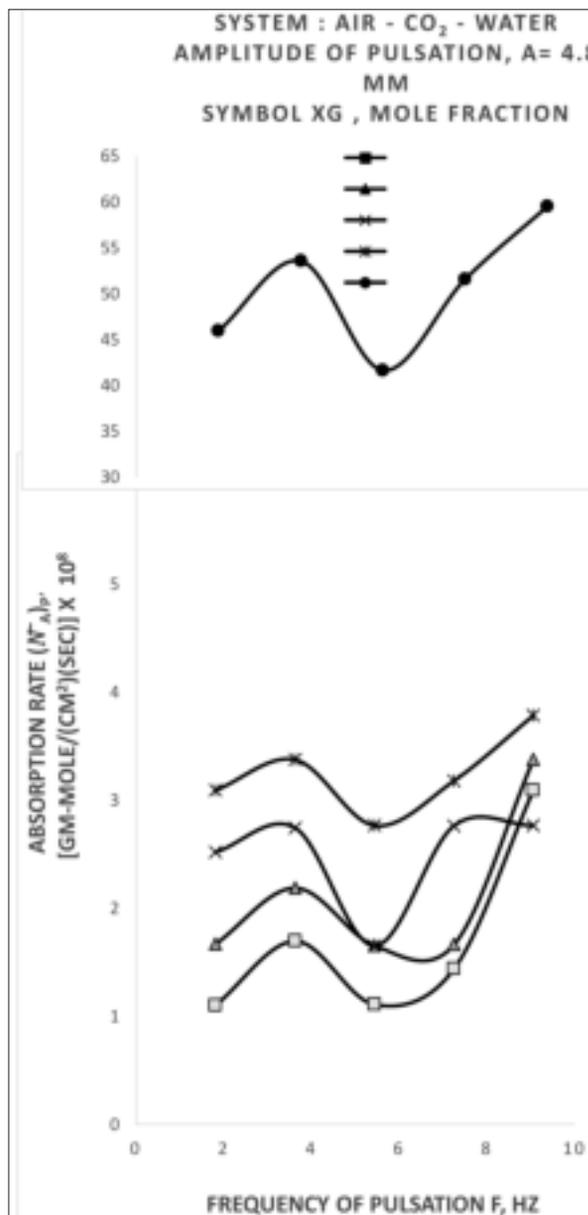


Figure 2

the pulsation frequency with solute gas concentration (0.05 – 1). As parameter in **Figures 5 to 8** corresponding to the amplitude of 2, 4.5, 8, 15, 21.3 and 26 MM, respectively. It is observed from figure that attainment of peak values is achieved at frequencies of 3.63 and 9.06, respectively up to the amplitudes of 15.0 MM at 1.81 and 6.7 Hz, respectively for higher amplitudes.

**Figures 9 and 12** are shown for the system ammonia water, corresponding to 6 amplitudes of 2.5, 10, 15, 20 and 25, respectively. The solute gas concentration  $X_g$ , has been varied from 0.01 to 100%. In the investigation the attainment of peak absorption rate is achieved at frequencies of 3.63 and 9.06 Hz, respectively for the amplitude up to 10 MM and 1.81 and 6.7 Hz, respectively for higher amplitudes of 15, 20 and 25.5 MM corresponding to **Figures 13 to 16**, respectively.

It is concluded from the figures that the magnified interfacial turbulence caused by resonance phenomenon, while in

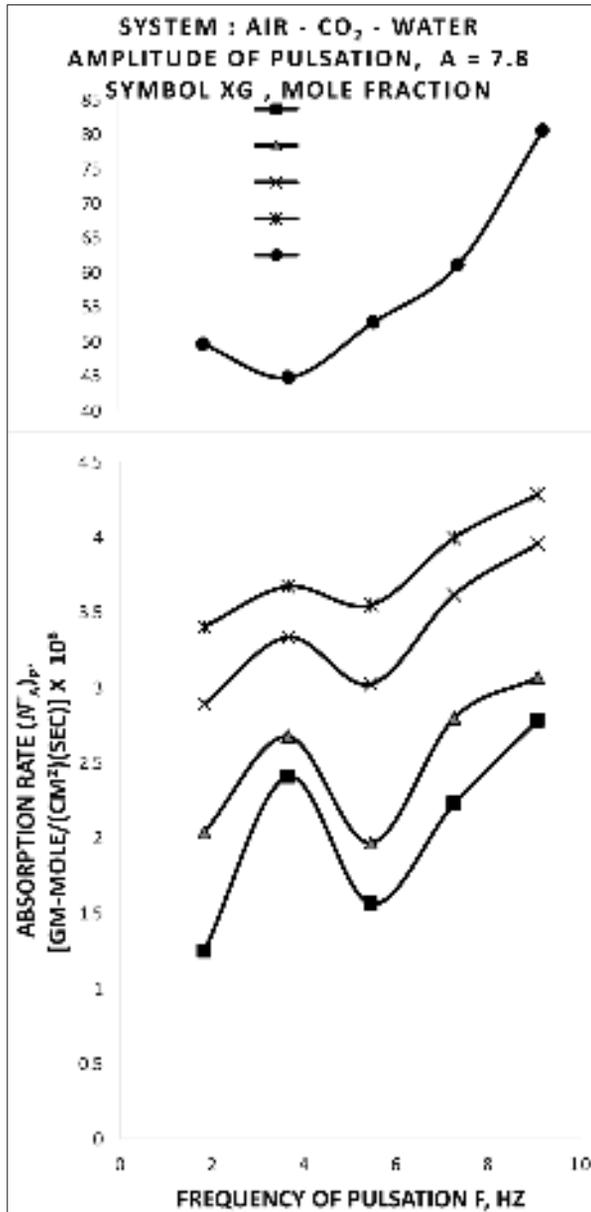


Figure 3

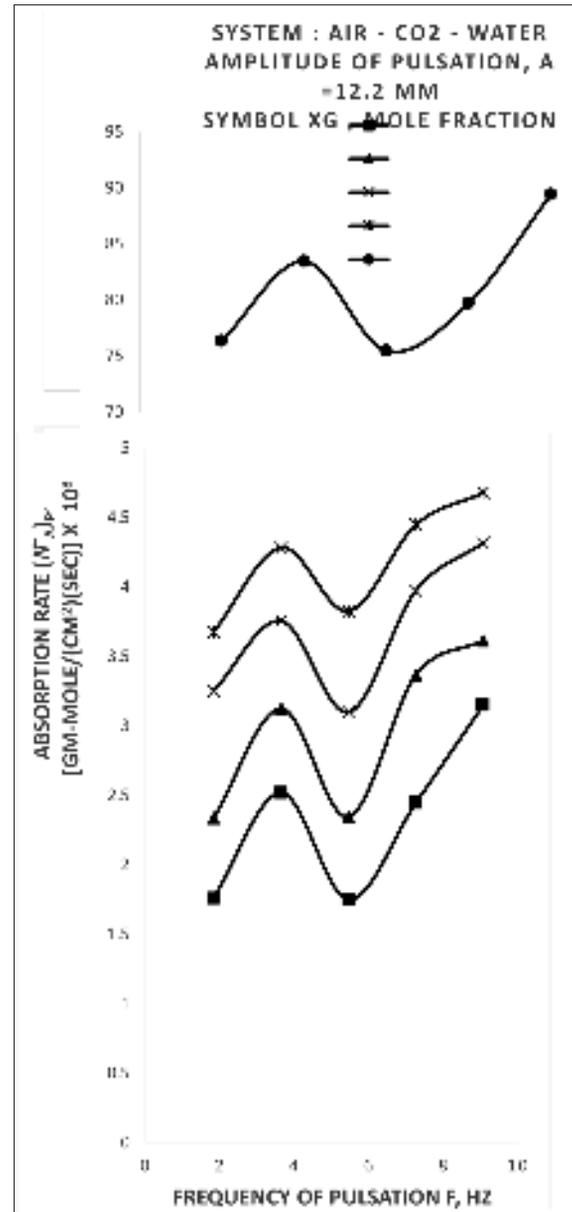
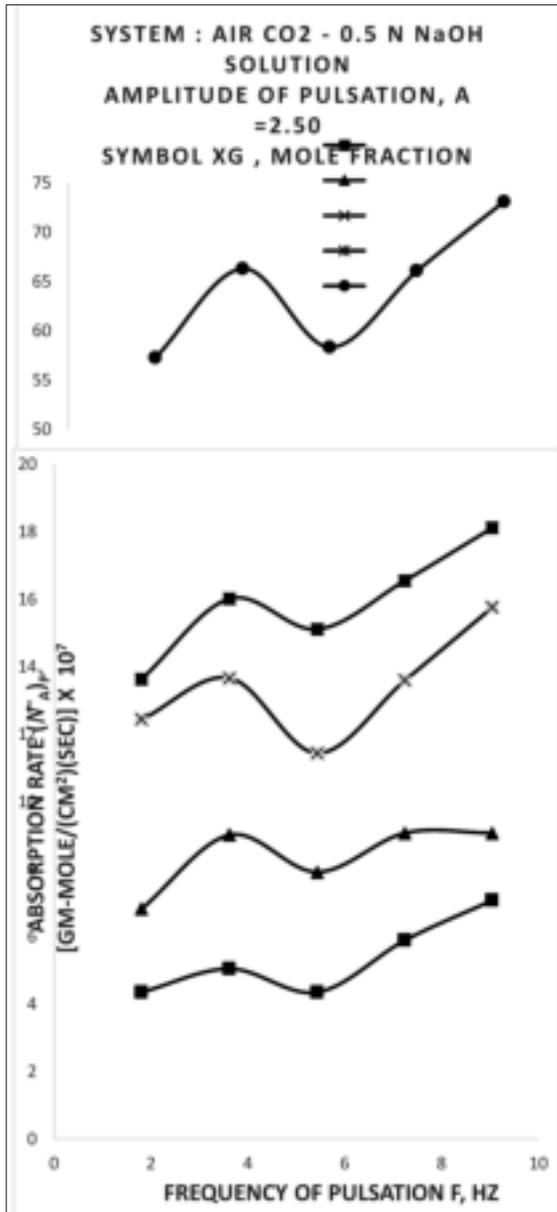


Figure 4

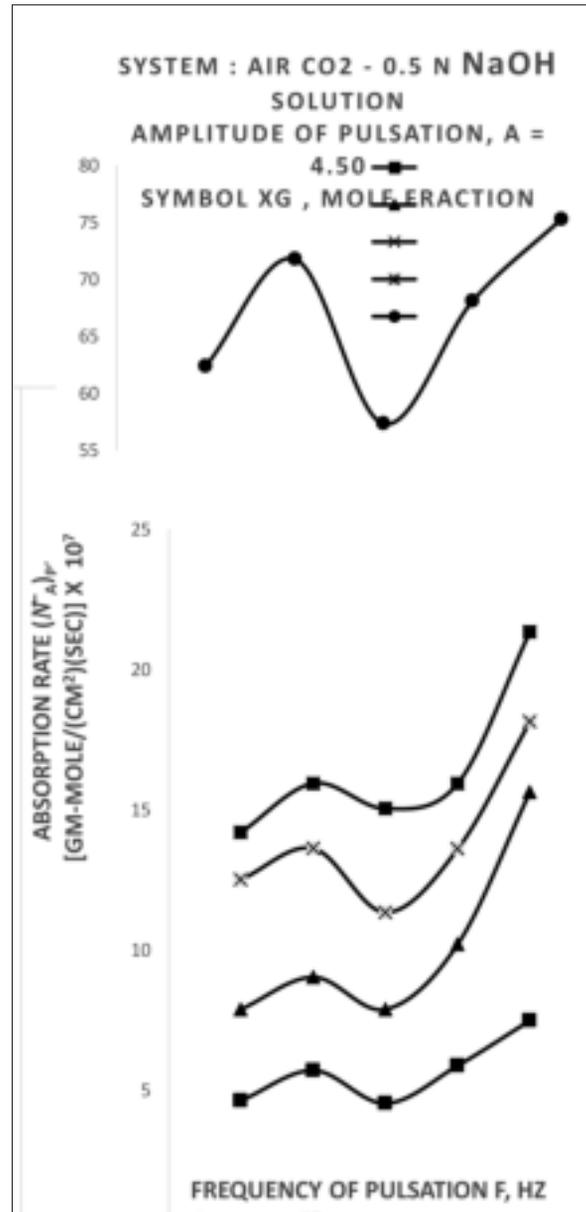
pulsation gives an increased absorption rate when the time period of liquid phase and gas phase oscillation matches. This is completely in agreement with the observation of several investigators [1-3, 7,12]. For CO<sub>2</sub> system the resonance phenomenon shows a 90° degree shift in peak values attainment at amplitudes higher than 21.3 MM. For a gas film controlled process like ammonia water system this is observed at still earlier amplitudes of 15 MM.

#### Effect of Pulsation Amplitude

Figures 13 and 14 shows the relation between the absorption rate and the pulsation amplitude for CO<sub>2</sub>-water system with solute gas concentration X<sub>g</sub>, as parameter. These figures correspond to the peak pulsation frequencies of 3.63 and 9.06 Hz, respectively.



**Figure 5**



**Figure 6**

For CO<sub>2</sub>-0.5 NaOH solution, the experimental data are represented in **Figures 15** and **16** corresponding to the same frequencies as above, respectively.

**Figures 17** and **18** shows the effect of pulsation amplitude on the overall absorption rate for ammonia water system. These figures also correspond to the same frequencies as stated earlier.

It is seen from the figures that the absorption rate increases with the increase of amplitude up to a certain value and thereafter decreases with the increase of amplitude. This optimum amplitude corresponds to 12 MM for both carbon dioxide water and carbon dioxide 0.5 NaOH solution systems, and 8.0 MM for ammonia water system. The increase in absorption rate may be due to the added interfacial turbulence caused by pulsations, Fr the decrease in absorption rate at higher amplitudes the following reasons are assigned:

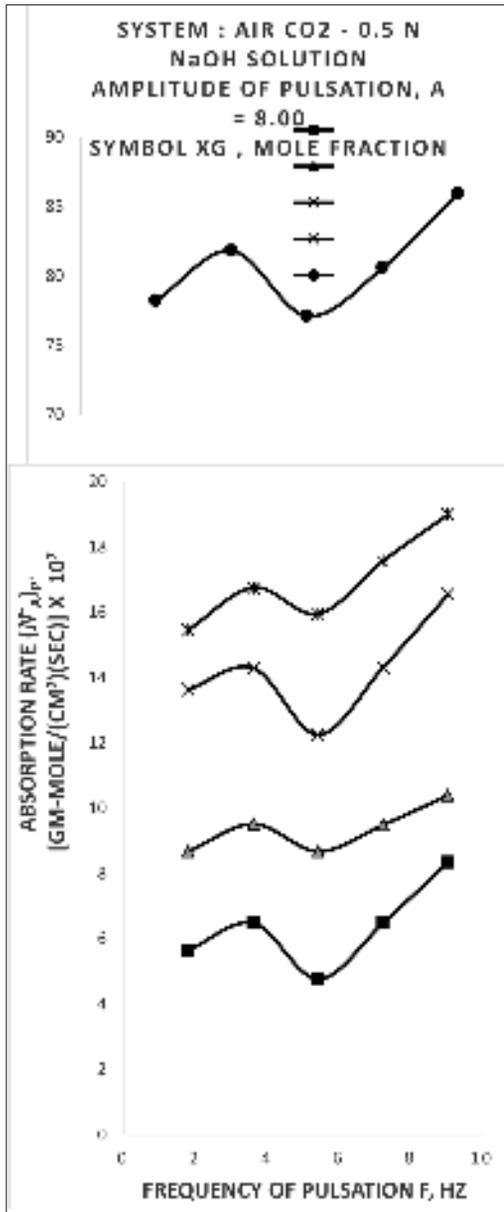


Figure 7

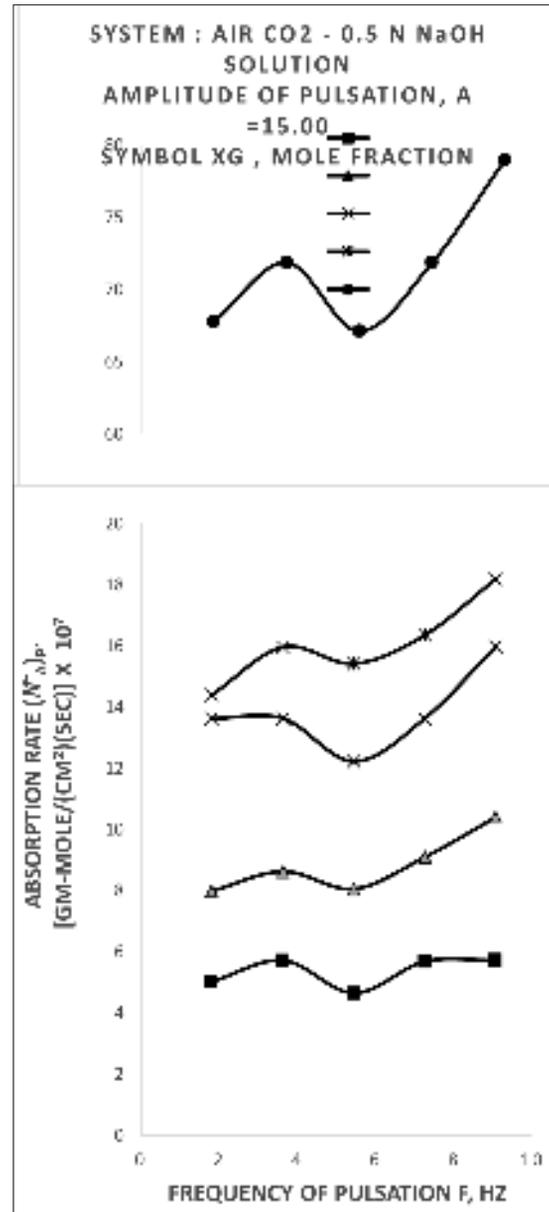


Figure 8

Increase in splashing may be reducing mass transfer rates it was experimentally observed that liquid splashing increased with the increase of amplitudes[1].

Due to splashing, it is obvious that the liquid flow rates on discs are decreasing to some extent, which might be reducing the mass transfer coefficient.

Due to pulsation at very high amplitude, wetted surface area may be getting lost. Because of the high amplitude of induced ripples, the tip of the ripples are touching the discs and thus some surface area are getting lost. As mass transfer rate calculated on the basis of total area of discs and wires, the reduction in area is observed, which is a quite a reasonable probability. It was experimentally observed that liquid splashing increased with the increase of amplitudes. Splashing was particularly intensive at higher amplitudes corresponding to oscillations above 12 MM amplitudes of carbon

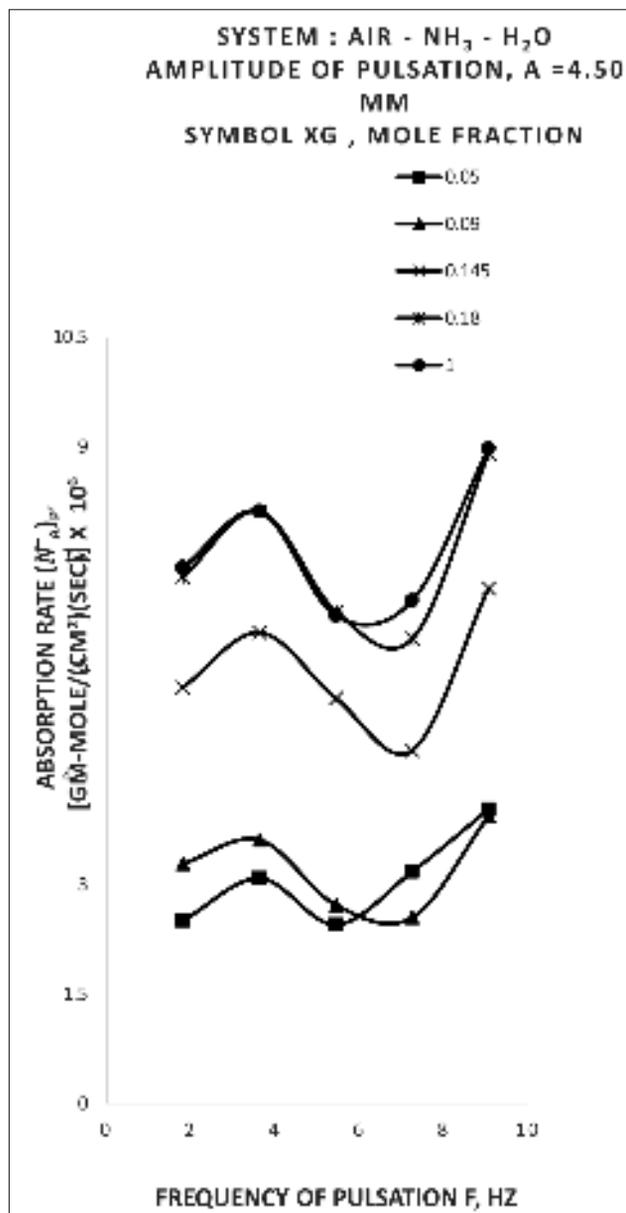


Figure 9

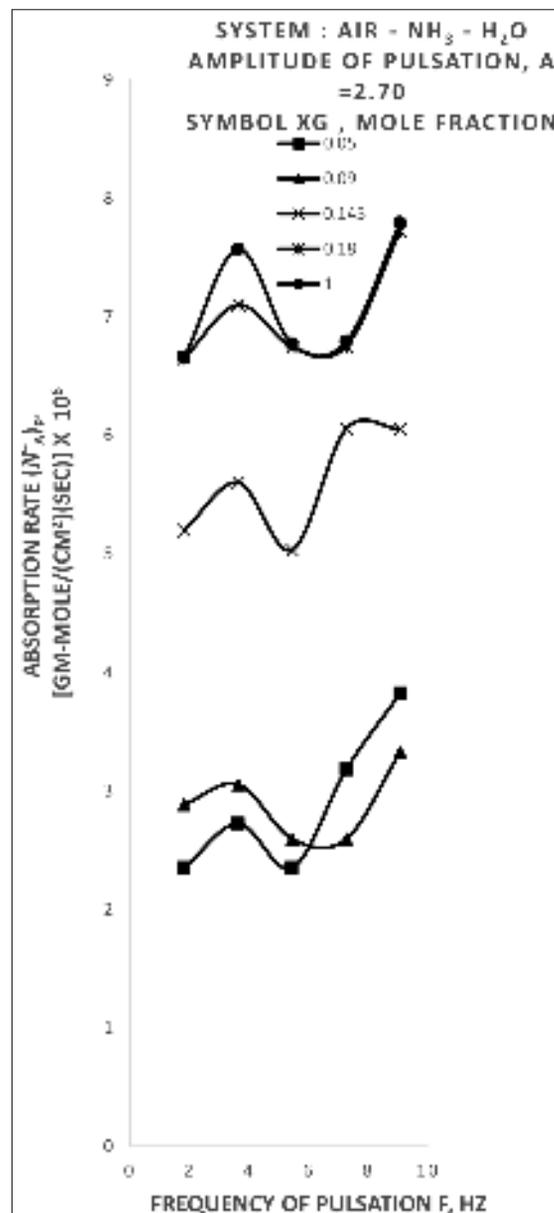


Figure 10

dioxide water and carbon dioxide – 0.5 NaOH solution (liquid-film controlled system) and 8 MM amplitude for ammonia-water (gas-film controlled) systems, respectively and at very high amplitudes the rippings were so intense that surface-films become very thick at one location and very thin at other. After attaining critical thickness, the solid surface liquid splashed out of the disc surface, thus, showing low concentration in the outlet liquid stream. This happened at various locations all along the length, although more show near the bottom of the column.

#### Why Peak?

The reason for peak can be considered same as interfacial turbulence. In the present case the increase in rippling quite visible. The liquid was flowing in a pulsating manner on discs and wires. So, when the time period of liquid phase oscillations and gas phase oscillations matches, resonance occur and this interfacial turbulence is magnified which gives

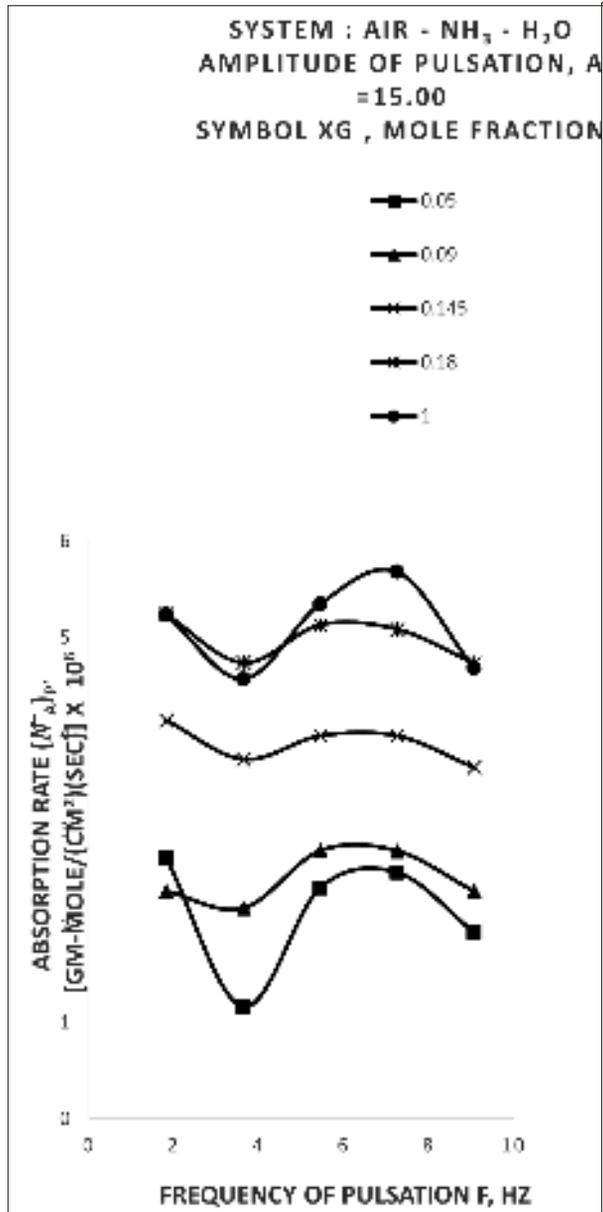


Figure 11

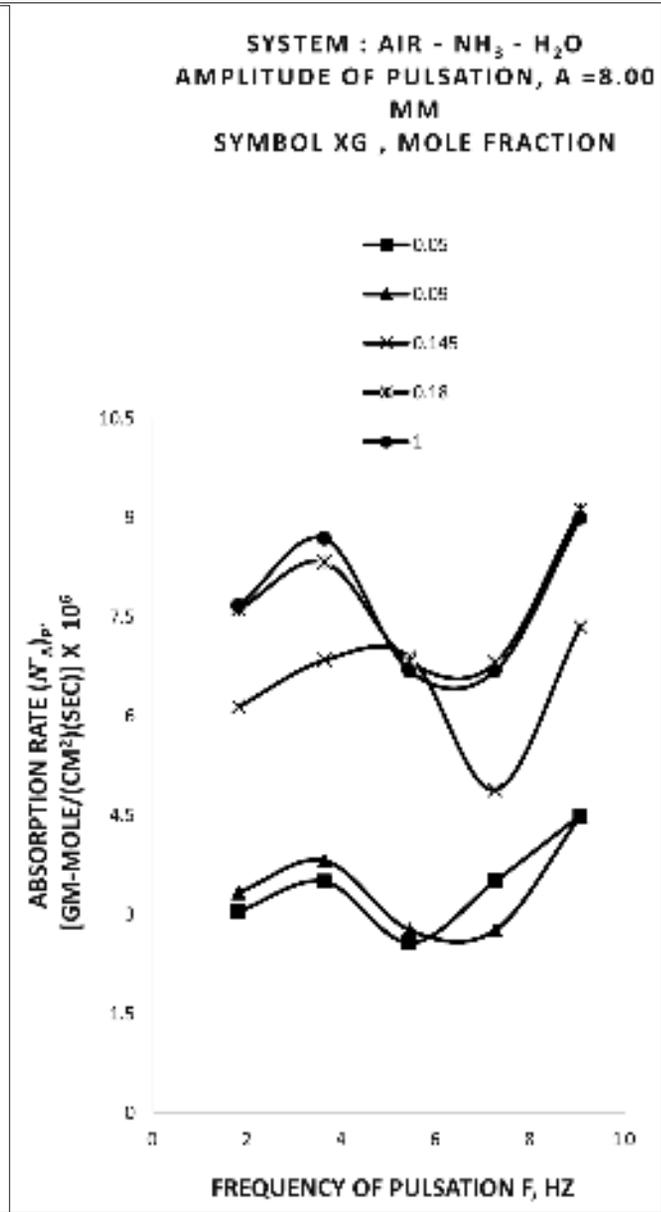


Figure 12

an increase in mass transfer rate. That is the reason why peak was found at value of 3.6 Hz irrespective of the system.

At high amplitudes the gas molecules are getting energized and thus, when touched the liquid surface, the attraction force encounter due to difference in chemical potential is quite low compared to the kinetic energy they have, so they are not getting absorbed.

The phenomenon can be visualized looking at the temperature effect on gas absorption. At high temperature, the absorption rate is low. High temperature is just state of very high energized state of the gas.

The above reasons may have some effect which are combined and reducing the mass transfer rate.

For the ammonia water system (gas film controlled process) the mass transfer coefficient for both pulsed and unpulsed

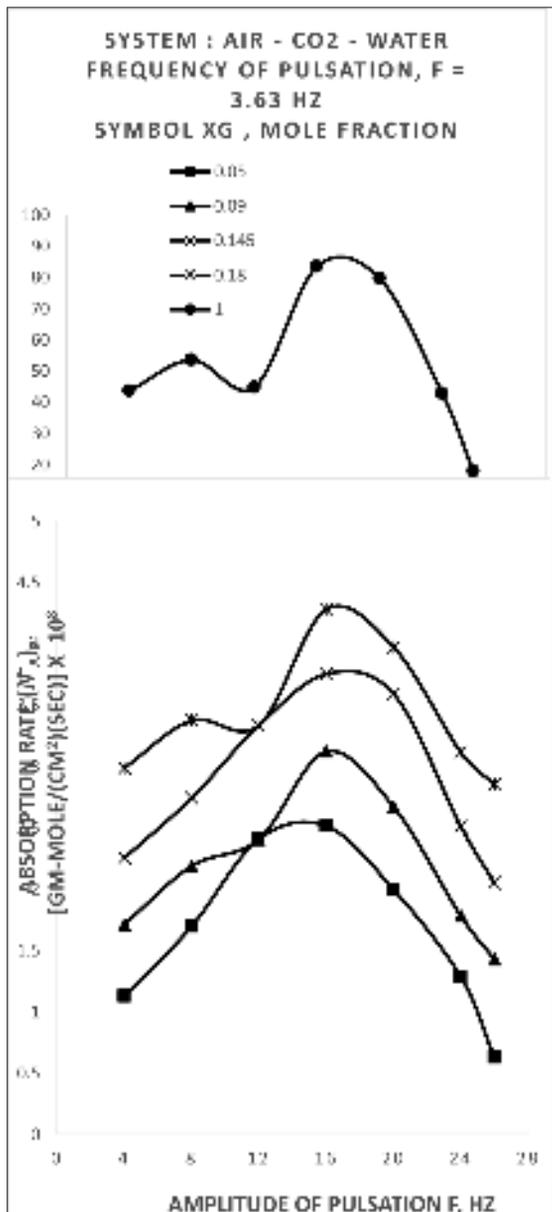


Figure 13

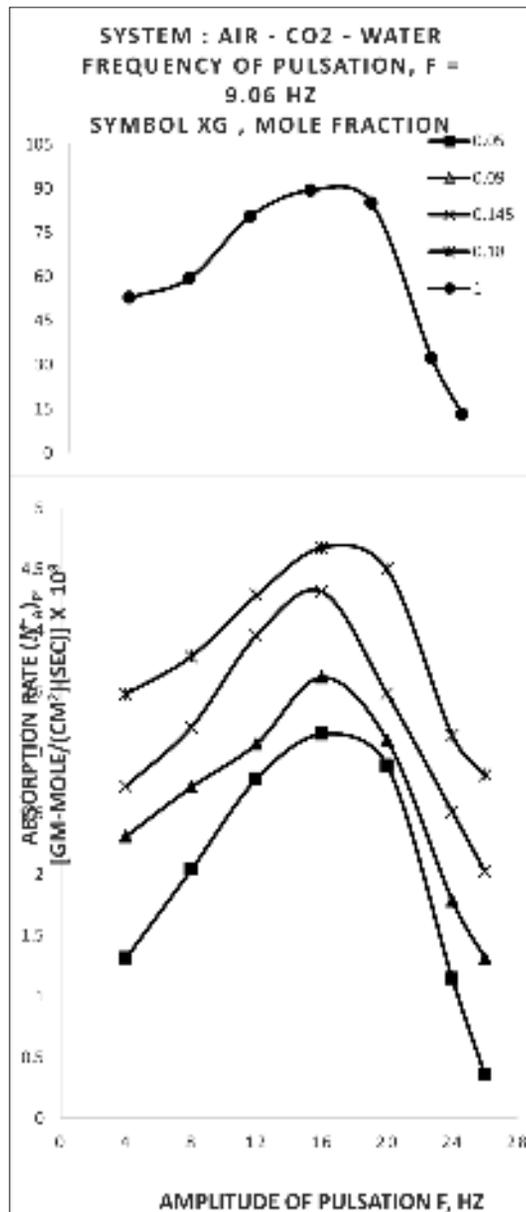


Figure 14

are plotted against the liquid flow rate in figure. It is seen that the coefficient varies with liquid flow rate with a power of 0.17 the same slope is achieved for pulsed system but with higher coefficients. This is comparable to the values reported in the literature[15,17].

#### Effect of Gas Flow Rate

In the present investigation, the gas flow rate has been varied from 6.0 to 36.0 liter per minute. Studies have been carried out for both the pulsed and unpulsed conditions, changing frequency and amplitude of pulsation and keeping other parameters constant. For liquid film controlled systems studied that is carbon dioxide – water and carbon dioxide – 0.5 NaOH solution, the change of gas flow rate has absolutely no effect on the mass transfer rate **Figures 39 to 41**.

However, the data obtained for the gas film controlled system (air -ammonia/ water) shows that mass transfer coefficient

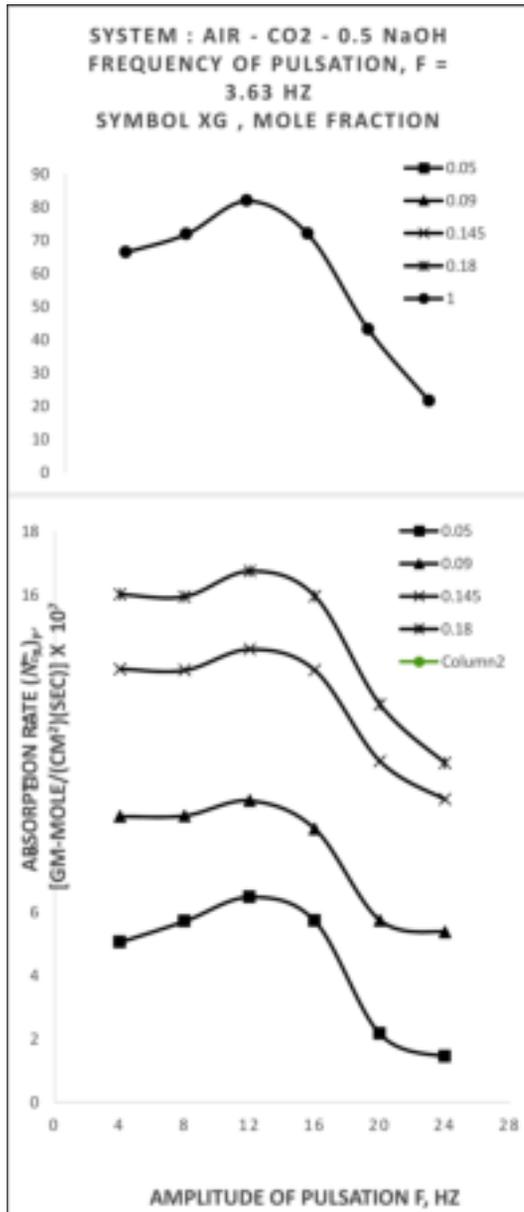


Figure 15

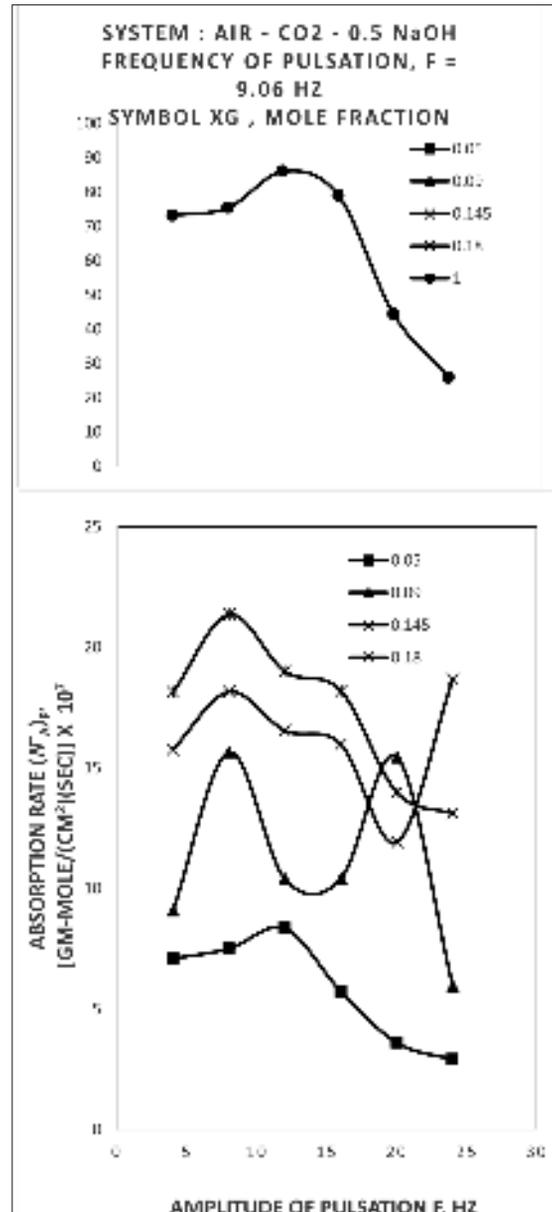


Figure 16

is proportional to the gas flow rate to the power of 1.07 (Figures 35 to 38).

These results are quite in confirmative with the reported literature[15,17] for unpulsed systems.

#### Effect of Solute Gas Concentration

Results of investigation all the three systems as stated above, carried out to study the effect of gas concentration XG, on the mass transfer rate are presented in the Figures 62 to 64. It is seen from figures that the mass transfer rate increases with increasing the solute gas concentration in air.

#### Effect of Sodium Hydroxide Concentration

The mass transfer coefficient is plotted against the normality of sodium hydroxide solution in Figure 5.27 and Table 5.6

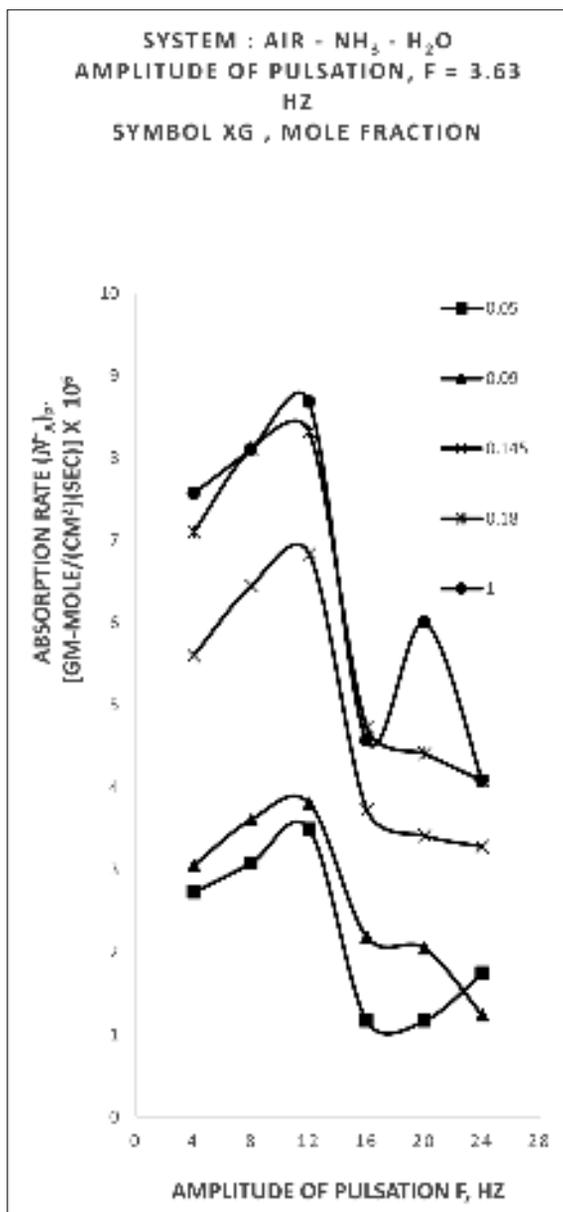


Figure 17

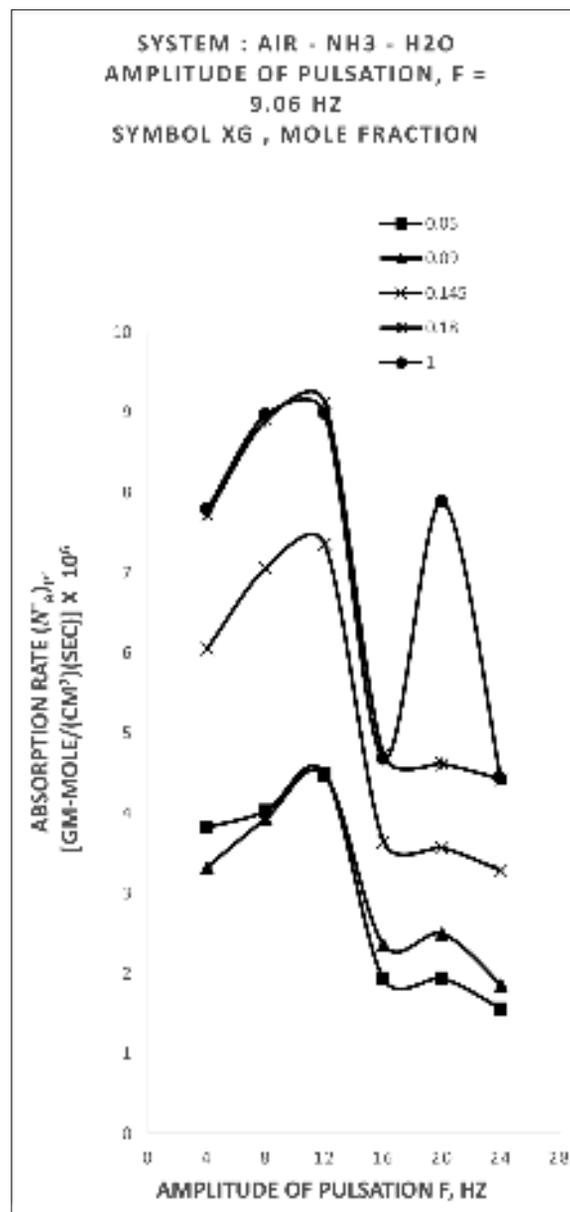


Figure 18

for both the pulsed and unpulsed systems. The concentration has been varied from 0 – 4 (N) in order to study its effect. It is observed from the figure that the coefficient increases in the same fashion for the both pulsed and unpulsed condition with the increase in normality. At lower value of NaOH concentration (0.25 N) the degree of CO<sub>2</sub> removal from the gas increased with pulsation amplitude. It is seen in all cases removal was higher that conducted without pulsation keeping all other dynamic parameters constant. From 0.5 to 2.5 N yielded the similar result even with increasing the gas flow rate, the result found is same but further increase in sodium hydroxide concentration from 2.5 N to 4 N, there is enhancement of mass transfer with pulsation than without pulsation, But instead of increasing trend as happened from 0.25 to 2.5 N, Here it started in slight decreasing from 2.5 N to 4 N.

#### Varying Number of Discs (Figures 54 to 61)

The rate of absorption for all the three systems are carried out in both pulsed and unpulsed condition in varying the

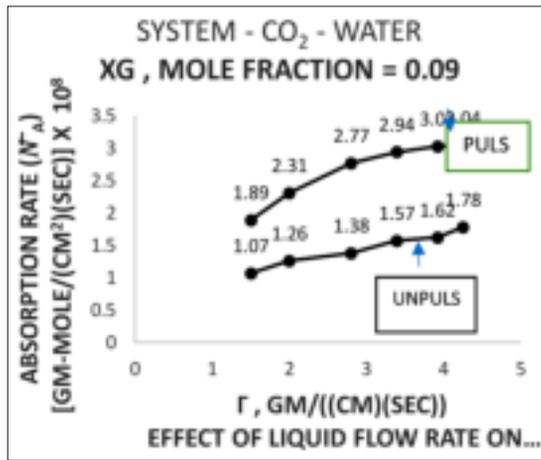


Figure 19

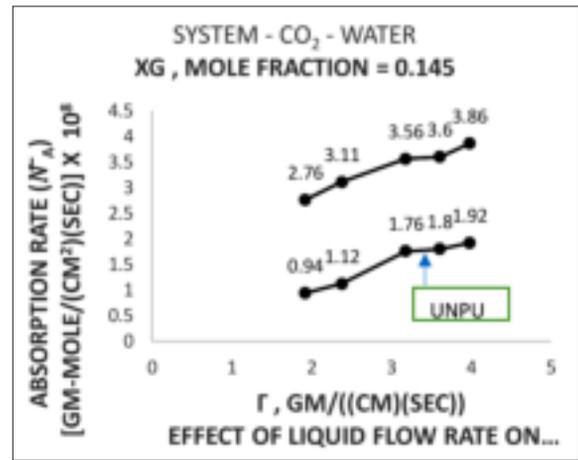


Figure 20

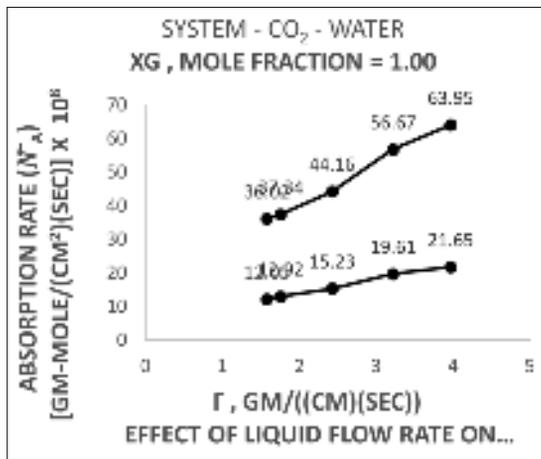


Figure 21

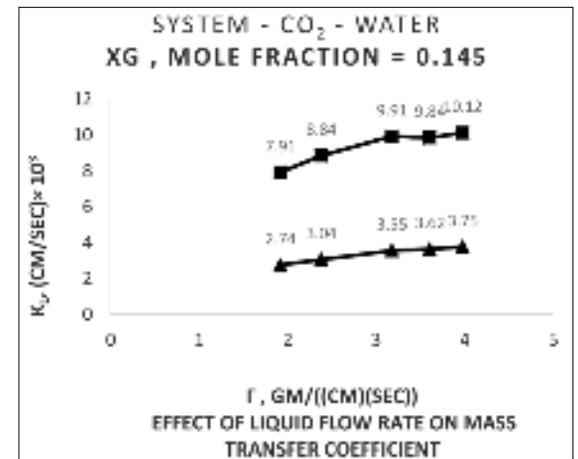


Figure 22

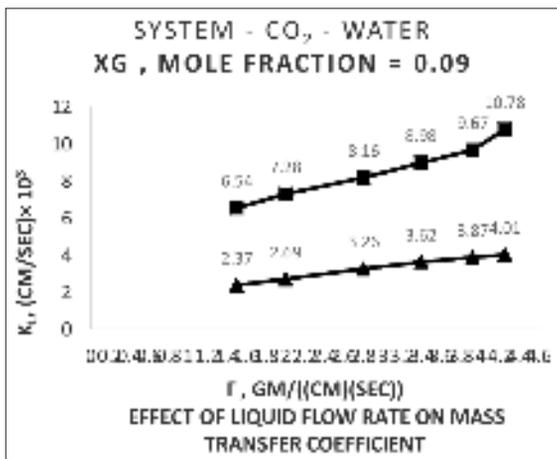


Figure 23

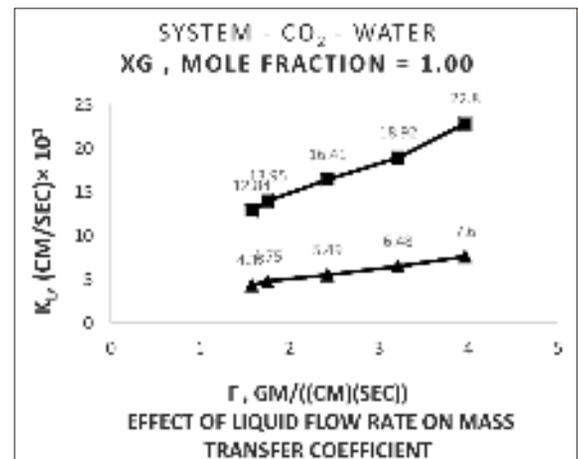


Figure 24

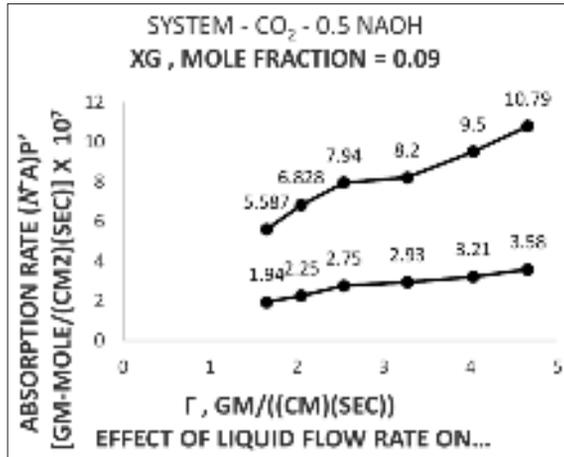


Figure 25

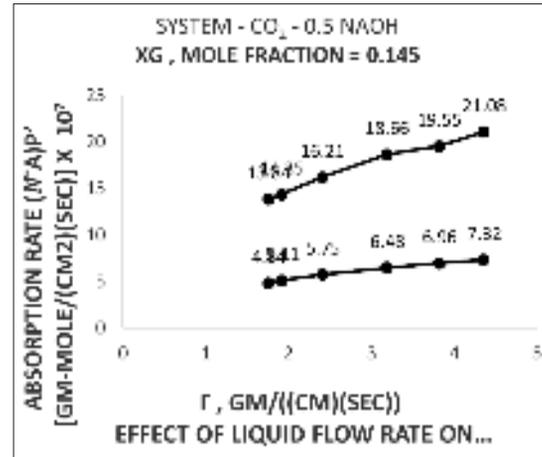


Figure 26

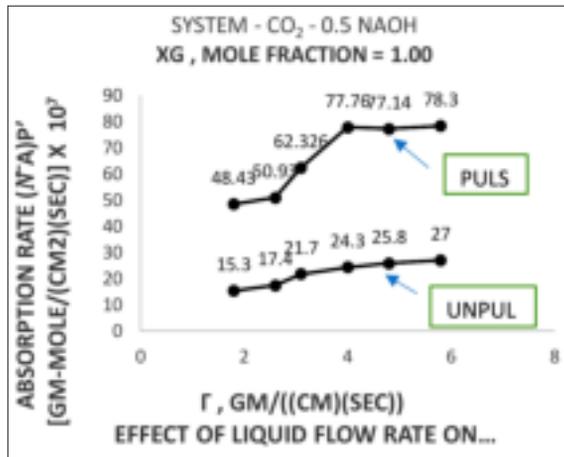


Figure 27

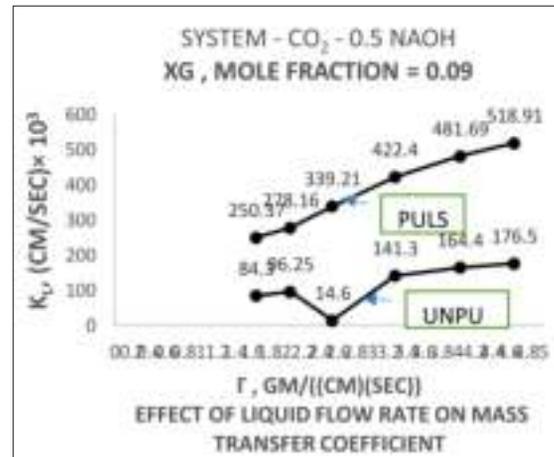


Figure 28

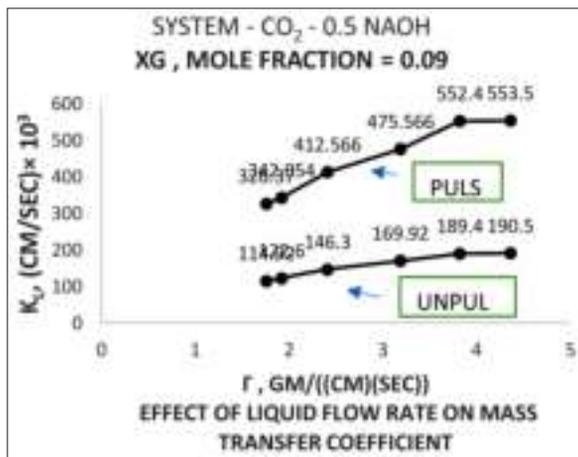


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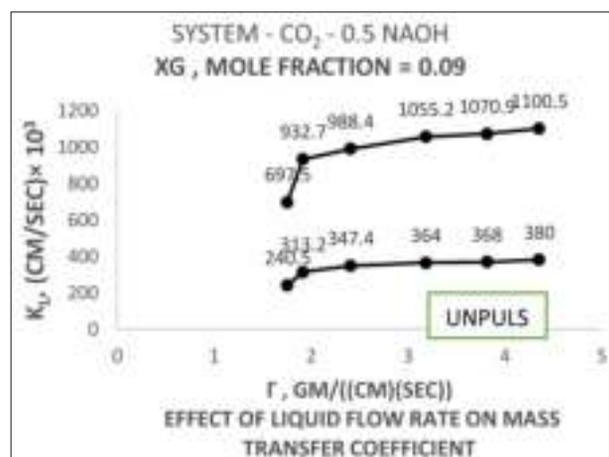


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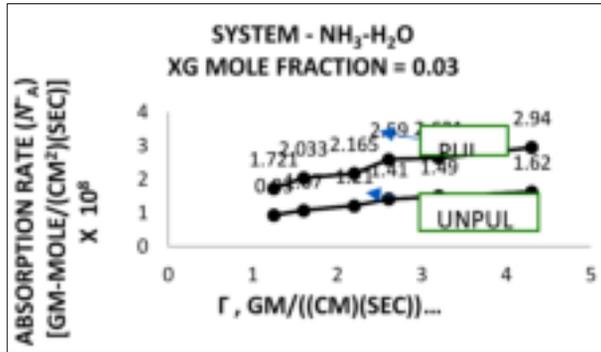


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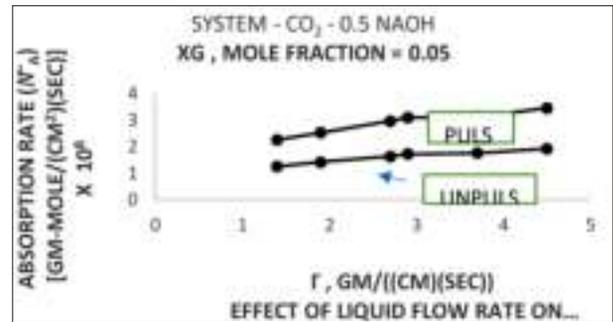


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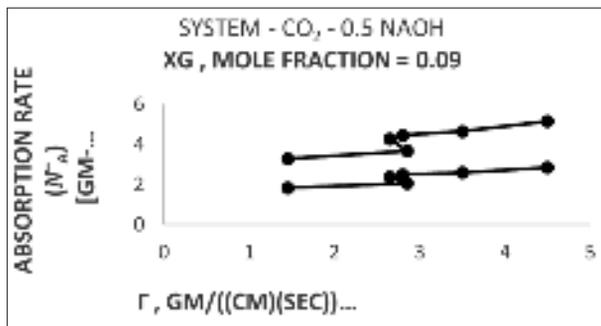


Figure 33

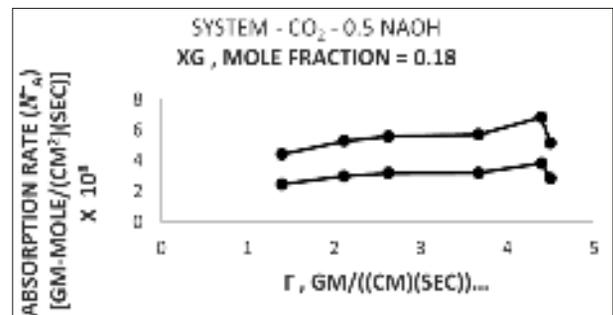


Figure 34

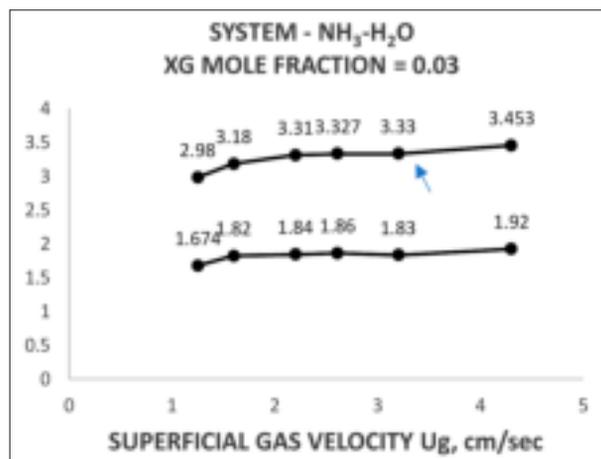


Figure 35

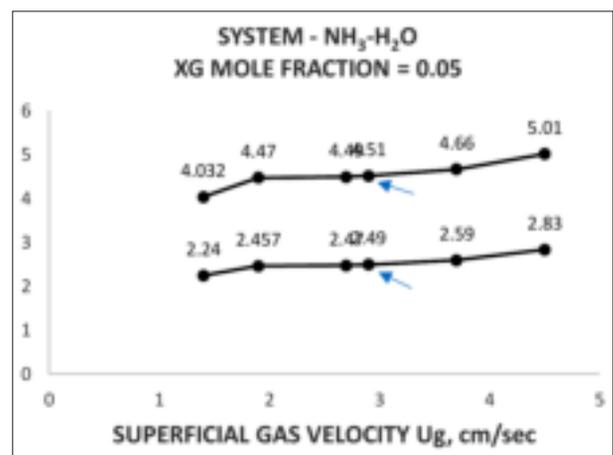


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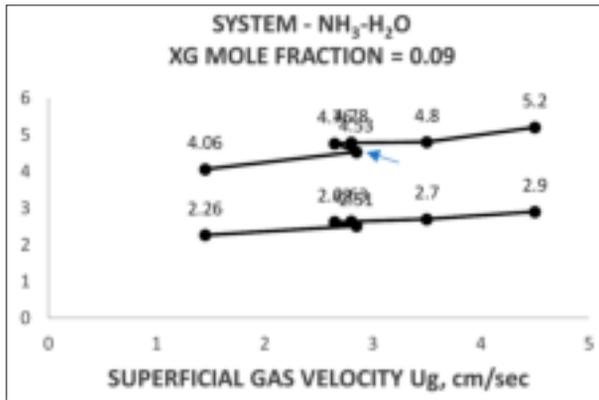


Figure 37

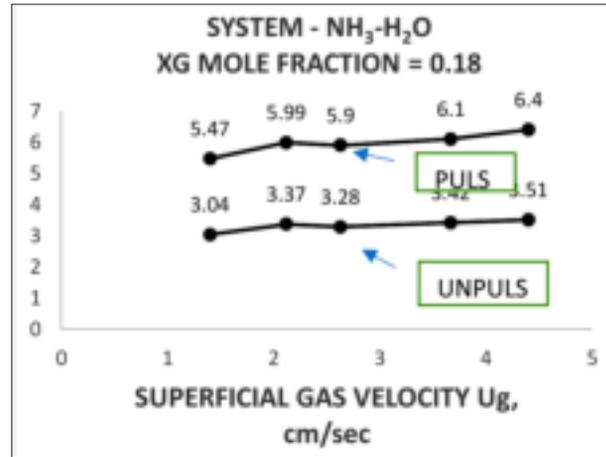


Figure 38

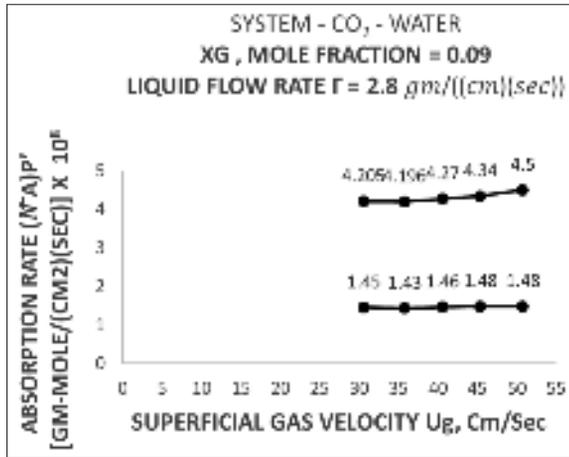


Figure 39

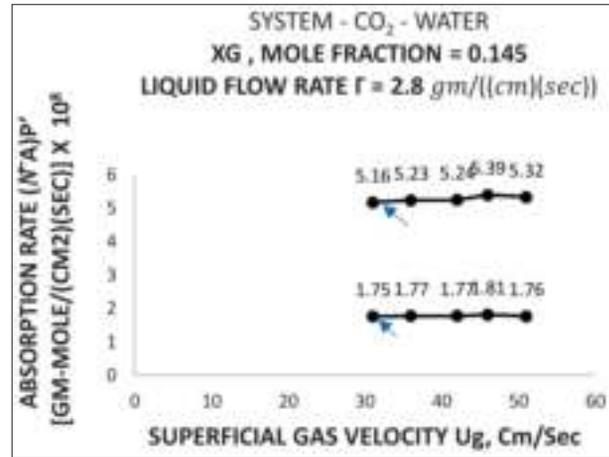


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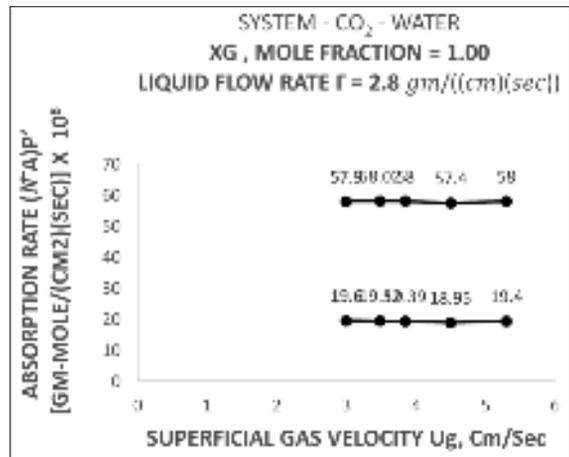


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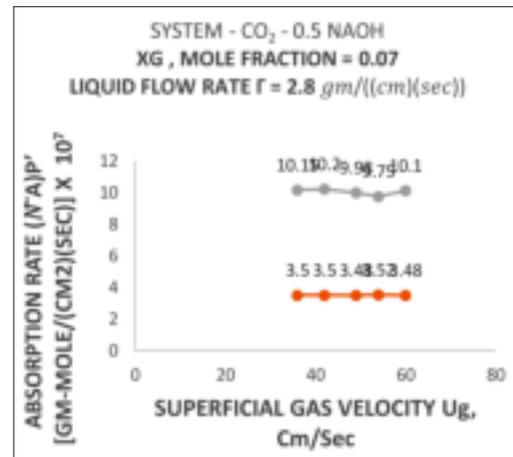


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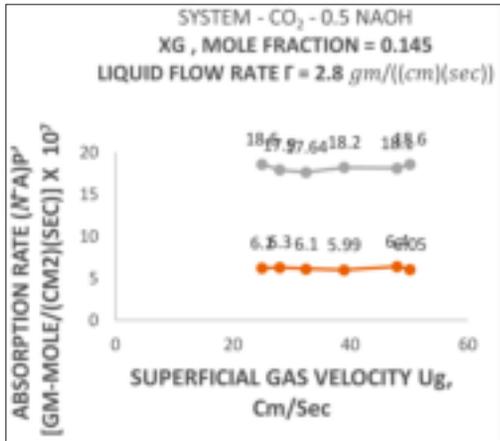


Figure 43

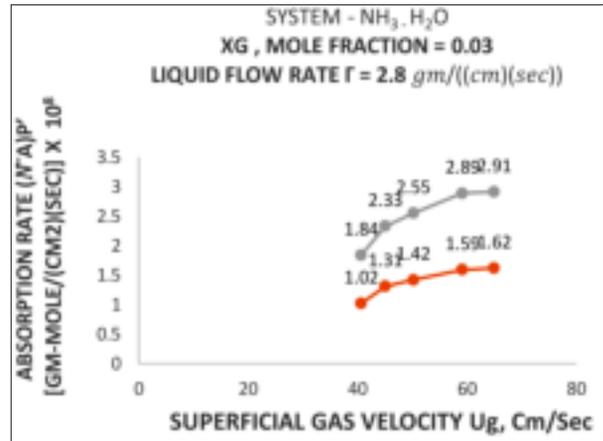


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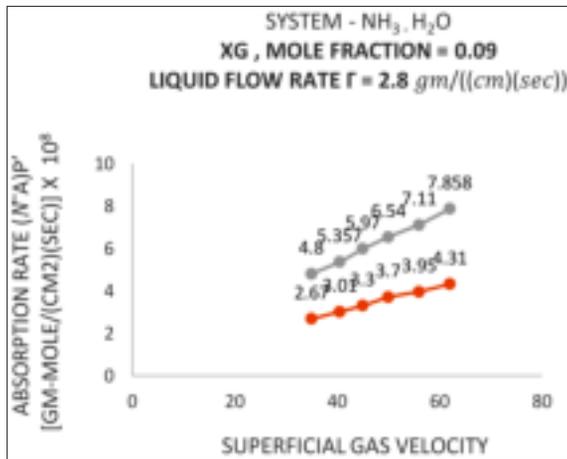


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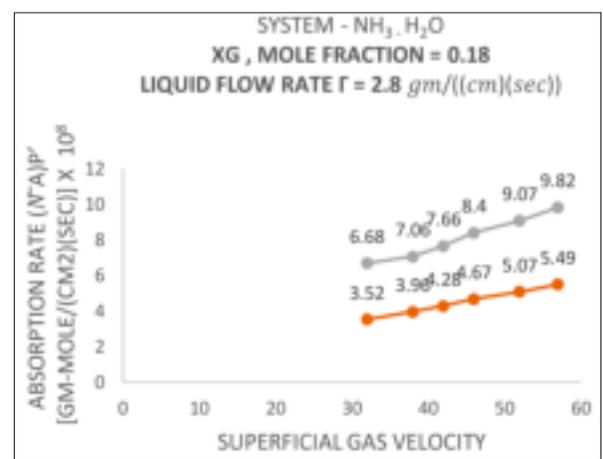


Figure 46

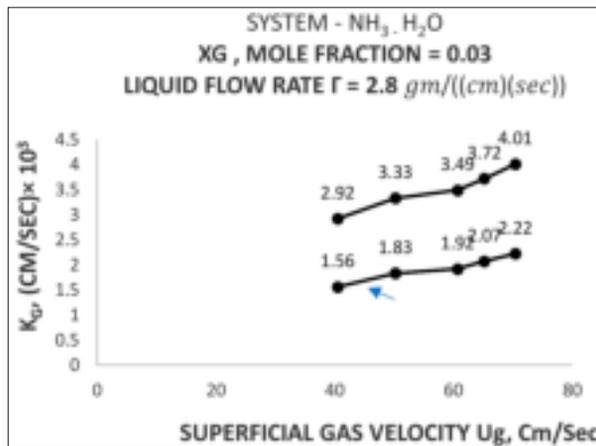


Figure 47

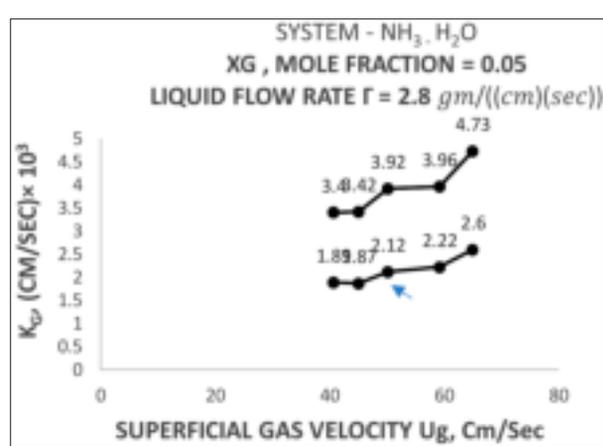


Figure 48

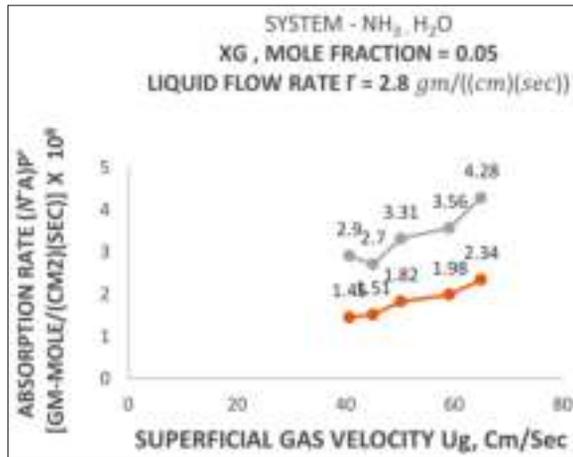


Figure 49

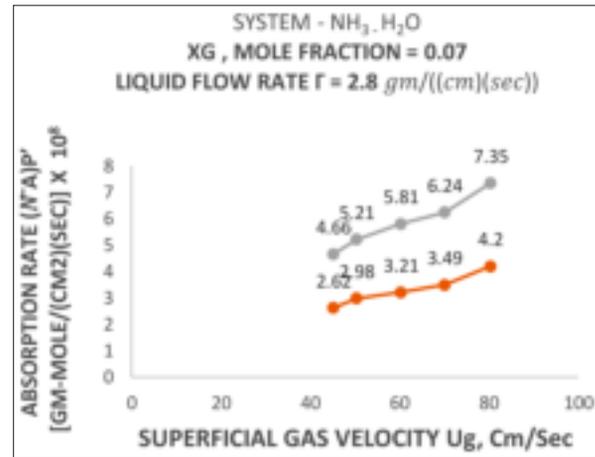


Figure 50

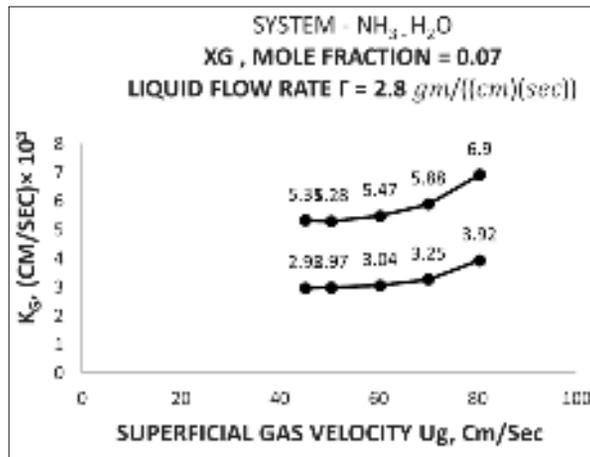


Figure 51

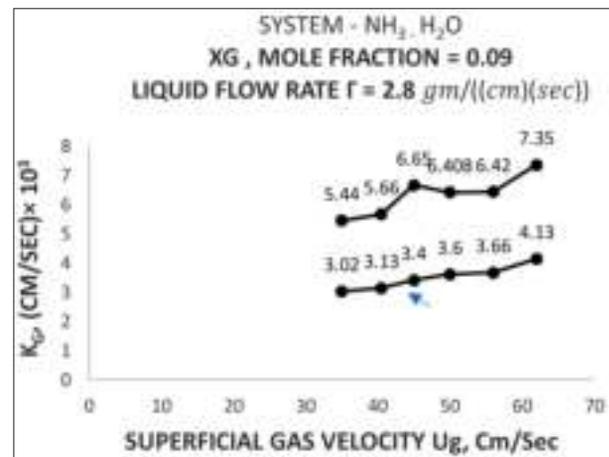


Figure 52

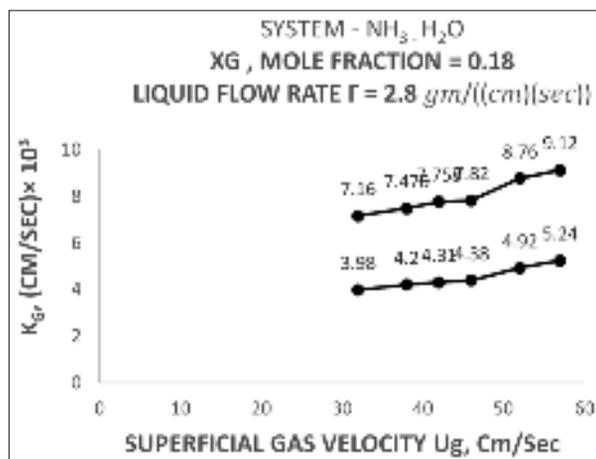


Figure 53

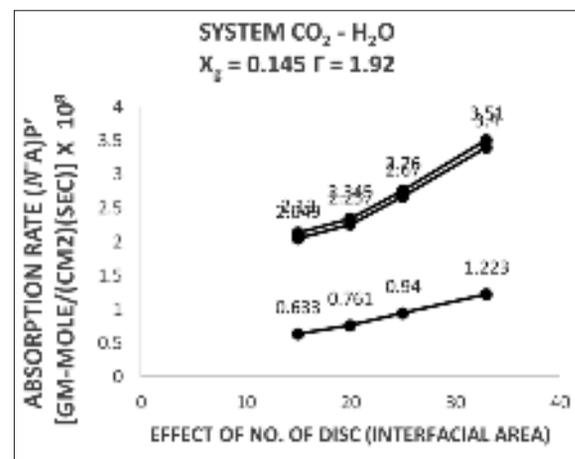


Figure 54

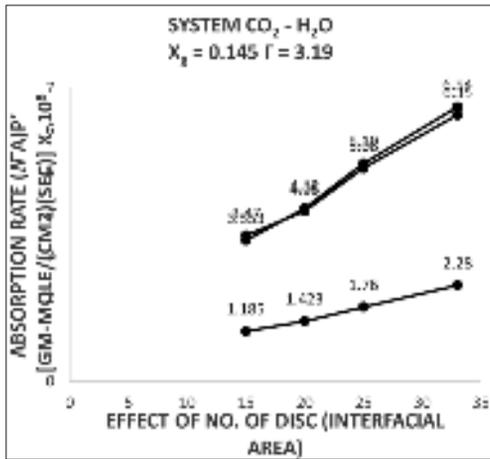


Figure 55

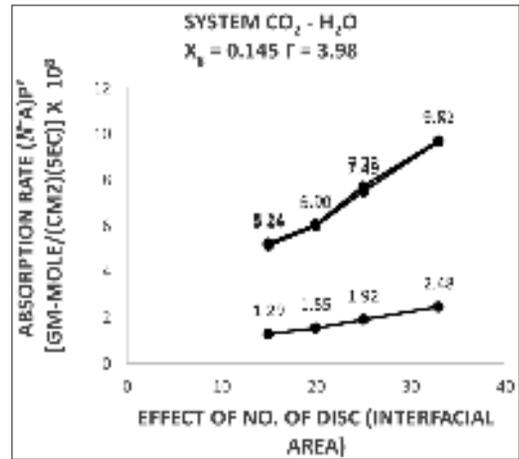


Figure 56

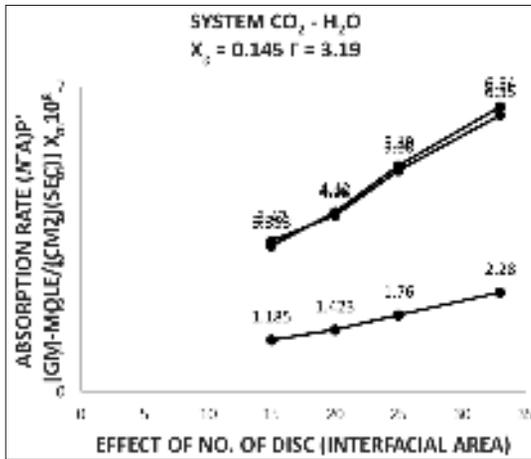


Figure 57

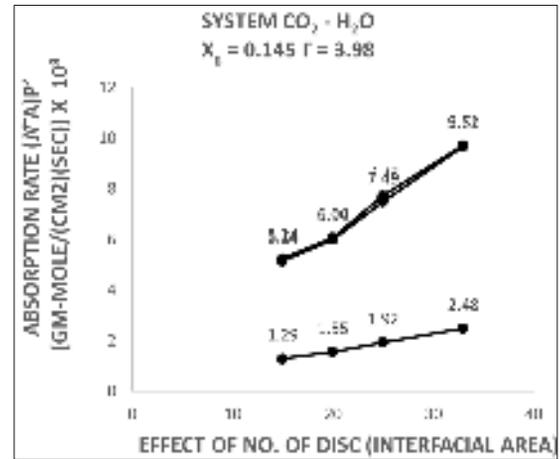


Figure 58

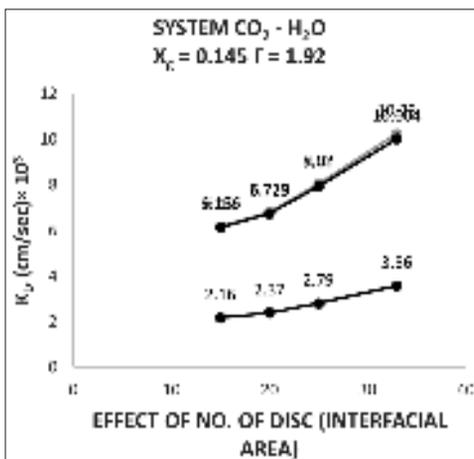


Figure 59

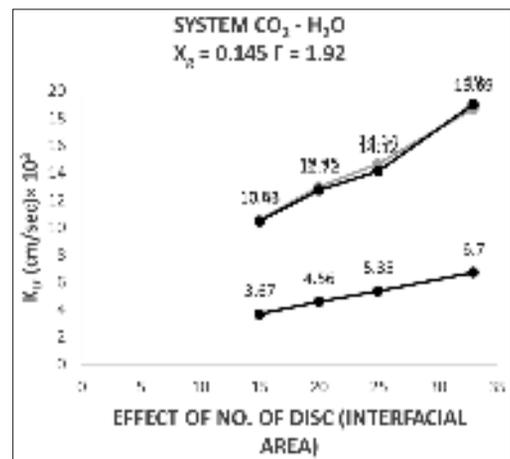


Figure 60

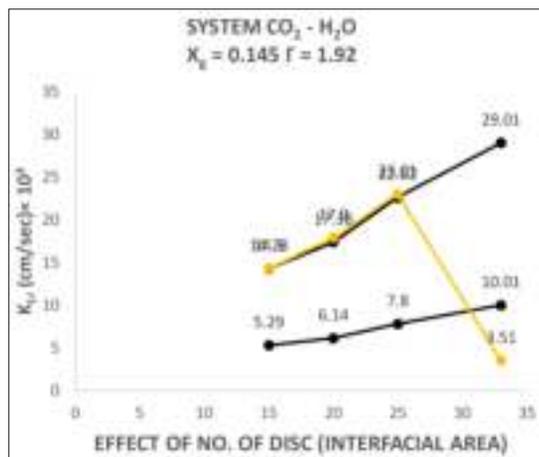


Figure 61

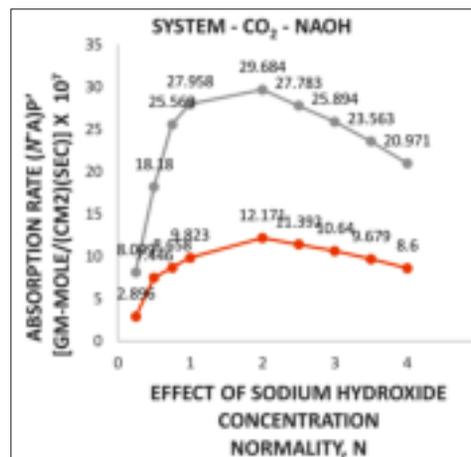


Figure 62

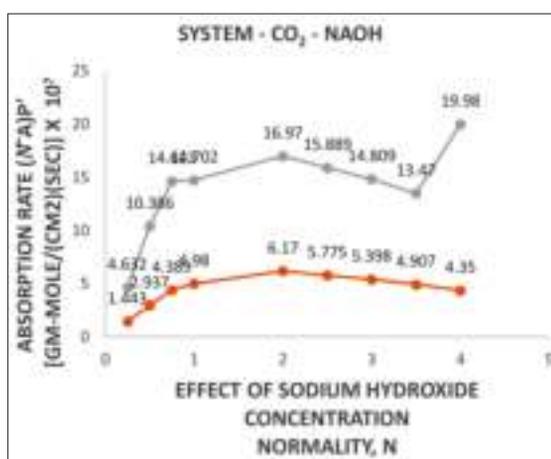


Figure 63

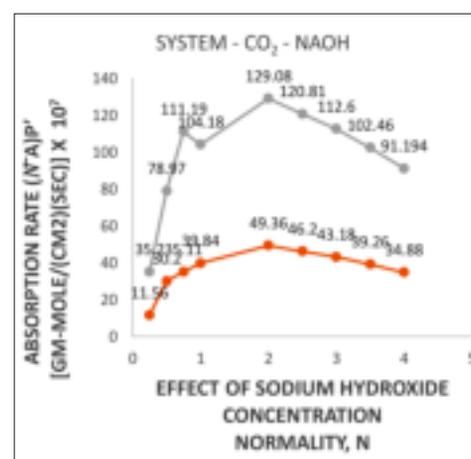


Figure 64

number of disc [15, 20, 25,33]. Increasing the number of discs means the increase in the surface area for mass transfer and increasing the length in the absorption column. It is observed that in the pulsed condition due to the flow disturbances caused due to pulsation effect, the absorption rate for all the three systems increases with increasing number of disc both in pulsed and unpulsed condition. The intensification of mass transfer is higher in case of higher number of disc meaning the high surface area available for mass transfer. It indicates that there is a good agreement of the results between four lengths of the column.

## CONCLUSION

From the experimental investigation, it may be safely concluded that due to the effect of pulsations, high ripples are developed which might have caused for increasing the rate of mass transfer. In most of the cases in all three systems studied, only at peaks were analyzed to have a better picture about the systems.

Mass transfer coefficient increases with increasing the sodium hydroxide normality to 2.5 N in carbon dioxide-caustic soda system for unpulsed packed bed, further increase in concentration beyond 2.5 N to 4 N reduces the mass transfer coefficient slightly. The reason being beyond these value carbon dioxide increases quite appreciably which reduces the mass transfer rate.

Considering the resonance occurred, interfacial area is magnified which gives an increase in mass transfer rate. This is the reason why peak was found at 3.6 Hz irrespective of the system and in some cases peaks were also observed at a



multiple of frequencies. But this finding arises one question in mind that changing the disc dimension and liquid flow rate is possible to get peak at any other value. That was tried here but no control over varying liquid flow rates could be obtained for a particular gas flow rate, maximum liquid flow rate was limited depending on splashing and for low values full area was not wetted. This has to be verified by changing the disc dimensions, may be tried further investigation.

A peak was analyzed for its stability of operation at close frequency range at constant amplitude. Thus for industrial applications before applying, first characteristics are to be studied and system has to be operated at peak frequency (lowest possible) and peak amplitude.

At the present stage of study the following conclusions can be drawn—given a proper selection of pulsation parameters, the pulsation of the gas phase during flow through a packed absorption column has a beneficial effect on mass transfer. This leads to a very important practical conclusion when working with a gas of low solubility, in which case the main resistance of the process is located in the liquid phase, process can be intensified by pulsating the gas phase, provided the flow is sufficiently high.

## REFERENCES

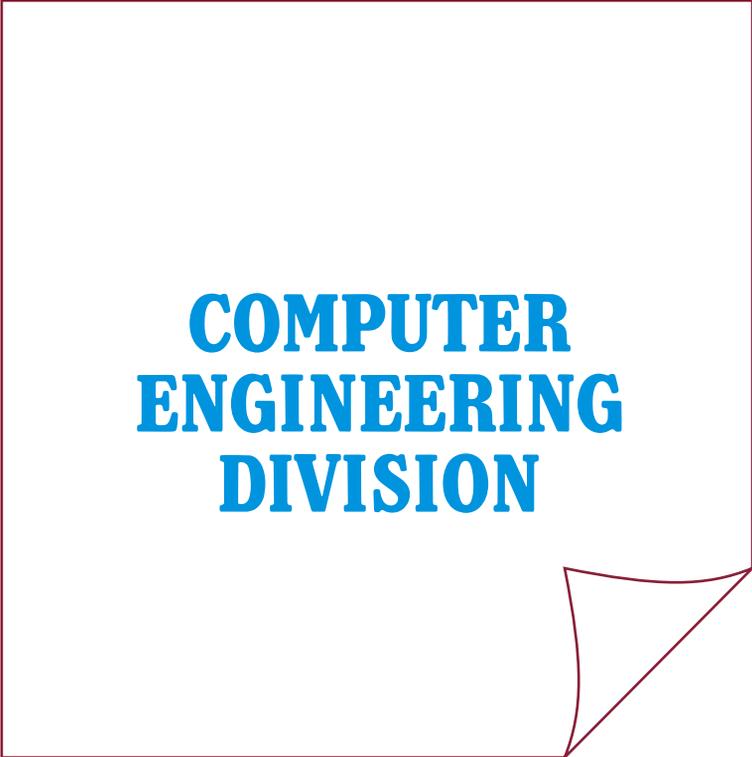
1. AA Hussain, T-B Liang and M J Slater, *Chem Eng Res Des*, 66, 1988, pp 541-554.
2. AB Jahya, H R C Prat and G W Stevens, *Minprex 2000*, Melbourne, Vie 11-13 September 2000, pp 281-284.
3. H-J Bart, C Drumm and M M Attarakin, *Chem Eng Process* 47, 2008, pp 745-754.
4. R L Yadav and A W Patwardhanchem, *Eng J* 138, 2008, pp 389-415.
5. M Torab-Mostaedi, J Safdari, M A Moosavian and M Ghannadimaragheh, *Braz J Chem Eng* 25, 2008, pp 473-481.
6. W A Chantry, R L Von Berg and A F Wiegndt, *Industr Eng Chem* 47, 1153, 1955.
7. A Karr, *Amer Inst Chem Engrs J*, 5, 446, 1959.
8. G Sege and F W Woodfield, *Chem Engng Progr* 50, 396, 1954.
9. T Shiotsuka, N Honda and H Oya, *Kagaku Kogaku*, 22, 687, 1958.
10. L D Smoot and A L Babb, *Industr Eng Chem (Fundamentals)*, 1, 2, 1962.
11. S Bretznajder, L Lesniewicz and W Pasiuk, *Chem Stos*, 3, 275, 1958.
12. R Saint-James and G P Graham, *Genie Chim*, 86, 1, 1961.
13. T Shiotsuka and N Honda, *Kagaku Kikai* 21, 287, 1957.
14. H Kusama, *Nihon Kingakkaiho*, Tokio, Japan Soc Mech Engrs Trans. 18, 27, 1952.
15. P Lambossy, *Helv Physicaacta* 25, 371, 1952.
16. J R Womerslry, *J Physiology* 127, 553, 1955.
17. A Karr, *A I Ch E JI* 5 446, 1959 .
18. L D Smoot and A L Babb, *Ind Engng Chem Fundls* 1 93, 1962.
19. T Miyauchi and H Oya, *A I Ch E JI* 10, 395, 1964.
20. J H Krasuk and J. M Smith, *A I Ch E JI* 7, 759, 1961.
21. R Lemlich and M R Levy, *A I Ch E JI* 7, 240, 1961.
22. H Gordan Harris, Jr and L Simon, *Goren Chem Eng Sci*, 1967, pp1571-1576.
23. S Bretznajder and W Pasiuk, *Bull Acad Pol Sci Ser Sci Chim* 10, 153, 1962.
24. Idem, *Int Chem Engng* 1964 4 61.
25. R H Buchanan, D R Teplitsky and D Oedjoe, *Ind. Engng Chem Process Design Devel* 2, 173, 1963.
26. K L Harbaum and G Houghton, *J Appl Chem, Lond* 12, 234, 1962.



27. G J Jameson, PhD Thesis, Cambridge 1963.
28. D Mirev, L Boyadzhiev and K Balarev, *Izv Inst Obshchakhim, Bulgar, Akad Nauk* 8 47, 83, 1961.
29. M M Veviorvskii, W V Dilman and M B Aizenbud, *Knim Prom* 42, 783, 1966.
30. M H I Baird, *Chem Engng Sci* 18, 685 1963.
31. Idem, *Can J Chem Engng* 41, 52 1963.
32. C G Fritz, C A Ponder and D H Blount, *NASA Memorandum Tm X-53180* 1966.
33. R H Buchanan, G J Jameson and D Oedjoe., *Ind Engng Chem Fundls* 1 82, 1962.
34. M H I Baird *Et Al Chem Eng Sci* 22 December 1967, pp 1663-1673.
35. E Rubin, *Can J Chem Engg* 46, June 1968, pp 145-159.
36. J D Helliums *Et Al A.I Ch E J* 15, 1969, pp 164-170.
37. K Kubo et al, *Kogaku Kagaku* 34, 1970, pp 856-863.
38. Baird et al *Chem Eng Sci*, 27, 1972, pp 823-833.
39. H Sakata, et al, *AI Ch E J* 18, 1972, pp 572-581.
40. O A Kremnev, et al, *Heat Transfer Soviet Research* 54, 1972, pp 19-24.
41. Zielkowald et al, *Inzynieria Chem*, 3(1), 1973, pp 187-205 (Polish).
42. Vasin, et al, *Theoretical Foundation Chem Eng B*, 1974, 100-101.
43. J Molinier, et al, *International J Heat & Mass Transfer*, 20, 1977, pp 247-257 (French).
44. H Lamb, *Hydrodynamics*, 450, 639, 1945, pp 473.
45. R Z Tudose, *Inter Chem Eng* 4, 219, 1964.
46. R Z Tudose, *Inter Chem Eng* 4, 664, 1964.
47. T Sexl, *Z Physics*, 61, 349, 1930.
48. S Bretsznajder and W Pasiuk, *Bull Acad Pol Sci, Ser Sci Chim Geol Geogr* 7, 591, 1959.
49. M Minnaert, *Phill Mag* 16, 235, 1933.
50. K L Harbaum, et al, *Chem Engg Sci* 13, 90, 1960.
51. R H Buchanan, et al, *Ind Chem Eng (Fund)* 1, (2)82, 1962.
52. G J Jameson and J F Davidson, *Chem Eng Sci*, 21, 29, 1966.
53. G J Jameson, *Chem. Eng Sci*, 21, 35 1966.
54. E B Tunstall and J F Davidson, *Chem. Eng Sci*, 23, 1067, 1968.
55. G Houghton, *Can J Chem Engg* 44, 90, 1966.
56. G Houghton, *Proc Roy Soc, A* 272, 33, 1963.
57. G Houghton, *Chem. Eng. Sci.*, 23, 287, 1968.
58. G Houghton, *Can J Chem Engg*, 46, 79, 1968.
59. F Vyarawalla, PhD Thesis, IIT, Kharagpur, 1970.
60. R Lemlich, *AI Ch E J* 7(3), 102 (1961).
61. P Noorderji and J W Rotte, *Chem Engg Sci* 22, 1475, 1967.
62. M H I Baird, *Can J of Chem Engg* 452, 1963.
63. E B F Albastro and J D Helliums, *AI Ch E J*, 15, 164, 1969.



64. M J Lighthill, Proc Roy Soc, London, A 224, 1, 1954.
65. K L Harbaum and G Houghton, J Appl Chem 12, 234, 1962.
66. N W Belga and I W Bigelow, Atomic Energy Commission Declassified Report KT 133, January 1952.
67. A C Healous and H F Johnson, Ind Eng Chem, 47, 1159, 1955.
68. M H I Baird, and J H Garstang, Chem Eng Sci, 27, 823, 1972.
69. Z Ziolkowski and S Fillip, Int Chem Engg 3(3) July 1963.
70. A Gianetto and S Sicardi, Ing Chem Ital 5, 47, 1969.
71. A Gianetto and S Sicardi, Ing Chem Ital 8, 173, 1972.
72. A Gianetto and S Sicardi, Ing Chem Ital, 11, 25, 1975.
73. S Bretsznajder and W Pasiuk, Bull Acad Pol Sci, Ser Sci Chim Geol Geogr 10, 639, 1962.
74. S Bretsznajder and W Pasiuk, Przemysl Chem. 42, 435, 1963.
75. K L Harbaum and G Houghton, J Appl Chem 12, 234, 1962.
76. Z Ziolkowski and S Filip, Przemysl Chem 42, 99, 1963.
77. R Z Tudose, Rev Chim, Bucuresti, 13, 425, 1962.
78. R Z Tudose, 13, 319, 1962.
79. R Z Tudose, Studiisicercetari Chim Fil Lasi 14, 281, 1964.
80. R Z Tudose, Bul Politech Lasi SN 9, 163, 1963.
81. R Z Tudose, Rev Roumaine De Chimie 11, 607, 1966; 1, 621, 1966.



**COMPUTER  
ENGINEERING  
DIVISION**



# An Emphasis on the Role of Artificial Intelligence for Achieving Sustainable Development Goals

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**Abstract:** Artificial Intelligence has become the pioneer and seems to be a buzz word that leads every field of life. The United Nations has put forth various Sustainable Development Goals (SDG) for the betterment of our Society. This SDG concentrates over 17 individual domains, on which we could concentrate and upgrade them for the flourishing of human life. As human life is the most valuable part, it is not good that we exploit the natural resources and make our lives better. If nature is not preserved, then it affects the entire human life. So, it is high time, at least now we must concentrate on nature, clean energy and environment, clean water and land, good and well-being, construct smart cities, Innovations in Industry but with safety, proper recycling, Improve and support climatic actions as well as build better relationships with the nature as well as other countries / organizations for everyone's well-being. This paper concentrates on how AI can help and support human beings for safe and successful construction of SDG especially in avoiding food waste, which in turn preserves energy, water, land fertility and biodiversity. Apriori based frequent and associated food items that co-occur and relatively bought together could be retrieved. Based on the resultant, we could identify the buying pattern and increase them thereby avoiding food waste. This is the place, where technology could enter at least now in preserving and safeguarding the Human, against all Pandemic situations.

**Keywords:**

## INTRODUCTION

Food, energy and water were termed to be the 'nexus' of Sustainable Development goals. As population grows, the demand of these grows as well. All these three are interconnected with each other. Food production involves water and energy, that is, starting from Production, Yield handling, Storage, Processing, Distribution and Consumption, the other two factors are completely involved. So when food is wasted, all the other entities are also wasted. It is stated that nearly 6%-8% of greenhouse gas emissions are mainly due to food waste (**Figure 1**). If waste food gets dumped into the land and rots, this in turn produces methane (greenhouse gas). Food production contributes to 26% and food waste contributes for 6% of global greenhouse gas emissions (Hannah Ritchie).

And the noteworthy point is that, "Not all produced food is consumed completely". It gets wasted by retailers, consumers, spoiled/ wasted in supply chains (Poor storage and bad handling methodologies) or in restaurants, everywhere. So now it is time to think to stop wasting food to avoid carbon emission, water wastage and preserve fertility of land, cut down environmental costs and taking care of Biodiversity. Preventing food waste does help in fighting against climate change (**Figure 2**).

So, here creeps in the Artificial Intelligence to reduce food waste by inculcating various methodologies like Apriori Association rule mining algorithm and Hash based algorithm.

## PROPOSED METHODOLOGY

The concept of Artificial Intelligence penetrates into the notion of avoiding food waste. This aims at providing dynamic prices for food products. As it is stocked, its price is lesser and as the days go the rate for the same item is given at higher cost. This would make the customer to purchase at the early fresh stage of any item and with less price. Association rule mining algorithms could be used to find the closely related/ associated items that are frequently bought and these associated pairs could be provided at some lower cost when fresh. So sales increases and customers are also benefitted which in turn may reduce food waste.

### MIMO Engine for Data Preprocessing

For non-explicit transactional data needs pre-processing and after that it is applied to DAM algorithm. Multiple input streams with multiple output streams engine provides initial set values from the dataset by discovering time series vector



Figure 1 Source1 from world data

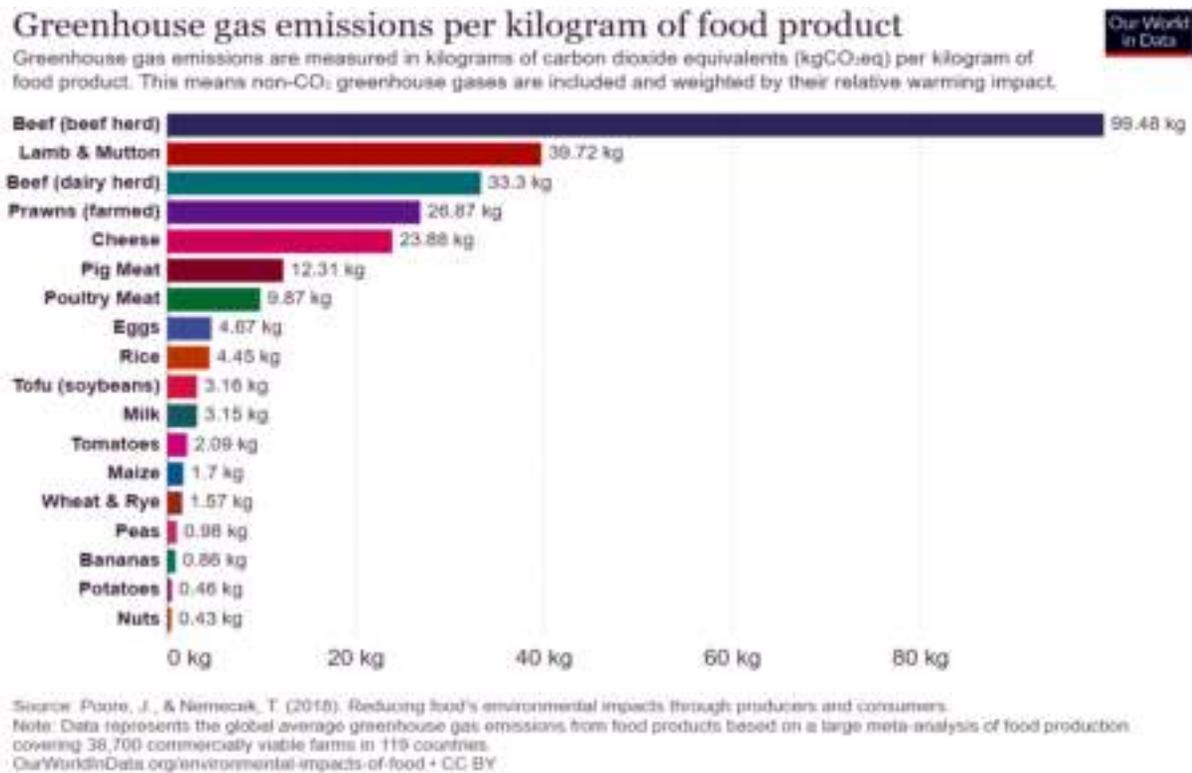


Figure 2 Source2 from world data

format. The preliminary values are predicated by employing explanatory values that is found in data set. The Forecasting values for every item is correlated with the preliminary values and then gives deviation. Deviations are remarked as the new data values in data set (Figure 3).

#### Frequent Pattern Generation

Enhanced module contains two-part Hash table generation and frequent pattern mining. From candidate item set hash table created. In every hash table creation contains infrequent item as well as infrequent transaction removal. A table is created that contains item name as well as its support count for next level reference. From hash table large item set are

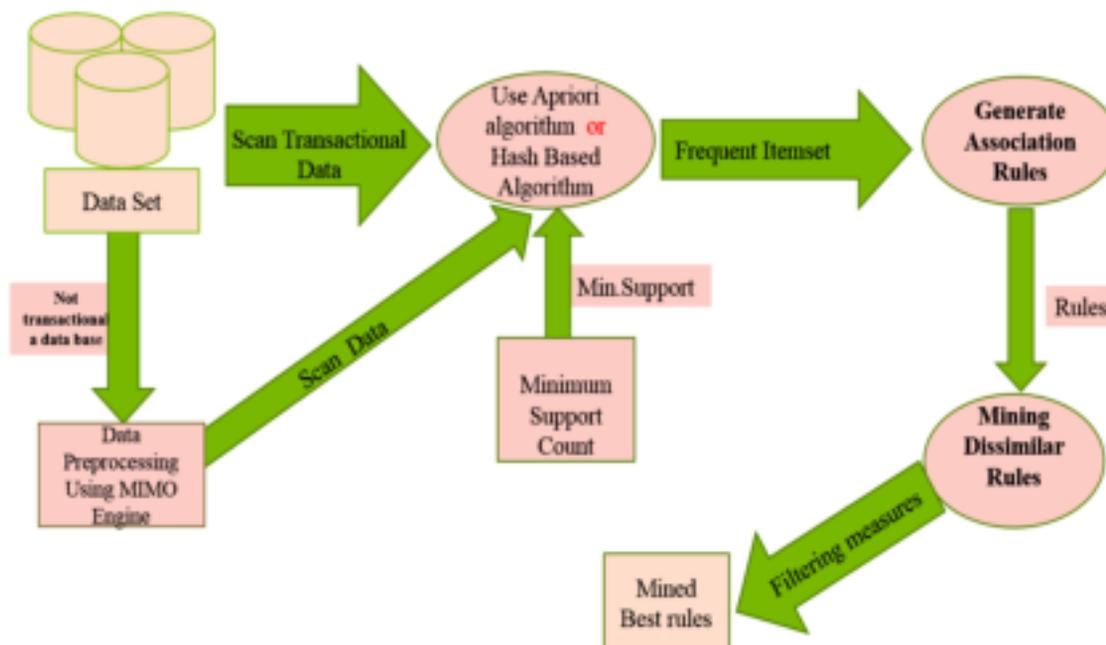


Figure 3 Workflow of proposed system

created. Final aggregation of large item set taken as frequent item set. This Module contains Association rule generation. It consists of two sub operation, namely rule body creation and then its corresponding rule head generation. The Rule body and their corresponding rule head that has been created from frequent item set prevails now. Finally combined both rule body and head as mined rules.

Apriori algorithm and hash based algorithm are used in this project. Apriori algorithm as reference algorithm and compare the performance hash based algorithm with it.

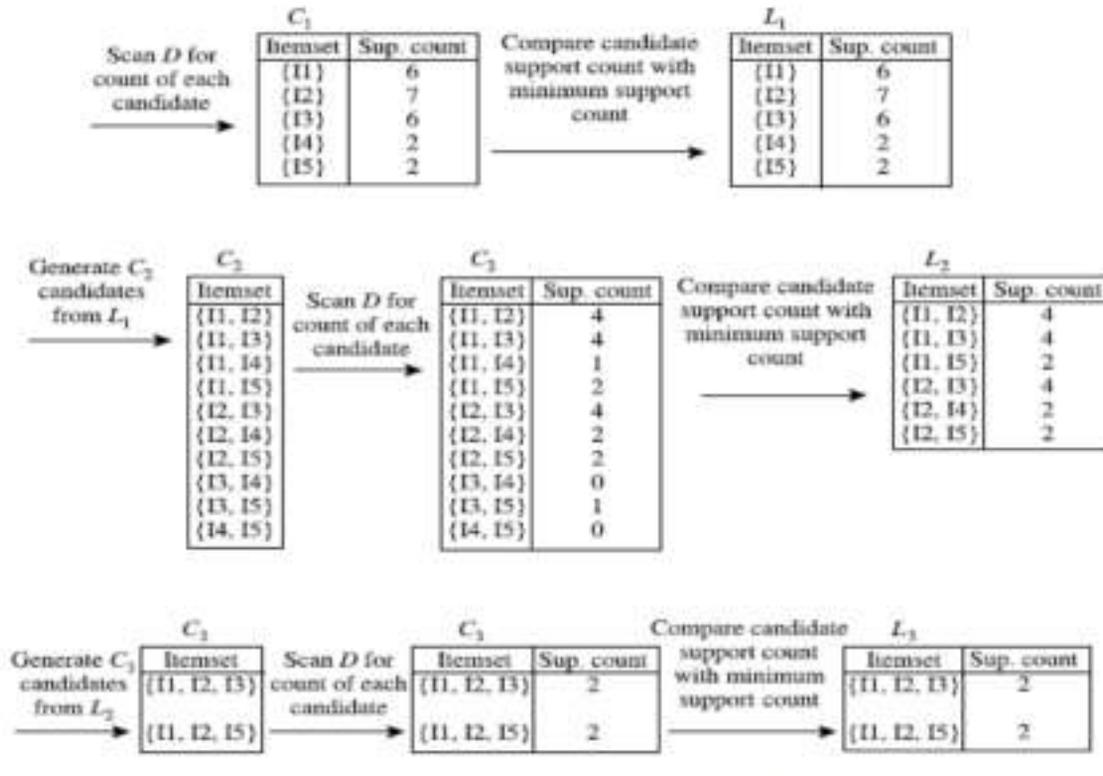
#### Apriori Algorithm

Apriori algorithm is used for finding the frequent item set. It has two main process, candidate generation and large itemset creation. From the algorithm 1 to 7 step indicate candidate generation. After garneting candidate item set, large itemset are created with pruning the item with minimum support count. Large combination of itemset is considered as the frequent pattern. From these frequent items, rules are generated.

Pseudocode:

```

Scan D //Dataset D
h = ||D|| //h is total number of transaction
L1 = {large(D), 1-itemset} //Large itemset of 1-itemset
k = 2 // count need for each itemset iteration above 2
While Lk-1 ≠ NULL, do
An itemset including k items, Ck, is generated using Lk-1
For each transaction T | T ∈ D do.
Ct = subset (Ck, T); %- itemset that are subset of T
c = 0
For each - itemset s/s belong to Ct do
c = c + 1
Endfor
Sup(s) = c/h
Lk = {s belongs to Ct / sup(s) ≥ min_sup}
    
```



Generation of the candidate itemsets and frequent itemsets, where the minimum support count is 2

Figure 4 Finding frequent Itemsets

End for  
 $k = k + 1$   
 End while.

Hash Based Algorithm

Hash based algorithm have mainly three step. First one is hash table creation, after that large itemset created from this hash table. From this large itemset combination frequent patterns are mined.

Pseudocode:

```

Input: Data set  $D$ , Min_Support  $S$ .
Output: Frequent Items  $FI$ , Best Rules  $BR$ .
Generate candidate itemsets –  $C1$ 
//Scan data set and count support count for each item in every transaction
sc_itemset = colSums(data)
c1_table = data.frame(data)[itemname]
Prune the  $C1$  to retrieve  $L1$ 
//Create large item 1 have greater than min. support count
L1_table = subset(c1_table, S <= sc_itemset)
Generating Hash table and large item set of itemset - 2 to above.
//Construct  $H_k$  for candidate  $k$ -itemsets
 $k = 2$ ;
 $D_k = D$ ;
  
```



```
get large itemsets  $L_k$  ( $k \geq 2$ )
While ( $D_k \neq \emptyset$ ) do
   $D = D_k$ ;
  //Hash table
  For each transaction  $t \in D_k$  do
    For all 2-itemsets  $x$  of  $t$  do
       $H_k \text{add}(x)$ ;
    //Record the relationship
    If the itemsets has support  $\geq S$ 
      For each itemsets  $y$  in  $H_k$  do
        If  $H_k \text{count}(y)$  then record the coding relationship on;
      Remove transaction  $t_i$  with less than  $S$ 
    Create ( $L_{k+1}$ )
  End End
  Find new hash table
  For each transaction  $t \in D$  do
    Concatenate joinable pairs of 2-itemsets in  $t$  and then transform them into
    New 2-itemsets by looking them up in hash table
     $FI_k = FI_k \cup \{t\}$ 
   $k++$ 
  Frequent items  $FI_k$  created after  $k$  iteration
  End
  //Rule generation and filtering Algorithm.
  //Rules generated after filtering
  //Rule head and rule body combinations are joined from frequent itemset
  Rule (body)  $\Rightarrow$  rule (body)
   $R = FI_k > \{Confidence, Lift, Leverage, Interest Factor\}$ 
  Dissimilar rules mining
  //Right hand side rule of frequent item set ( $R_{rhs}$ )
   $R_i = R_l$ 
   $R_{irhs} = R_{lrhs}$  equal 1 item
   $= R_{lrhs}$  equal 1 item
   $= R_{lrhs}$  equal 1 item
  // ( $R_{irhs}$ ) compare with other rules ( $R_{rhs}$ )
  For each  $R \in RU_{rhs} = 1$ 
    If  $R_{irhs} = R_{(i+1)rhs}$  {
       $G1 = \text{group}(R_{irhs})$ 
    } Else  $G2 = \text{group}(R_{irhs})$ 
  }
  //Grouping similar one
   $G = \text{merge}((G1) \neq (G2))$ 
  //eliminate same rule body
  For each rules  $R_i \in G$  {
     $R_i = R_l$ 
     $R_{ilhs} = R_{(i+1)lhs}$ 
     $= R_{(i+1)lhs}$ 
    Eliminate ( $R_{ilhs}$ )
  }  $BR = \text{sort}(G)$ 
  End.
```



### *Rule Generation*

This Module contains association rule generation. It consists of two sub operation namely, rule body creation as well as its corresponding rule head generation. The Rule body and their corresponding rule head is constructed from frequent item set. Finally aggregate both the rule body as well as the head as finally mined rules.

### *Example Rules*

Lettuce & Tomatoes -> Cucumber [Coverage=0.250; Support=0.239; Strength=0.956; Lift=2.91; Leverage=0.1568;  
Bread & Milk -> Eggs

### **CONCLUSION**

Therefore, this work attempts at providing a better AI model food waste management. As these are the places where technology could enter at least now in preserving and safeguarding the Human against all Pandemic situations. The work has also shown the best AI model for supporting us to work together for achieving Sustainable Development Goals.

# An Efficient Way to Detect Spam SMS Messages using Deep Learning Techniques

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**Abstract:** With the advancements of the digital communication, the usage of mobile phones has been also increased drastically and with this, the common way of information transfer platform i.e. Short Messaging Services (SMS) are in wide range of usage. It is a way of communication through which billions of users exchange numerous messages in an easy manner. But with the increase of SMS services, it has become very easy for the cyber attackers in this developing era of digital communication to attack people just by sending them unwanted messages or malicious links as well, such incidents come under the cyber frauds and are growing rapidly. So in order to protect the people from such frauds, this research paper aims to classify the SMS' as Ham or Spam. To achieve this, this paper will focus on various Deep Learning and Machine Learning Techniques for Spam detection such as SVM, Naive Bayes Algorithm, Logistic Regression, K-Nearest Neighbour and many more & then make comparisons among them to find out which algorithm is more efficient based on different parameters and outperforms the others to detect the Spam messages. Nowadays, it is very crucial to identify the spam messages because with just one wrong click, users' personal information can easily be leaked so to prevent people from this, this model will prove beneficiary.

**Keywords:** Spam Detection; SMS Classification; Cyber Crime Detection

## INTRODUCTION

The advancements of the technology has led to the increased usage of the mobile phones, laptops, PC's etc. Majority of the people use mobile for communication purpose. Short Messaging Service (SMS) is a way of communication through which billions of users exchange numerous messages. Nowadays, such type of communication is highly insecure due to insufficient message filtering mechanisms. One cause of such insecurity is SPAM. Spam is basically a junk or unwanted messages for the receivers, received by the users unknowingly without their permission. It contains various forms like winning cash prizes, claiming fake scholarships, job with higher pays, and services etc. Due to large number of usage of text messaging services, the number of spam messages has also increased proportionally. In today's scenario, almost 80% to 85% of the messages received are categorised as SPAM. SMS has grown into a multi-billion dollars commercial industry and spam SMS has increased proportionally and nowadays, out of every 10 SMS, 5 are SPAM. This is so because cost of the message is very minimal for senders but is very high for those who are receiving. Passwords, credit/debit card details etc are stored in their mobile phones and if any person opens such messages then there is higher chance that this will cause some harm to their data, it could be accessed by third person or their details could be viewed by the sender. In terms of spam SMS, India came in eighth, with consumers receiving 61 spam SMS on average each month. Additionally, in May 2018, more than a dozen Bengalureans were scammed out of lakhs of rupees by fraudsters using a new SMS-spoofing malware (given to the victim as an SMS link to obtain remote access to the latter's smartphone photos, call records, and texts). Since more people own smart phones, they run a bigger risk of losing their data if they click on a bad link.

Therefore, an effective method to identify spam SMS would be helpful in preventing consumers from putting their personal data at risk. The goal of this paper is to review the machine learning models for detecting spam SMS messages and compare them to find the most effective model for the given data. To address these issues, various machine learning models will be used to classify the messages as Ham or Spam using an effective model of classification.

## LITERATURE REVIEW:

Navaney, et al (2018) suggested that The naive Bayes algorithm, support vector machines, and maximum entropy algorithms are only a few examples of the supervised machine learning methods that are tested in this study for their effectiveness in detecting spam and ham communications. SMS spam is growing more prevalent as people participate in more Web-based activities and businesses disclose more sensitive information. The Ee-mail spam filtering provides a lot



of the functionality for the SMS spam filter. The most accurate supervised learning algorithm, according to comparisons of the outcomes of several algorithms, is the support vector machine algorithm[1]. Raza, et al(2021) observed that email is the most often used form of formal communication for commercial purposes. Email usage has increased despite the availability of alternative communication methods. Over 55% of all emails have been classified as spam. This paper's major objective is to use machine learning methods to classify spam. Furthermore, this research provides a thorough examination and analysis a summary of research on various machine learning techniques and email features used in many applications. Methods based on machine learning future research is also provided directions and problems in the realm of spam classification Future researchers may find it beneficial[2]. Sethi, et al(2017) suggested that The quantity of spam emails and messages has increased in recent years. Nowadays, there are legal, economic, and technical issues to consider. In this study, we assessed and compared the relative benefits of different machine learning approaches for detecting spam messages sent over mobile devices. Accuracy in identifying spam messages was the main factor taken into account while ranking these systems. Our research demonstrates that when given different parameters, several machine learning systems identify spam messages in different ways[3]. Tunçtan, et al (2017) observed that one of the most extensively utilized mobile communication services is SMS. Unwanted messages, known as spam, are, however, a significant element of this communication. A new approach for SMS spam filtering is presented and developed in this study, as well as an Android application for this approach. Spam detection is carried out using this method, which is based on changes in the UTF-8 values of the characters. The created approach has been evaluated on two separate data sets, with success rates of 94.64% and 98.85%, respectively. The obtained findings show that the devised strategy can be implemented successfully[4]. Ishtiaq, et al (2019) suggested that The use of short messages has exploded, including SMS, tweets, and status updates. Afterward, unlabeled SMS is categorized based on the tokens' centrality scores in the unclassified SMS. For spam messages, degree centrality had the highest precision (0.81), as well as recall (0.76)[5]. Peng, et al (2020) observed that the Short messaging service (SMS) has grown in popularity as smartphones and mobile communication technologies have advanced, owing to its low cost and ease of use. During smartphone forensics, if several spam messages are kept on users' smartphones, removing the spam will take a lot of time and work on the part of the investigators. We offer a smartphone forensics model that employs machine learning to isolate key data for inquiry and filter SMS spam in order to swiftly conduct a smartphone investigation[6]. Sharma, et al (2019) observed that the SMS spam has become a common and rising problem. Using the Genetic Programming Approach, the model suggested in this research creates regular expressions as individuals in a population. It is capable of removing False Positive mistakes, saving valid data, communications from being categorized incorrectly. With a larger number of generations, the performance tends to improve. The performance and confusion matrices for various generations are tabulated[7]. Kural, et al (2021) suggested that One of the most extensively utilized communication services is short messaging services. The TF-IDF and RF word weighting approaches, which are commonly used in text mining applications, were compared in this study in order to classify spam SMS and make better use of the limited content of SMSs The TF-IDF and RF term weighting methods were used to weight the vectors from the data set, and five different classifiers were used to classify them[8]. Baaqeell, et al (2020) suggested that the widespread use of Short Message Service (SMS), spammers have developed an interest in digging their way into it in the hopes of reaching more targets. This description is ideal for our situation because it divides SMS into two categories: spam and ham. This research will address SMS spam filtration solutions by presenting a hybrid system that employs two types of machine learning algorithms: supervised and unsupervised machine learning algorithms. The goal of the new hybrid system is to accomplish F-measures and improved spam filtration accuracy[9]. Ali, et al (2018) observed that In today's electronic world, Short Message Service is the most widely utilized mode of communication. While there have been numerous studies on email spam detection, we haven't had access to information on spam sent by SMS. This dataset was then utilized to test several algorithm strategies in order to determine the most effective algorithm in terms of accuracy and recall. The Random Forest technique was then implemented as a cross-platform application framework written on C#. Development of the internet This library is capable of classifying a new dataset for spam and ham using a prebuilt model[10]. Katpatal, et al (2018) observed that Spam on Twitter has become a common occurrence these days. We keep an eye on the spam's measurable qualities. A new dataset of unlabeled tweets will be used in the future and will be trained using the new training dataset. Lately, I've been focusing on using machine learning systems to detect spam on Twitter, and I've been using discarding too old samples after a specified period of time. This will get rid of useless data and save space[11].

## PROPOSED APPROACH

The proposed methodology for this article includes a few stages which are as follows :

### Data Preprocessing

Data is a requirement before we can create any useful algorithms. Because our data could contain a lot of noise and



unnecessary characters like punctuation, white space, digits, hyperlinks, and etc.

Typical methods that people typically employ include:

- change every letter to upper- or lowercase;
- eliminating numbers, punctuation;
- deleting hyperlink, white space and words like “a”, “around”, “above”, “below”, “doing”, etc.

### Dataset

A group of SMS-tagged messages known as the SMS Spam Collection have been gathered for SMS Spam research. It has a single batch of 5,574 English SMS messages that have been classified as spam or ham (legitimate) messages.

### Feature Extraction

We require a feature extraction layer in the middle to convert the words to integers or floats because our method always assumes that the input is an integer or float.

There are a few approaches to doing this, which are as follows

- CountVectorizer;
- TfidfVectorizer.

#### (a) Count Vectorizer

The first step is to enter all of the training data into Count Vectorizer, which will maintain a dictionary of every word and its corresponding id. This id will be related to the word count of this particular word within the entire training set.

#### (b) Tfidf Vectorizer

Could word counts, while good, be increased? Basic word counts have the drawback that certain words, such as “the” and “and”, will appear frequently yet offer little in the way of important information. The Tfidf Vectorizer is yet another popular option. In addition to calculating the word count for each word, the vectorizer will seek to downscale words that often occur across numerous documents or phrases.

### Different Models to be used

Depending on the type of input data needed for each classifier, various preprocessing techniques have been used. Here is a basic explanation of these strategies.

- Support Vector Machine: In SVM, data point is plotted as a point in n-dimensional space using the method, which takes each feature’s value as the value of a specific coordinate. It then breaks two line .data into two groups that have been categorized differently and based on this line and separated the data points using hyperplanes. If the data is not linear then kernels are used.
- Naive Bayes: This classification method relies on the Bayes theorem and assumes predictor independence. The Bayesian classifier will treat each of the desired properties as an independent contributor to the probability, even if they do depend on one another or the presence of the feature. When the dimensionality of the desired input is high, the classifier maintains its accuracy. It is thought to be both easy and reliable.
- Decision Tree: The supervised learning algorithm DT is frequently selected for classification issues. With categorical and continuous variables, the method works effectively. It starts by segmenting the population into a variety of homogeneous sets according to the most crucial traits or independent variables.
- Logistics Regression: It is regarded as the preferred technique for categorizing data with binary outcomes. It is mostly used to estimate discrete values that are based on a group of independent variables. LR, which aids in prediction, outputs the probability of an event by fitting it into a logistic function, to put it in more relative terms. The most common logistic function is sigmoid.

### Training and Testing

We divided the data into two distinct datasets: one for testing our classifiers, and the other for training them. We divided our datasets so that training would use 80% of the data and testing would use 20% as shown in **Figure 1**.

### Performance Metrics

To get the data needed for the verification of any hypothesis or comparison, it is crucial to select the appropriate performance metrics for any experimental setup. We have taken into account the following well-known metrics in order to compare and analyze the detection capacity of the classifiers under consideration:

- (a) Accuracy - It is described mathematically as the degree to which a calculated value resembles an actual value.
- (b) Precision - It can be described more simply as the proportion of obtained correct results to the total number of results.
- (c) Recall - It is the ratio of the actual number of correct answers to the desired number of correct answers. Or to put it another way, it's the percentage of related text that is actually retrieved.

### RESULT ANALYSIS

In order to arrive at our results, we compared the classifiers while taking into account the aforementioned criteria. The most important criterion to evaluate various strategies is nearly usually accuracy. The methods we are using on our dataset demonstrate that SVM has the highest accuracy as shown in **Figure 2** and the highest precision, depicted in **Figure 3** however Naive bayes achieve the highest recall as shown in **Figure 4**.

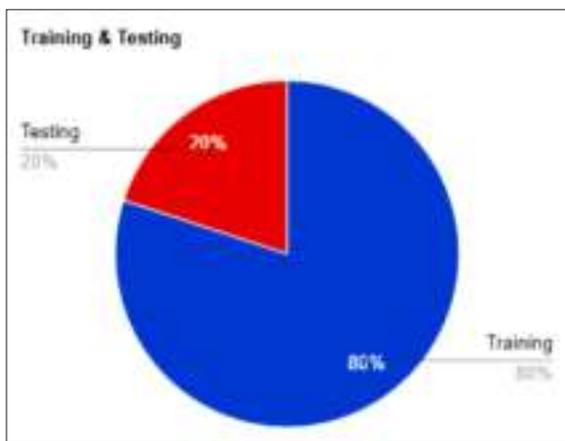


Figure 1

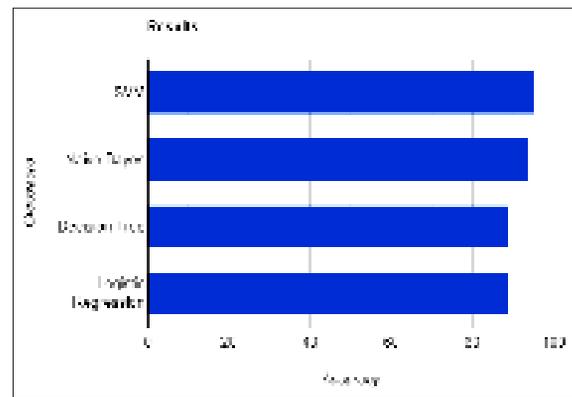


Figure 2

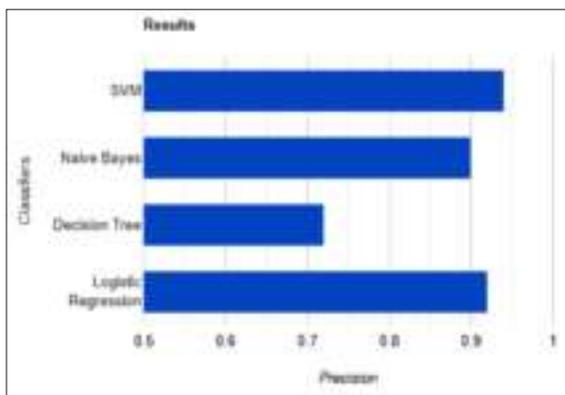


Figure 3

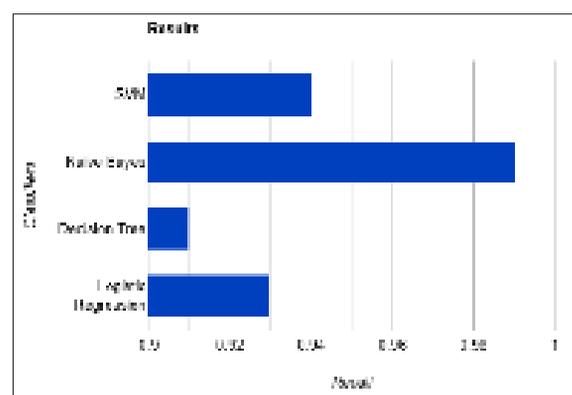


Figure 4



## CONCLUSION AND FUTURE SCOPE

The main focus of this research was on analysing and assessing machine learning approaches for SMS spam detection. We conducted tests comparing four distinct classifiers. According to the outcomes of our study of the classifiers, SVM Classifier has the highest accuracy in the dataset (98.02%), according to the results. With regard to the ability to apply this research to a practical level for the detection of spam SMS, significant outcomes have been produced from this effort. SVM and NB perform well among classical classifiers, as expected. Since the dataset only focuses on the English language, other languages may also be taken into account in the future.

## REFERENCES

1. P Navaney, G Dubey and A Rana, SMS Spam Filtering using Supervised Machine Learning Algorithms, 8th International Conference on Cloud Computing, Data Science & Engineering (Confluence), 2018, <https://doi.org/10.1109/confluence.2018.8442564>.
2. M Raza, N D Jayasinghe, and M M A Muslam, A Comprehensive Review on Email Spam Classification using Machine Learning Algorithms, 2021, International Conference on Information Networking (ICOIN). <https://doi.org/10.1109/icoin50884.2021.9334020>.
3. P Sethi, V Bhandari and B Kohli, SMS Spam Detection and Comparison of Various Machine Learning Algorithms, International Conference on Computing and Communication Technologies for Smart Nation (IC3TSN), 2017, <https://doi.org/10.1109/ic3tsn.2017.8284445>.
4. O Tunctan and Y Kaya, A Novel Approach to Filter Spam SMSs and Android Application, International Artificial Intelligence and Data Processing Symposium (IDAP), 2017, <https://doi.org/10.1109/idap.2017.8090265>
5. A Ishtiaq, M A Islam, M Azhar Iqbal, M Aleem and U Ahmed, Graph Centrality Bbased Spam SMS Detection, 16th International Bhurban Conference on Applied Sciences and Technology (IBCAST), 2019, <https://doi.org/10.1109/ibcast.2019.8667174>.
6. L Peng, X Zhu and P Zhang, An Efficient Model for Smartphone Forensics using SMS Spam Filtering, 3rd International Conference on Hot Information-Centric Networking (HotICN), 2020, <https://doi.org/10.1109/hoticn50779.2020.9350843>.
7. D Sharma and A Sharaff, Identifying Spam Patterns in SMS using Genetic Programming Approach, International Conference on Intelligent Computing and Control Systems (ICCS), 2019, <https://doi.org/10.1109/iccs45141.2019.9065686>.
8. O E Kural and S Demirci, Comparison of Term Weighting Techniques in Spam SMS Detection. 2020 28th Signal Processing and Communications Applications Conference (SIU), 2020, <https://doi.org/10.1109/siu49456.2020.9302315>.
9. H Baaqeel and R Zagrouba, Hybrid SMS Spam Filtering System Using Machine Learning Techniques. 21st International Arab Conference on Information Technology (ACIT), 2020, <https://doi.org/10.1109/acit50332.2020.9300071>.
10. S S Ali and J Maqsood, Net library for SMS Spam Detection using Machine Learning: A Cross Platform Solution, 15th International Bhurban Conference on Applied Sciences and Technology (IBCAST), 2018, <https://doi.org/10.1109/ibcast.2018.8312266>.
11. R Katpatal and A Junnarkar, An Efficient Approach of Spam Detection in Twitter, International Conference on Inventive Research in Computing Applications (ICIRCA), 2018, <https://doi.org/10.1109/icirca.2018.85972>.



# Role of Machine Learning Techniques in the Early-Stage Diagnosis of Diabetic Peripheral Neuropathy

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**Abstract:** Diagnosis of diabetic peripheral neuropathy is very difficult in the early stages. It is because of the slowing of conduction characterizes in sensory and motor nerves. The patients underlying are poorly managed because of its masked onset, delayed diagnosis, and more complex sources resulting from the contribution of ageing and other related diseases. The research work proposes the implementation of machine learning algorithm for the early-stage diagnosis of diabetic peripheral neuropathy. The study concentrated in the deviations of nerve conduction parameters of lower extremities. The peripheral nerve is stimulated with controlled electrical signals and the nerve conduction parameters of peroneal, tibial and sural nerves of legs are captured. Artificial Neural Network and Machine Learning techniques are employed for the analysis and prediction. The parameters such as amplitude, area of the curve and conduction velocity are considered for the classification purpose. The classification is accomplished with five different types of algorithms. The models are analyzed for of both left and right legs with parameters such as accuracy, precision, recall, F measure and specificity.

**Keywords:** Diabetic Peripheral Neuropathy; Early-stage Diagnosis; Machine Learning; Nerve Conduction Velocity; Diabetic Foot Ulcer

## INTRODUCTION

Diabetic peripheral neuropathy is one of the most common complications of chronic diabetes which may lead to foot ulceration and amputation. Identification and prediction of diabetic foot at their earlier stages are much important, so as to prevent the extremity. The slowing of conduction characterizes in sensory and motor nerves in diabetic neuropathy. The patients underlying are usually poorly managed because of its masked onset, delayed diagnosis, and more complex sources resulting from the contribution of ageing, hyperglycemia and hypertension. The factors such as duration of diabetes, age, glycosylated hemoglobin and diabetic retinopathy are associated with significantly increased risks of diabetic peripheral neuropathy among diabetic patients. Electromyography and nerve conduction studies can assess peripheral nerve functions without subjective biasing of diabetic patients. Comprehensive evaluation methodologies of sensory and motor conduction studies on multiple nerves in the upper and lower limbs permits to detect and categorize peripheral neuropathy. The research work aims to predict Diabetic peripheral neuropathy by analyzing the nerve conduction characteristics of lower extremities with advanced machine learning algorithms.

## LITERATURE REVIEW

In the absence of early stages diagnosis of diabetic peripheral neuropathy, the opportunity to prevent the development of the major clinical neuropathic endpoints of the lower limb and the neuropathic ulcer shall be missed. Changes in sensation and reflexes happens because of the loss of motor function in these patients [1]. Pin-prick testing and Semmes-Weinstein monofilament testing are some of the initial methods of identifying sensory neuropathy[2]. Diabetic peripheral neuropathy is one of the critical factors related to the development of diabetic foot ulcer [3].

The reference values of the sensory branches of the superficial peroneal nerve and information to the fourth interdigital web space was provided in the study conducted in Korea[4]. A study was performed to define the early pathological changes in the sural nerve of diabetic patients with minimal evidence of neuropathy. It was identified that the neuropathy developed in higher rate in patients with type 1 and type 2 diabetes. The structural pathology of the myelinated fibres is extracted from the nerve conduction velocity and amplitude of responses[5]. Motor Nerve Conduction Velocity is found an independent predictor for the development of new foot ulcers in people with diabetes[6]. The morphological findings in sural nerve were quantitated to the conduction abnormalities with diabetic neuropathy[7]. The expected conduction



velocity from the diameter of the largest fibres is found slowing of 20% to 30% with the causes other than fibre loss. This is found in most of the sensory nerves in the lower extremities. Slowing in conduction occurred in the lower as along with the upper extremities of the patients under diabetic neuropathy.

Clinical features of peripheral neuropathy were correlated with nerve conduction study in Type 2 diabetes mellitus for detecting sensory motor neuropathy [8]. In the study conducted for the assessment of diabetic neuropathy by analyzing the population based data found that the F-wave latency was the most predominant peroneal abnormality. In sural nerve studies, the response latency and amplitude parameters also have similar abnormality rates [9]. The Michigan Neuropathy Screening Instrument (MNSI) is one of the methods of assessing distal symmetrical diabetic peripheral neuropathy. Here, a self-administered questionnaire of 15 parts and lower extremity examination which includes direct inspection, assessment of vibratory sensation and ankle reflexes [10], [11].

The Artificial Neural Network (ANN) has started using for the interpretation of various type of diseases from its data sets. ANN was effectively examined for the classification of peripheral Neuropathy on nerve conduction study (NCS). The study identified the feed-forward back propagation model has the highest accuracy compared with other models [12]. Schafer, et al used machine learning techniques to assess the risk factors for the prediction and analysis of foot ulcers and amputation [13]. A multilayer feed forward neural network is employed to classify the evoked response of ulnar nerve for the identification of moderate to acute diabetic neuropathic conditions [14]. In this study the features are extracted using Prony's feature extraction method.

## NERVE CONDUCTION STUDIES

Neuromuscular disorders can be evaluated by electrodiagnostic studies such as nerve conduction studies, late responses, repetitive nerve stimulation, blink reflexes, needle electromyography etc. Nerve Conduction Studies are most prominent method of the diagnosis of the disorders in peripheral nervous system for detecting high risk diabetic neuropathy. The differential diagnosis methods can be effectively employed for identifying the clinical abnormalities. The electrodiagnostic studies provides key information of fiber types and the underlying pathophysiology of the localized disorders of the peripheral nerves.

The developed potentials are because of the extracellular recording of intracellular actions, being measured from the muscle or nerve. The recording is accomplished on the skin by surface electrode and the electromyogram (EMG) signals are captured from the muscle with needle electrodes. The intracellular electrical potentials are transmitted through tissue to the recording electrodes, referred as volume conduction. Electrodiagnostic studies yield crucial information about the underlying neuromuscular disorders and help to apply other types of laboratory tests in appropriate manner. The key objectives of Electrodiagnostic study are to localize the disorder and assess its severity.

## METHODOLOGY

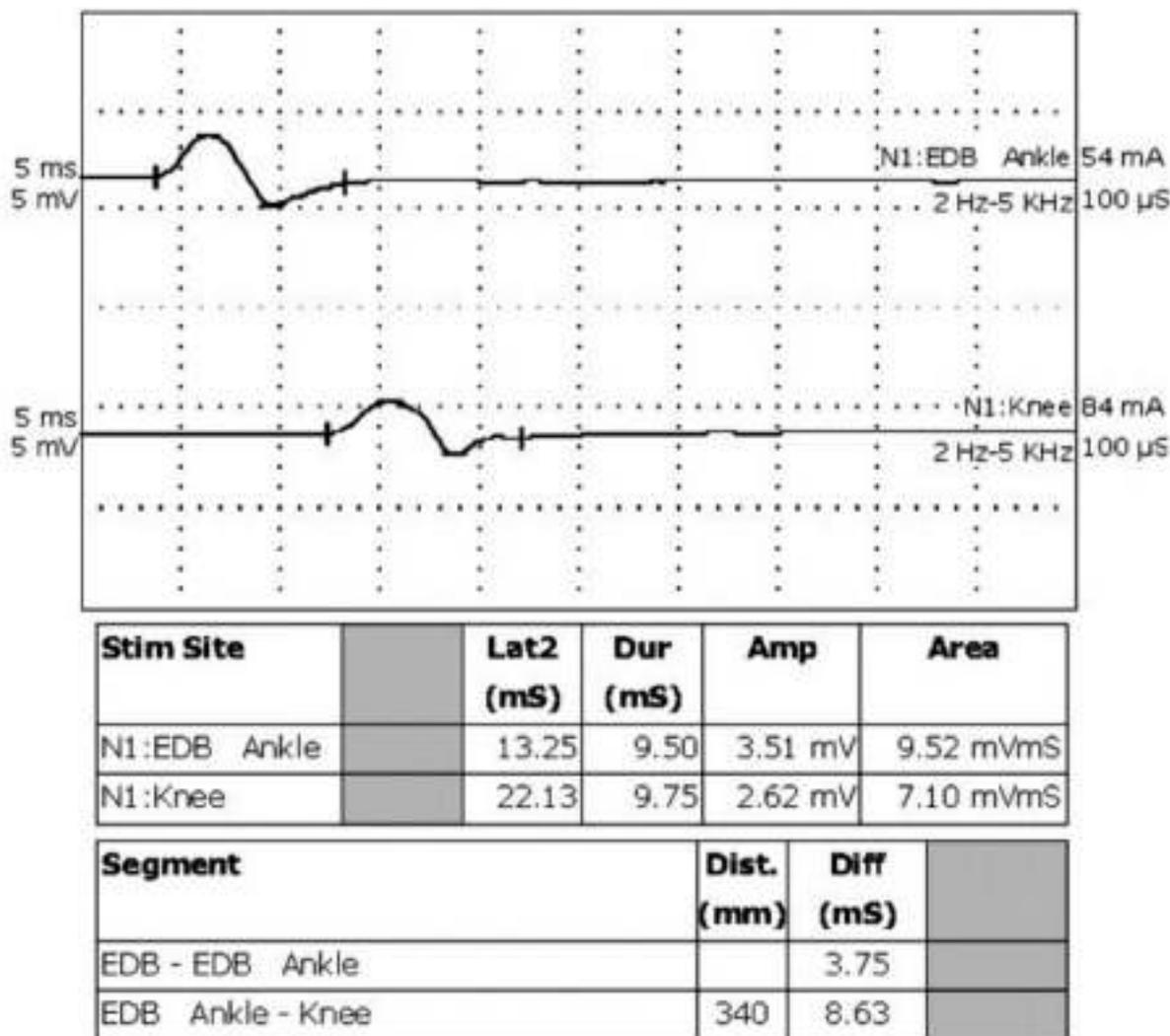
The study has been conducted among the patients of Jubilee Mission Medical College and Research Institute, Thrissur, India with the approval of institutional ethics committee. The patient data has been captured with EMG Machine (Octopus- Clarity Medical). The machine has 8 channel amplifiers with integrated stimulator. The Personal Computer based system is capable of storing data in the hard disk with an application software. This equipment is capable of performing electromyography analysis and Nerve Conduction studies such as MNC, SNC, F-Wave, H-Reflex, Blink-Reflex etc.

Prolonged diabetic patients, who were suffering from more than 5 year, are included in the study. The subjects are grouped into two.

Group 1: Subjects who have visible symptoms of Neuropathy.

Group 2: Subjects who do not have any symptoms of Neuropathy.

The nerve conduction studies have been accomplished on the left and right legs. There are some recommended protocols for the nerve conduction studies. The diagnostic process should begin with motor conduction studies of lower extremity. The routine peroneal and tibial motor studies can be performed along with their F responses. The F wave is a late response generating from antidromic activation of motor neurons during conduction to and from spinal cord and arises at the interface between the central and peripheral nerve system. In the case of absent motor responses of distal muscles, such as Extensor Digitorum Brevis (EDB) and Abductor Hallucis Brevis (AHB), the peroneal motor studies can be performed with more proximal muscle using tibialis anterior nerve. **Figure 1** depicts the motor nerve conduction test details of peroneal nerve at the recording site of EDB. Lower extremity sensory responses of the sural or superficial peroneal can be accomplished after the motor studies. The amplitude differences of more than 50% comparing side to



**Figure 1** Motor nerve conduction test: peroneal – left, recording site: extensor digitorum brevis

side are considered abnormal.

In the Nerve Conduction studies the patient is in supine, sitting or reclining position. In peroneal studies, surface plate electrodes are placed in the middle of extensor digitorum brevis. The reference electrode is on the fifth metatarsophalangeal joint and the stimulation is employed on the ankle, 80mm proximal to the recording electrode and lateral to the tendon of tibialis anterior. Below knee, 20-50 mm distal to the proximal part of caput fibulae. Above knee, 50-90 mm above caput fibulae, medial to the tendon of biceps femoris.

#### MACHINE LEARNING APPROACH

The detection and classification of peripheral neuropathy is very complex, as it involves a correlation between the nerve conduction studies and other physical parameters such as motor nerve conduction velocity, compound muscle action potentials, F response latencies, distal motor latencies, sensory latency, sensory nerve action potentials, H reflexes etc. Only an intelligent system can make fruitful diagnostic results. Recently, approaches based on machine learning have achieved excellent performance in computer vision and medical data analysis tasks. Artificial Neural Network and Machine Learning techniques are considered to be the best solution and such techniques are employed for the classification purpose. Many of the methods from machine learning and statistics can be used for prediction and inference of biological systems. Generalized predictive pattern can be extracted from Machine Learning methods.

Prediction helps to identify best courses of action without requiring and understanding the whole underlying mechanisms [15].

The purpose of Machine Learning is to build computer systems that can adapt and learn from their experience and predictive models can be built with these algorithms. The data set is undergoing the process of training, validation and testing. The machine learning algorithms such as K-Nearest Neighbours Algorithm (KNN), Naive Bayes classifier (NB), Recurrent neural network (RNN), Support Vector Machine (SVM) and Decision Trees (DT) are employed for the analysis.

K-nearest neighbours is a non-parametric method used for classification and regression. Here the neighbourhood is explored assuming the test data point to be similar to them for deriving the output. The pattern in the test data is classified by calculating the distance to all the patterns in the training data [16]. The class of the training pattern that indicates the shortest distance determines the class of the test pattern. Euclidean distance between two points can be calculated as:

$$d_E(p, q) = \sqrt{\sum_{i=0}^R (p_i - q_i)^2} \quad (1)$$

Where R is the number of features.

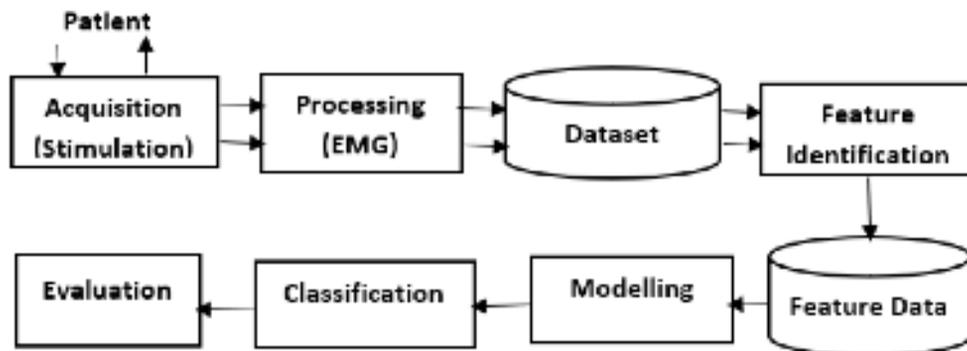
Naive Bayes classifiers are probabilistic classifiers and the algorithms are based on Bayes' Theorem. The RNN is a class of artificial neural networks recognize the sequential characteristics of data and the patterns are used to predict the next likely scenario. SVM can handle non-linear solutions whereas logistic regression can only handle linear solutions. Decision tree has hierarchical tree structure consists of root node, branches and leaf nodes. It is utilized for both classification and regression tasks. Non-parametric supervised learning algorithm is being employed in decision tree models.

**Figure 2** shows the block diagram of the machine learning approach. A patient interface is used for acquiring waveform corresponding to the stimulation. Required features have been selected from the patient dataset. The machine learning algorithms are used for the evaluation and testing purposes. The programming works was accomplished with various tool boxes of MATLAB software.

### RESULT

The analysis has been conducted with the features of amplitude, area and conduction velocity of the peroneal, tibial and sural nerves. In addition to this the F response latencies of peroneal and tibial nerves are also considered.

The parameters such as Accuracy, Precision, Recall, F measure and Specificity are calculated for the machine learning algorithms. **Table 1** and **Table 2** shows corresponding calculations of as K-Nearest Neighbours Algorithm, Naive Bayes classifier, Recurrent neural network, Support Vector Machine and Decision Trees with respect to the values of left leg and right leg of the individual. The accuracy indicates overall correctness of the model and it is the cost of false positives and false negatives predictions. The precision is a measure of predicting factor. It quantifies the total number of positive class predictions that actually belong to the positive class. Recall indicates the number of positive class predictions made out of all positive examples in the same dataset. It is the harmonic mean of precision and recall. Specificity measures how the test is effective when used on negative individuals. It is the true negative rate and the



**Figure 2** Pulse wave analysis and evaluation- block diagram

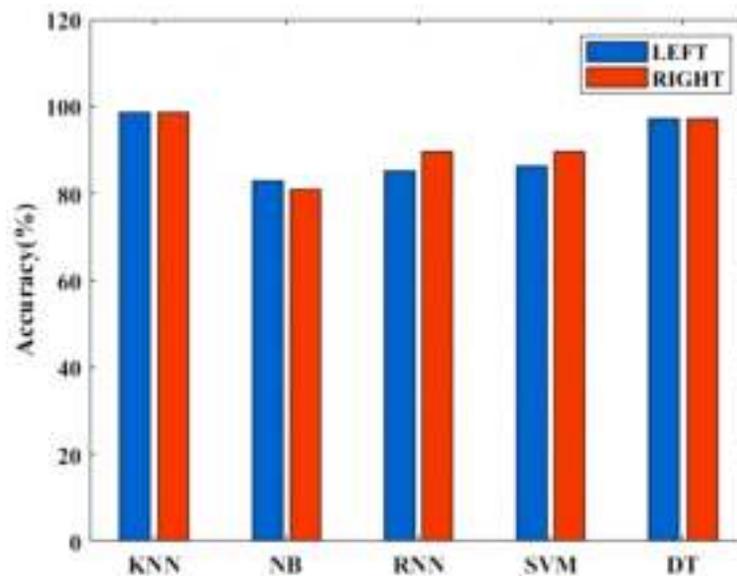


**Table 1** Result analysis - left leg

Classification	KNN	NB	RNN	SVM	DT
Accuracy	98.55	80.95	85.00	86.07	97.14
Precession	97.10	61.90	70.00	72.15	94.28
Recall	98.52	76.47	82.35	83.82	97.05
F measure	97.81	68.42	75.67	77.55	95.65
Specificity	96.28	61.83	69.43	71.35	93.51

**Table 2** Result analysis - left leg

Classification	KNN	NB	RNN	SVM	DT
Accuracy	98.55	82.92	89.47	89.47	97.14
Precession	97.10	65.85	78.94	78.94	94.28
Recall	98.52	79.41	88.23	88.23	97.05
F measure	97.81	72.00	83.33	83.33	95.65
Specificity	97.00	65.57	78.40	77.98	93.32



**Figure 3** Accuracy of machine leaning algorithms for left leg and right leg features

measure of the proportion of True Negatives to the Sum of Predicted False Positives and Predicted True Negatives.

**Figure 3** shows the accuracy of Machine Learning Algorithms for Left Leg and Right Leg features. There are slight variations in the clinical features of left and right legs of the same individual. Some of the analyzed parameters also reflect the same.

The results shows that the KNN model has the highest values in all computed parameters compared to other models. It provides the highest accuracy of 98.55%. The Decision Trees model is next to KNN for providing better results. The Naive Bayes classifier provides the least results compared to other models of this analysis.

## CONCLUSION

The results indicates that the machine learning algorithms are highly assistive for the classification of diabetic peripheral neuropathy. These learning algorithms provide rapid and excellent localization performance for the quantification of neuropathy. Among the demonstrated models, the K-Nearest Neighbours Algorithm is the best suited for the early stage prediction, This model has potential for adoption into clinical screening of diabetic peripheral neuropathy.



## ACKNOWLEDGMENT

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## REFERENCES

1. Robert J Tanenberg and Peter D Donofrio, *Neuropathic Problems of the Lower Limbs in Diabetic Patients, The Diabetic Foot*, 7th Ed. Philadelphia, Mosby Elsevier, 2008.
2. A Nather, W Keng Lin, Z Aziz, C Hj Ong, B Mc Feng and C B Lin, Assessment of Sensory Neuropathy in Patients with Diabetic Foot Problems., *Diabetic Foot and Ankle*, 2(1), 2011, 6367.
3. K S Sures and A Sukesh Kumar, Multi Signal Pulse Wave Analysis for the Identification of Vascular Diseases Leading to Diabetic Foot, *IEEE Second International Conference on Control, Measurement and Instrumentation (CMI)*, 2021, pp 206-209.
4. Y A Ko, Y J Ko, H W Kim, S H Lim, B W Yang, S H Jung and S Im, Nerve Conduction Study of the Superficial Peroneal Sensory Distal Branches in Koreans. *Annals of Rehabilitation Medicine*, 35(4), 2011, 548.
5. R A Malik, S Tesfaye, P G Newrick, D Walker, S M Rajbhandari, I Siddique, A K Sharma, A J M Boulton, R H M King, P K Thomas and J D Ward, Sural Nerve Pathology in Diabetic Patients with Minimal but Progressive Neuropathy, *Diabetologia*, 48, 2005, pp 578–585.
6. A L Carrington, J E Shaw, C H Van Schie, C A Abbott, L Vileikyte and A J Boulton, Can Motor Nerve Conduction Velocity Predict Foot Problems in Diabetic Subjects Over a 6-year Outcome Period? *Diabetes Care* 2002, 25, 2010-5.
7. F Behse, F Buchthal and F Carlsen, Nerve Biopsy and Conduction Studies in Diabetic Neuropathy, *Journal of Neurology, Neurosurgery & Psychiatry*, 40(11), 1977, pp 1072-1082.
8. G Mohan, et al, Comparative Study of Detection of Diabetic Neuropathy by Clinical and Nerve Conduction Study in Type 2 Diabetes Mellitus Patients, *International Journal of Advances in Medicine* 5, 2018, pp 380-383.
9. X Kong, et al, Utilization of Nerve Conduction Studies for the Diagnosis of Polyneuropathy in Patients with Diabetes: A Retrospective Analysis of a Large Patient Series, *Journal of Diabetes Science and Technology*, 2.2, 2008, pp 268-274.
10. Ali Moghtaderi, Alireza Bakhshipour and Homayra Rashidi, Validation of Michigan Neuropathy Screening Instrument for Diabetic Peripheral Neuropathy, *Clinical Neurology and Neurosurgery*, 108(5), 2006, pp 477-481.
11. W H Herman, R Pop-Busui, B H Braffett, C L Martin, P A Cleary, J W Albers and E L Feldman, DCCT/EDIC Research Group, Use of the Michigan Neuropathy Screening Instrument as a Measure of Distal Symmetrical Peripheral Neuropathy in Type 1 Diabetes: Results from the Diabetes Control and Complications Trial/Epidemiology of Diabetes Interventions and Complications, *Diabetic Medicine : a Journal of the British Diabetic Association*, 29(7), 2012, pp 937-944.
12. M Barthakur, A Hazarika and Manabendra Bhuyan, Classification of Peripheral Neuropathy by using Ann based Nerve Conduction Study (NCS) Protocol, *International Journal on Communication* 5.1, 2014, pp 31.
13. Schäfer, Zeinab, et al. Toward Machine-learning-based Decision Support in Diabetes Care: A Risk Stratification Study on Diabetic Foot Ulcer and Amputation, *Frontiers In Medicine*, 2021, pp 957.
14. V Sajith, A Sukesh Kumar and J Jacob, Identification of Moderate to Acute Diabetic Neuropathic Conditions of Simulated Ulnar Nerve Response using Prony's Method, *Lecture Notes in Engineering and Computer Science, Proceedings of the World Congress on Engineering and Computer Science*, 2012, pp 1092-1097.
15. D Bzdok, N Altman and M Krzywinski, Statistics versus Machine Learning. *Nat Methods* 15, 2018, pp 233-234.
16. R Palaniappan, *Biological Signal Analysis*, Book Boon, 2011.

# A Data Compression and Transmission Algorithm for a Real Time Database

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**Abstract:** In today's information system data transmission, storage of data and processing of data are the integral part of this world. Transmission and storing the huge amount of data is a very crucial task in spite of today's advancement in technology. People still used to store this huge amount of data inside their personal storage and when the storage reaches beyond its fullness then they any how try to compress that important part of the data to minimize its size and in order to store and transmit the data it requires very large memory and increase in the bandwidth utilization. Hence it's a really important task before storage or transmission to reduce the size of data without affecting the information containing those data. Lossless method when applied with the management system of data yields a significant saving. So the proposed algorithm gives a very optimal yet productive dimensionality reduction while also maintaining the variance. Principal Component Analysis is a unsupervised machine learning algorithm which will manipulate each bit of the data containing inside the file by reducing the size of the data without losing any data and by correlating the different features. The algorithms were applied on a real time data set used in the real time database of different domain to verify the compression and determine the accuracy of the proposed technique. The performance of the used algorithm is measured on different parameters by comparing with different existing data compression algorithms.

**Keywords:** Data Compression; PCA; Correlation; Lossless

## INTRODUCTION

In the past, various devices have been developed for society and the growing population. the rise in cardiovascular conditions and the enthusiasm for personal healthcare. The majority of health devices rely on sensor networks, which connect various devices of various types and functions to one another. Bioelectric signals are one of the signals that are typically generated as a result of the ongoing operation of various psychological processes that occur in the human body. One of the most significant biological systems among all processes is the cardiovascular system, which is frequently triggered by the continuous contraction and relaxation of the human heart. The cardiovascular system's two most important bioelectric signals are the electrocardiogram (ECG) and photoplethysmogram (PSG) (ECG). The Photoplethysmogram, which has a single channel and measures The optimal radiation from the skin is used by the blood volume during each cardiac cycle. The electrocardiogram is typically measured by positioning the electron at a particular point and location on the human body. It is a representation of the entire cardiac cycle [1-2]. Heart disease is one of the most significant and frequent causes of death worldwide, according to a World Health Organization survey[3]. Precision in signal measurement, storage, and transmission is therefore essential. Therefore, the real-time data compression and transmission method must utilise wired or wireless communication resources effectively. Lossless and lossy data compression techniques are the two main categories. Because lossy compression only approximates the original data, it is impossible to fully reconstruct the original data after it has been compressed. High compression ratios associated with lossy compression cause the loss of unimportant data and the emergence of reconstruction errors.

Due to its simple yet effective method for reducing the dimensions of a challenging data collection, the PCA is a frequently used tool in modern data analysis. The main objective of PCA is to obtain the orthogonal basis, which is composed of various PCs [4]. The PCA is essentially used to minimise the dimension of the data by distributing the original data across the most significant PCs. Seismic data compression has long made extensive use of PCA work. In order to reduce redundancy in the real-time data, our primary objective in this paper is to develop a transformation by collecting and organising all of the seismic traces that a sensor collected.

## RELATED WORKS ON LOSSLESS COMPRESSION

Numerous papers have been published on various compression techniques used with ECG signals on single [5] as well as multi channel[6] data. However, there aren't many papers on lossless compression that are readily available. In the past, the linear prediction model was a well-liked time-domain compression method[7]. In addition, a number of transform



domain techniques have been proposed on the basis of time domain analysis. The Walsh-Hadamard Transform was used by the author to eliminate low energy frequency components from the provided data[8-9]. Additionally, ortho-normal basis projection, a generalisation of wavelets that typically rely on dynamic windowing, is used to compress seismic data as a wave packet[10]. The use of a hybrid compression model that includes variable length coding, different filters, like subbands, is discussed. Additionally, multidimensional wavelet transform is used on various marine acquisition recordings[11]. It is discussed in a theoretical analysis that uses high-dimensional wavelength transformed marine seismic data[12]. Various works use the Golomb-Rice coding (GRC)[13] was primarily employed for compressing signals that were used in hardware applications using the optimal prefix code[14]. Furthermore, multilead Electrocardiogram uncompressed compression is postulated using the recently applied Levinson-Durbin recursion technique[15]. In tele-monitoring applications ASCII character coding is used to compressed PPG data[16]. The author suggested runtime PPG compression using low PRD Huffman coding, which is typically thought of as quasi lossless[17].

### COMPARISON WITH EXISTING TECHNIQUE

This section contrasts newly proposed work that has typically been tested on the cited database with every piece of lossless ECG compression research that has ever been written (with the exception of Mukhopadhyay, et al, 2011)[18], since the analysis was conducted using the PTBDB database and the given proposed work is typically based on a lossy compression algorithm). Miaou, et al[19] has put forth an algorithm based on the wavelet coefficients found in ECG data and a lossless compression technique called SPIHT. 3.02 is a respectable compression ratio based on what is typically accomplished in their work. The new efficient encoding technique called Huffman encoding, which is based on a two-stage method [20] with regard to all the predictions that are currently available, the compression ratio is 2.43, which is a very low number. The dataset is then subjected to modified run length coding using various multistage adaptive region predictors[21], which managed to produce a 2.67 increase in the compression ratio. LP-based lossless compression technique, a new short-term yet efficacious algorithm that was proposed by Li in [21], where the achieved compression ratio was marginally reduced to 2.28. The method of lossless compression put forth by Deepu, et al[13-14] which relies on hardware implementation for QRS detection. This work was carried out on the ECG database and produced a compression ratio of 2.15 as a result. Tsai [22] et al introduced a new method named GRC along with a further technique called adaptive LP topology for the compression method that enshrines data. The author used a suitable packet format with a compression ratio of 2.77 for run-time decoding purposes. Implementing the hardware-based Huffman encoding model and the new Log2-Sub-Band' Encoding (L2SB) algorithm around each other recently recorded a respectable compression ratio of 2.43[23]. A new algorithm that process quite fast is Levinson-Durbin recursion technique given in [15] which has a high compression ratio of 2.92 and therefore is utilised in multichannel ECG. In [24], authors made an attempt to introduce a novel technique based on data preservation. The three distinct algorithms, which also include GRC techniques, linear signal predictor variables, and error modelling, miraculously increased the compression ratio to a level of 3.04 as a result. In juxtaposition to the methodologies previously mentioned, the proposed work introduces the concepts of a principal analysis component and second order data encoding, which attempt to compress data signals without exacerbating any loss in the case of the ECG signal. In the proposed work, the algorithm's computational complications were also very minimal. In [18], with a 7.18 compression ratio, the author applied the concept of ASCII character coding-based ECG compression to the relevant database. Their work was not typically based on a completely lossless algorithm because they were able to achieve a very low compression ratio (caused by compression) of 0.023. Tsai, et al[25] A proposed algorithm that uses adaptive LP and GRC and is based on the idea of lossless compression produced a compression ratio of 4.073 when it was applied to the database.

### METHODOLOGY

#### Hardware Connection

This section outlines how to connect the hardware such that data processing and transmission can be managed to carry out using a Raspberry Pi-4 and an easily accessible single channel electrocardiogram module (AD8232). The monitoring module (AD8232), which primarily runs on 3.3 volts DC voltage, is used to track heart rate. The Raspberry Pi-4 is a multitasking, memory-intensive piece of hardware with up to 8 GB of memory and a desktop processor speed of 1.5 GHz. This device can output an analogue signal from a single channel of an electrocardiogram. Since the Raspberry Pi cannot handle analogue signals, an analogue to digital convertor device (ADC) is used to transform analogue signals into digital signals.

#### Signal Processing

The second order delta encoding, which provides a very high compression ratio without any data loss, is used to remove

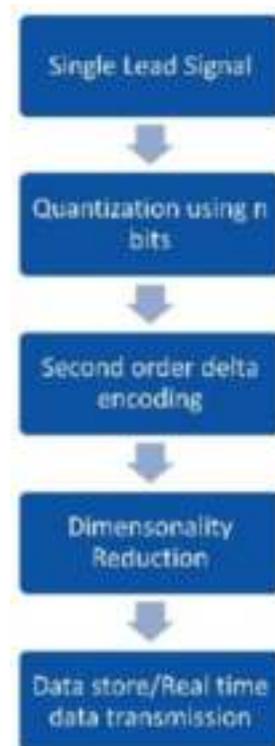


Figure 1 Signal flow diagram of lossless compression

the sample to sample coherency of the signal that were used in the hardware setup. The user-provided quantization level  $n$  is used to first quantize the single channel signal. After that, the given signals are subjected to second order delta encoding. The signal's compression ratio typically depends on the ideal value that the user provides.

### Noise Reduction of the Raw Signal

because the signals contain a variety of noise signals. Before data compression, de-noising becomes one of the really essential processes. for both the photoplethysmogram and electrocardiogram signals that are present in the noise channel. An order two band moves by To remove all the too-low-frequency signals that will result in a baseline artefact, the Butter-worth filter is used, which has a lower cutoff frequency of 0.5 Hz. The upper cutoff frequency falls within the same 100–3.4 Hz range. An amplitude ratio that is limited to less than 10 was used to determine the frequency range that was used in the signal channel. The data compression algorithm was started after removing all the unwanted noise without affecting the data.

Table 1 Comparison with existing technologies

S No.	Related Work	Data Base	NOR	CR	FRD	Remarks
1	S. G. Misra et al., 2005 [7]	MITDR	48	3.068	N1	So: the hierarchical tree to partitioning.
2	S. L. Chen et al., 2015 [8]	MILDU	48	2.43	N1	Linear predictor (LP) - 2stage entropy en- coding
3	K. Li et al., 2014 [9]	MITDD	48	2.67	N1	Multi order adaptive prediction (AP)
4	C.J. Daspa et al., 2015 [10]	MITDR	48	2.38	N1	linear predictor. So: the short term
5	C.J. Deepa et al., 2016 [11]	MITDD	48	2.15	N1	Joint QRS detection and lossless data com- pression for ECG on Chip
6	T. Tsai et al., 2018 [12]	MITDD	48	2.77	N1	AP, Golomb - Rice coding (GRC)
7	C. Bailey et al., 2009 [13]	MITDR	48	2.43	N1	Huffman coding using $\log_2$ -valued (L2SD) encoding
8	D. Rzepka et al., 2020 [14]	MITDR	48	2.92	N1	Fast Levinson-Durbin recursion
9	M. Jia et al., 2020 [15]	MOTDB	48	3.04	N1	LP+ error-modelling, GRC
10	S.K. Mukhopadhyay et al., 2011 [16]	FIBDB	-	7.18	10.23	ASCII character coding
11	T. Tsai et al., 2020 [17]	FIBDB	548	4.075	N1	Adaptive LP+GRC



**Algorithm 1** Algorithm for Dimensionality Reduction  
1: Initialization  
2: Input:  $I_{in} \leftarrow$  Write N datapoints  $P (X_{1i}, X_{2i}, X_{3i}, \dots, X_{Mi})$  as row vectors  
3: Input: Function  $PCA(X)$   
4: Put the vectors in  $X$  (size  $N \times M$ )  
5: By taking away each column's mean and centering the data in matrix  $B$   
6: Compute the covariance matrix  $C = 1/NBTB$   
7: Compute the eigen-values and eigen-vectors of  $C$ ,  
8: for  $V -1CV = D$  where  $V$  has eigen-vectors of  $C$  and  $D$  is the  $M \times M$  diagonal eigen-value matrix do  
9: Sorting the  $D$  column's eigenvalues in decreasing order,  
10: Put the  $V$  column's rows in the same order.  
11: if eigenvalue  $\rightarrow Q$  then, reject  
12: Leave  $L$  dimension in the data  
13: end if  
14: end for

### Algorithm for Compression

This section  $X$  is a  $T$ -dimensional random vector, where  $T$  is the number of samples in a trace. to implement a compression algorithm for various seismic traces that were observed throughout the process.

Principal component analysis is used to project all of the traces used during the analysis process over an orthogonal basis before the concept of dimensionality reduction using principal component analysis is used to complete the entire process.

### Quality Measures

Principal component analysis, which is typically a linear dimensionality reduction technique, must be projected to all the principal components as a basis vector in order to compress all the zero mean data that were obtained during the dimensionality reduction process.  $zX_u U_t$ , where  $U_t$  is a set of all principal components.

Projecting back all the original dimensions and combining all the average vectors now makes decompression and data recovery simple.

$$X' = zU_t + U$$

### Compression Ratio

The amount of compression is expressed therefore as compression ratio for the performance evaluation indices in the work, which is essentially a measurement of the amount of bits required to store all the compressed data.

The compression ratio can be explained as in the form given here.

Bits required to store the original signal divided by Bits required to store compressed data is the compression ratio.

### LITERATURE REVIEW

In 2022, Yang, et al [26] since machine learning algorithms deal with various concepts related to compression and in the field of neural compression, which can be challenging due to an excess of information theory, the author has used the technique of neural compression in this paper as an application of neural networks and other machine learning algorithms for the data compression. The author has attempted to fill in the background information by reviewing fundamental coding topics such as entropy.

When compared to early works, the modern approach to image processing — which uses market-scale neural architectures — differently draws on a rich history of learning based approaches.

In 2020, Ni, et al [27], the author has attempted to create a new deep learning method in this paper that is divided into two phases and typically based on a data compression and reconstruction framework. Convolution neural networks are designed to extract features directly from the input signal in order to detect abnormal data, and this phase is used to verify the model's high accuracy. Another method is SHM, a data compression and reconstruction method based on an auto

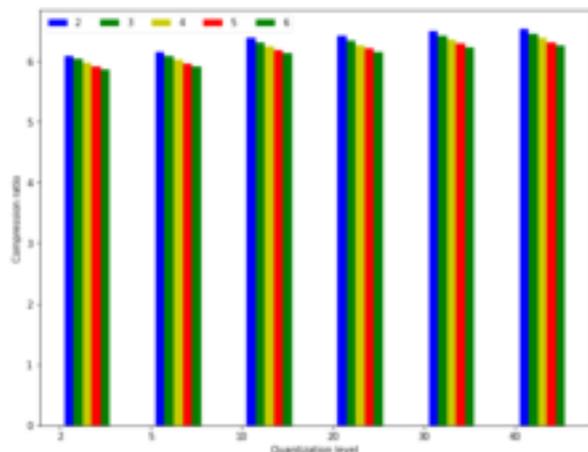


Figure 2 Variations of average CR w.r.t signal length

Table 2 Mean compression results of database 1

CR	$\beta$	Samples of signal length					
		5000	5000	10000	150000	20000	30000
CR	2	5.97	5.15	5.38	5.41	6.49	6.52
	3	6.00	5.08	5.3	5.33	6.42	6.45
	4	5.97	5.02	5.24	5.26	6.35	6.38
	5	5.97	5.06	5.18	5.31	6.29	6.31
	6	5.86	5.9	5.13	5.14	6.22	6.25
	PRD ( $10^{-2}$ )		149	156	174	178	190

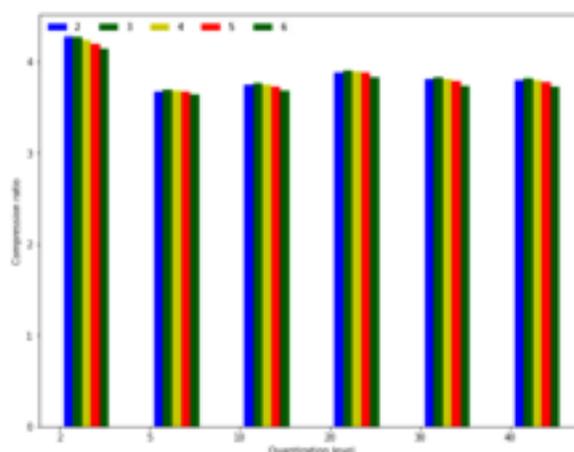


Figure 3 Variations of average CR w.r.t signal length

Table 3 Mean compression results of database 2

CR	$\beta$	Samples of signal length					
		5000	5000	10000	150000	20000	30000
CR	2	4.38	3.68	3.75	3.88	3.81	3.8
	3	4.25	3.7	3.78	3.91	3.83	3.82
	4	4.21	3.69	3.74	3.89	3.81	3.8
	5	4.1	3.68	3.73	3.88	3.78	3.78
	6	4.16	3.67	3.69	3.82	3.74	3.72

encoder structure that has been improved for improved performance. This technique is employed because it's necessary to accurately recover the data with such a low compression ratio. The given algorithm is also validated using acceleration data from the SHM system of a bridge that has been in use in China for a long time. The output from the phase of abnormal data detection shows the quick and precise abnormality detection capability of the proposed method.

In 2022, Renes, et al[28], in this paper, the author attempts to present a physics-based compression algorithm that is divided into two parts: first, a reduction of the primary data with a specified bounded error and second, preservation of the quantities of interest during compression.

The author attempted to finish the tensor decomposition auto encoder in its entirety in the first step, and as a result, two boundary constructions — a quantizer and an error-bounded lossy compressor — were produced that have error at very high compression levels. The author attempts to take into account the constraint of post-processing in the following step, after the primary data and all of the interest that typically focuses on simulation data generated by large scale fusion code.

In 2018, Uthayakumar, et al [29], the author of this paper attempted to explain the world's explosive growth in data, which has typically necessitated the development of an effective yet efficient method for storing and transmitting data on a wider scale. Due to the limited resources available, the author suggests using data compression to reduce the amount of data that is being stored or transmitted. Different approaches were developed by different authors in different aspects as data compression technique result to a very effective utilisation of all the available data storage area and as well as the communication bandwidth. A thorough survey of the various data compression techniques is conducted to identify the current requirements in terms of all the available properties, such as data quality, coding scheme, types of data, and various applications, in order to analyse how all these data compression techniques and applications have evolved. Then, a comparative analysis of all the performance algorithms is carried out to determine how each technique's various characteristics, concepts, experimental factors, and limitations contribute to the overall picture.

In 2019, Azar, et al [30], the author of this paper has suggested an energy-efficient method for gathering and analysing all internet of things data. Prior to transmission, the first author attempted to apply all of the fast error bound loss on a compressor to the data that had been collected.

This is as a result of the fact that it is the IoT device with the highest energy consumption. In order to verify the suggested



approach, the author now attempts to reconstruct all of the re-transmitted data and processes it using all of the supervised learning techniques. All factors that will impact the behaviour of the monitoring intelligent system were taken into consideration by the author is usually based on a vehicle system that needs critical science data from the driver to be collected using a wireless body network (WBSN) and variable devices to send to every edge node for the experiment's stress level detection. According to the findings, the amount of data transmitted is typically reduced by 103 times without compromising the accuracy of medical data or the driver's stress level during accuracy prediction.

In 2020, Christopher, et al[31], the author of this paper has developed a novel deep neural network architecture based on rate distortion theory. One of the most important properties of this architecture is that to train all the operating raw procedural input end to end rather than at the intermediate level of abstraction. The author also introduced multiple memory systems that are operating at different time scales to show how efficient compression can explain all the attached phenomena that are occurring in the visual search of this algorithm. In this case, the most psychological model is used to explain how an efficient compression can occur in memory over time.

In 2018 Mohit, et al [32], in this study, the author has combined all of the recurrent neural network predictors already in use with the archimetric coder and a lossless compression technique with a variety of synthetic text and genomic data sets, among other different properties. The algorithm that the author suggests has a compressor that works on real-time data and achieves the best possible compression for this artificial data set. The outcome produced by this algorithm also contributes to a better understanding of how and why neural networks are superior to all currently used finite context models. due to the fact that a given sequential data is generated in various pieces and formats, including all text and genomic data. This allows the author to create the need for an efficient compression mechanic that enables a better storage and transmission process for the real time data set.

In 2011 Sang Joo, et al[33], an innovative real-time based data compression and transmission technique has been presented by the author in this paper. The suggested algorithm uses various compression and reconstruction techniques. due to the fact that various arrhythmia databases are used to evaluate the performance of the given algorithm.

The results from measuring the various parameters were quite impressive. When compared to various algorithms that were introduced by others, the proposed algorithm's performance with the existing algorithm is quite impressive. The given algorithm has been found to be superior and efficient in every situation. The author also made an effort to explain how the suggested algorithm can conveniently compress and send data in a real-time data set. For the constrained bandwidth communication between all of the available e-health devices, it can act as the best bio signal data transmission method.

In 2011 Patauner, et al[34], in order to reduce the amount of data coming from pulse digitising electronics, this paper attempted to explain a compression system called optimisation. In order to collect signals from calorimeters, time projection chambers, and detectors generally used to produce a signal amplified to a linear pulse, pulse digitising electronic systems were frequently used in high energy physics experiments. There would be several steps to the suggested method. A set of various digitised reference vectors that were stored in a memory and only retained when the difference between these vectors using Huffman compression were used by the author to first approximate all the incoming vectors created by the digitisation of the shaped pulse. The describe compression method's results were evaluated in matlab using input data.

In 2012, Hung, et al[35], in order to compare all of the existing data compression techniques, the author attempted to present all of the empirical research on the effectiveness of the model-based compression technique in this paper. The current data compression techniques are assessed using a number of parameters, such as compression ratio, computation time, model upkeep, cost approximation quality, and robustness to noisy data. Various real-time data sets comprised of more than 350 different types of sensor data signals are used by the author in an effort to analyse all of the results. The amount of redundant and repeated information was attempted to be minimised after the author calculated the dependencies for all available methods, including time dependencies. Because they have a high tolerance for error and can utilise all the information available, compression techniques are advantageous.

## CONCLUSION

In this study, a lossless data compression method — typically based on second-order delta encoding and principal component analysis — is used for the single-channel electrocardiogram signal. The main task is to eliminate all of the redundant information that is transmitted and processed during the signal, so the proposed algorithm can be applied to all other varying signals that share the same intra-sample coherency. To test the compression ratio of this algorithm, various databases that could be compressed in real time were used. In addition, runtime data collection on an electrocardiogram



signal and a raspberry-pi module was carried out to demonstrate all the data transmission that was carried out throughout the process. The runtime database that was compiled from various volunteers in this work experienced no data loss. The whole algorithm was implemented using the Python programming language, after which it was tested on a Raspberry Pi. It makes all the operations carried out during the algorithm simple to understand. This paper also includes a comparison with other published work to show that the method is simple, less computationally demanding, and provides lossless data compression for all signals with a high compression ratio and no loss in reconstruction.

## REFERENCES

1. R Gupta, M Mitra and J Bera, ECG Acquisition and Automated Remote Processing, 20, Springer, 2014.
2. A B Hertzman, Photoelectric Plethysmography of the Fingers and Toes in Man, Proceedings of the Society for Experimental Biology and Medicine, 37(3), 1937, pp 529–534.
3. WH Organization, World Malaria Report 2015, World Health Organization, 2016.
4. K Y Huang, Neural Networks for Seismic Principal Components Analysis, IEEE Transactions on Geoscience and Remote Sensing, 37(1), 1999, pp 297–311.
5. S M Jalaeddine, C G Hutchens, R D Strattan, W A Coberly, ECG Data Compression Techniques - a Unified Approach, IEEE Transactions on Biomedical Engineering, 37(4), 1990, pp 329-343.
6. S Banerjee, G K Singh, Quality Aware Compression of Multilead Electrocardiogram Signal using 2-mode Tucker Decomposition and Steganography, Biomedical Signal Processing and Control 64, 2021, 102230.
7. AJ Davis, Linear Prediction Coding for Compressing of Seismic Data, US Patent 4,509,150, April 2 1985.
8. LC Wood, Seismic Data Compression Methods, Geophysics 39(4), 1974, pp 499-525.
9. S B Jonsson and A Spanias, Seismic Data Compression, 1990 Ninth Annual International Phoenix Conference on Computers and Communications, IEEE Computer Society, 1990, pp 276–277.
10. Y Luo and G Schuster, Wave Packet Transform and Data Compression, SEG Technical Program Expanded Abstracts 1992, Society of Exploration Geophysicists, 1992, pp 1187–1190.
11. R A Ergas, P L Donoho and J Villasenor, Method for Reducing Data Storage and Transmission Requirements for Seismic Data, US Patent 5,745,392 (Apr. 28 1998).
12. J D Villasenor, R Ergas and P Donoho, Seismic Data Compression using High-dimensional Wavelet Transforms, Proceedings of Data Compression Conference-DCC'96, IEEE, 1996, pp 396-405.
13. C J Deepu and Y Lian, A Joint Qrs Detection and Data Compression Scheme for Wearable Sensors, IEEE Transactions on Biomedical Engineering, 62(1), 2014, pp 165-175.
14. C J Deepu, X Zhang, C H Heng and Y Lian, A 3-lead ECG-on-chip with Qrs Detection and Lossless Compression for Wireless Sensors, IEEE Transactions on Circuits and Systems II: Express Briefs 63, 12, 2016, pp 1151-1155.
15. D Rzepka, Low-complexity Lossless Multichannel ECG Compression based on Selective Linear Prediction, Biomedical Signal Processing and Control 57, 2020, 101705.
16. S K Mukhopadhyay, M O Ahmad and M Swamy, ASCII-character Encoding based PPG Compression for Tele-monitoring System, Biomedical Signal Processing and Control 31, 2017, pp 470–482.
17. R Gupta, Lossless Compression Technique for Real-time Photoplethysmographic Measurements, IEEE Transactions on Instrumentation and Measurement 64(4), 2014, pp 975-983.
18. S K Mukhopadhyay, S Mitra and M Mitra, A Lossless ECG Data Compression Technique using ASCII Character Encoding, Computers & Electrical Engineering 37(4), 2011, pp 486–497.
19. S-G Miaou, S-N Chao, Wavelet-based Lossy-to-lossless ECG Compression in a Unified Vector Quantization Framework, IEEE Transactions on Biomedical Engineering 52(3), 2005, pp 539–543.
20. S-L Chen, G-A Luo and T-L Lin, Efficient Fuzzy-controlled and Hybrid Entropy Coding Strategy Lossless ECG Encoder VLSI Design for Wireless Body Sensor Networks, Electronics Letters 49(17), 2013, pp 1058–1060.
21. K Li, Y Pan, F Chen, K-T Cheng, R Huan, Real-time Lossless ECG Compression for Low-power Wearable Medical



- Devices based on Adaptive Region Prediction, *Electronics Letters* 50(25), 2014, pp 1904–1906.
22. T-H Tsai, W-T Kuo, An Efficient ECG Lossless Compression System for Embedded Platforms with Telemedicine Applications, *IEEE Access* 6, 2018, pp 42207–42215.
  23. C Crispin-Bailey, C Dai and J Austin, A 65-nm cmos lossless bio-signal compression circuit with 250 femtojoule performance per bit, *IEEE Transactions on Biomedical Circuits and Systems* 13(5), 2019, pp 1087-1100.
  24. M Jia, F Li, Y Pu and Z Chen, A lossless electrocardiogram compression system based on dual-mode prediction and error modeling, *IEEE Access* 8 (2020) 101153–101162.
  25. T.-H. Tsai, F.-L. Tsai, Efficient lossless compression scheme for multichannel ecg signal processing, *Biomedical Signal Processing and Control* 59 (2020) 101879.
  26. Y Yang, S. Mandt, L. Theis, An introduction to neural data compression, *arXiv preprint arXiv:2202.06533* (2022).
  27. J. Lee, Q. Gong, J. Choi, T. Banerjee, S. Klasky, S. Ranka, A. Rangarajan, Error-bounded learned scientific data compression with preservation of derived quantities, *Applied Sciences* 12 (13) (2022) 6718.
  28. U. Jayasankar, V. Thirumal, D. Ponnuramgam, A survey on data compression techniques: From the perspective of data quality, coding schemes, data type and applications, *Journal of King Saud University-Computer and Information Sciences* 33 (2) (2021) 119–140.
  29. F. Ni, J. Zhang, M. N. Noori, Deep learning for data anomaly detection and data compression of a long-span suspension bridge, *Computer-Aided Civil and Infrastructure Engineering* 35 (7) (2020) 685–700.
  30. J. Azar, A. Makhoul, M. Barhamgi, R. Couturier, An energy efficient iot data compression approach for edge machine learning, *Future Generation Computer Systems* 96 (2019) 168–175.
  31. C. J. Bates, R. A. Jacobs, Efficient data compression in perception and perceptual memory., *Psychological review* 127 (5) (2020) 891.
  32. M Goyal, K Tatwawadi, S Chandak and I Ochoa, Deepzip: Lossless data compression using recurrent neural networks, *arXiv preprint arXiv:1811.08162* (2018).
  33. S Lee, J Kim and M Lee, A real-time ecg data compression and transmission algorithm for an e-health device, *IEEE Transactions on Biomedical Engineering* 58 (9) (2011) 2448–2455, doi:10.1109/TBME.2011.2156794.
  34. C Patauner, A Marchioro, S Bonacini, A U Rehman and W Pribyl, A lossless data compression system for a real-time application in hep data acquisition, *IEEE Transactions on Nuclear Science* 58 (4) (2011) 1738–1744.
  35. N. Q. V. Hung, H. Jeung, K. Aberer, An evaluation of model-based approaches to sensor data compression, *IEEE Transactions on Knowledge and Data Engineering* 25 (11) (2012) 2434–2447.

# Diabetes Prediction using Data Science

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**Abstract:** Diabetes is a chronic disease that could lead to a global health care disaster. 382 million people worldwide have diabetes, according to the International Diabetes Federation. This will double to 592 million by 2035. Diabetes is a condition brought on by elevated blood glucose levels. The symptoms of this elevated blood sugar level include frequent urination, increased thirst, and increased hunger. One of the main causes of stroke, kidney failure, heart failure, amputations, blindness, and kidney failure is diabetes. Data Science is a young discipline of science that examines how to analyse data and draw conclusions from it. The proposed system is to develop a system which can perform early prediction of diabetes for a patient with a higher accuracy by combining the results of different machine learning techniques. The algorithms like K Nearest Neighbour (KNN), Logistic Regression, Random Forest, Support Vector Machine (SVM) and Decision tree are used. The accuracy of the model using each of the algorithms is calculated in which the best accuracy is taken as the model for predicting the diabetes.

**Keywords:** KNN; Logistic Regression; Random Forest; SVM; Decision Tree

## INTRODUCTION

Diabetes is a chronic (long-lasting) health condition that affects how your body turns food into energy.

Your body breaks down most of the food you eat into sugar (glucose) and releases it into your bloodstream. When your blood sugar goes up, it signals your pancreas to release insulin. Insulin acts like a key to let the blood sugar into your body's cells for use as energy.

With diabetes, your body doesn't make enough insulin or can't use it as well as it should.

There are three main types of diabetes viz.

1. Type1
2. Type2
3. Gestational Diabetes

### A. Type 1 Diabetes

Type 1 diabetes is thought to be caused by an autoimmune reaction (the body attacks itself by mistake). This reaction stops your body from making insulin. Approximately 5-10% of the people who have diabetes have type 1. Currently, no one knows how to prevent type 1 diabetes.

### B. Type 2 Diabetes

With type 2 diabetes, your body doesn't use insulin well and can't keep blood sugar at normal levels. About 90-95% of people with diabetes have type 2. It develops over many years and is usually diagnosed in adults. You may not notice any symptoms, so it's important to get your blood sugar tested if you're at risk. Type 2 diabetes can be prevented or delayed with healthy lifestyle changes, such as:

- Losing weight.
- Eating healthy food.
- Being active.

### C. Gestational Diabetes

Gestational diabetes develops in pregnant women who have never had diabetes. If you have gestational diabetes, your baby could be at higher risk for health problems. Gestational diabetes usually goes away after your baby is born.



However, it increases your risk for type two diabetes later in life. Your baby is more likely to have obesity as a child or teen and develop type 2 diabetes later in life.

### **FEATURES FOR PREDICTION**

The following features have been provided to help us predict whether a person is diabetic or not:

Pregnancies: Number of times pregnant

Glucose: Plasma glucose concentration over 2 hours in an oral glucose tolerance test

Blood Pressure: Diastolic blood pressure (mm Hg)

Skin Thickness: Triceps skin fold thickness (mm)

Insulin: 2-Hour serum insulin ( $\mu$ U/ml)

BMI: Body mass index (weight in kg/(height in m)<sup>2</sup>)

Diabetes Pedigree Function: Diabetes pedigree function (a function which scores likelihood of diabetes based on family history)

Age: Age (years)

Outcome: Class variable (0 if non-diabetic, 1 if diabetic)

### **PREDICTION USING DATA SCIENCE**

Data Science is one of the budding fields which helps you to arrive at a conclusion based on previous experiences letting you draw relations between the most independent variables and lets you find the key factor connecting the elements of a theme. There are various algorithms and graphs provided by this domain letting you analyse the given dataset.

The various steps in Data Science Project are:

1. Data Ingestion
2. Data Storage and Data Processing
3. Data Analysis
4. Communicate

Data Science uses the concepts of Probability, Sampling and Sampling Distributions, Hypothesis Testing, Two Sample testing, ANOVA and linear regression, multiple regression, concepts of MLE and logistic regression, Clustering Analysis and Classification and Regression Trees.

### **EXAMPLE**

- Predicting the profit of a new venture based on previous similar ventures.
- Predicting Credit Card fraudulence activities.

### **TKINTER**

Tkinter is a GUI toolkit used in python to make user-friendly GUIs. Tkinter is the most commonly used and the most basic GUI framework available in python. Tkinter uses an object-oriented approach to make GUIs.

Some other Python Libraries available for creating our own GUI applications are:

- kivy
- python qt
- wxpython

### **WIDGET**

Widgets in Tkinter are the elements of GUI application which provides various controls (such as Labels, Buttons, Combo Boxes, Check Boxes, Menu Bars, Radio Buttons and many more) to users to interact with the application.

### **TEXT WIDGET**

Text Widget is used where a user wants to insert multiline text fields. This widget can be used for a variety of applications where the multiline text is required such as messaging, sending information or displaying information and many other tasks. We can insert media files such as images and links also in the Text widget.



Figure 1 Creating a quiz

### MESSAGE BOX

The Message widget is used to show the message to the user regarding the behavior of the python application. The message text contains more than one line.

### SPINBOX WIDGET

The Spinbox widget is used to select from a fixed number of values. It is an alternative Entry widget and provides the range of values to the user.

### GEOMETRY MANAGEMENT

Geometry Management allows the developer to determine the places of widgets. These specifications help the Interface to be more presentable and understandable rather than being in its usual haphazard fashion and resulting in confusions.

### DIABETES PREDICTION

Diabetes is a chronic ailment with no proper cure other than major lifestyle changes. The aim of the project is to develop a software with a GUI that allows any individual to predict their chances of diabetes in future.

The dataset consists of number of pregnancies, glucose, blood pressure, skin thickness, Insulin, BMI, Age and Diabetes positive or negative.

Healthcare: The diabetes prediction can let to predict a person's chances of having diabetes in present or in future, thus preventing complications and resultant ailments.

Machine Learning Classification Techniques such as Logistic Regression Method, K-Nearest Neighbor Classifier, Support Vector Machine (SVM), Naïve Bayes Classification Method, Decision Tree Classification Method and Random Forest Classification are used for Diabetes Prediction.

### CONCLUSION

One of the global health issues is to identify the risk of diabetes at its early phase. This study attempts to structure a



framework which forecasts the risk pertaining to diabetes mellitus type 2. Few machine learning classification methods were analysed, and their results can be compared with different statistical measures. Tests can be performed on the dataset collected through online and offline questionnaires consisting 18 questions relevant to diabetes. The experimental result will show that the accuracy of Random Forest of our dataset is the highest among the rest. Random forest is giving highest accuracy for diabetes dataset. Among six different machine learning algorithms applied, all the models produced good results for some parameter like precision, recall sensitivity etc. This study still holds a scope for further research and improvement including other machine learning algorithms to predict diabetes or any other disease.

#### REFERENCES

1. D K Choubey and S Paul, GA\_RBF NN: a Classification System for Diabetes, *International Journal of Biomedical Engineering and Technology* 23 (1), 2017, pp 71-93.
2. R M Anjana, R Pradeepa, M Deepa, M Datta, V Sudha, R Unnikrishnan, A Bhansali, S R Joshi, P P Joshi, C S Yajnik and V K Dhandhanika, Prevalence of Diabetes and Prediabetes (Impaired Fasting Glucose and/or Impaired Glucose Tolerance) in Urban and Rural India: Phase I Results of the Indian Council of Medical Research–INDIA DIABetes (ICMR–INDIAB) Study, *Diabetologia* 54 (12), 2011, pp 3022-3027.
3. H Wu, S Yang, Z Huang, J He and X Wang, Type 2 Diabetes Mellitus Prediction Model based on Data Mining, *Informatics in Medicine Unlocked* 10, 2018, pp 100-107.
4. X H Meng, Y X Huang, D P Rao, Q Zhang and Q Liu, Comparison of Three Data Mining Models for Predicting Diabetes or Prediabetes by Risk Factors, *The Kaohsiung Journal of Medical Sciences* 29 (2), 2013, pp 93-99.
5. Y Huang, P McCullagh, N Black and R Harper, Feature Selection and Classification Model Construction on Type 2 Diabetic Patients' Data, *Artificial Intelligence in Medicine* 41 (3), 2007, pp 251-262.
6. T Eswari, P Sampath and S Lavanya, Predictive Methodology for Diabetic Data Analysis in Big Data, *Procedia Computer Science* 50, 2015, pp 203-208.
7. M J Gurka, S H Golden, S K Musani, M Sim, A Vishnu, Y Guo, M Cardel, T A Pearson and M D DeBoer, Independent Associations Between a Metabolic Syndrome Severity Score and Future Diabetes by Sex and Race: the Atherosclerosis Risk in Communities Study and Jackson Heart Study. *Diabetologia* 60 (7), 2017, pp 1261-1270.

# Speech Emotion Recognition using Data Science

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**Abstract:** Speech emotion recognition is an act of predicting human's emotion through their speech along with the accuracy of prediction. It creates a better human computer interaction. Though it is difficult to predict the emotion of a person as emotions are subjective and annotation audio is challenging, "Speech Emotion Recognition (SER)" makes this possible. This is the same theory which is used by animals like dogs, elephants and horses etc do to be able to understand human emotion. There are various states to predict one's emotion, they are tone, pitch, expression, behaviour etc. Among them, few states are considered to find the emotion through the speech. Few samples are used to train the classifiers to perform speech emotion recognition. This research work considers the superkogito SER- datasets. Initially it is done using a data set. The voices of multiple people is recorded. The audio file is then used to judge the person's emotion. The different languages accepted, range from Chinese, English, Greek, French to Russian, Arabic, Italian, Danish and so on. The access is of two categories, either open or restricted. A new study identifies 27 categories of emotion and shows how they blend together in our everyday experience. Psychology once assumed that most human emotions fall within the universal categories of happiness, sadness, anger, surprise, fear, and disgust. But this project ensures to classify human's emotions based on the 6 main universal categories. Based on these parameters can a person's emotions be recognized.

**Keywords:** Speech Emotion Recognition; Human Emotions; Data Science; Language

## INTRODUCTION

Speech Emotion Recognition abbreviated as SER, is the act of attempting to recognize human emotion and their states from the speech. This states the fact that voice often reflects underlying emotions through tone and pitch. This is also the phenomenon that animals like dogs and horses employ to be able to understand human emotion[1].

Emotions in a speech play a vital role in expressing one's feelings. Based on different emotions, human speak in different ways, and the characteristics of speech changes, accordingly.

Artificial intelligence (AI) speech recognition is a method used on computer programmes to help them comprehend spoken language.

- Reading a file for audio signals is the first step.
- The second step is changing the audio frequencies.



- The third step is to extract features from speech.
- The fourth step is Listening for Spoken Words

#### A. Need for Speech Emotion

1. Emotion recognition is the part of speech recognition which is gaining more popularity and need for it increases enormously. Although there are methods to recognize emotion using machine learning techniques, this project attempts to use deep learning to recognize the emotions from data[2].
2. Speech Emotion Recognition (SER) is used in call centre for classifying calls according to emotions and can be used as the performance parameter for conversational analysis thus identifying the unsatisfied customer, customer satisfaction and so on for helping companies improving their services.
3. It can also be used in-car board system based on information of the mental state of the driver can be provided to the system to initiate his/her safety preventing accidents to happen.

#### B. Data Science

Data Science is one of the budding fields which helps you to arrive at a conclusion based on previous experiences letting you draw relations between the most independent variables and lets you find the key factor connecting the elements of a theme. There are various algorithms and graphs provided by this domain letting you analyse the given dataset[3].

The various steps in Data Science Project are:

1. Data Ingestion
2. Data Storage and Data Processing
3. Data Analysis
4. Communicate

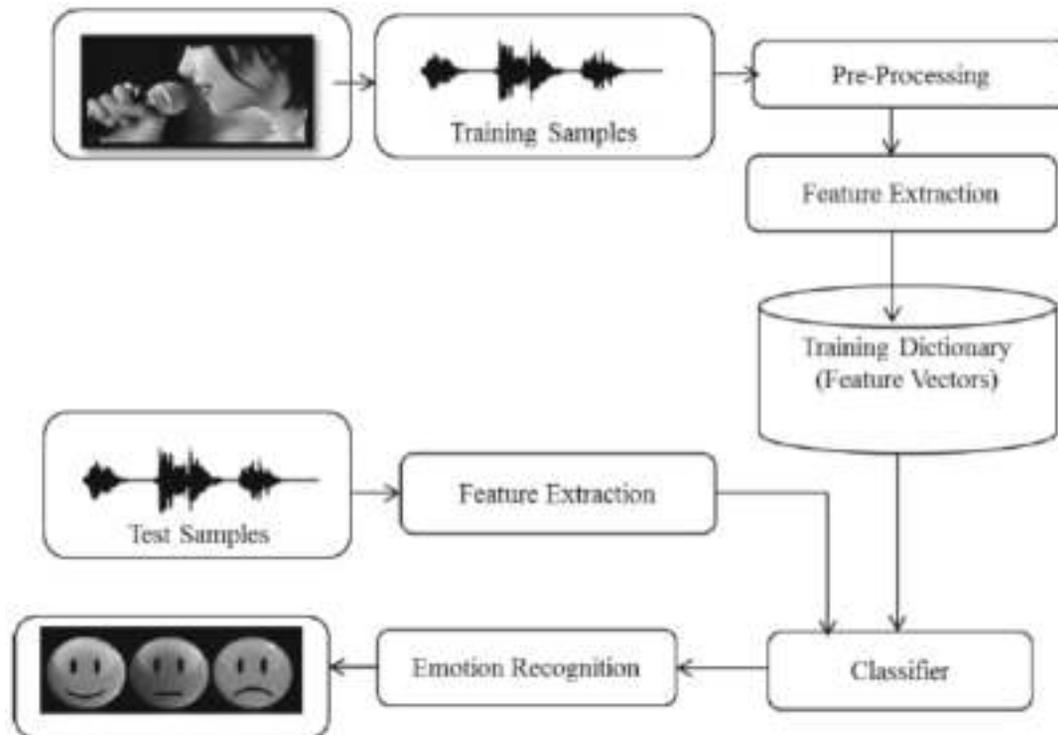
Data Science uses the concepts of Probability, Sampling and Sampling Distributions, Hypothesis Testing, Two Sample testing, ANOVA and linear regression, multiple regression, concepts of MLE and logistic regression, Clustering Analysis and Classification and Regression Trees[4].

#### C. Recognising a Person's Emotion

Due to their related natures, many speech feature vectors carry various emotions. In this, the emotions are divided into categories such as anger, happiness, sadness, fear, neutrality, and surprise. Extrapolated from Marathi voice, Mel Frequency Cepstral Coefficient (MFCC) feature parameters Signals are influenced by the speaker, the spoken word, and emotion. The development of an emotion classification model employs Gaussian mixture models (GMM). Here, a classifier and recently developed feature extraction technique are applied [5].

Initially it is done using a data set. The voices of multiple people is recorded. The audio file is then used to judge the person's emotion. The different languages accepted, range from Chinese, English, Greek, French to Russian, Arabic, Italian, Danish and so on. The access is of two categories, either open or restricted. A new study identifies 27 categories





of emotion and shows how they blend together in our everyday experience. Psychology once assumed that most human emotions fall within the universal categories of happiness, sadness, anger, surprise, fear, and disgust. But this project ensures to classify humans emotions based on the 6 main universal categories. Based on these parameters can a person's emotions be recognized.

Due to their related natures, many speech feature vectors carry various emotions. In this, the emotions are divided into categories such as anger, happiness, sadness, fear, neutrality, and surprise. Extrapolated from Marathi voice, Mel Frequency Cepstral Coefficient (MFCC) feature parameters Signals are influenced by the speaker, the spoken word, and emotion. The development of an emotion classification model employs Gaussian mixture models (GMM). Here, a classifier and recently developed feature extraction technique are applied.

#### D. Advantages

Emotion recognition can be used to understand how candidates feel during interviews and to measure how they react to certain questions. This information can be used to optimize interview structure for future candidates and streamline the application process.

#### E. Limitations

It is a challenge to make emotion available in different languages. There are limitations with different types and versions of the software such as dataset input is only textual data, image, pattern, video and audio inputs are invalid.

#### F. Applications

Nowadays, device control is commonly using the human body feature or voice recognition technology. To expand the functionality of voice recognition, plenty of researchers have developed speech emotion recognition. By recognizing sound emotions, a system can provide better and beneficial decision-making output [6].

#### CONCLUSION

Speech emotion recognitions is still a topic of study. This still has space for improvement. But it overall creates an impact in human life in the long run. With better improvements made it can be used help people psychologically.



## REFERENCES

1. S Agrawal, Emotions in Hindi Speech-Analysis, Perception and Recognition, IEEE, 978-1-4577-0931-9, 2011.
- [2] Ayadi, M.E., Kamel, M.S., Karray, F,” Survey on Speech Emotion Recognition: Features, Classification Schemes, and Databases. Pattern Recognition, IEEE, 44, 2011, pp 572-587.
3. L W Chew, K P Seng, L M Ang, V Ramakonar and Gnanasegaran, Audio-Emotion Recognition System using Parallel Classifiers and Audio Feature Analyzer, Third International Conference on Computational Intelligence, Modelling & Simulation, 2011.
4. A A Razak, M H M Yusof and R Komiya, Towards Automatic Recognition of Emotion in Speech, Proceedings of the 3rd IEEE International Symposium of Conference on Signal Processing and Information Technology, ISSPIT 2003, pp 548-551.
5. K V Krishna Kishore and P Krishna Satish, Speech using MFCC and Wavelet Features, 3rd IEEE International Advance Computing Conference (IACC), 2013
6. M King, B Zhu and S Tang, Optimal Path Planning, Mobile Robots, 8(2) , March 2001, pp 520-531.
7. Recognition Using Support Vector Machine, International Journal of Smart Home, 2012.
8. Yixiong Pan and Peipei Shen and Liping Shen, Recognition using Support Vector Machine, International Journal of Smart Home, 2012.



**CIVIL  
ENGINEERING  
DIVISION**



# Assessment of Copper Slag as an Eco-friendly and Sustainable Alternative Construction Material

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**Abstract:** Rapid industrialization and increasing urbanization has led to two major issues that needs immediate attention-(i) increasing demand for building materials to cater to the growing requirements of construction industries and (ii) increased production of industrial wastes which needs to be effectively disposed. Researchers and engineers have hence been working relentlessly to address these problems and have been exploring the possibilities of utilizing industrial waste slags as an alternative, environment friendly, sustainable construction material. In this paper we discuss in detail the possibilities of utilizing copper slag, a by-product obtained during the smelting and refining of copper, as an alternative for river sand as fine aggregate in reinforced cement concrete through systematic evaluation of physical, mechanical and chemical properties along with the direct shear analysis, ultrasonic pulse velocity analysis and rapid chloride permeability tests to understand the quality and durability of the concrete. A careful assessment of these properties are essential considering the fact that the slags can vary in their chemical compositions with possible presence of high concentrations of heavy metals making them hazardous and also significantly altering the properties. The results suggest that copper slag can indeed be used as a fine aggregate replacement of natural river sand in reinforced cement concrete, without compromising on the quality, thereby contributing to the direction of environment friendly building materials with economic benefits, which is the need of the hour.

**Keywords:** Copper Slag; Compressive Strength; Chloride Permeability; Direct Shear; Non-Destructive Test Microstructure

## INTRODUCTION

One of the most contributing factors adversely affecting the environment is the massive production and consumption of concrete in construction industry owing to their greenhouse gas emission and global warming potentials. Hence there is a pressing need to look for alternate construction materials which are environment friendly and sustainable. One major step in this regard could be exploring ways to utilize waste materials and industrial by-products as an alternative for conventional concrete which helps in optimizing the usage of natural resources as well as provide an option for the safe industrial waste disposal. In this regard, copper slag (Cu slag), an industrial waste generated from the copper industry, can be a suitable alternative to the natural river sand as a fine aggregate replacement in concrete. Considering the fact that around 2.2 tons of Cu slag is generated for each ton of copper produced, such a possibility of utilizing this slag in construction can be a suitable option for economically viable construction materials without adversely affecting the natural resources [1-3].

In the present manuscript detailed systematic investigations and evaluation of the physical, mechanical and chemical properties of copper slag in comparison to natural river sand in reinforced cement concrete construction were carried out. Detailed experiments were carried out to assess the compressive strength, split-tensile strength and flexural strength of various mix designs obtained by partial/full replacement of river sand by copper slag by casting cubes, beams and cylinders up to 28 days of aging in comparison with the concrete prepared with natural river sand as fine aggregates [4]. Other relevant properties including specific gravity, water absorption, ability to hold surface moisture, compositional analysis, direct shear analysis, ultrasonic pulse velocity test to assess the quality of concrete as well as rapid chloride permeability test to check the durability of the material were also carried out [5], thereby examining the possibility of utilizing copper slag as a green, alternative material to natural river sand as a fine aggregate replacement in concrete.

## MATERIALS AND METHODS

### Properties of Materials

Properties of the cement used in the mixture greatly influences the performance of the concrete prepared. In the present

**Table 1** Physical properties of Portland cement used for present research work

Physical Property	Values Obtained	IS: 269 (2015) Specifications <sup>4</sup>
Fineness of Cement (m <sup>2</sup> /kg)	480	370 (minimum)
Soundness of Cement (mm)	2.3	10
Specific Gravity	3.15	3.15
Initial Setting Time (minutes)	143	30 (minimum)
Final Setting Time (minutes)	275	600 (maximum)
Compressive Strength (MPa)		
3 days	26.79	23.0 (minimum)
7 days	36.55	33.0 (minimum)
28 days	47.44	43.0 (minimum)

set of experiments ordinary Portland cement (OPC) grade 43 was used whose physical properties are summarized in **Table 1**, along with the required specifications as per IS:269(2015) [6].

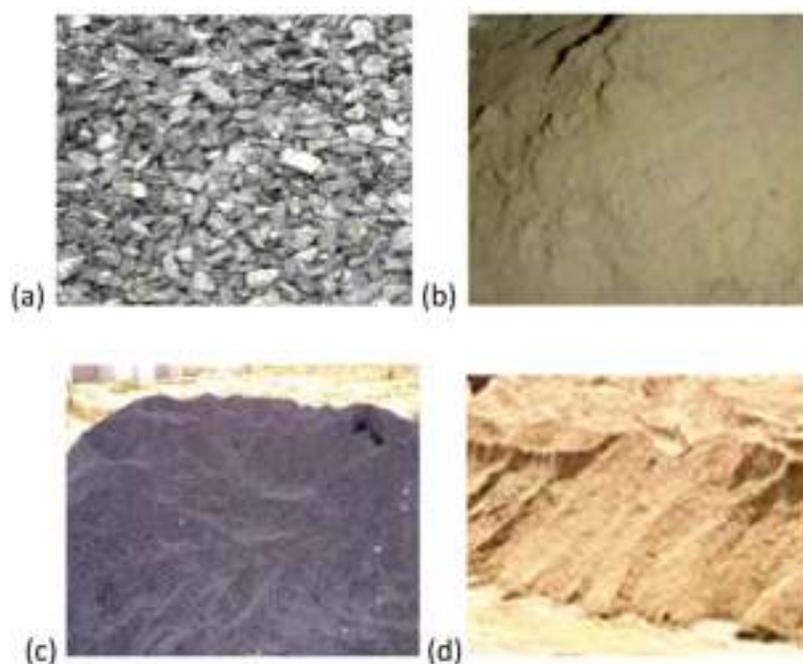
Clean and dry river sand with specific gravity of 2.65, fineness modulus of 2.38 and passing through IS 4.75 mm sieve and crushed granite aggregate with specific gravity of 2.75, fineness modulus 5.87 and passing through 12.5 mm and 20 mm sieves were used for preparing fine and coarse aggregates, respectively, for casting all the specimens [7-9]. Cu slag is an industrial by-product generated during the copper smelting and refining process. Two types of slags can be produced as the by-product (i) an air-cooled slag with light black colour and glassy texture and (ii) porous granulated copper slag with vesicular structure [10]. Based on the presence of iron content in the slag, its specific gravity can have values between 3.2 to 3.8 kg/m<sup>3</sup> and its water absorption can vary depending on the porosity [11]. Cu slag obtained from Vedanta Ltd., Thoothukkudy, India was used in the present study which had a specific gravity of 3.42 and bulking factor of 1 [9]. A comparison of the physical properties of river sand and Cu-slag used for the present experiments are presented in **Table 2**.

### Experimental Methods

Sieve analysis was carried out as per IS:383-2016[8]. Compositional analysis of the Cu slag was carried out using energy dispersive analysis of x-rays in a JEOL SEM system with OXFORD XMX N attachment. Direct shear measurements were carried out to evaluate the cohesion and angle of friction values for the river sand and copper slag. Here the tests were performed with three normal stresses of 100, 200 and 300 kPa in a direct shear test apparatus. Compressive strength, split-tensile strength and flexural strength were evaluated for mix designs, M25 and M30, prepared by partial/full replacement of River-sand by Cu slag varying proportions (IS: 10262-2019, IS: 516-1978 (reaffirmed 1997) and IS: 5816-1999)[12-14]. For M25 the mix proportion of the cement, fine aggregate and coarse aggregate followed were 1:2.08:3.283 with the water cement ratio being 0.47. The mix proportion of 1:1.815:2.973 with a water cement ratio of 0.44 was used for M30, respectively. The proportions (by weight) of copper slag added to concrete mixtures were as follows: 0% (for the control mix), 10%, 20%, 30%, 40%, 50%, 70% and 100%. The control mixture was designed to have a target 28 day characteristic compressive strength of 38.25 N/mm<sup>2</sup> (M30) and 31.60 N/mm<sup>2</sup> for M25. The chemical admixture used was conplast SP430. Compressive strength was evaluated by preparing cubes of 15 cm × 15 cm × 15 cm using various proportions of Cu-slag in place of river sand as fine aggregate in both the mix designs [12,13]. The cubes were then cured in water and tested using compression testing machine for adjudging the compressive strength after 7 days and 28 days of curing. Split tensile strength of cylindrical specimen of respective samples of 15 cm diameter and 30 cm length were evaluated using universal testing machine after 28 days of curing in water as per IS: 5816-1999

**Table 2** Properties of river sand and Cu-slag used for present research work.

Particulars	River Sand	Cu-Slag
Bulk Density (kg/m <sup>3</sup> )	1.70	2.056
Void Ratio	0.641	0.664
Porosity	0.390	0.339
Specific Gravity	2.65	3.42



**Figure 1** (a) Coarse aggregates (b) Cement (c) Copper slag and (d) River-sand used for experiments

[14]. Flexural strength of various samples were assessed by casting concrete beams of size 150 mm × 150 mm × 700 mm, cured in water for 28 days followed by testing in Flexural testing machine (IS: 516-1978 (reaffirmed 1997)) [13]. Rapid chloride Permeability test were performed to assess the durability of concrete for various replacements of river sand with Cu slag. In this method water saturated 50 mm thick, 100 mm diameter concrete specimen is subjected to a 60-V applied DC voltage for 6 hours. One end of the sample is maintained in 3% NaCl and the other in 0.3M NaOH solution and the total charge passed is determined which is then used to rate the concrete[5]. Ultrasonic pulse velocity test is a non-destructive test performed to assess the quality and strength of concrete by measuring the velocity of an ultrasonic pulse passing through the concrete specimen. This test is conducted by passing an ultrasonic pulse wave through the concrete to be tested and measuring the time taken by pulse to pass through the structure in cross probing method [17].

## RESULTS AND DISCUSSION

### Physical and Mechanical Properties

Size distribution of the aggregate particles were determined using sieve analysis and the semi-log graph representing the zoning and the results for river sand and Cu slag are shown in **Figures 2(a)** and **(b)**, respectively. Tabulation based on sieve analysis is shown in **Table 3** and a comparison of the particle size distribution and mechanical property evaluation between river sand and Cu slag are presented in **Tables 4** and **5**, respectively. The results of the sieve analysis clearly suggests that Cu slag falls into the category of Zone 2 which is recommended for mass concrete as per IS: 383-2016 [8].

### Compositional Analysis

Since Cu slag is a by-product of the smelting process, the slags can vary in their chemical compositions with possible presence of high concentrations of heavy metals like arsenic, cadmium and lead making them hazardous. Hence it is important to assess the chemical composition of the slag carefully. Considering this elemental composition of the copper slag used in the present experiments were investigated using EDAX and the results are summarized in **Figure 3**. The table clearly suggests that the slag is essentially a ferrous silicate material.

### Direct Shear test Analysis

Since bonding of materials is important in reinforced cement concrete, it is essential to understand the bonding of the fine aggregate which in turn depends on the cohesion and the angle of friction. Direct shear test is carried out to find out the friction of the materials in order to know the quality of the copper slag utilized as the fine aggregate replacement of river

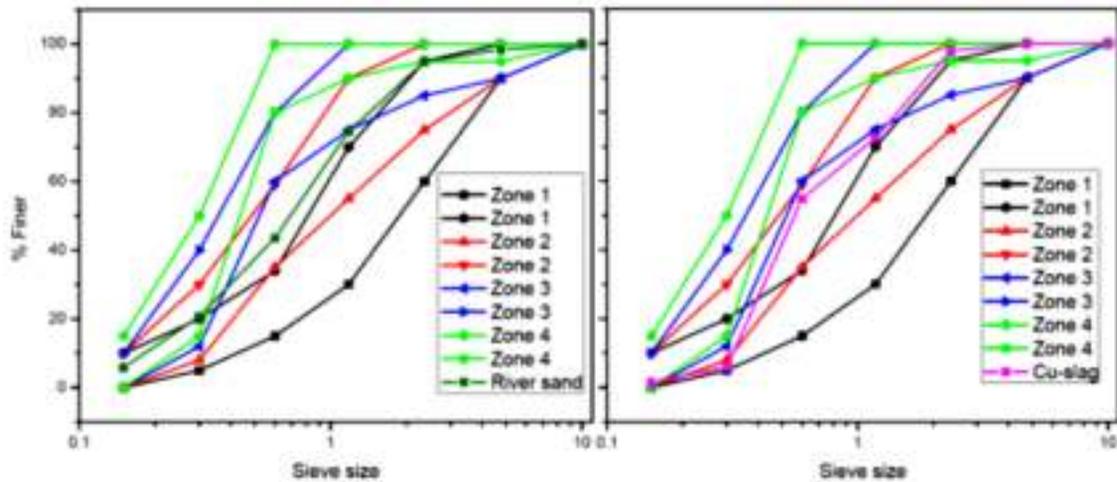


Figure 2 Semi log graph showing the sieve analysis of river sand (a) and Cu-slag (b)

Table 3 Tabulation based on sieve analysis

IS SIEVE	% Passing Standard Values			
mm	Zone 1	Zone 2	Zone 3	Zone 4
10	100	100	100	100
4.75	90 - 100	90 - 100	90 - 100	95 - 100
2.36	60 - 95	75 - 100	85 - 100	95 - 100
1.18	30 - 70	55 - 90	75 - 100	90 - 100
0.6	15 - 34	35 - 59	60 - 80	80 - 100
0.3	5 - 20	8 - 30	12 - 40	15 - 50
0.15	0 - 10	0 - 10	0 - 10	0 - 15

Table 4 Comparison of particle size distribution between river sand and Cu-slag

IS Sieve Size	River Sand % of Passing	Copper SLAG % of Passing	% Passing for single sized aggregates of Normal Sand (IS 383 - 2016) [8] Zone 2
10 mm	100	100	100
4.75 mm	98.4	99.9	90 - 100
2.36 mm	94.9	97.8	75 - 100
1.18 mm	74.5	72.6	55 - 90
600 Microns	43.6	54.8	35 - 59
300 Microns	20.7	11.0	08 - 30
150 Microns	5.8	1.5	0 - 10

Table 5 Mechanical property evaluation of river sand versus Cu-slag

Sl. No.	Property	River Sand	Cu-Slag	Remarks
1	Shape	Spherical particle	Granular particle, irregular, glassy and black	Good
2	Gradation	Cannot be controlled	Can be controlled	Good
3	Specific gravity	2.3-2.7	3.3-3.9	May vary
4	Water absorption	1.5 - 3%	0.15-0.35 %	Limit 2 %
5	Ability to hold surface moisture	Up to 7 %	Up to 0.5 %	Endurance limit
6	Grading zone	Zone 2 and 3	Zone 2	Recommends Zone 2 for mass concrete

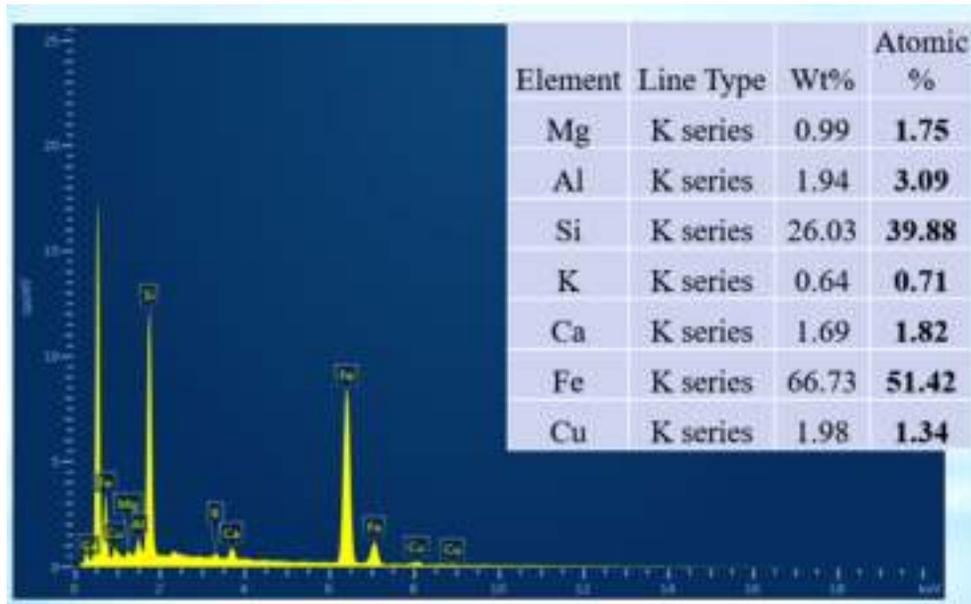


Figure 3 EDAX pattern and the corresponding elemental analysis of Cu-slag.

sand in concrete. Variation of shear stress with respect to shear displacement obtained for river sand and copper slag when subjected to normal stress values of 100 kPa, 200 kPa and 300 kPa are shown in **Figures 4(a)** and **4(b)**, respectively. The corresponding direct shear parameters are summarized in **Table 6**. The values of cohesion (C) and angle of friction ( $\Phi$ ) for river sand and Cu sand are comparable suggesting that it is possible to explore the utilization of copper slag as a replacement for river sand.

**Mix design- Replacement of River Sand by Cu-slag**

Compressive strength, split-tensile strength and flexural strength were evaluated for mix designs M25 and M30 by partial/full replacement of river sand by copper slag in various percentages (IS: 10262-2019, IS: 516-1978 (reaffirmed 1997) and IS: 5816-1999 [12-14]. Maximum size of the aggregate used was 20 mm. Results of the compressive strength evaluated after 7 and 28 days of curing for both the mix designs M25 and M30 for various replacements is tabulated in **Table 7** and the respective graphs are shown in **Figures 5(a)** and **5(b)**, respectively. The results clearly suggests that the compressive strength systematically increases initially for up to 40% replacement of Cu slag, beyond which the values starts to decrease with increasing replacement. Comparing with our previous studies we may infer that the initial

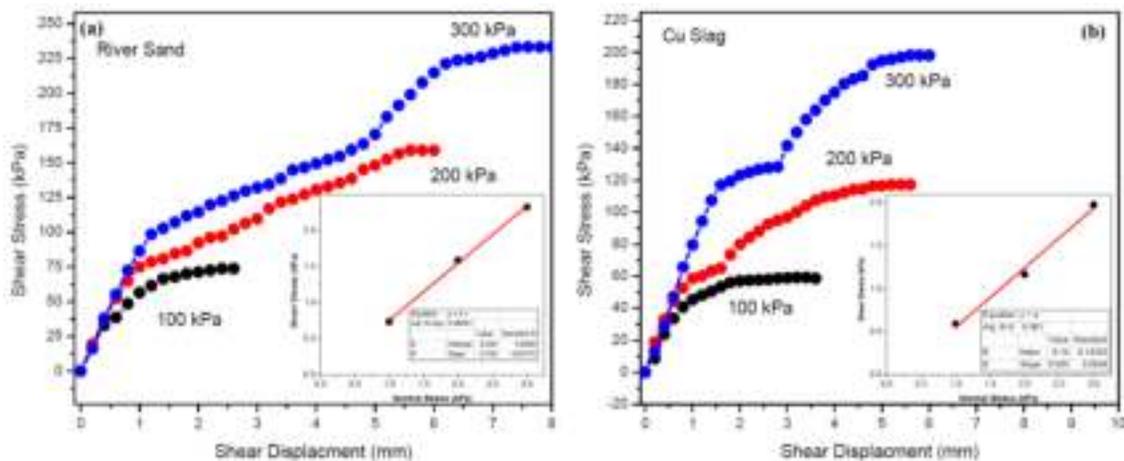


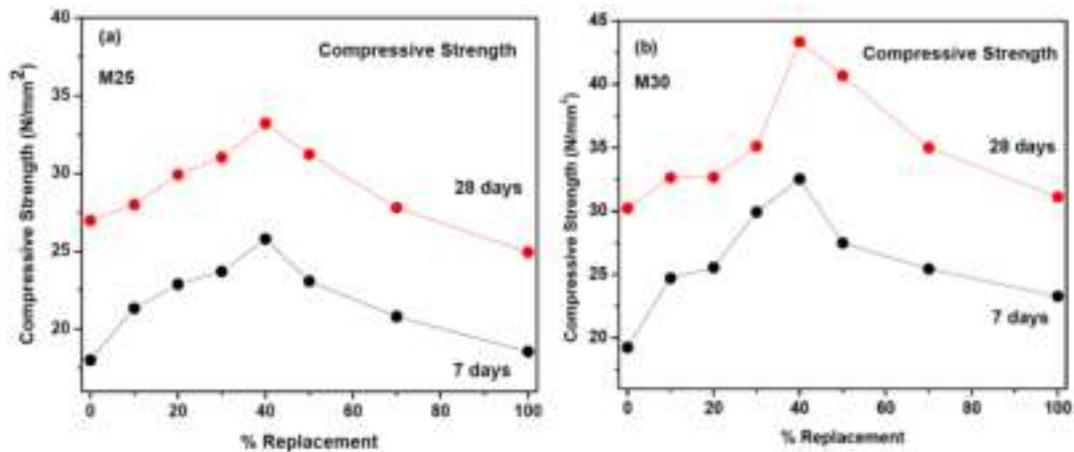
Figure 4 Direct shear test analysis of (a) river sand and (b) Cu-slag

**Table 6** Direct shear parameters of river sand and Cu-slag

Parameters	River Sand			Copper Slag		
	1	2	3	1	2	3
Normal Stress						
Shear Stress	0.74	1.59	2.33	0.59	1.17	1.98
Cohesion (C)	0			0		
Angle of Friction ( $\Phi$ )	38.48			34.79		

**Table 7** Results of compressive strength test for mix designs M25 and M30 after 7 days and 28 days of curing

% Replacement of River-Sand by Cu Slag	Compressive Strength (N/sq. mm)			
	M25		M30	
	7 days	28 days	7 days	28 days
0	18.01	26.98	19.25	30.22
10	21.33	28.00	24.71	32.64
20	22.88	29.92	25.55	32.67
30	23.70	31.03	29.93	35.11
40	25.79	33.21	32.53	43.33
50	23.08	31.22	27.49	40.67
70	20.81	27.80	25.44	34.99
100	18.56	24.94	23.28	31.11



**Figure 5** Compressive strength with varying percentage replacements of Cu-slag in river-sand for mix designs M25 and M30 after (a) 7 days and (b) 28 days of curing

improvement in compressive strength can be attributed primarily due to the pozzolanic reaction and the improved particle packing behavior [15]. However, excessive slag added beyond 40% remain unreacted and acts only as a filler leading to a reduction in the compressive strength. Increasing Cu slag content leads to an increase in voids due to the fact that Cu slag possess lesser fine particles than river sand. Also, Cu slag absorbs less water than the natural fine aggregates which may lead to an increase of the free water content with higher Cu slag percentages which might also contribute to the reduction in compressive strength.

Split tensile strength as well as flexural strength for both the mix designs M25 and M30 were evaluated for various percentages of replacements after 28 days of curing and the results are summarized in **Tables 8** and **9** and the corresponding graphs are shown in **Figures 6** and **7**, respectively. In all the cases, it is clearly evident that the optimum percentage of replacement of Cu slag in place of river sand is 40% beyond which the values are decreasing.

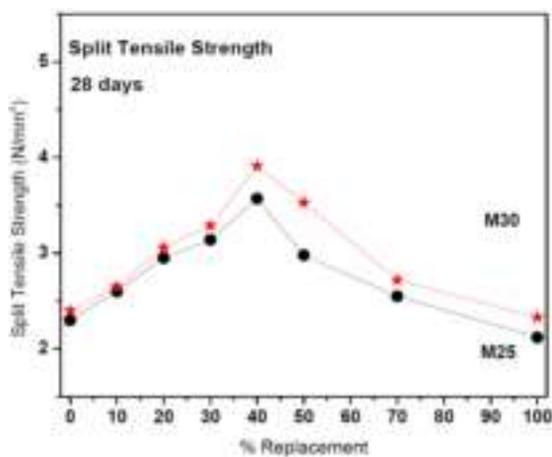


**Table 8** Results of split tensile strength test for mix designs M25 and M30 after 28 days of curing

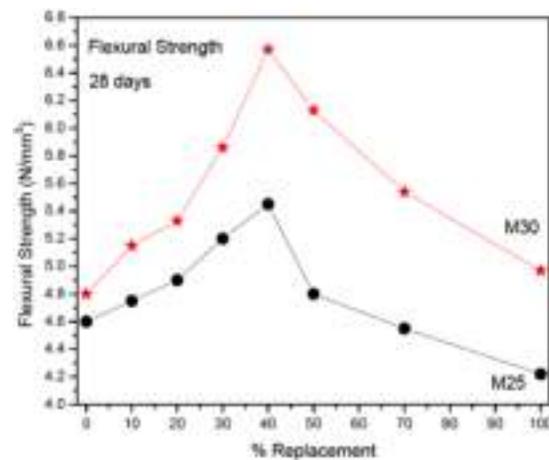
% Replacement of River-sand by Cu-slag	M25		M30	
	Maximum load, P (kN)	Split Tensile Strength (N/sq. mm) 28 days	Maximum Load, P (kN)	Split Tensile Strength (N/sq. mm) 28 days
0	162.57	2.30	170.0	2.40
10	183.78	2.60	187.5	2.65
20	208.52	2.95	217.0	3.06
30	321.95	3.14	233.0	3.29
40	352.34	3.57	277.0	3.91
50	219.64	2.98	250.0	3.53
70	180.24	2.55	192.0	2.72
100	149.85	2.12	163.0	2.33

**Table 9** Results of flexural strength test for mix designs M25 and M30 after 28 days of curing

% Replacement of River-sand by Cu-Slag	M25			M30		
	Maximum Load, P (kN)	Crack Length, a (mm)	Flexural Strength (N/sq. mm) 28 days	Maximum Load, P (kN)	Crack Length, a (mm)	Flexural Strength (N/sq. mm) 28 days
0	25.87	260	4.60	27.0	245	4.80
10	26.71	235	4.75	29.0	236	5.15
20	27.56	245	4.90	30.0	240	5.33
30	39.25	255	5.20	35.0	270	5.86
40	30.65	260	5.45	37.0	265	6.57
50	27.0	225	4.80	34.5	230	6.13
70	25.59	220	4.55	31.2	226	5.54
100	23.73	215	4.22	28.0	220	4.97



**Figure 6** Split tensile strength with percentage replacement of Cu-slag in river sand for mix designs M25 and M30 after 28 days of curing



**Figure 7** Variation in flexural strength with percentage replacement of Cu-slag in river sand for mix designs M25 and M30 after 28 days of curing

### Rapid Chloride Permeability Test

In order to further understand the utility of copper slag as a possible replacement for natural fine aggregate, it is important to examine the durability properties of concrete prepared using various percentages of partial/full replacement of river sand by Cu-slag. Rapid chloride permeability tests were carried out on both the mix designs, M25 and M30 with various percentage replacements and the obtained results are tabulated in **Table 10**. Chloride ion permeability based on charge

**Table 10** Results of rapid chloride permeability test for mix designation M25 and M30

Sl. No.	%	M25		M30		
		Replacement of River Sand by Cu Slag	Total Charge Passed (C)	Chloride Ion Permeability	Total Charge Passed (C)	Chloride Ion Permeability
1	0		2100	Moderate	2125	Moderate
2	10		1790	Low	1850	Low
3	20		1650	Low	1600	Low
4	30		1420	Low	1450	Low
5	40		1325	Low	1310	Low
6	50		1475	Low	1495	Low
7	70		1550	Low	1515	Low
8	100		1680	Low	1650	Low

passed (ASTM C1202-94) is summarized in **Table 11** [5]. A comparison of the results suggest that the control mix with 0% Cu-slag (100% river sand) comes under the category of moderate permeability whereas mixes with 10%, 20%, 30%, 40%, 50%, 70% and 100% replacements of Cu- slag come under the category of low chloride ion permeability. The rate of ingress of chloride into concrete depends on the pore structure of concrete. Hence a reduction in permeability with increase in Cu slag content may indicate an improvement in the microstructure and thereby an improvement in the durability of concrete [16].

#### Ultrasonic Pulse Velocity Test

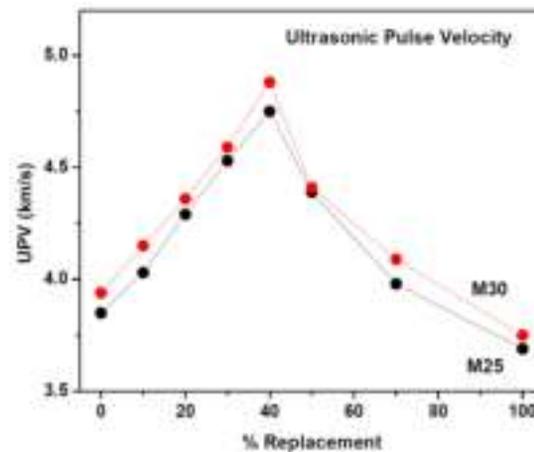
Ultrasonic pulse velocity of concrete cubes casted for both the mix designs M25 and M30 were evaluated for various percentage replacements after 28 days of curing and the results are summarized in **Table 12** and the corresponding graphs are shown in **Figure 8**. Ultrasonic pulse velocity is a measure of quality of concrete being mainly related to its modulus of elasticity and density of concrete which in turn depends on the materials and mix proportions used in the concrete preparation as well as the method of placing, compaction and curing of concrete. Higher velocities indicate the good quality of concrete and continuity of the material while lower velocity indicate that the concrete may be having many cracks or voids. From the graph it is observed that the maximum pulse velocity for M25 and M30 mix concrete cube is 4.75 km/s and 4.88 km/s for the 40% replacement of fine aggregate with Cu-slag. This may be due to the high density of mix and lesser pores in concrete for this composition. In addition to that it is also observed that the concrete at all replacement levels showed good quality as per **Table 1** of IS 516 (part-5/sec-1):2018 [17].

**Table 11** Chloride ion permeability based on charge passed (ASTM C1202-94) [5]

Charge Passed (Coulombs)	Chloride Ion Permeability
> 4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very Low
< 100 High	Negligible

**Table 12** Ultrasonic pulse velocity of cubes casted with varying percentages of Cu-slag in river sand.

Replacement of River sand by Cu Slag (%)	Concrete Mix Designation for 28 day Strength (cubes)			
	M25		M30	
	Ultrasonic Pulse Velocity V (km/sec)	Quality of Concrete	Ultrasonic Pulse Velocity V (km/sec)	Quality of Concrete
0	3.85	Good	3.94	Good
10	4.03	Good	4.12	Good
20	4.29	Good	4.36	Good
30	4.53	Excellent	4.59	Excellent
40	4.75	Excellent	4.88	Excellent
50	4.39	Good	4.41	Good
70	3.98	Good	4.09	Good
100	3.69	Good	3.75	Good



**Figure 8** Variation in ultrasonic pulse velocity of concrete cubes casted with varying percentage replacements of Cu-slag in river sand for mix designs M25 and M30 after 28 days of curing

## CONCLUSIONS

In conclusion the possibilities of utilizing copper slag, an industrial waste product, as an eco-friendly building material is explored in detail through systematic evaluation of physical, mechanical and chemical properties. The results suggest that the physical properties of Cu-slag aids in increasing the workability of concrete. Also, the fineness modulus, specific gravity, angle of friction and water absorption coefficients of Cu-slag are within the permissible limits. Elemental composition analysis suggests that the copper slag is predominantly composed of ferrous silicates. Evaluation of the compressive strength, split tensile strength and flexural strength for various mix designs indicated that the best results were obtained for an optimal replacement of 40% of river-sand by Cu-slag. It was also observed that the maximum ultrasonic pulse velocity for concrete cube is for the replacement of 40 % of river sand by Cu-slag. The reduction in values beyond 40 % replacement may be due to the increase in voids as well as the free water content with increasing slag content due to its modified properties. Above results suggest that an effective utilization of copper slag in reinforced cement concrete as a fine aggregate replacement of natural river sand is a possible alternative contributing to sustainable development with added economic benefits resulting from the utilization of industrial waste product, thereby moving towards a waste to wealth generated economy.

## REFERENCES

1. Holmer Savastano Junior and Juliano Fiorelli and Sergio Francisco dos Santos, Sustainable and Nonconventional Construction Materials using Inorganic Bonded Fiber Composites, Woodhead Publishing, 2017, ISBN 978-0-08-102001-2
2. Krishna Murari, Rafat Siddique and K K Jain, Use of Waste Copper Slag — A Sustainable Material, J Mater Cycles Waste Manag 17, 2015, pp 13–26.
3. Nagan S Brindha, Utilization of Copper Slag as a Partial Replacement of Fine Aggregate in Concrete. Int J. Earth Sci. Eng., 3 (4), 2010, pp 579–585.
4. IS: 456–2000, Plain and Reinforced Concrete Code of Practice (Fourth Revision). Bureau of Indian Standard, New Delhi, India.
5. ASTM C 1202-94, Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
6. IS: 269(2015), 43 Grade Ordinary Portland Cement-specification, Bureau of Indian Standard, New Delhi, India.
7. IS: 2386 (part I)-1963(reaffirmed 1997), Methods of Test for Aggregates for Concrete, Part 1-Particle Size and Shape, Bureau of Indian Standard, New Delhi, India.
8. IS: 383-2016, Specification for Coarse and Fine Aggregate from Natural Sources for Concrete, Bureau of Indian



Standard, New Delhi, India.

9. IS: 2386 (part III)-1963 (reaffirmed 1997), Methods of Test for Aggregates for Concrete, Part III-Specific Gravity, Density, Voids, Absorption and Bulking, Bureau of Indian Standard, New Delhi, India.
10. Ravindra K Dhir OBE, Jorge de Brito, Raman Mangabhai and Chao Qun Lye, Use of Copper Slag as Concrete Sand, Sustainable Construction Materials: Copper Slag, 2017, pp 87-163.
11. Bipra Gorai and Jana R K Premchand, Characteristics and Utilisation of Copper Slag — a Review, Resources, Conservations and Recycling 39, 2003, pp 299-313.
12. IS: 10262–2019, Recommended Guidelines for Concrete Mix Design, Bureau of Indian Standard, New Delhi, India.
13. IS: 516-1978 (reaffirmed 1997), Methods of Sampling and Analysis of Concrete, Bureau of Indian Standard, New Delhi, India.
14. IS: 5816–1999, Splitting Tensile Strength of Concrete-method of Test, Bureau of Indian Standard, New Delhi, India.
15. Rahmathulla Noufal E and Unnikrishnan Manju, I- Sand: An Environment Friendly Alternative to River Sand in Reinforced Cement Concrete Construction, Constr. Build. Mater. 125, 2016, pp 1152–1157.
16. A N Cheng, Ran Huang, Jiann-Kuo Wu and Cheng-Hsin Chen, Influence of GGBS on Durability and Corrosion Behaviour of Reinforced Concrete, Mater. Chem. Phys. 93, 2005, pp 404–415.
17. IS: 516 (part-5/sec-1):2018, Non-Destructive Testing of Concrete -Methods of Test, Bureau of Indian Standard, New Delhi, India.

# Composite RCC Deck and Prestressed Parabolic Bottom Chord Underslung Open Web Steel Girder Bridge Superstructure

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**Abstract:** Composite decks increase bridge strength and stiffness. Prestressed composite open web steel girder has added advantage of high strength cable support. Results of typical 125 m span bridges having heights of 9.0 m, 10.0 m and 12.5 m, and another 50.0 m span and 2.5 m height are given. Member stresses and bridge deflections during erection remained safe. Average steel off take for the 125 m bridge is 2.65 t/m and for the 50 m span bridge it is 1.77 t/m for limiting live load deflection of Span/800. Its reserve strength is 3.2 times service condition live load.

The girders are panel wise workshop fabricated, assembled at site, jacked up or crane lifted to secure over bearings. Connection of the cross members, and onsite deck casting in parts with stage wise bottom chord prestressing is carried out. Medium to long span bridges for single or multiple lanes in road, rail, metro rail, and coastal link projects are feasible.

This invention is under the process of Indian and PCT patents by the author

**Keywords:** Composite; Prestress; Parabolic Bottom; Underslung; Steel Superstructure

## BACKGROUND

In road, rail and metro rail like transportation systems, bridges are frequently required to cross rivers, as flyovers and sea links etc. For bridges high tensile strength (HTS) steel cables are very economical, using which long span suspension bridges, cable stayed bridges, and more recently stressed ribbon bridges are constructed. However, HTS cables are very flexible and this results in structural disadvantage in the bridge.

Using shear connectors, when RCC deck slab is made composite with the top chord of an under slung open web steel girder bridge superstructure, its buckling is prevented and strength and stiffness of the bridge significantly increase. Prestressing of the bottom chord counters its tension due to the applied loads and it also exerts balancing upward thrust. This type of bridge using HTS cables in the bottom chord, is invented for its high strength.

Bottom chord profile of the bridge, if made parabolic or catenary shaped, it results in its uniform tension under uniformly distributed load due to self weight or live load, which facilitates its prestress. Thus, 'Composite RCC deck and prestressed parabolic bottom chord underslung open web steel girder bridge superstructure' is invented.

## OBJECTIVES OF THE INVENTION

It was aimed to invent a robust prestressed composite bridge superstructure, which has high strength, low structural steel consumption, low cost, high reserve strength and easy erection, where substructure and superstructure constructions may be planned as parallel activities reducing the construction time and cost. It was also aimed to provide a bridge superstructure solution of this kind, which is suitable for medium spans (30 m), as well as for long spans (200 m), for single or multiple lane road, rail, metro rail, fly over and projects like coastal links.

## SUMMARY OF THE INVENTION

Typical design and approximate erection stage analysis examples of the prestressed composite bridge for 125 m span and 50 m span are given. While girder stresses under all erection stages are low and safe, member stresses under Serviceability Limit State (SLS) condition are also very safe, as the limiting deflection in SLS condition is governing.

Maximum deflections under SLS condition for 2- lanes of class-A IRC loading are 155.6 mm with 2.65 t/m average steel off take for 125 m span, and 57.6 mm with 1.77 t/m average steel off take for 50 m span bridges.

Due to low SLS condition stresses, conservative reserve strength of the bridge beyond SLS condition up to yield

condition for the 125 m span bridge is 3.2 times the live load in SLS condition, and for the 50 m span it is 2.8 times. Therefore, design and construction methodology of this type of bridge supported with design guidelines as per existing codes of practice is invented.

Summary of design and erection stage analysis results for the 125 m and 50 m span bridges in terms of steel off take, member stresses, prestress applied and deflection under live load are given in **Table 1**.

From the results it is seen that the prestressed composite bridge superstructures are economical, stiff, and have high reserve strength.

### BRIEF DESCRIPTION OF THE DRAWINGS

For the 125.0 m × 9.0 m bridge case, **Figure 1** shows line diagram of the girder where top chord (1), bottom chord (2) and web members (3) are shown. Cable anchorage details at 'A' are shown in **Figure 2**. The 27T15 standard cables (4) and anchorages (5) are shown within and aligned along bottom chord. The composite RCC deck is cast over top chord, supporting cross girder and stringer beams, using shear connectors (6). End cross girder (7) connects the two main girders. Girders at the ends are supported over bearings (8), and RCC deck slab, beyond the girder, is supported over dirt wall (9). **Figure 3** shows STAAD model of the bridge. **Figure 4** shows service load stresses for the prestressed composite 125 m × 9 m bridge [**Figures 5(a)-5(f)**]. For better comprehension, figure titles and brief descriptions are also given in **Table 2**.

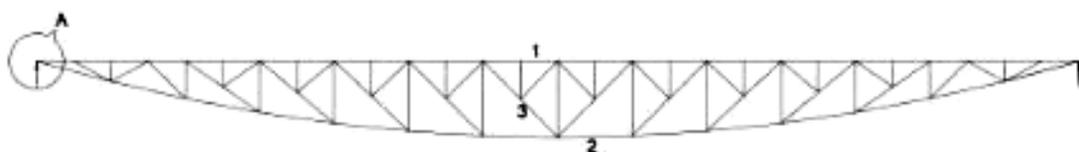
### DETAILED DESCRIPTION OF THE INVENTION

A typical 125 m span and 9 m deep composite prestressed 2-lane open web steel girder bridge is designed for which 2-d line sketch is given in **Figure 1**. The top chord consists of 500 mm × 500 mm × 16 mm box section, the bottom chord is 500 mm × 600 mm × 22 mm box section, and the web members have the section of 500 mm × 200 mm × 16 mm.

Typical anchorage system at the supports of the under slung bridge superstructure is shown in **Figure 2**. E410 grade steel having 410 N/mm<sup>2</sup> yield stress is used in the end panels for high strength in the anchorage, support and the transition zones. Two number 27T15 cables for the 125 m span case for each girder are used. Loads from the cable anchors, apart from the top and bottom plates, are transmitted through the extended two number E410 grade bottom chord side plates and one number central stiffening plate (10). The anchorage system must be designed with high f<sub>os</sub>, shop fabricated, and

**Table 1** Design and erection stage analysis results

Span (Height)	Prestress (kN)	Member stress (N/mm <sup>2</sup> )		Structural steel off take (t)	Deflection under LL (mm)	Permissible deflection under LL (mm)
		Top chord	Bottom chord			
125m (9m)	2 × 9100 (4 × 27T15)	99.2 (C) (support)	95.5 (C) (support)	331 (2.65 t/m)	151.3	156.2
125m (10m)	2 × 8500 (4 × 27T15)	72.1 (C) (support)	73.1 (C) (support)	310 (2.48 t/m)	135.5	156.2
125m (12.5m)	2 × 8200 (4 × 27T15)	63.1 (C) (support)	65.4 (C) (support)	299 (2.40 t/m)	140.1	156.2
50m (2.5m)	2 × 4500 (2 × 27T15)	22.7 (C)	-8.3 (T)	88.5 (1.77 t/m)	57.6	62.5



**Figure 1** 2-d line sketch of the girder

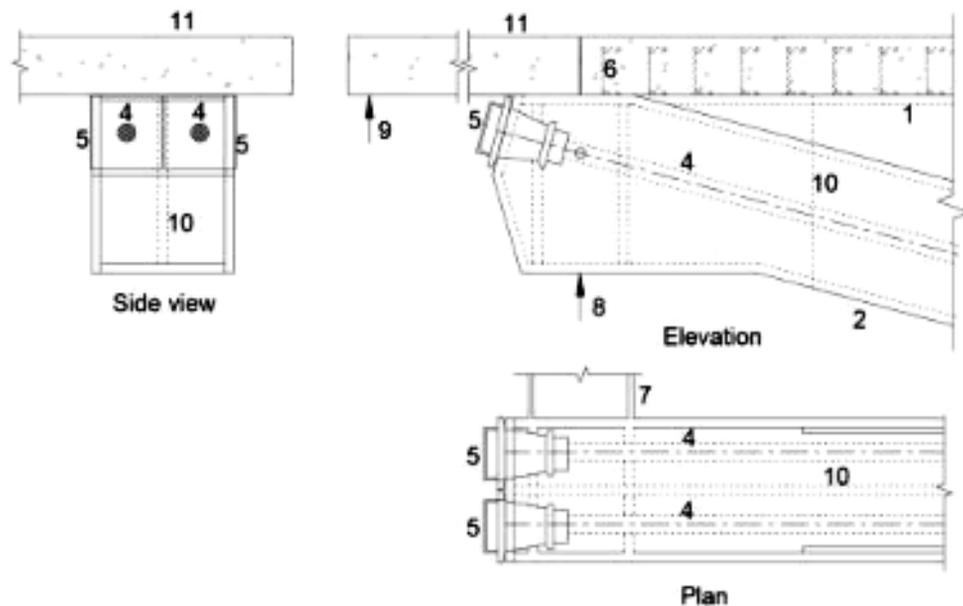


Figure 2 Anchor details

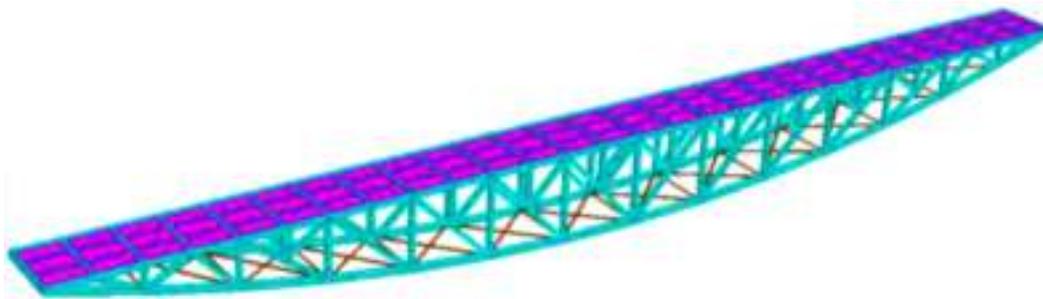


Figure 3 FEM model



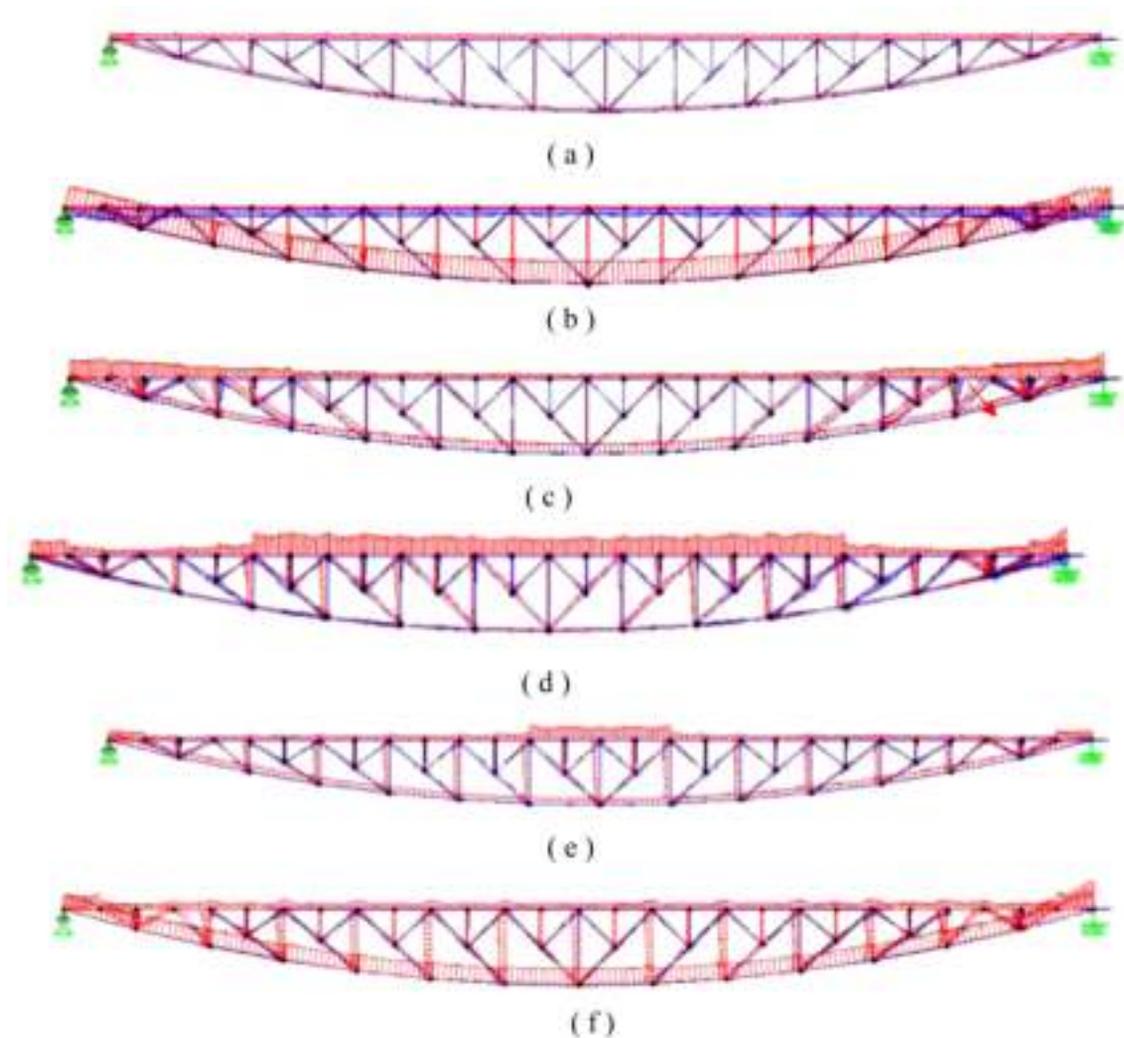
Figure 4 Stress diagram for service condition

tested before assembly.

The bridge is analyzed for two lanes of Class A (IRC:6-2017) and the axial stress diagram in service condition is given in **Figure 4**. Maximum deflection of the bridge under live load is 155.6 mm, which is within the prescribed limit of  $\text{Span}/800$ . Average steel off take of the bridge superstructure is 2.65 t/m, which is significantly lower than similar open web steel girder superstructure steel off take. Parallel 125 m span 10 m deep and 12.5 m deep girder models are also analyzed and the results of the 9 m, 10 m and 12.5 m deep girders are compared.

Another typical 50 m span and 2.5 m deep composite prestressed 2-lane open web steel girder bridge is designed . The top chord consists of 300 mm  $\times$  300 mm  $\times$  16 mm box section, the bottom chord is 300 mm  $\times$  450 mm  $\times$  22 mm box section, and the web members have the width of 300 mm, thickness of 16 mm and depth of 250 mm.

The typical examples of 125 m span, 9 m deep and 50 m span 2.5 m deep, 2-lane highway superstructure girders are optimized to result in steel off take of 331.0 t and 88.5 t, respectively. The maximum deflections due to live load at mid span are 151.3 mm and 57.6 mm, respectively for the 125 m and 50 m spans which are within the permissible deflection



**Figure 5** (a) Stress diagram for Stage 1; (b) Stress diagram for Stage 2; (c) Stress diagram for Stage 3; (d) Stress diagram for Stage 4; (e) Stress diagram for Stage 5; and (f) Stress diagram for Stage 6

of Span/800.

For the 125 m span bridge, the axial member stresses during erection and concreting of the deck are checked with prestressing applied at different stages as per design to be safe. The limiting live load for elastic condition is found to be 3.2 times the SLS live load for the 125 m span, and 2.8 times for the 50 m span, confirming their robustness. In the case of the 125 m span, for parallel 10 m and 12.5 m deep girder examples, steel off takes are 310 t and 299 t, and corresponding live load deflections are 135.5 mm and 140.1 mm, respectively.

#### **ERECTION OF THE BRIDGE SUPERSTRUCTURE**

The bridge girder panels may be fabricated in the workshop using welded or HCFG bolted connections. The panels are transported to the site where these are assembled and connected, and the individual girders are lifted to securely placed over the bearings using jacks or cranes or any other suitable device. The cross members for top and bottom chords may be then connected. Deck slab for the superstructure is cast in symmetrical parts using bonding agent and stage prestressing.

HTS prestressing cables are laid in the parabolic bottom chord. Prestressing of the strands is carried out in stages as per design. Results of the different construction stages for member stresses and maximum deflection are shown in **Figures**



**Table 2** Figure title and brief description

Fig. no.	Title	Brief description
1		2-d line sketch of the girder
2	Anchor details	2x27T15 anchorage detail
3	FEM model	3-d view of super structure
4	Stress diagram for service condition	Mid stress: Top chord - 38.1 N/mm <sup>2</sup> (C) Bottom chord - 19.4 N/mm <sup>2</sup> (C)
5.a	Stress diagram for Stage- 1	Max stress: Top chord - 31.2 N/mm <sup>2</sup> (C) Bottom chord - 17.1 N/mm <sup>2</sup> (T)
5.b	Stress diagram for Stage- 2	Max stress: Top chord - 18.1 N/mm <sup>2</sup> (T) Bottom chord - 87.6 N/mm <sup>2</sup> (C)
5.c	Stress diagram for Stage- 3	Max stress: Top chord - 113.2 N/mm <sup>2</sup> (C) Bottom chord - 55.3 N/mm <sup>2</sup> (C)
5.d	Stress diagram for Stage- 4	Max stress: Top chord - 106.2 N/mm <sup>2</sup> (C) Bottom chord - 7.4 N/mm <sup>2</sup> (T)
5.e	Stress diagram for Stage- 5	Max stress: Top chord - 89.3 N/mm <sup>2</sup> (C) Bottom chord - 47.7 N/mm <sup>2</sup> (C)
5.f	Stress diagram for Stage- 6	Max stress: Top chord - 33.4 N/mm <sup>2</sup> (C) Bottom chord - 95. N/mm <sup>2</sup> (C)

**5(a) - 5(f)** for the 125 m × 9 m bridge case.

Typical example for stage prestressing is given below for the two number 27T15 cables in each bottom chord.

Stage 1: Launch the girder including cross members, cross girders and stringer beams and suitably apply a prestress of 2000 kN [**Figure 5(a)**]. Deflection at mid span of the girder in this stage is 17.8 mm (downward).

Stage 2: Apply additional 2000 kN prestress [(**Figure 5(b)**)]. Deflection at mid span of the girder in this stage is 151.7 mm (upward).

Stage 3: Cast deck slab in 1/5th spans from either end. This stage includes construction load of 5 kN/m<sup>2</sup>. Deflection at mid span of the girder in this stage is 3.5 mm [upward - **Figure 5(c)**].

Stage 4: Apply additional 1000 kN prestress after 10 days of concreting in Stage 3 and cast next 1/5th spans. Deflection at mid span of the girder in this stage is 121.7 mm [downward - **Figure 5(d)**].

Stage 5: Apply additional 1000 kN prestress after 10 days of concreting in Stage 4 and cast central 1/5th span. Deflection at mid span of the girder in this stage is 7.6 mm [downward - **Figure 5(e)**].

Stage 6: Prestress by additional 3100 kN force after 28 days of applying SIDL on the deck . Deflection at mid span of the girder in this stage is 75.5 mm [upward - **Figure 5(f)**].

Live load is now applied on the bridge. Deflection at mid span of the girder in this stage is 80.5 mm (downward). Additional prestress can be applied in due course of time to make up for time dependent losses etc., reflected in terms of sagging deflection.



### PRESTRESS CALCULATION USING LOAD BALANCING

It is assumed that after application of prestress, the girders become horizontal and cables carry total permanent load. Finer prestress adjustment for losses etc. may be carried out as required for the final deck profile.

$$Y = ax^2, a = 2.5/25 \times 25 = 0.004$$

$$(dy/dx)_{\text{end}} = 2ax = 0.008 \times 25 = 0.2 \text{ rad}$$

$$\text{Permanent load} = \text{SW} - 750 + \text{Deck} - 2700 + \text{WC} - 82 + \text{CB} - 940 + \text{LL}/2 - 604 = 5076 \text{ kN}$$

$$\text{Prestress required per girder} = 5076 / (2 \times 2 \times 0.2) = 6345 \text{ kN}$$

Pair of 27T15 and 19T15 may be used in each girder.

### CONCRETE GROUTING:

Dead weight of the superstructure is fully supported by the prestress alone with favorable precompression in the RCC deck, and hence, expansive concrete grouting of the box sections is desirable. The Concrete Filled Steel Tubes (CFST) now become composite, providing additional strength and stiffness to the girders.

### CONCLUSION

HTS steel cable ( $f_p = 1800 \text{ N/mm}^2$ ) has about 7-times strength and lightness, and 1.5- times cost of structural steel ( $f_y = 250 \text{ N/mm}^2$ ). In the composite prestressed open web steel girder, full dead load and half live load are supported by the cables, making it very economical and light weight. The composite RCC deck increases strength and stiffness of the girder by about 2-times. Stage wise girder launching, deck casting and prestressing further reduces the steel requirement in the girder. Thus, the unique technology of composite prestressed open web steel girder, incorporating all the above techniques, is economical, light weight and robust having the following features.

1. It is most economical, as full dead load and half the live load are taken by the cables.
2. Anchorage of the cables at the ends induces desirable precompression in the RCC deck, rendering its design possible longitudinally on no crack basis.
3. It is very light weight due to maximum load supported by the cables, making it suitable for high seismicity areas.
4. Structural steel requirement in the girder reduces due to the composite deck, and stagewise girder launching, deck casting and prestressing as per design.
5. Due to the light weight superstructure, cost of the sub structure is also low, making the overall cost of bridge very competitive.
6. It is very suitable for medium to long spans due to its light weight.
7. As major part of the load is supported by the cables, rise of the girder at the mid-span can be reduced from the normal 1/10 to 1/20 of the span or so.
8. Due to long span and light weight superstructure and substructure, the bridge has sleek and elegant look.
9. It is possible to launch the individual long span girders first, followed by cross members, and deck casting in parts with designed prestress.
10. Reserve strength of the girder in ULS condition is more than 3-times its strength in SLS condition.
11. Due to hogging deck for half the live load, girder deflection from the mean is reduced to half, and consequently the girder fatigue is also reduced.
12. CFST houses the cables in the bottom chords and apart from preventing its corrosion from within, it increases the strength and stiffness.

The invented unique superstructure is applicable to infrastructure projects related to transportation systems like highways, railways, metro rail, flyovers and mega projects like sea links.

# Construction Challenges — Executing the Deep Foundations in Metros and Hydro Power Projects

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**Abstract:** The construction requirements of the deep foundations for the Urban Infrastructure and Hydro power projects in terms of the equipment, manpower and other resources planning, are similar in nature. However, the construction and sequencing are the challenging issues for each activity. The paper makes an attempt to bring all the construction challenges in executing the deep foundations starting from the equipment planning, logistics, execution, geographical constrains, work front availability and uncertainties in the geological conditions. Maneuvering of the key construction equipment's like the trench cutters, hydraulic piling rigs and cranes movement in the metros is limited by the working space while on the contrary its limited spaces within the mountains. In terms of the geological constrains metros have the utility diversions and underground debris to be cleared before start of the works, while the fresh and completely weathered rock with shear zones and cavities pose challenges during the construction. In this paper, author makes an attempt to bring in case studies of the projects executed in metros and hydro power project with the same equipment highlighting the insights for better planning and scheduling of the activities.

**Keywords:** Metros; Hydro; Trenching; Piling; Geological Formations

## INTRODUCTION

This paper discusses deep foundation works of two typical projects executed in the urban and hilly terrain for the construction of Metro and Hydro power projects. The challenges encountered during the execution of foundation works for Cairo Metro, Mangdechhu Hydroelectric Project and Janna Dam projects are described in detail in this paper. This paper makes an effort to detail the equipment's used for construction and other challenges encountered during the execution. The equipment used for the both the projects are the same whose details are shared in below section.

## MAIN EQUIPMENT

### Diaphragm Wall (D-wall) or Cut-off Wall (CoW)

For the execution of the Diaphragm Wall or Cut-Off Wall trench cutter systems are used. The trench cutters have cross-sectional area of 2.80 m × 1.20 m. These trench cutters are mounted on base carriers equipped with Hose Drum System (HDS) or Hose Tension System (HTS). To ensure the high-quality standards. During cutting operation bentonite slurry circulation ensures the continuous working process of the D-wall construction by stabilizing the trench and removal of the excavated spoil. The polluted slurry from the trench are sent to the centralized desanding units/ slurry treatment plant to separating the excavated material from the slurry fluid. After the separation the slurry is available for reuse within the system. Up to 1000 m<sup>3</sup> of working slurry is processed every hour by the installed Bauer BE500 and BE550 desanding plants.

## PERMEATION GROUTING

BAUER BG 28 piling rigs with extended mast along with grout or soft gel containers with grout pumps are used on site along with several mixing plants.

## JET GROUTING

BAUER BG 28 piling rig, Jet grouting pump and a complete mixing plant for the Jet Grouting Works.

## MANGDECHHU HYDROELECTRIC PROJECT, BHUTAN

Concrete Cut-off Wall in place of permeation grouting was executed in the upstream coffer Dam of Mangdechhu Project. The work was carried out by the Bauer, Germany. The induction of Concrete Cut-off Wall was done primarily because the River Borne Material (RBM) had the silt content more than 18%. As per the research carried out worldwide, it is

established that the permeation grouting is effective only when the silt content in the RBM is less than 18%. Henceforth, profession Engineers on ground shall appreciate that Concrete Cut-off Wall is the best solution for controlling the river side seepage in the RBM as the same has been seen on ground in Mangdechhu Project, Bhutan. As far as the cost per sq meter of the cross-sectional area of the river is concerned, the Concrete Cut-off Wall is slightly costlier than permeation grouting but 100% effective in controlling the seepage.

Underground Powerhouse (UGPH) of Mangdechhu HE Project had the low dipping shear zones on both the long walls of the UGPH and the consultant advised for shifting the Underground Power House as above along the longitudinal axis by 40 m. However, the UGPH as above was not shifted by the MHPA and the 3 DEC software was used for Numerical Modelling by the NIRM to find out the deformations in the Crown and the Sides of the UGPH. Based on the results of the analysis as above, the rock supports were modified and intensive grouting was carried out by deploying Mahi Pumps. With the above, MHPA saved one year construction time for the Project.

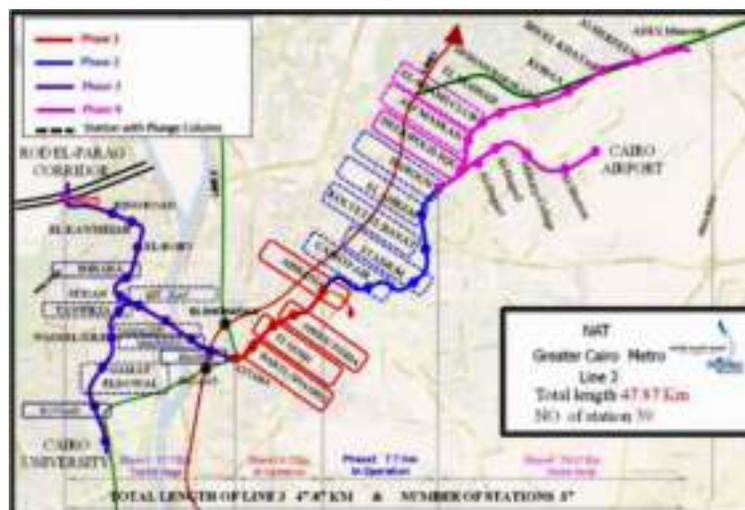
### CAIRO METRO

Cairo, the capital of Egypt, is the biggest city of the Islamic hemisphere, with approximately 21 million inhabitants in Greater Cairo. The first tram opened in 1896 and this tram system formed an important part of public transportation. But sharing the streets, additionally with busses transporting approximately two billion passengers per year, called for the establishment of an underground infrastructure as being the efficient solution. Consequently, the Cairo Metro has become the most important public transport system. Two lines with a total length of 61.5 km are in operation and transporting approximately 950 million passengers a year by 2004. The National Authority for Tunnels (NAT), a department of the Ministry of Transport, Arab Republic of Egypt, is the owner and in charge of all constructions. When Metro Line 1 was opened in 1987, it consisted of 4.7 km long tunnel section. In 1990's, the first tunnel under the river Nile was constructed for Metro Line 2. The works for Line 3 started in 2008. The total lengths are divided into four phases of which phases 2 and 3 with a length of 12 km are already in operation. The works executed by Bauer shown in **Figure 1**.

### GEOTECHNICAL WORKS FOR METRO LINE 3

Bauer commissioned the specialist civil engineering works i.e. 18 of the 22 underground stations on Line 3 and constructed approximately 600,000 m<sup>2</sup> of diaphragm walls and 58,000 m<sup>2</sup> of silicate gel grout plugs. BAUER executed open excavation pits, for the start shaft of TBM, several Metro stations and ventilation shafts. Excavation and foundation levels for stations planned up to 32 m below ground water level requiring retaining walls (Diaphragm walls) with connection to deep-lying silicate gel grout plugs down to a maximum depth of 86m, allowing for the excavation of the construction pit in dry conditions controlled by dewatering of limited seepage.

Mostly, the stations are located under existing roads. Depending on traffic, the concerning road was closed partly or



**Figure 1** Cairo Metro, Line 3 -Stations awarded to Bauer are surrounded by a rectangle with the same color as the phase. Plunge columns were used in station where the boxes are dotted.

completely by temporary traffic diversions. After the completion of D-Walls and silicate gel grout plug, the main contractor shall start excavation and construction using the top-down method with temporary struts. The execution was based on the following general construction sequence:

- Construction of the vertical retaining walls by means of diaphragm wall technique;
- Installation of Plunge Columns;
- Construction of cut-off walls to divide a station box into smaller boxes;
- Construction of the sealing base as a silicate gel grout plug.

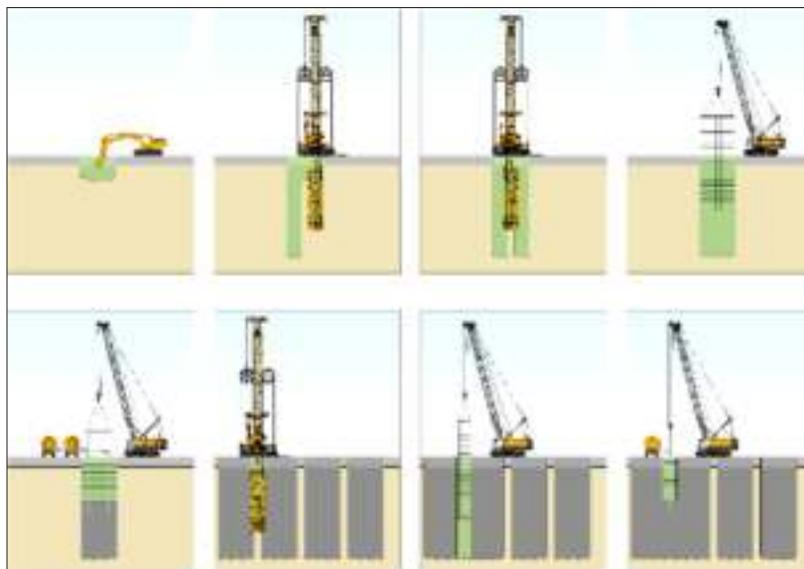
The general soil profile at awarded sites are investigated had cultural fill, clay, silt, and sand profile. There was no presence of natural impervious soil layer within acceptable depth in typical Cairo soil conditions for Line 3, construction pits usually also needed cut-off from ground water at the bottom by a horizontal grout plug in form of soft gel.

The grouting activities for the horizontal sealing of the excavation pits started after completion of the reinforced diaphragm walls in two main phases. Preparation of actual permeation grouting by drilling vertical holes in a defined grid and installation of grouting tubes into the holes supported by a self-hardening bentonite-cement-slurry. When this slurry gained sufficient strength, the actual grouting with soft silicate gel was commenced valve by valve and layer by layer. The silicate gel grout plugs for Cairo Metro Line 3 had thicknesses varying from 4.5-12 m, complying with the individual specifications of site. To allow for grouting up to five layers, the same number of tubes with one valve each per hole were installed at the various layer's elevations accordingly. For mixing the silicate gel, sodium silicate and reactant are required so that the water becomes a gel. Grout by Silicate gel is highly sustainable, as it requires less transportation produce silicate gel on site with less material consumption thus reducing carbon footprint. Before excavation, the water level is lowered inside by internal wells. By means of residual dewatering, the water level is kept at the required level below the bottom of the excavation pit.

### DIAPHRAGM WALL

The underground retaining structure/ wall is constructed by means of the diaphragm wall technique formed of individual panels, each of panel length varying between 2.80 m to 6.80 m having nominal thickness of 1.20 m. To create a structural and watertight bond between the respective adjacent panels, primary panels are overcut during the excavation of the secondary panels depending on the required depth. Static calculation of the walls

require reinforcement in all panels, so prefabricated reinforcement cages are installed in the primary panels in an exact position, to avoid any subsequent contact between the cutter and the reinforcement during the trenching of the secondary panels. The construction sequence is shown in **Figure 2**.



**Figure 2** Schematic construction sequence of diaphragm wall using cutter



## TRENCH STABILIZATION

Technically and economically appropriate option for the construction of diaphragm wall is the use of supporting bentonite slurry to stabilize the open trench. However, considering the conditions (e.g., the price and availability of bentonite, properties of the subsoil, storage, disposal, etc.) there may be reasons to consider alternatives. Polymers are used in diaphragm wall construction sites.

## PERMEATION GROUTING

Permeation grouting by means of silicate gel is used in the excavation pits at Cairo Metro project mainly for safety against uplift as the subsoils mostly consists of sand. Grouted horizontal cut-offs for which the safety against hydraulic uplift is to be verified are assumed to be totally impervious with an imaginary membrane located at the proposed underside of the horizontal cut-off. In the analysis the uplift pressure acting on the underside of the grouted horizontal cut-off is balanced against the total weight of all soil layers above the imaginary membrane.

## JET GROUTING

The objective of the jet grouting between the existing Sewer and the CML3 tunnel is to allow the TBM to bore the tunnel in a safe way that there is no filling of the sewer with the slurry. In addition, the settlement and the differential settlements of the sewer tunnel should be limited to the minimum possible while the TBM is crossing below the Sewer. The jet grouting soil treatment zone is extended to 20 m along the sewer on each side of the crossing. As per the geometry and design of the treatment zone, a network of Jet Grouting points had to be installed with different inclinations in both directions and different depths. The design Jet Grout column was 2.0 m. In reality the actual diameters reached upto 2.20 m to 2.30 m. The main advantage of Jet grouting is that large solidified elements can be executed in the ground using a relatively small drill rod of approximately 150 mm and the method is applicable within limited working space.

## SOIL FREEZING

During the tunnel boring works for Cairo underground metro line 3, a collapse caused by one of the segmental liners having failed during tunnel construction. Inflow of water and soil flooded the tunnel boring machine (TBM) resulting in a sink hole at the ground surface. The TBM was buried at a depth of about 30 m under the street level.

After evaluation of different options considering jet grouting, ground freezing and mixed solutions using both techniques, finally the construction of a shaft directly in front of the TBM and horizontal ground freezing was chosen to rescue the TBM. Two rings of bore holes, with the holes tapering towards each other, were necessary for this. These holes were drilled from a previously constructed rescue shaft.

The frozen soil body to be produced to act as sealing and structural member. In general, ground freezing technology was used for temporary groundwater control and excavation support in shaft construction and tunnelling projects. The main application is, however, the creation of a water cut off (groundwater control) with a certain aspect of ground stabilization. Therefore, the methodology depends in general on soil material in conjunction with adequate volumes of natural water. The technology is environmentally friendly as it takes temporarily advantage of the physical properties of the soil and water without changing their quality and natural condition permanently. There are two principal artificial ground freezing procedures that are used to convert groundwater to ice, creating a strong watertight soil body in the ground: ground freezing with brine or with liquid nitrogen (**Figure 3**).

This method utilizes large portable freezing / refrigeration plants where the refrigerant solution is passing through the following circular process. The basic principle involves:

- Compression of gaseous ammonia; this increases the temperature of the gas to approximately 70°C and a pressure of 12 bar;
- Cooling down of the gas to 35°C with the pressure remaining at 12 bar, thereby liquefaction;
- Decompression of the liquid ammonia (evaporation), thereby lowering of the temperature to approximately -35°C.

## JANNAH DAM, LEBANON

The water shortage in the Mount Lebanon and Greater Beirut area in the year 2035 is estimated by the World Bank at more than 350 million cubic meters. Jannah Dam, with a design capacity of up to 38 million cubic meters, along with other envisaged dams, is expected to help alleviate the problem of water scarcity. The planning study, as well as the dam design, was carried out by the engineering firm Khatib and Alami and the Artelia Group respectively. The construction was entrusted to Andrade Gutierrez Group, as the main contractor. The project site extends over a length of 500 m in a



relatively narrow, steep and rocky section of the Jannah Valley. The soil conditions are characterized by Quaternary alluvial deposits with a thickness of up to 53 m and underlying limestone and dolomite. Several tectonic folds do exist adjacent to or across the project area.

The alluvial deposits consist mainly of the following:

- Gravels, cobbles and blocks of limestone and dolomite in fine- to coarse-grained sandy-clayey matrix;
- Medium-dense to dense, slightly loamy to clayey sand, partly with gravel inclusions. Intermittent areas of loosely bedded sand were also recorded;
- Soft to very stiff clay with intercalated bands of sand.

## MAIN WORKS

The major deep foundation works executed on this project included :

- Cut-off wall at Upstream cofferdam;
- Cut-off wall at Downstream cofferdam;
- Diaphragm walls to create a bulkhead;
- Consolidation and curtain grouting;
- Ground improvement by means of piles.

A major challenge of the project was the required deep excavation below the river level. Special concepts to control the water ingress and ensure the stability of the excavation and the footing had to be implemented.

## CUT-OFF WALLS AT COFFERDAMS

The cut-off wall at the upstream cofferdam extended to a depth of 42 m and stretched to about 128 m. The excavation was predominantly in alluvial deposits. On the slopes, the cut-off walls are keying into the bedrock. The cut-off wall at the downstream cofferdam extended over 161 m, and the maximum depth reached 50 m. Bauer proposed the utilization of the cutter technique. In addition to the reliable verticality control and higher performance, this technology mitigates the so-called hydraulic windows at the connection to the bedrock.

## BULKHEAD—AS A BLOCK OF DIAPHRAGM WALLS

One of the remarkable challenges on this project was the execution of the bulkhead required for the excavation down to the foundation depth of the dam main body in the non-rocky soil. The relatively limited dimensions of the stretch available for the construction and the related hydraulic conditions prohibited an open excavation.

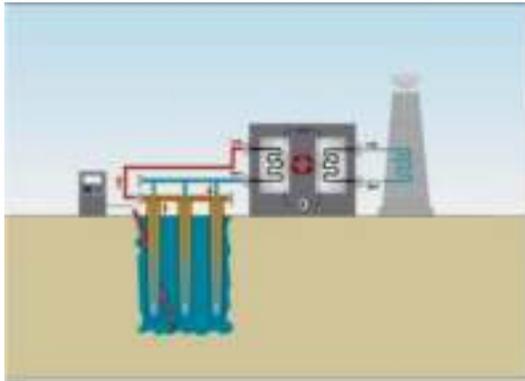
The arch-shaped bulkhead was designed with a thickness of 4 m, supported in the bottom part with tie-back rods. The compressive strength of the bulkhead was specified with 7 MPa, a fully realistic strength magnitude for jet grouting columns executed in non-cohesive soil layers.

The consideration of a different version of the jet grouting technique, besides the much longer retrieval rate, associated with almost total replacement of eroded soil by a viscous and solid-rich grout filling, results in much higher quantities of back-flow sludge.

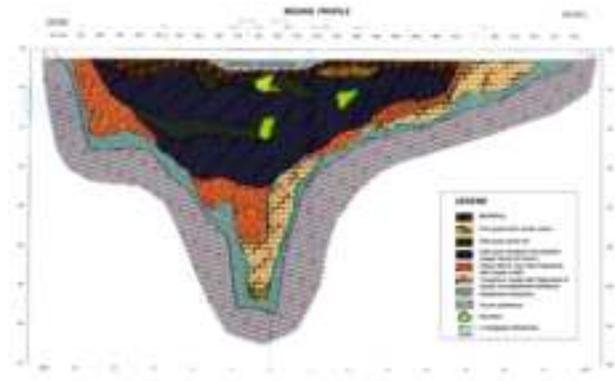
The construction of the diaphragm walls had to be associated with preliminary grouting measures. Some zones, with boulders and bedrock fragments adjacent to the trenches, had to be pre-treated to prevent them from falling onto the cutter during the excavation. The statically required use of structural concrete presupposed that the cutting of the already concreted panels was carried out as symmetrically as possible. For this reason, the two outer diaphragm wall rows were constructed first, followed by the middle row of the bulkhead structure. The coarse-grained soil between the two outer diaphragm wall rows therefore had to be pre-treated as well. Otherwise, during the construction of the second external row, the slurry would penetrate into this zone and lean against the previously produced first external row. The supporting effect would be lost, and the entire soil package located between the external rows could fall into the open trench. Apart from the acute risk for the cutter in the open panel, such a situation would require full-scale concrete cutting, together with the associated considerable wear and loss of performance.

## GROUTING

The grouting works on the project consisted of consolidation grouting under the footprint of the dam and three rows of grouting curtains extended into the abutments through several layers of galleries, with the related QA/QC measures,



**Figure 3** Soil freezing with brine (schematically only)



**Figure 4** Soil profile in the bulkhead section

such as coring and water pressure tests. The maximum depth reached some 80m in the foundation section and extended down to 100m at the abutments. The co-existence of cavities on one side and relatively tight joints in the rock stratum on the other side impaired the suitability of the GIN method on the given project. Possibly, the rock properties in the sense of the pattern of the discontinuities at the dam location, have been particularly affected by the tectonic movements manifested by the encountered faults.

#### CONCLUDING REMARKS

In addition to the challenging mountainous terrain for the execution of works with fractured rock profiles. The reassessment of the shear zone has saved the construction schedule of the project by nearly 1 year in Mangdechhu HEP. The successful implementation of the single-valve method for the execution of silicate gel grout plugs, and completion of several excavation pits for Metro Line 3, increased the confidence of client and contracted Bauer for six more stations for new Line 4 in Cairo Metro. The conditions at Jannah Dam required a flexible adaptation of the design and execution. The thickness of the clay layers, the diversity of the ground properties and the high static and hydraulic demands on the bulkhead imposed the use of a soil replacement method instead of a soil improvement method for its construction. The frequent and extensive fault zones in the rock called for a flexible adaptation of the originally specified GIN injection method.

#### REFERENCES

1. SATCOM: Geotechnical Investigations Jannah Dam Project, February 2015.
2. A Flora, et al, The Diameter of Single, Double and Triple Fluid Jet Grouting Columns: Prediction Method and Field Trial Results, *Géotechnique*, 63(11), 2013.
3. The National Authority for Tunnels (NAT) 2004 Tender Documents – Cairo.

# Repurposing of Industrial Waste as Sustainable Building Materials for Pre-Cast Applications

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**Abstract:** With the ever-increasing demand for Ordinary Portland Cement (OPC) due to global urbanization, construction industry is faced with two major challenges – (1) scarcity of natural resources for raw materials, and (2) significantly higher contribution to environmental pollution due to CO<sub>2</sub> emission during cement manufacture. Apart from these, global environmental issues are also on the rise, because of industrial waste accumulation that lacks useful avenues for recycling or repurposing. This paper aims at increasing the awareness about the possibility of using industrial waste products as substitutes for OPC and natural aggregates in concrete formulation. In addition to iron slag and copper slag as aggregates, alkali activated alumino-silicate waste products such as fly ash and Ground Granulated Blast-furnace Slag (GGBS) can be used as the binder for generating sustainable building material. As of now alkali activated alumino-silicates are approved (IS: 17452 – 2020) in various proportions for pre-cast applications. However, here we report that activation of GGBS with Sodium silicate alone, in the absence of corrosive Sodium hydroxide, can generate strong, and durable high quality binding materials, free from efflorescence, for extended applications. It is worth mentioning here that the concrete made from these materials could be cured to completion at ambient temperature with no requirement for water curing. Cube compressive strength of this concrete varied from 20 MPa to 70 MPa for various mix proportions ranging from 1:4:8 to 1:1.5:3 by weight. Due to the specific shape and thickness, 100mm paver blocks made with conventional aggregates demonstrated strength about 20 to 50% higher than the corresponding 'grade of concrete' used for its production. Field trials conducted since 2018 had proven durability even after multiple exposures to extreme weather conditions and physical stress, for the past four years. We anticipate a wider acceptance of this product for various applications such as paver blocks, tetrapod, manhole cover, concrete road construction, aerated light weight panel etc. just to name a few. In conclusion, we have demonstrated that GGBS can be repurposed in construction industry as a replacement for OPC with added advantage in terms of field applicability, durability, and low cost: benefit ratio. A comparison of compressive strength, by replacement of conventional aggregate with iron slag for coarse aggregate and copper slag as fine aggregate in alkali activated concrete is also made in this study.

**Keywords:** Geopolymer Concrete; Alkali Activated Concrete; Pre-cast Construction; Pre-cast Components; Paver Blocks

## INTRODUCTION

The two major problems faced world over is waste management and reducing carbon emission. The solutions to these burning issues are multi prong. In construction industry cement is an un avoidable binder material. Concrete is such a wonderful building material that its per capita consumption is one tone per annum, next only to water. For making cement concrete we need cement, aggregates and water. Cement industry makes use of natural resources like lime stone, clay, silica etc. Production of cement is highly energy intensive and about 7% world's total CO<sub>2</sub> emission is the contribution of cement industry. Quarrying of stone poses many environmental issues. We are facing the dearth for natural resources, energy intensive operations and emission of CO<sub>2</sub> on one side and accumulation of industrial waste on the other side. This investigation is about finding substitutes for cement and aggregates making use of industrial waste materials like GGBS, iron slag and copper slag without compromising on strength, durability, economy and ease of use.

Currently there is a dearth for conventional crushed stone aggregates. Lime stone reserve is also getting depleted due to cement manufacture. IS 456-2000 stipulates the quality of water using for making of concrete as potable grade. Quality and quantity of water available for concrete production is also becoming a problem. Much more quantity of water is required for curing than it is required for making concrete. All these issues are faced by construction industry individually and collectively at different parts of the world apart from other environmental issues thereof.

This study is about suitability of using iron and copper slag as aggregate with alkali activated binder made using GGBS. GGBS is activated by user friendly alkali sodium silicate. This study target fully replacing cement and partially the



conventional aggregates for pre-cast applications. IS 383-2016 permits 50% replacement of conventional coarse aggregate by crushed iron slag aggregate for plain concrete and 100% replacement for lean concrete. Similarly, replacement of fine aggregate using copper slag is permissible by 40% for plain concrete and 50% replacement for lean concrete. However, in this study it was found that 100% replacement of coarse aggregate by crushed iron slag and 50% replacement of fine aggregate by crushed copper slag yielded fairly good strength making it suitable for all pre-cast applications. IS 17452-2020 permits use of alkali activated binders for pre-cast applications.

### Literature Review

In our earlier study sodium silicate alone was used as activator solution. Mix of fly ash and GGBS was used as binders. Maximum strength was obtained when GGBS alone used as binder[1]. Hence in this study GGBS alone was used as binder material. Studies by replacement of fine aggregate from 0 to 100% using copper slag in fly ash-based heat cured Geopolymer showed increase in compressive strength compared to conventional fine aggregate[2]. In fly ash-GGBS based Geopolymer concrete, cured at ambient temperature, 40% replacement of fine aggregate with copper slag performed higher in compressive strength, split tensile strength, flexural strength and density, but water absorption and sorptivity was high. Modulus of elasticity and bond strength was lower[3]. Similar study based on fly ash-GGBS has also shown significant increase in density and compressive strength, when 40% of fine aggregate was replaced with copper slag [4]. Studies with heat cured fly ash based Geopolymer with copper slag as coarse aggregate and crusher dust as fine aggregate keeping their content constant found that the compressive strength depends on composition of alkaline solution and curing temperature[5]. Replacing 60 to 80% fine aggregate by a mix of copper slag and marble dust marginally improved the engineering properties of Geopolymer concrete[6]. In fly ash based Geopolymer, when iron slag was used as 100% substitute for coarse aggregate the compressive strength increased by 6%[7]. Full replacement of coarse aggregate by steel slag in Fly ash-GGBS based geopolymer could attain marginally lower compressive, flexural strength and split tensile strength. When treated with 1% sulphuric acid and 5% sodium sulphate for 30 days, reduction in strength was found marginally lower than un-treated samples[8]. Studies on compressive strength, split tensile strength and flexural strength of Geopolymer concrete using fly ash showed optimum improvement with 30% replacement of coarse aggregate with steel slag[9]. In all these studies either fly ash or a combination of fly ash-GGBS was used as binder material. When fly ash alone was used, heat curing regime was adopted. The alkaline solution used in all the cases was a mixture of sodium silicate and sodium hydroxide. Copper slag was generally used as fine aggregate and Iron or steel slag was used as coarse aggregate. Combination of iron slag and copper slag is seldom done. Air cooled blast furnace slag when used as replacement of fine aggregate in cement-based mortar and concrete varying from 25 to 100%, it was found that results of pull-off strength, compressive strength, sorptivity, water absorption, porosity, and total charge passed in Rapid Chloride Penetration Test (RCPT), at par with use of conventional fine aggregate [10].

In this study we have used only GGBS as binder powder and sodium silicate as activator solution based on our previous study. Full replacement of coarse aggregate by iron slag and 50% replacement of fine aggregate by copper slag was adopted.

### Materials and Methods

The raw materials used as binder is a mix of GGBS with sodium silicate as alkaline activator maintaining binder powder to sodium silicate ratio 0.50. Water to binder solids ratio was maintained constant at 0.30 in all the trials by adding extra water. Material characterization details are given in our earlier study[1]. The coarse aggregate used is crushed iron slag without grading, as such it was received from iron industries in Kanjikode, Kerala. The fine aggregate used was crushed copper slag received from Cochin ship yard Ltd, Kochi and locally available crushed stone sand in 1:1 proportion. The physical properties of aggregates are given in **Table 1**.

Mix design was done based on our previous study [1]. From that study 4 proportions 1:4:8, 1:3:6, 1:2:4 and 1:1.5:3 was adopted. While designing alkali activated concrete using GGBS, crushed iron slag as coarse aggregate and crushed

**Table 1** Physical properties of aggregates

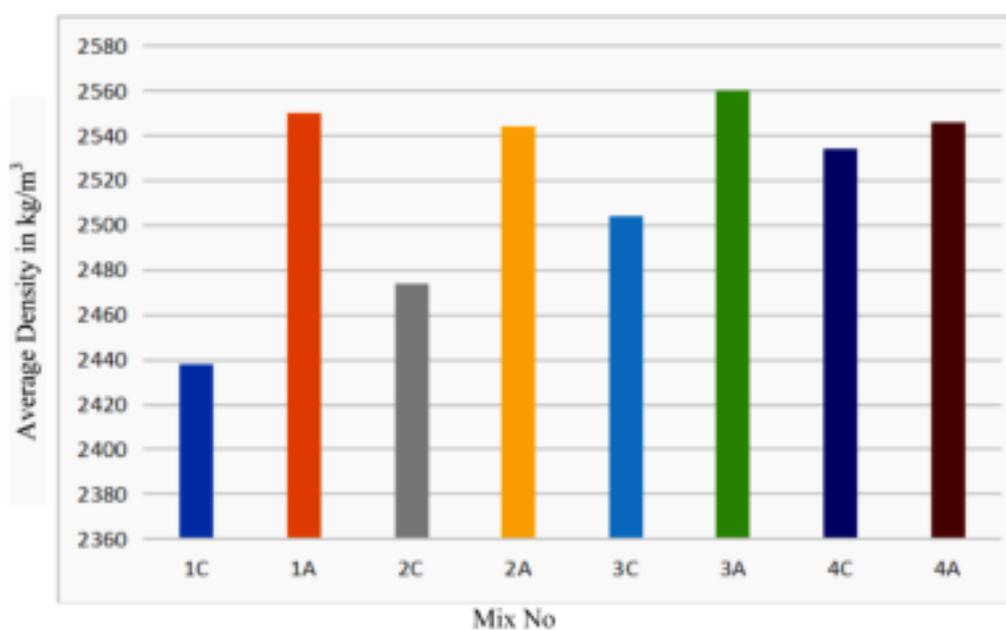
Material	Specific Gravity	Bulk Density (Loose) in kg/m <sup>3</sup>	Void Ratio (Loose)	Porosity in % (Loose)
CA	2.76	1319.00	1.03	50.70
MS	2.61	1700.00	0.44	30.52
IS	2.71	1320.00	1.00	50.00
CS	3.50	2160.00	0.67	40.00



copper slag as fine aggregate, it was found that more quantity of fine aggregate was required to fill the voids. The specific gravity of crushed stone aggregate and iron slag aggregate is almost equal. The specific gravity of copper slag (3.5) is much higher than that of iron slag, broken stone or crushed stone sand. When ingredients were taken in weight proportion, due to the higher specific gravity, the volume of copper slag per unit weight was less to fill the voids in iron slag coarse aggregate. Due to this, supplementary quantity of crushed stone sand was required, equal in weight of the copper slag used as fine aggregate to completely fill the voids in coarse aggregate. For two parts of coarse aggregate one part copper slag and one-part crushed stone sand was used as fine aggregates. For cubic meter of concrete the binder contents varied as 150, 200, 300 and 400 kg depending on proportion. The aggregates used per cubic meter of concrete are coarse aggregate 1200 kg, fine aggregate in a combination of 600 kg copper slag and 600 kg crushed stone sand. Due to above reasons the density of concrete made using iron slag and copper slag as aggregate was higher than that of concrete made using conventional aggregates for all mix proportions (**Figure 1**).

The mix design notations shown in **Table 2** indicate CA: conventional crushed stone coarse aggregate, IS: Crushed iron slag coarse aggregate, MS: Crushed stone manufactured sand fine aggregate (M.Sand), CS: Crushed copper slag fine aggregate and GG: Ground granulated blast furnace slag (GGBS). Numeric values given in subscript indicate the proportion by weight. Numeric digits (150,200,300,400) along with mix designation indicate the quantity of GGBS used per cubic meter of concrete. In mix number (C) denotes mix with conventional aggregate and (A) denotes alternate aggregates.

Mixing of aggregates and GGBS was done in dry condition in a drum mixer initially for 2 minutes and alkaline solution was poured while in rotation and continued mixing for another 3 minutes and delivered the concrete to wheel barrow



**Figure 1** Densities of alkali activated concrete using conventional (C) and alternate (A) aggregates.

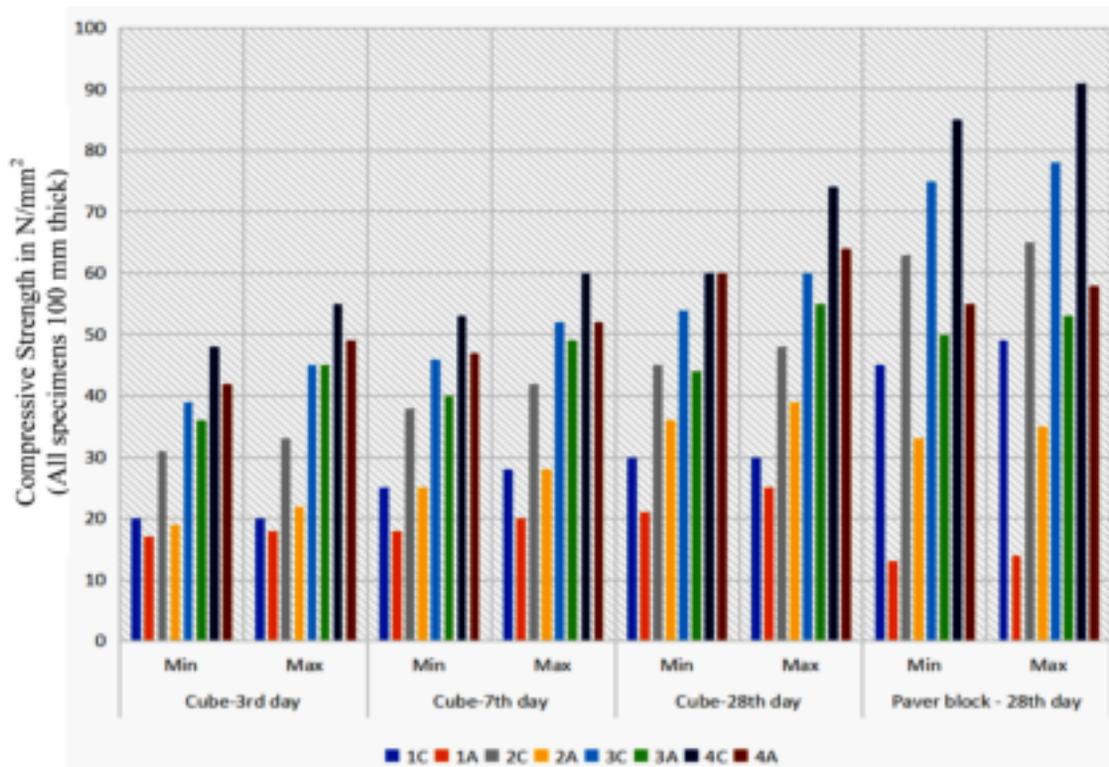
**Table 2** Mix no and designation

Mix No	Mix Designation
1C	CA <sub>8</sub> MS <sub>2</sub> GG <sub>1</sub> -150 Conventional aggregate
1A	IS <sub>4</sub> CS <sub>4</sub> MS <sub>2</sub> GG <sub>1</sub> -150 Alternate aggregate
2C	CA <sub>6</sub> MS <sub>2</sub> GG <sub>1</sub> -200 Conventional aggregate
2A	IS <sub>3</sub> CS <sub>3</sub> MS <sub>2</sub> GG <sub>1</sub> -200 Alternate aggregate
3C	CA <sub>4</sub> MS <sub>2</sub> GG <sub>1</sub> -300 Conventional aggregate
3A	IS <sub>2</sub> CS <sub>2</sub> MS <sub>2</sub> GG <sub>1</sub> -300 Alternate aggregate
4C	CA <sub>2</sub> MS <sub>1</sub> GG <sub>1</sub> -400 Conventional aggregate
4A	IS <sub>2</sub> CS <sub>2</sub> MS <sub>1</sub> GG <sub>1</sub> -400 Alternate aggregate

after attaining uniform consistency. The mix was very harsh and less cohesive with lower workability, though it contained equal quantities of fine and coarse aggregates. This is mainly due the irregular shape of iron slag and copper slag. The concrete was placed immediately in to the moulds in three layers and each layer was compacted on vibration table for 20 seconds. The setting occurred within 8 hours and was demoulded after 36 hours. Specimens were kept at ambient indoor temperature (25 to 32 degree Celsius) for respective curing period and was tested under room dry condition without any water curing. Compressive strength testing was done at respective age with 2000 kN compression testing machine with 10kN least count. The compressive strength attained for the alkali activate concrete mixes using conventional aggregate in our previous study [1] was compared with similar concrete using alternate aggregate with identical quantities of GGBS and sodium silicate binder (**Figure 2**). The minimum (Min) and maximum (Max) values obtained for three samples are shown separately.

## RESULTS AND DISCUSSION

The compressive strength obtained for alkali activated concrete using crushed iron slag as 100% replacement of coarse aggregate and crushed copper slag as partial replacement of fine aggregate (along with M.Sand in the ratio 1:1) was compared with alkali activated concrete made with conventional crushed stone aggregate for identical quantities of binder. In general, it was found that when slag was used as aggregate, there was a reduction in compressive strength for about 35 % for lower binder content (150 and 200 kg/m<sup>3</sup>). At higher binder content (300 and 400 kg/m<sup>3</sup>) the reduction in compressive strength was about 15%. Paver blocks of 100 mm thickness made with conventional aggregates exhibited about 20 to 50% higher compressive strength compared to cube compressive strength for identical thickness. When alternate aggregates were used for 100mm thick paver blocks the compressive strength obtained was slightly lower than the corresponding grade of concrete by which it is made up. In the economic analysis in our previous study[1], it was found that alkali activated concrete is cheaper than conventional concrete for grades up to M40 and slightly higher for M40 to M70 grades of concrete. When crushed iron slag and copper slag are used as coarse and fine aggregates even though there is reduction in compressive strength with identical mix with conventional aggregates, it is comparable with



**Figure 2** Minimum (Min) and Maximum (Max) compressive strength of alkali activated concrete cubes and paver blocks using conventional (C) and alternate (A) aggregates



**Table 3** Summary of compressive strength and densities of alkali activated concrete with conventional aggregate (C) and alternate aggregates (A)

Mix No	Compressive Strength in N/mm <sup>2</sup>																Average Density in kg/m <sup>3</sup>
	Cube-3rd day				Cube-7th day				Cube-28th day				Paver block - 28th day				
	Min	% Reduction	Max	% Reduction	Min	% Reduction	Max	% Reduction	Min	% Reduction	Max	% Reduction	Min	% Reduction	Max	% Reduction	
1C	20		20		25		28		30		30		45		49		2438
1A	17	15	18	10	18	28	20	29	31	30	25	17	15	21	14	21	2550
2C	31		33		38		42		45		48		63		65		2474
2A	19	38	22	34	25	35	28	34	36	20	39	19	25	48	35	46	2544
3C	39		45		46		52		54		60		75		78		2504
3A	36	8	45	0	40	15	49	6	44	19	55	9	50	33	53	32	2560
4C	48		55		52		60		60		74		85		91		2534
4A	43	15	49	11	47	12	52	14	60	0	64	14	55	35	58	36	2546

cement concrete in terms of strength and economy. The density of alkali activated concrete using alternate aggregate was higher than that was made using conventional crushed stone aggregate. This is mainly because of higher specific gravity of copper slag being used as fine aggregate.

## CONCLUSION

1) Alkali activated concrete can be used as substitute for cement concrete for all plain concrete pre-cast applications. 2) Crushed iron slag and copper slag can be used as substitutes for conventional crushed stone aggregates. 3) Use of industrial wastes like GGBS, iron and copper slag will reduce embodied energy and CO<sub>2</sub> emission in construction industry minimizing environmental hazards and saving many natural resources. 4) Alkali activated concrete uses very little water for its manufacturing and no water for curing. 5) Alkali activated concrete is a suitable material for highway construction.

## FUTURE SCOPE

1) Crushed iron slag can be tried as alternate fine aggregate. 2) Crushed copper slag can be tried as substitute for coarse aggregate. 3) Use of fly ash in combination with GGBS can be tried while making alkali activated concrete using alternate aggregates. 4) The economic studies for particular location and savings in embodied energy and reduction in CO<sub>2</sub> emission is worth analyzing for considerations as green building product.

## ACKNOWLEDGMENT

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## REFERENCES

1. Thomas J V and Thomas R. M, Improvement in Field Applicability of Concrete using Fly Ash and Ground Granulated Blast Furnace Slag by Sodium Silicate Activation, Asian Journal of Civil Engineering, 2022, pp.337-349. <https://doi.org/10.1007/s42107-022-00426-y>
2. K Mahendran and N Arunachalam, Performance of Fly Ash and Copper Slag based Geopolymer Concrete, Indian Journal of Science and Technology, vol9.2, 2016, pp 1-6.
3. Neethu Susan Mathew SU, Effects of Copper Slag as Partial Replacement for Fine Aggregate in Geopolymer Concrete, IOSR J Mech Civ Eng, 2016, pp 73-77.
4. Burri Yakshareddy, et al, Preliminary Study on Geopolymer Concrete using Copper Slag and Vermiculite, International Journal of Research and Scientific Innovation (IJRSI), 2018.
5. Asudullah Khan, et al, Design and Development of Sustainable Geopolymer using Industrial Copper Byproduct,



Journal of Cleaner Production, vol 278, 2021, 123565.

6. Amrinder Singh and Mehta Shalika, Partial replacement of Fine Aggregate with Copper Slag and Marble Dust Powder in Geo-polymer Concrete: A Review, IOP Conference Series: Earth and Environmental Science, vol 889. no 1, IOP Publishing, 2021.
7. O M Omar, et al, Effect of local Steel Slag as a Coarse Aggregate on Properties of Fly Ash Based-geopolymer Concrete, Egypt, World Academy of Science, Engineering and Technology, vol9, 2015, pp 508-516.
8. Suganya N, Geopolymer Concrete using Scrap Steel Slag as Coarse Aggregate, International Journal for Research in Applied Science and Engineering Technology, vol 7, 2019, pp 781-785, 10.22214/ijraset.2019.1122.
9. Sirajudeen Mahaboob, Bhupal Ch and Vasugi K, Strength Behaviour of Geopolymer Concrete Replacing Fine Aggregates by M- Sand and E-waste, International Journal of Engineering Trends and Technology, vol 40, 2016, pp 401-407. 10.14445/22315381/IJETT-V40P265.
10. R Ramna, Subhadra Sen, Ritesh Kumar, Ajay Gupta, Anil Kumar, S Rakesh, Smrati Jain and Manu Santhanam, Utilization of Air-cooled Blast Furnace Slag as a 100 % Replacement of River Sand in Mortar and Concrete, Indian Concrete Journal, vol 96, 2022, pp 6-21.

# Protection of River Embankment for Sustainability

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**Abstract:** Rivers flowing over gently sloping ground begin to curve back and forth across the landscape cause a threat to embankment. The rivers continuously transfer water and sediment load in the downstream direction. The Himalayan Rivers continuously change courses in their lower reaches, and the Ganga and its tributaries are no exception. These rivers have the tendency to shift their courses within limits. The changing course may be by processes of meander migration or by adopting new distributaries. Scouring side is always subjected to erosion and requires certain river training works depending on particle size of sub soil. In the article some temporary and permanent protective measures are discussed considering techno commercial aspects including sustainability. Crores of Rupees are spent by Central Government and various State Governments to protect embankments but scheme preparations and implementations many times fail to yield proper result. Holistic approach is very pertinent in planning river training activities. Modern Engineering materials can do a lot in mitigating embankment failure. Particularly with the introduction of woven and non woven synthetic geotextile, there is enough scope to arrest erosion; such materials allow water to percolate and restrict movement of soil particles. Ground improvements also help strengthening of existing embankments. Scheme of Embankment Protection should be chosen by Engineers with holistic approach for sustainability in mind.

**Keywords:** River; Meandering; Embankment; Scour; Spur; Pitching and Protection

## INTRODUCTION

The rivers continuously transfer water and sediment load in the downstream direction. The Himalayan rivers continuously change courses in their lower reaches, and the Ganga and its tributaries are no exception. These rivers have the tendency to shift their courses within limits. The changing course may be by processes of meander migration or by adopting new distributaries. The Ganga has continuously changed its geometry of meandering in West Bengal during the last three centuries, and former courses are left behind as moribund channels.

As a result of such meandering one bank is subjected to silt deposit and another scouring. Generally external face becomes scouring (**Figure 1** shows erosion image) and internal face becomes subject to silt deposits.

**Figure 2** shows typical meandering view. Engineering activities are required for river training works for maintaining navigability, for protecting adjacent locality and water supply and irrigation purposes. The present article is for discussion on Embankment protection with sustainability through some practical cases of various districts of West Bengal.

## MATERIALS AND METHODS FOR PROTECTION OF RIVER EMBANKMENT

### Temporary Protective Measures

- (a) Sand filled bag dumping (**Figure 3** shows such dumping);
- (b) Bamboo piling and Sal/ Eucalyptus Bullah piling (**Figure 4** shows such piling);
- (c) Cubical bamboo porcupine cages with bamboo of 60 mm to 75 mm dia. having length of 2 m each for all horizontal and vertical struts and 2.8 m length for diagonal struts, 3 nos horizontal and 3 nos vertical struts should be placed equi-distant from each face to make the square cage of outer dimension 75 cm × 75 cm and projecting each strut by 60 cm on all directions.

Two nos diagonals or cross bamboo posts should be placed on each face having their centre tied with the centre of cage properly including fitting, fixing corners, vertical, horizontal and diagonal struts with iron nails not less than 20 cm long and tying corners with 16 SWG galvanized iron wire, filling in the cages with boulders / lump aggregates. Cages built with 10 SWG hexagonal or square pattern 10 cm mesh, with proper lapping, tying and sewing with 10 SWG GI wire including cost of all materials, carriage to site and laying the same in the bed or slope of the river, filling the same with the filler materials complete (**Figure 5** shows making of porcupines).



**Figure 1** River bank erosion



**Figure 2** Meandering of river explained in detail, one side deposition and the other side erosion



**Figure 3** Bamboo porcupines (making in progress)



**Figure 4** Semi permeable spur

(d) Semi permeable spurs made of locally available indigenous materials bamboo, dry bushes etc (**Figures 4 and 5** show such spurs).

#### Semi Permanent Measures

1. Brick block pitching / boulder pitching with/without rectangular / circular sausage cage with 10 SWG galvanized iron wire with proper lapping (**Figure 6** shows boulder pitching with sausages) [**Figures 7(a)** and **7(b)** also show pitching]. Brick block pitching with geotextile layers underneath protects the embankment better.
2. Gabion wall/ brick guard wall (**Figure 8** shows stone boulder gabion wall)

#### Permanent Measures

1. RCC retaining wall
2. Cold or hot pressed steel sheet pile (**Figure 9** shows steel sheet piling)

#### Analysis of Erosion Potential

An advance and new improved soil erodibility index was developed by the name of EIROM or 'ROM' Scale [Bouyoucos GJ. Hydrometer method improved for making particle size analysis of soil. Agr. J. 54: 3, 1962]. This new equation is still using the original principal of Bouyoucos which is analyzing the soil textural composition of sand, silt and clay. The new equation clearly has shown the significant value and threshold for soil erodibility demarcation and at the same time indicated the expected erosion feature. With the new EIROM equation as in Equation (1), the more realistic and



Figure 5 Semi permeable spur



Figure 6 Sausage used to protect embankment



Figure 7(a) Brick block pitching



Figure 7(b) Boulder pitching



Figure 8 Gabion wall used to protect embankment



Figure 9 Steel sheet piling

significant value of soil erodibility index can be used simultaneously with its risk category as shown in **Table 1** to indicate the degree of soil erodibility.

$$\text{Erodibility Index in 'ROM' Scale} = (\% \text{ Sand} + \% \text{ Silt}) / 2(\% \text{ Clay}) \quad (1)$$



**Table 1** ‘ROM’ scale with regards to soil erodibility category

‘ROM’ Scale	Soil Erodibility Category
< 1.5	Low
1.5-4.0	Moderate
4.0-8.0	High
8.0-12.0	Very High
>12.0	Critical

Appropriate scheme to be considered considering erodibility of Bank, importance of habitation adjacent to river embankment, fund availability etc.

## RESULTS AND DISCUSSION

Every year thousands of people lose their land, houses because of River bank erosion throughout the country specially adjacent to meandering rivers. “The Ganga and Kosi were regulated with different objectives. However, in both cases there was a lack of understanding about the fluvial dynamics of the river. The bed and suspended load carried by the rivers were trapped in barrage-ponds. The bed of the Ganga experienced uninterrupted sedimentation in the reach upstream of Farakka Barrage, and the river now tends to outflank the barrage (Rudra, 2006).” “The Kosi was confined since 1955, and a barrage was constructed at Bhimnagar (in Nepal) in 1963 with the twin purposes of flood control and irrigation. The river bed upstream of the barrage and between the embankments gradually rose above the adjoining floodplains. The most recent avulsion (18th August, 2008) is not a secular one, but can be treated as a human-induced change (Mishra, 2008, Sinha, 2008, Rudra, 2009). However, the avulsion of Tista in 1787 and the westward shift of Jamuna (Brahmaputra) in Bangladesh in 1830 were guided by tectonic tilting (Morgan and McIntire, 1959). The Ganga in West Bengal has been encroaching to and fro within its meander belt, but after the construction of Farakka barrage, the dynamics of bend migration changed appreciably. What apparently seems to be bank failure is largely the response by the river system to the massive engineering intervention which impedes the flow of water and sediment load.”

After construction of Durgapur Barrage, The Damodar, after construction of Tilpara Barrage, The Mayurakshi changed behaviour. Lower reaches of the rivers are causing problems to inhabitants when barrages discharge huge water in a minimum period of time. The river bed experiences uninterrupted sedimentation when barrage gates are open result reduction of capacity of rivers which ultimately cause flood. To avoid breach of embankment regular monitoring of river embankment is very vital.

## CONCLUSION

Crores of Rupees are spent by Central Government and various State Governments to protect embankments but scheme preparations and implementations many times fail to yield proper result. Scour depth calculation and historical data collection are two pertinent tasks while scheme preparation. Without these two tasks the scheme preparation remains incomplete. Holistic approach is very pertinent in planning river training activities. Modern Engineering materials can do a lot in mitigating embankment failure. Particularly with the introduction of woven and non woven synthetic geotextile there is enough scope to arrest erosion; such materials allow water to percolate and restrict movement of soil particles. Ground improvements also help strengthening of existing embankments. Scheme of Embankment Protection should be chosen by Engineers with holistic approach and the sustainability in mind.

## REFERENCES

1. Different Papers of Dr Kalyan Rudra, River Expert
2. Personal Works of Er Snehashish Basu
3. Z A Roslan, Y Naimah and Z A Roseli, River Bank Erosion Risk Potential with Regards to Soil Eerodibility, Published in River Basin Management VII 289, WIT Transactions on Ecology and The Environment, vol 172, ©2013, WIT presswww.witpress.com, ISSN 1743-3541(on-line).

# Smart Village for Achieving SDGs and Sustainable Development of India

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**Abstract:** India and Indian cities cannot become smart if the villages of India are not smart. Every city is surrounded by some villages. These villages should be clean. Role of water and energy in rural transformation is vital. The importance of water, sanitation and health collectively cannot be ignored to make a smart village. Union Government's Ujjala Yojna to provide cooking gas to every household of villages and Swachh Bharat initiative to construct toilet in every house of a village are the steps towards making a smart village (SDG Target 6.2, End open defecation and provide access to sanitation and hygiene). Construction of low-cost houses under Pradhan Mantri Awas Yojna are strengthening the concept of Smart Villages (SDG Target 11.1, safe, affordable housing and basic services to all). The 193 member states of the United Nations adopted 17 new Sustainable Development Goals (SDGs) as a unanimous commitment to end poverty, fight inequalities and injustice and tackle climate change. The goals are to be achieved by 2030. SDG 6 deals with all aspects of water availability, accessibility and use, and calls upon all nations to "Ensure availability and sustainable management of water and sanitation for all". Target 7.1 and 7.2 ensure universal access to affordable, reliable and modern energy services, by increasing substantially the share of renewable energy.

The rural and urban societies are in fact complementary to each other. The industrial growth needs vast consumer base, which is easily provided by the urban and rural masses and agricultural production by the rural masses, is an essential requirement of the urban population. So that they can grow together while supporting each other. If the young boys and girls of our villages compelled to rush to urban parts for their education, and employment, who will work in the fields. If the best health care facilities are located only in the cities, then how do we expect the people to stay in village.

To achieve the target of doubling the agricultural productivity and income of small-scale food producers, (Target 2.3) and increasing productivity by implementing resilient agricultural practices, (Target 2.4) would be at the cost of universal access to safe drinking water (Target 6.1) and restoring water related eco-system, (Target 6.6). Hence in case of smart village Target 2.3 and 2.4 need to be taken forward along with Target 6.4 (water use efficiency).

In its first assembly in New Delhi in March 2018, International Solar Alliance (ISA), was formed by solar-resources rich countries to undertake joint efforts to reduce cost of finance and technology for development of at least 1000 GW, solar energy worldwide by 2030 (Target 7.1). Hydro-electric power is a renewable source of energy, which has immense potential in India, which can be harnessed to mitigate electricity shortage in India, both in urban and rural areas and even out the variability added to the grid system, due to solar and wind power generation (Target 7.2). Apart from the fact that water used for hydropower generation is non-consumptive in nature and is used for many purposes in the downstream of the project, such as irrigation, drinking water supply, restoration of forests (Target 15.1), and increase afforestation (Target 15.2) etc.

**Keywords:** Smart Village; Water; Sanitation; Health; Agriculture; Energy; Sustainable Development Goal

## INTRODUCTION

It is not possible to think about a smart village without water and energy. Government outlines the need to transform, energies and clean India. Water a crucial natural resource, and its management should also focus on these three ideals. India's progress hinges on access to safe and enough water for reviving the agricultural sector, improving public health and strengthening rural economy.

United Nations (UN) has provided valuable insights for developing interconnected Sustainable Development Goals (SDGs) and targets with a broad and ambitious vision for 2030. The SDGs are universal, interdependent and mutually reinforcing (and sometimes conflicting). It is recognized that achieving the 2030 Agenda for sustainable Development and its 17 Goals and 169 targets will only be possible through an integrated approach working across sectors, ministries and different administrative levels and geographical scales. [1]



Out of 17 SDGs and 169 Targets, adopted to transform the World water finds a role in ending poverty in all its forms everywhere including villages and cities in India; ending hunger, achieving food security and improved nutrition, promoting sustainable agriculture; ensuring healthy lives and promoting wellbeing for all at all ages; ensuring availability and sustainable management of water and sanitation for all (SDG6). SDG 6 places water and sanitation at the core of sustainable development agenda, cutting across sectors and regions.

Ensuring access to affordable, reliable, sustainable and modern electrical energy for all (Target 7.1) and increasing substantially the share of renewable energy (Target 7.2), without focusing on the sustainability of water resources, would impact Target 6.6 (protect and restore water-related ecosystems) and could potentially affect Target 6.1 (universal access to safe drinking water). Enhancing water-use-efficiency (Target 6.4) by reducing non-revenue-water (NRW), adopting decentralized system of water supply and wastewater treatment, and strictly adhering to the principles of Reduce, Reuse, Recycle and Rejuvenate would be pivotal in balancing the trade-offs between water-energy nexus[1].

### **ROLE OF WATER AND ENERGY IN RURAL TRANSFORMATION**

More than two third of population of our country live in villages and they depend upon agriculture for their livelihood. Despite impressive progress in reducing poverty and hunger and improving health of people during the past decades, humanity still faces enormous socio-economic and sustainability challenges. Water permeates all aspects of life; it is not only people who require a basic supply of reasonably good quality water in-order to survive. Water is essential for the survival and productivity of all life and all ecosystems, including agro ecosystems. Water is essential not only for basic drinking, cooking, hygiene and ecosystem functioning, but for producing food, energy and indeed all the material products needed for daily life, Swachh Bharat, is fully dependent on access to water.

Important role of energy in all developmental activities and particularly in raising the standard of living of people both in urban and rural areas is well known. Therefore, generation of more energy, ensuring distribution of energy to all corners of the country and all sections of society and working for energy efficiency constitute important action points for the Union and State governments.

Maintenance of main irrigation canals and related infrastructure, for optimal utilization of their designed capacities, is another challenge. If farmers of rural areas do not have access to the water and energy, the idea of smart village fails. Approximately 60% of the works completed under MGNREGA are water related. Additional funds allocated to the scheme should be used to construct farm ponds in areas where large canals are unviable or difficult to reach.

Agriculture consumes about 80% of India's total water utilization. Therefore, more efficient irrigation methods must be adopted, especially in the water scare regions of the country. The dedicated micro-irrigation fund that will be set up in NABARD to achieve the goal of per drop more crop is a positive step, and in alignment to the goals of the National Water Mission that envisages a 20% increase in water use efficiency[2]. The main objective of the National Water Mission (NWM) of India is: "Conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within states through integrated water resources development and management". This Mission is related to both SDG Target 6.4 (increase water use efficiency and ensure fresh water supply), and SDG Target 9.4 (upgrade infrastructure for resource efficiency).

### **FARMERS AND WATER**

Farmers are the largest consumers of water in irrigation for the fields. Water is a crucial input on which the entire agricultural sustainability is based and hence participation of farmers in the water management activities is of prime importance. Due to over growing demands and change in utilization pattern as well as climate effects the water availability scenarios have changed.

In India about 80% of the utilizable water resources of the country is being applied in irrigation purpose and about 40-50% of manpower is engaged with agricultural activities. Hence making the availability of water in correct measures at right time and space matters a lot for making the farming a beneficial one to the farmers.

Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) has hence been formulated with the over-arching vision of extending the coverage of irrigation in such a way as to provide required to every field("Har khet ko Pani") and improving water use efficiency addressing "more crop per drop" in a focused manner is a strong move towards building stability to the farmers of India and their livelihood sustainability. SDG Target 6.4 is being addressed by the programs and schemes of the Ministry of Agriculture and Farmers' Welfare. International Water Management Institute (IWMI) has analyzed recent irrigation reforms in several Indian states and identified the 112 most irrigation-deprived districts to help guide implementation of the government's PMKSY irrigation scheme. Need of the hour is to take various actions at the

farm and watershed in national levels. Important activities for different levels' integration include:

- (a) Introducing farm-level information systems on water resources, water quality, promotion of micro-irrigation techniques as Drip and Sprinkler irrigation etc.
- (b) Improving information systems on surface and groundwater flows and their quality.
- (c) Participatory Irrigation Management (PIM), recovery of water charges to meet the operation and maintenance cost, regulatory mechanisms etc. at watershed level.
- (d) Enforcing existing regulatory provisions on water use and water pollution, ensuring that charges for water supplied to agriculture at least reflect full supply costs with adjustment policies to compensate the poorest farmers, proper operation and maintenance of irrigation system etc. at national level.
- (e) Enhancing recharge of aquifers and introducing sustainable water conservation practices by exploring the feasibility of reusing treated municipal wastewater for peri-urban agriculture and attract greater private investment in precision irrigation system.

### WATER, SANITATION AND HEALTH IN RURAL AREAS

Water supply, sanitation and hygiene (WASH) is fundamentally important to live and livelihoods, and underpins poverty alleviation and sustainable development. At a basic level, everyone needs access to safe water in adequate quantities for drinking, cooking and personal hygiene, and sanitation facilities that do not compromise health or dignity. Various central Government's initiatives such as National Rural Drinking Water Program (NRDWP) was initiated in the year 2009, with a major emphasis on ensuring sustainability of water availability in terms of potability, adequacy, convenience, affordability, and equity. NRDWP is a centrally sponsored scheme with 50:50 fund sharing between the Centre and the States. SDG Target 6.1 is being addressed by NRDWP to make a village smart. Target 6.2 is being addressed by the flagship program, Swachh Bharat Mission-Grameen (SBM-G).

Water safety and quality is fundamental for survival and developmental of communities. Though, there is substantial improvement in use of improved drinking water sources, rural water supply remains a challenge. Water quality and safety has great impact on the livelihood sustainability and economic well being of poor and marginal communities of the villages in India. Water borne diseases largely preventable, take heavy toll on the finances of the individual families. It is therefore, necessary that these impacts are quantified and explained to the affected communities of the villages for making them adopt and maintain the measures implemented. Community-based solar DFU units, RO system and ATM-based water dispenser have resolved the problem of transmission of clean water to fluoride and TDS infected areas without any dependence on electricity, which has saved millions of lives by reducing the spread of various diseases like cholera, diarrhea, hepatitis and typhoid in rural India. By providing such efficient, sustainable and uniform water supply to around 7000+ villages under Jal Jeevan Mission, millions of people will be benefited.

Adaptation requires using innovative low-cost solutions in the villages, such as rainwater harvesting etc., broader engagement/ coalition with communities and other sectors viz. sanitation and health to build an enabling environment capable of managing better services are must. The biggest challenge to end open defecation in the villages is changing the behavior by generating awareness, to bridge the gap between building toilets and their proper use[2].

### JAL KRANTI ABHIYAN FOR SAFE DRINKING WATER FOR ALL VILLAGES OF THE COUNTRY

Water, which is considered as one of the five elements of the universe, is undoubtedly one of the most vital elements for survival. Drinking water is directly linked to the life and health of human beings. It is not less than a challenge to provide safe drinking water to a population spread across a country marked by varying climate zone and having different topography.



**Figure 1** Availability of ground water to the village women



**Figure 2** Village women fetching water from distant places [2]



As per national water policy, 2012, principle of equity and social justice must inform use and allocation of water. The policy further specifies that safe water for drinking and sanitation should be considered as pre-emptive needs, followed by high priority allocation of basic domestic needs. The policy suggests that equitable access to water for all and its fair pricing, for drinking and other uses such as sanitation, agriculture and industrial, should be arrived at through independent statutory Water Regulatory Authority, set up by each state, after wide ranging consultation with all stakeholders[2].

The Ministry of water Resources Government of India launched a program to organize “Jal Kranti Abhiyan,” during the period 2015-16 aimed to turning one Water stressed village in each district of the country into a water surplus or water secured village.

Under this Abhiyan, it is decided to take up water conservation and water security schemes to ensure optimum and sustainable provision of water to at least one water stressed village in each 672 district of the country ensuring effective involvement of all stakeholders. One village in every district shall be selected as “Jal Gram”. An Index value shall be assigned to each village (mainly based on the gap between demand and availability of water) and the village with highest index value or acute water scarcity condition will be selected as “Jal Gram”.

For the “Jal Gram”, a comprehensive integrated development plan will be framed, and several ones launched for converting it into a water surplus or water secured village. Depending upon the experience generated for the stressed village, the implementation is to be extended to other similar villages also. A cadre of local water professional, named as ‘Jal Mitra’ too will be created under this Abhiyan, for tackling water supply related routine issues. Associated woman panchayat members shall also be encouraged to become ‘Jal Mitra’. A card known as Sujalam Card (with the logo “Water Saved, Water Produced”) shall be prepared for every Jal Gram, which would provide yearly status/ information on quality of drinking water available for the village.

## CONCLUSION

While adopting the 17 SDGs, it is indicated that now is the time to take global action for the global resources and move the people and planet towards sustainable future. Water being the prime natural resources for sustaining lives and economies, finds an indirect implication in other goals as well.

Approximately 93% of total population is having access to improved use of drinking water sources. But still quality of drinking water is a matter of concern. A recent report by the United Nation says that in India, over one lakh people die of water-borne diseases annually. It is reported that groundwater in one-third of India’s 600 districts is not fit for drinking as the concentration of fluoride, iron, salinity and arsenic exceeds the tolerance levels. The UN reported that India’s water quality is poor - it ranks 120th among the 122 nations in terms of quality of water available to its citizen. Hence, we shall focus on leveraging various schemes of the Union and State Governments of India to provide necessary financial and technological inputs for implementing the solutions required for making a village smart.

Across India, it is estimated that women spend 150 million workdays every year fetching and carrying water which is equivalent to a national loss of income of INR 10 billion/160 million USD. By implementing different energy saving water supply schemes, we can reduce this number as much as possible so that women can contribute more and more towards the development of the nation.

The Economic Survey 2018-19 states that agriculture and allied sectors are critical in terms of employment and livelihoods for the small and marginal farmers, who dominate the agriculture ecosystem in India. It further states that to attain the Sustainable Development Goals (SDG) of ending poverty and bringing in inclusive growth, activities related to agriculture need to be closely integrated with the SDG targets and that agriculture is dependent highly on water.

The requirement is, to orient our development activities in such a manner that not only necessary facilities are made available in country side in respect of education, health care and other basic activities but also people living in villages, feel attracted to stay there and contribute in development of country side, thus making a reality of saying of Mahatma Gandhi that, ‘India lives in our villages’.

## REFERENCES

1. Girija K Bharat and Nathaniel B Dkhar, Reference taken from Discussion Paper of The Energy and Resources Institute, Aligning India’s Water Resources Policies with the SDGs .
2. Reference taken from seminar conducted by NWDA, New Delhi in, India Water Week, 2017.

# Augmentation of Collaborative Activity Oriented Learning in Civil and Electrical Engineering Subjects

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**Abstract:** Activity-oriented learning (AOL) is a critical component of the teaching and learning process in order to develop graduate-level skills in the field of engineering education. Problem-based learning (PBL) is one such method for acquiring the needed characteristics. The current paper provides guidelines for developing realistic PBL challenges in the fields of civil and electrical engineering. The issues under consideration might have varying lengths and be categorized into distinct phases based on the learners' knowledge and the needs of the difficulties. The augmentation of one phase of a PBL problem studied in this study is positive, demonstrating the learners' skill growth in solving real-world situations. The study indicated that the addition of PBL learning boosted the skills of engineering learners, and that the inclusion of PBL in the engineering curriculum may greatly affect the capacities of both educators and learners by which skilled engineers that are required by the industry can be produced from Academia.

**Keywords:** Engineering Education; Problem Based Learning; Sustainable Development; Capacities

## INTRODUCTION

The improvement in academic standards in the state-of-the-art of engineering education not only contributes significantly to the production of employable skilled graduates but also gives engineering graduates a combination of professional skills, social responsibility, accountability, and entrepreneurial skills. The accreditation bodies are firmly established in order to investigate the level of instruction provided by higher education institutions (HEI's) in order to achieve this objective. An independent organization called NBA, also known as the National Board of Accreditation in India, has established a system for programme accreditation for technical institutions' courses in order to guarantee their quality and relevance. Developing as year it became a permanent signatory to the Washington Accord 2014 saw the stringent implementation of the NBA accreditation process. Using the Outcome Based Education (OBE) model, "Keep the Goal in Mind and Work to Acquire It" is a way of thinking. This philosophy aims to clarify the educational objectives. The process of instructional design, which follows (outcomes) assists the students to achieve the objectives.

The results of such an educational system allow the Knowledge, Skills, and Abilities (KSA) enabled graduate engineers to prosper and Attitudes), which serves as the foundation for outcome-based Education (OBE). These particular goals are listed at several stages of the educational process beginning with a course levels (Program Levels), levels (Course Outcomes — CO's), Program Specific Outcomes (PSOs) and outcomes (POs) up until and during the 4-5 year program's conclusion (Program PEOs) for educational objectives.

Four phases make up the NBA accreditation process: (a) establishing the institution's goals and outcomes levels of the programme (b) Creating a well-framed curriculum to meet all the specified results, (c) development of a good a clearly defined and effective teaching-learning (TL) process (d) developing trustworthy assessment techniques and verification mechanisms the graduates' educational progress and use a method to keep an eye on them of the process of ongoing progress. Revised Bloom's taxonomy is used to estimate the skill sets the student has acquired.

The TL process and the techniques of assessment in this situation aim for an appropriate professionalism component within the teaching community. Restricted and Extended professionalism are the two subcategories of professionalism. The constrained one focuses solely on higher levels of competency in the classroom, such as effective teaching techniques and maintaining positive relationships with the students. The goal of extended professionalism, which is supported by theory and research, is to promote extra attitudes in educators, such as their competence in their work in relation to society and community. As a result, it is imperative that an educator identify professionalism and demonstrate



it to aid in gather the pupils' capacity for learning. The prolonged Educators' professionalism aids in obtaining well-qualified students developed graduate characteristics or NBA POs that cover each and every criterion of today's criteria for education. The addition of Activity-Oriented Learning is necessary to address the Pos. Learning (AOL) is essential to the T-L process. The development created AOL during World War II by a British man named Mr. David H, regarded as a pioneer in the idea of AOL. It is a method of instruction where many forms of activities including tests, debates in groups, and brain storming games, discussions, approaches to problem-solving, and field. The T-L includes works, projects, mind mapping process. With this approach, students learn by performing the tasks performed in a workplace simulation. Furthermore, they also urged to tackle current issues. In this specific pedagogical strategy, including both teachers and students participate actively. The main goal consists of that a student's education should be focused on doing the subject corresponding exercises and practical experiments. Not just AOL enables a learner's learning curve to be almost constant but enhances the learners' capacity for active participation analytical skills, critical thinking, knowledge sharing, teamwork, improving problem-solving abilities, and self-paced learning care about the environment, society, etc.,

The current study seeks to complement PBL in civil and electrical engineering students in order to expand and improve the learners' accomplishment of graduate qualities. The specifics of one problem on compaction by standard proctor test for civil & regulation of three-phase alternator by synchronous impedance method for electrical engineering learners are investigated and provided among numerous PBL problems implemented.

### **PROBLEMBASED LEARNING**

PBL is an example of Activity Oriented Learning (AOL). The students create a process for solving the problem by utilizing the given problem (related to real-time application).

A principle or many principles, combined with the essential processed data during the time of their education. It is a chronological process of instruction and learning when the teacher creates a real-world issue that the students are supposed solve tackle the given issue using the knowledge, abilities, and attitudes. Additionally, the student should have the extra information needed to tackle the issue, developing as a self-paced student Amazing research on this effective and Tambllyn, et al used an innovative technique, and they determined that this specific strategy is the outcome of the a technique for achieving a thorough comprehension of locating a pertinent answer to the stated issue [1]. PBL has made an appearance since then, many research fields, including diverse engineering and branches of architecture [2-6]. The role of PBL in improving many abilities such as problem solving, self-paced, and self-regulation learning talents, thinking abilities, and leadership abilities capacities, cognitive abilities, and team skills by taking into account the numerous learning factors from college to industry [7-8]. Furthermore, the addition of PBL in the field of biology. It has been discovered that pupils at the school level had a good time while studying at their own speed in addition to discovering new things outside of the syllabus [9] prescription. It is determined that PBL is more efficient than traditional teaching learning process in development of instructors' attitudes and viewpoints [10].

In any institution, the first and fundamental strategy is that the instructor must provide and display empirical data. It simulates life outside of the classroom institution that requires the pupils' handling experience to deal with a certain scenario, the types of vocations that provides attention to and indulges in a daily activity. They allow the student to accomplish something rather than just study something action is of such a character that it necessitates critical thought or the making an intentional link results in natural learning. The primary principle underlying PBL is that the key purpose for learning should be an issue, a question, or a riddle that the student seeks to solve [12].

The following are the primary characteristics of the PBL approach:

1. Learning should begin with a problem;
2. Compound and real-time events influence problems;
3. Although the data needed to answer the problem is not originally provided and learners should identify;
4. Identify and use appropriate resources, and work in permanent groupings.

In this technique, the learner becomes a dynamic facilitator who may switch between roles as a group member, dialogue-based facilitator, and consultant as needed.

### **CREATING PBL DIFFICULTIES**

The key to PBL is an effective issue, and creating an engineering problem is a difficult undertaking. In general, challenges may be divided into three categories: fictional, real-world, and authentic. Despite the fact that real-world problems are difficult to locate, when they are discovered they must be used immediately for academic reasons since they can be simply modeled and replicated. Additionally, it will be difficult for teachers to translate real-world field



difficulties into written exam questions since they are too technical for students to understand. Therefore, in order to effectively use real-world situations in the teaching and learning process in the classroom, modification and simplicity are absolutely necessary. Formulating the problem to include the intended learning goals and adapted to the norms of industry that encourage higher order thinking abilities, lifelong learning, team building, and working skills is an effective strategy to address this practical challenge. As a result, creating real PBL challenges is fundamentally the best option and the PBL practitioners' favorite method.

A PBL problem's conceptualization requires both science and art. It must instil zeal in the students and inspire them to put the fundamentals of theory and practice they have learned to use; this zeal should also include zeal for higher characteristics of self-paced learning and assure success in locating the proper answers to the challenges presented. The use of scientific concepts in PBL, according to research, has encouraged and supported effective learning as well as adoption and implementation. Along with creativity, the creation of PBL issues requires a lot of work that involves researching relevant practical information for the course and effectively communicating with industry specialists.

The five fundamental ideas that are included into PBL problems are

- (a) Authentic and Realistic [Pr1];
- (b) Constructive and Integrated [Pr2];
- (c) Increase complexity appropriately [Pr3];
- (d) Encouraging lifelong learning and self-paced learning [Pr4];
- (e) Encourage meta cognitive and critical thinking abilities [Pr5].

A PBL problem design with an engineering focus includes a number of iterative steps [13].

Stage 1: Highlighting the LO's that are intended

The knowledge and ability gap within a particular problem shouldn't be too wide at this point. There is a danger that the students would give up on the issue if they feel the margin is too wide. Before acquiring the ultimate answer, it is highly advised to divide the issue into a number of sections by stressing each portion with a specific consequence if any unforeseen circumstance develops and the gap is too wide.

Stage 2: Acknowledging the issue in the present

This is a vital step in the process since it's here that the LO's meet the requirements and work environment. Since they are involved with the real-world applications of the issues, the industry experts' insights and opinions are urgently needed at this point.

Stage 3: Writing up the initial problem draft

At this stage, the problem's rough or initial draft — which lists the LOs learned from it and the workplace demand — is created. The issue can be presented in a manner similar to that used in traditional professional settings. However, in terms of this component, generating a comparable circumstance that occurs in the field is the ideal approach. Additionally, it is a good idea to list the materials needed for this element and suggest any potential strategies. The issues can be transmitted in a number of formats, including software or hardbound books. Instead of techniques and processes to address the problem, the problem should include objectives and expected outcomes from the students.

Stage 4: Creating the Rubric

Guidelines are created at this step to ensure that students' learning stays on track. Additionally, a grading rubric is created for the problem at hand, and it should be communicated with students to outline the expected results.

Stage 5: Making of a Worksheet

The findings of the problem's solution are provided at this point. It is important to have a worksheet with a made-up firm so that students may experience a more realistic setting, which would greatly boost their confidence levels.

Stage 6: Review, Revise and Refine (RRR) Process

Once the problem has been established, it has to be carefully reviewed, revised, and refined to make sure that it can really be solved by the students within the allotted time frame. It is advised to solve the problem independently for the allotted time frame before presenting it to the students.

Stage 7: Defining the problem to the students

Stages 1-6 are iterative, while stage 7 is the last stage where the learners are presented with the challenge.

## **PBL ENGINEERING PROBLEMS**

PBL issue formulation for the engineering stream is both difficult and exciting. Electronics and Communications



Engineering (ECE) students are taught using the PBL idea, and it has been found that this method of instruction is considerably more effective for student learning than traditional methods[2]. For chemical engineering students, a control and dynamics issue was constructed, and it was shown that PBL fostered effective learning coupled with the development of engineering skills, knowledge, and qualities[3]. It is reported that the hybrid model of implementation of conventional as well as PBL in the classroom teaching and learning process enhances the knowledge base of the learners along with critical and independent thinking abilities, problem solving skills that are highly required for the future[14-17]. Additionally, a PBL problem is developed for Civil Engineering Students in the field of Geo-technical Engineering and for electrical engineering in the field of electrical machines in order to understand the real time practical knowledge.

The implementation of PBL might focus on a specific area of an engineering stream, according to previous studies. At this study, the implementation experiences of the PBL process with reference to the civil engineering domain is described. Each unique task has a 24-hour time limit for each domain. The PBL issue is structured over a 24-hour period with four cycles in a month and is designed as a two-month program. Each cycle is broken down into three smaller cycles, each of which includes three hours of activity-based learning. Based on their prior theoretical and experimental expertise, this curriculum is tailored to third-year UG students. Additionally, this procedure is used to develop the daily lab practice for electrical students and civil engineers in the geotechnical engineering lab. Additionally, similar investigations are carried out in virtual laboratories. The formulation of the issue ensures that the LOs generated are based on the prior cycles. In **Tables 1** and **2**, the specifics of one identified issue are shown, including “Regulation of three-phase alternator by synchronous impedance approach” for electrical engineering and “Standard Proctor Test for compaction of soils” for civil engineering. The end goal of the learners and the educators is to accomplish the desired and expected learning outcomes (LOs), which are prepared for each cycle in the form of two sub-cycles.

### PBL IMPLEMENTATION

The III B.Tech Civil and Electrical Engineering students are exposed to the PBL idea by examining two distinct topics within their respective fields. The challenge is presented in the form of a presentation that details its learning objectives, the expected results of the study, and the time frame. Due to the fact that this problem is based on a laboratory exercise, the students expressed a strong desire to complete the task. The learners are split into groups of four, with a total of 15 groups for a strength of 60 in each area. They were instructed to solve their problem in three steps, and the provided work flow procedure is listed here.

### Work Flow Process

Phase: 1

In this phase, the students first work in groups to try to solve the problem that has been presented. They highlight and ideate the problem, specify the conditions that must be met to solve it, and then attempt to do so using their newly gained information.

**Table 1** Civil Engineering PBL problem details

Cycle	Problem Statement: Compaction of Soils by Standard Proctor Test	Time Duration (Minutes)	PBL Principles[13]
I	Sub-cycle: 1 Identification of ingredients required to perform the test	15	Pr1-Pr5
	Sub-cycle:2 Sieving and Collection of required amount of soil sample	45	Pr1-Pr5
	Sub-cycle:3 Application of theoretical knowledge to perform lab experiment (Whole process of test)	120	Pr1-Pr5
II	Sub cycle:4 Taking down the observations	30	Pr1-Pr5
	Sub-cycle:5 Calculation and drawing of graph for related values	60	Pr1-Pr5
	Sub cycle:6 Discussions related with the total process, Experiences of Learners and Evaluation of Outcomes The same process is performed in Virtual Labs in order to interpret and validate the experimental and analytical value	90	Pr1-Pr5



**Table 2** Electrical Engineering PBL problem specifications

Cycle	Problem Statement: Regulation of three-phase alternator by synchronous impedance approach	Time Duration (Minutes)	PBL Principles[13]
I	Sub-cycle: 1 Identification of apparatus to perform the experiment of ingredients required to perform the test	15	Pr1-Pr5
	Sub-cycle:2 Connecting as per the circuit diagram	15	Pr1-Pr5
	Sub-cycle:3 Application of theoretical knowledge to perform lab experiment (Whole process of test)	30	Pr1-Pr5
II	Sub cycle:4 Taking down the observations	60	Pr1-Pr5
	Sub-cycle:5 Calculation and drawing of graph for related values	60	Pr1-Pr5
	Sub cycle:6 Discussions related with the total process, Experiences of Learners and Evaluation of Outcomes The same process is performed in MATLAB in order to interpret and validate the experimental and analytical values	150	Pr1-Pr5

Phase: 2

In this step, the students debate the issue, determine the need for more, appropriate resources, research, acquire appropriate information, and collaborate with one another to find a solution.

Phase: 3

In this stage, the students reassemble, share their newly gained knowledge, conduct a peer review, and complete the answer to the set of problems.

The students are invited to submit their opinions and input on this exercise after receiving the desired and anticipated answer to the presented difficulty from the learners. All students in the classroom participate in the feedback process.

**Table 3** Inputs from the students

S.No	Question	Question Type	Response and Feedback
1	Have you heard about PBL before this activity?	Closed Ended (Yes/No)	5%, Yes, we have done this task before, when we were still in school. 95%, No, we have not previously engaged in this conduct. It is a brand-new idea to us.
2	If there was a deadlock throughout the PBL process, did the teachers assist?	Closed Ended (Yes/No)	100%, Absolutely, the teachers assisted us in the PBL process.
3	Do you think the aforementioned issues are related to real-time applications?	Closed Ended (Yes/No)	100%, definitely. Because the offered issue is a model that combines a laboratory experiment with a theoretical component, this activity allowed us to experience practically.
4	Did you like solving the offered challenge in a group or individually?	Closed Ended (Yes/No)	100%, yes, Some of the participants were reluctant to work in groups during the early phases of the exercise, but as time went on, they began to cooperate to find a solution.
5	Did you like solving the offered challenge in a group or individually? Did the PBL facilitate the improvement of interpersonal and teamwork skills?	Closed Ended (Yes/No)	100%, yes
6	Please share your thoughts about PBL activity.	Open Ended (Yes/No)	a. We can clearly grasp how to solve an issue with the aid of sub-cycles, and it was a positive experience. b. It can also be used to other disciplines.



**Table 3** provides input from the students.

## CONCLUSIONS

Even though the PBL issue formulation for engineering streams is rather difficult, it is fascinating. Many real-world issues may be formulated throughout the problem-solving process, and these problems can be developed across a variety of time periods and with a variety of sub cycles. The PBL-based activity is also highly engaging and motivating for the students. The results of PBL are positive in that they help students acquire the specified graduate qualities that might be challenging to acquire through conventional teaching and learning methods. The students noted that this activity's execution improved their teamwork and team building abilities, which helped their overall growth.

## REFERENCES

1. H S Barrows and R M Tamblyn, *Problem-based Learning: An Approach to Medical Education*, Springer Publishing, New York, 1980.
2. P Mahendru and D V Mahindru, *Problem-based Learning: Influence on Students' Learning in an Electronics & Communication Engineering Course*, *Global Journal of Researches in Engineering*, 11(8), 2011, pp 1-10.
3. M Z Jamaludin, K Mohd Yusof, N F Haron and S A H S Hassan, *Crafting Engineering Problems for Problem- Based Learning Curriculum*, *Procedia Social and Behavioral Sciences*, 56, 2012, pp 377-387.
4. G Rodriguez and B Fernández, *A Review of Problem-based Learning Applied to Engineering*. *International Journal on Advances in Education Research*, 3(1), 2016, pp 14-31.
5. N Holmes and U Beagon, *Introducing PBL into Civil and Structural Engineering*. DIT Teaching Fellowship Reports, Technological University, Dublin, 2015.
6. J S Larson, K Farnsworth, L S Folkestad, H K Tirkolaei, K Glazewski and W Savenye, *Using Problem-based Learning to Enable Application of Foundation Engineering Knowledge in Real-world Problem*. IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE), Wollongong, NSW, Australia, 2018, pp 500-506.
7. P Thakur, S Dutt and A Chauhan, *Learning Biology through Problem Based Learning– Perception of Students*. *i-Manager's Journal of Educational Technology*, 15(2), 2018 a, 44.
8. P Thakur, S Dutt and A Chauhan, *Problem Based Learning Strategy for Development of Skills-- A Review*. *Journal of Educational Technology*, 15(1), 2018b, pp 53-62.
9. M Barg, A Fekete, T Greening, O Hollands, J Kay, J H Kingston and K Crawford, *Problem - Based Learning for Foundation Computer Science Course*. International Foundation for Research and Development.
10. M Kuvac and I Koc, *The Effect of Problem-based Learning on the Environmental Attitudes of Pre Service Science Teachers*. *Educational Studies*, 45(1), 2019, pp 72-94.
11. John Dewey. *Democracy and education*. Macmillan Publishing, New York 1916.
12. D Boud and G J Feletti, *Introduction*, D Boud and G J Feletti (Eds.), *The Challenge of Problem-based Learning* London: Kogan, 1991, pp13–18.
13. M Z Jamaludin, K Mohd. Yusof, N F Haron and S A H S Hassan, *Crafting engineering problems for problem-based learning curriculum*. *Procedia Social and Behavioral Sciences*, 56, 2012, pp 377-387.
14. Kerry Quinn and Leonard Albano, *Problem-Based Learning in Structural Engineering Education*, *Journal of Professional Issues in Engineering Education and Practice*, J Prof Issue Engeducpract. 134, 2008, 10.1061/(ASCE)1052-3928(2008)134:4(329).
15. E Justo, Delgado Trujillo, Antonio, Vázquez-Boza, Manuel and Branda, Luis. *Implementation of Problem-Based Learning in Structural Engineering: A Case Study*. *International Journal of Engineering Education*, 32, 2016, pp 2556–2568.
16. C E Hmelo-Silver, *Problem-Based Learning: What and How Do Students Learn?*. *Educational Psychology Review* 16,235–266 (2004).<https://doi.org/10.1023/B:EDPR.0000034022.16470.f3>

# Hydropeaking in Himalayan Rivers Associated Effect on Aquatic Life, Flood Management and Sediment Transport

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**Abstract:** India has hydropower capacity of 46,000 MW. For many decades hydropower in India especially of Himalayan Rivers have functioned as base load power stations like thermal, nuclear and other fossil fuel projects. No peaking or off peaking power was being generated by such hydropower stations except during dry seasons of few months and that also for limited time in a day.

India is aiming to have 40% of the total installed capacity by the year 2030 based on non-fossil fuel sources. This translates to about 235 GW of renewable energy.

Due to intermittent nature of renewable power, large hydropower stations in near future will be involved in system stabilization of power grid by peaking up and down of power generation mainly due to capability of fast adjustment in generation. This is termed as hydropeaking.

Sudden rise and fall of water level in downstream due to hydropeaking may cause serious problem in environmental flow and aquatic life specially fishes.

The 2000 MW Lower Subansiri at present the largest hydropower project under construction in Brahmaputra valley is discussed as a case study.

**Keywords:**

## INTRODUCTION

India has hydropower capacity of 46,000 MW. Large number of projects are in the category of run of the river schemes with daily pondage. For many decades hydropower in India specially of Himalayan rivers have also functioned as base load power stations like thermal, nuclear and other fossil fuel projects. No peaking or off peaking power was being generated in such hydropower stations except during dry seasons of few months and that also for limited time in a day.

In the latter part of twentieth century as the requirement of power went on increasing and search of sustainable power generation became primary goal, generation of power by Renewable Energy Source (RES) i.e., power from wind, sun and small hydro became priority. In last few decade growths of renewable power in India has been phenomenal. Unfortunately, in a day of 24 h daily generation of renewable power is possible for few hours depending upon the effective wind in a day, sunlight hours in a day and intermittent flow in small stream.

## POWER GENERATION PLANNING

As on date, the flexible operation of hydro plant is being done occasionally to cope with the variation of peak and off-peak demand. More flexing of hydro generation is expected during integration of large-scale renewable generation. Quick start up and stop time of hydro plants make them suitable to handle the fluctuation of solar and wind generation.

The generation scenario for highest demand day of August 2018, sourced from National Load Despatch Centre, India, is in the **Table 1**. The current installed capacity of renewables is 70 GW out of which maximum power during the day produced by RES is around 23.5 GW, which reduces to around 11.7 GW at night. Even though quantum of total ramp up done by coal is more, it is still running at a much stable load, in comparison to hydro, due to its larger installed base. Compared to coal, hydro is a major contributor here due to its ability of quick start-stop and quick ramping.

More flexing of hydro generation is expected especially from state sector by introducing incentive, two-part tariff etc.

Presently Indian installed capacity of hydropower is about 46,000 MW out of which States own around 27,000 MW and Central Government owns about 15,500 MW, balance is owned by private entities. Out of 46000 MW about 27,000 MW



**Table 1** Generation scenario for highest demand day of August 2018 Ref[1]

Fuel Sources	Minimum Demand Met (GW)	Max Demand Met (GW)	Differences (GW)	% Variation
Coal	107	118	11	10.28%
Hydro	22	29	7	31.28%
Gas	5	6	1	20.00%
RES	11.7	23.5	11.8	100.85%

are from Himalayan Rivers. All most all hydropower stations on Himalayan Rivers as constructed and planed for construction, have perennial flow with lean period of flow during summer of few months. Such projects are of high head and some of them are medium head and almost of them are of high discharge.

In 2019 out of hydropower capacity 46,000 MW, which includes import of about 4500 MW from Royal Kingdom of Bhutan (RKB), and RES was 82,600 MW. Presently the status is that hydropower capacity remains unchanged but RES has reached to 175GW. This quantum jump of RES has to be absorbed by grid. As understood, this unstable generation of renewable energy can be absorbed in the grid by backing down or up the thermal and other fossil fuel generation but simultaneously it is planned to involve the hydropower for peaking up and down of the generation system.

CEA envisages of 420 gigawatts (GW) of renewable energy capacity by 2030 vis a vis 61,000 MW hydro capacity. The high penetration of intermittent renewable energy will bring up issues around managing system flexibility in terms of steeper ramps and peaking load requirements. In India, coal-fired power plants have historically met system flexibility. Till now majority of hydropower stations are not involved in system stabilization of power grid by peaking up and down of power generation mainly due to following reasons

- (1) Hydropower can pick up and down fast than other power generation mode but it has also its secondary cost and detailing requirement. Cost requires being compensated and remunerative.
- (2) Sudden rise and fall of reservoir level in many cases may endanger the stability of reservoirs bank. It is geotechnical issue and has to be taken care in advance
- (3) Sudden rise and fall of water level in downstream due to hydropeaking may cause serious problem in environmental flow and also stranding, drift and movement of spawning ground, taxa, refuge in the sediment of all aquatic life specially fishes.
- (4) Another issue, which adds up if the reservoir, has storage for flood control over and above power generation. These two sometime are conflicting requirement and balancing them is a tricky issue and requires to be properly planned

#### CASE STUDY: SUBANSIRI LOWER HE PROJECT

The Subansiri River is one of the largest tributaries of the Brahmaputra. Its total length up to confluence of River Brahmaputra is about 500 km and its drainage area up to its confluence of River Brahmaputra is 37, 000 sq.km of which 30,000 sq.km. lies in state of Assam and Arunachal Pradesh, India balance is in Tibet.

Average slope of the riverbed from the foothills to 5 km downstream of the dam is about 0.826 m in 1 km, from 5 km to the confluence of Brahmaputra it varies between 0.354 in 1 km to 0.165 in 1 km.

**Figure 1** is the view of river u/s and **Figure 2** dam under construction.

Proposed power capacity is 2000 MW and the dam will be of about 116 m high above riverbed. The concrete dam has been designed with idea of effective sediment movement and minimum sediment accumulation in the reservoir. Large capacity low-level spillway 9 no of size 11.5 M × 14.7 M each, has been provided for this purpose, with crest level of the spillways being as close as riverbed level. Design flood is 37,000 cumec. During flood season, the low-level spillways will flush sediment and help passage of fishes and other aquatic life.

River is quite wide and deep and at dam site, the width is about 350/400 m well bound by rock. As the river flows down the valley becomes highly braided and then forms a small island at around 4/5 km downstream with two small streams on both side joining the island and total width reaches to around 1500 m to 2000 m. The island formation has been due to high sediment transport mainly by these streams.

Stream flow near the dam site varies significantly between monsoon and non-monsoon period. Average lean period flow is in the range of 300 cumec and the monsoon period flow is in the range of 2500 cumec.



**Figure 1** Subansiri River just upstream of dam under construction



**Figure 2** Dam under construction October 2022

The reservoir has an extended stretch of about 60 km with an average width of 0.4 to 0.5 km (maximum width being about 1 km).

Two Google Earth map **Figures 3** and **4** give a bird's eye view of the channels and island formation of the river downstream.

The Subansiri is one of the highest sediment-carrying rivers. Long-term data prediction at dam site aided by method of



**Figure 3** Google view of Subansiri dam site and down



**Figure 4** 4 to 6 km downstream of dam site there is an island formation



estimation has indicated about 24 m cum average annual silt load but may be as high as 50-60 m cum. The main quantum of sediment flows down around the monsoon period, which is from middle of May to about middle October.

The Lower Subansiri H E is a power project, has also provision of flood management. Therefore, the reservoir is of multipurpose. Full reservoir level corresponding to a storage capacity of 1365.0 m cum and at maximum water level with storage volume of 1470.0 m cum. About 440 m cum, flood cushion is provided for the period of high inflow like June, July and August months. The minimum draw-down level has storage capacity around 700 m cum. Operation of such reservoir requires a detail planning keeping view of power, flood management, environmental/ecological flow etc. Initial study has been done in planning stage, but would require continuous updating and review during construction and operation stage. Operation of the project will also generate farther data on ecological requirement and hydrological character. Shall further help in planning and modifying operation.

### **ECOLOGY AND AQUATIC LIFE STUDY**

Central Water Commission (CWC), Government of India in consultation with Ministry of Environment and Forest (MOEF) had undertaken the task of conducting, "Cumulative Impact and Carrying Capacity Study of Subansiri basin including Downstream Impact in Brahmaputra River Valley" with an objective to assess the cumulative impacts of hydropower development in the basin. IRG Systems South Asia Private Ltd. was awarded the study by CWC. The Study has been published as Ref[2] Cumulative Impact and Carrying Capacity Study of Subansiri Sub Basin including Downstream Impacts".

Discussion here on aquatic life is mainly from the above report. Fishes are important food resource and good indicators of the ecological health of the waters they inhabit. Running water of Himalaya comprise many torrential rivers and streams providing a wide variety of ecological niche. The higher elevations generally support cold water fishes and the foot hills region and mid elevations comprises of fishes which are economically important, but most of the fish resources in the lotic systems (of organisms or habitats) inhabiting or situated in rapidly moving fresh water of this region.

Four migratory fish species of major importance are recorded in Subansiri Basin namely acrossocheilus hexagonolepis (Copper mahaseer / Chocolate mahaseer) Tor putitora (golden mahaseer), Tor (mahaseer) and Schizothorax richardsoni (snow trout). Other fishes it seems do not migrate further upstream.

The project planning, has ensured that at least 240 cumec water will always be available for aquatic flora and fauna downstream of proposed Lower Subansiri HEP, which would safeguard aquatic habitat from drying and bringing drastic changes in the local biodiversity.

The ecological requirement of Gangetic River Dolphin for sustenance in River Subansiri is adequate water availability throughout the year to sustain its habitat. Report states presence of Dolphins in Subansiri River mainly confined to 100-110 km upstream of the confluence with Brahmaputra. They attributed absence of dolphins in the first 20 km stretch below proposed Subansiri HEP due to rocky nature of the riverbed and harsh riverine conditions because of transported debris from the site. Report added that dolphins prefer deeper pools of the Subansiri River as natural habitats. The major issue is to maintain the constant source of water flow for sustainability of dolphin and other aquatic biodiversity downstream, which can be addressed by maintaining minimum average flow discharge to the tune of 240 cumec as already stated. To mention here that Subansiri dam and its surface Power House are adjacent themselves. So, managing the environmental flow and intermittent reservoir flushing would not be difficult to handle. Undoubtedly, they are important species needing attention for conservation in Subansiri River below Lower Subansiri downstream until confluence with Brahmaputra River in Assam. Further downstream in River Brahmaputra also they are available.

Further, according to the report, Subansiri dams may obstruct the migration route of the Mahaseer species, which can be one of the major impacts. The Mahaseer species undertake upstream migration in River Subansiri during summer and monsoon months for feeding and breeding. As the winter sets in the upper reaches, the species takes a downstream journey as far as up to its confluence with River Brahmaputra. In addition, certain species of Schizothorax (snow trout) also undertake migration from upper reaches during winter months. This fish species breeds in the lower reaches.

Amongst the aquatic animals, it is the fish life that would be most affected. The migratory fish species, e.g., Mahaseer and Snow trout are likely to be affected due to obstruction created by the proposed dams. The Mahaseers migrate from warm water to the upstream sometime in April-May for breeding and feeding purposes. The fish remains upstream much beyond Gerukamukh, until optimal conditions are met for breeding during the months of August-September. The wide stretches of River Subansiri in the project area have deeper pools. A shallower area with gravel substratum is one of the essential requirements for spawning of Mahaseers. This situation is likely to change, once the dam is constructed. Because of obstruction in the migratory route and reservoir due to the construction of the dam, the Mahaseers are likely to



congregate below the toe of the dam and adjacent powerhouse. For mature fish, upstream migration may not be feasible. Schizothorax (snow trout) also undertake migration from upper reaches during winter months. This fish species breeds in the lower reaches.

**Figure 4** shows an island in the middle of River Subansiri where two small streams from both banks are joining the river about 4 to 6 km downstream of proposed dam site. Like all other major tributaries of river Brahmaputra, Subansiri transport huge quantities of sediment during monsoon months. This upstream sediment along with contribution of the two small streams have resulted in the formation of the island.

This island with two upstream streams joining here may be able to contribute following

- (a) The island with many braided channels can act as shelter for the fishes during high flood and sediment release from dam;
- (b) The two streams with steeper slope and reasonable flow may act as channel for upstream movement of fishes if they are not able to move up through the low-level spillway.

Operation of Lower Subansiridam and reservoir will be complex due to high sediment transport, high flood during monsoon month and power generation requirement. During last 12-14 years construction of the project was halted effectively about 7/8 years due to conflict and apprehension of downstream people of getting flooded or their highly fertile land being eroded.

There is an apparent contradiction between flood moderation and hydropower generation in such multipurpose project. The transport of high sediment volume during the same period of wet months adds further complexity. Such conflict has repeatedly been observed in Damodar Valley Corporation project in State of West Bengal as recently as 2015 though the project was established 50 years or more back. Operation has remained the problem and sources of conflict between two priorities functions namely maximum power generation a commercial requirement and optimum flood moderation a social distress mitigation.

Study for operation procedure of the dam requires to be taken up as follows

- (a) Flood moderation vis-à-vis hydropower generation;
- (b) Sediment transport and flushing the reservoir;
- (c) Effect of reduced sediment transport in initial years of operation in case not managed;
- (d) If hydropeaking is resorted, what shall be effect on aquatic life especially on fish?
- (e) Continuous monitoring the life of fish and other aquatic life now onward.

The frequent fluctuations in water level downstream of the turbine outlet i.e., hydropeaking is likely to seriously affect the natural functioning of river until many kilometres downstream. To prevent these negative tendencies, the Swiss Water Protection Act (WPA 2011), similar to the European Water Framework Directive (WFD 2000), demands the mitigation of hydropeaking by constructional measures, Ref [3] Christine Weber and Nico Batz, Ref [4] A.J. Schleiss, et al also discuss a case study for a compensation basin in Alpine stream.

However, in Subansiri, constructional measure may not be feasible due to high sediment and quantum of flow and other mode of mitigation would be required.

Fishes in hydropeaking rivers may be affected by stranding along the changing channel margins, downstream displacement of fishes and drift, redd (spawning habitat) dewatering, spawning interference, untimely or obstructed migration, loss of food and increased predation. Redds are exposed to scouring risk (at peak flow) and dewatering (at off-peak flow), which might impair egg development and recruitment success as observed by Ref [5] Schmutz, et al.

Because many characteristics of the flow regime influence the structure and functioning of river ecosystems, an improved understanding of the ecological effects of hydropeaking is needed.

Regarding discontinuity/ obstruction of passage of some fishes due to dam construction it will be helpful to study in the field or otherwise to plan the travel path of Mahasheer fish being diverted to the streams up specially the left bank one, of the river island, so that it can travel upstream during breeding. Suggest studying such alternative will generate useful data.

## **FLOOD MANAGEMENT IN DOWNSTREAM ASSAM**

Flood management of Subansiri in the downstream is an issue in Assam lowland. It appears that in intense flood it



submerges considerable agricultural land in Assam and there is associated erosion problem.

A multi discipline organization or institution engaged to study all aspect continuously during construction stage and few years after commissioning of the project will help.

### **CONCLUSION**

Presuming that in coming years, the hydropeaking will be required in such big dam, a complex study as discussed above requires on two burning issues i.e., flood moderation and power generation in tandem. Study on aquatic life and sediment movement are other two important subjects for continuous study.

### **REFERENCES**

1. Flexible Operation of Thermal Power Plant for Integration of Renewable Generation, Published by Central Electricity Authority, Govt. of India
2. Cumulative Impact and Carrying Capacity Study of Subansiri Sub Basin including Downstream Impacts, Submitted by IRG Systems South Asia Pvt. Ltd. to Central Water commission, Govt. of India
3. Nico Bätz and Christine Weber, Hydropeaking Mitigation in Switzerland Collaborative Learning between Research and Practice.
4. M Bieri, M Müller, S Schweizer and A J Schleiss, Flow Restoration in Alpine Streams Affected by Hydropower Operations — a Case Study for a Compensation Basin.
5. S Schmutz, T H Bakken, T Friedrich, F Greimel, A Harby, M Jungwith, A Melcher, G Unfer and A B Zeiringer, Response of Fish Communities to Hydrological and Morphological Alteration in Hydropeaking Rivers of Austria.



# 3D Printing Technology in Construction Industry

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**Abstract:** The success of fast engineering growth everywhere in the ecosphere may be due to mechanized developments important to earlier and inexpensive manufacturing systems. Over the past three decades, the technique of mixing and pouring concrete on location consumes increasingly substituted by prefabricated construction techniques in some developed countries. Construction manufacturing benefits from innovative technology, which also decreases labor necessities and construction period, saves charges, progresses development quality, and decreases environmental impact. The article presents the current status of 3D printing research applications in the construction industry and provides an outlook and plan for its growth. Additive industrial, more widely known as 3D printing, has driven large growth in these respects in other industries, and a number of national and international projects have helped to present the method to the building industry. As with other state-of-the-art developments not covered by uniform standards, suitable valuations and testing procedures to control the quality of the 3D-printed end products, while not obligatory, are advisable.

3D printing has extended stayed used in the engineering division as a way to mechanize, quicken manufacture and decrease surplus resources. By using this technology, it is possible to build a wide variety of objects if the necessary specifications are provided to the printer and no problems are presented by the limited range of materials available.

This paper shows that regulation is not an obstacle to the use of an innovative product, such as 3D printing, by proposing quality-control tests and an assessment methodology, in the understanding that standardization ensures the viability of a technology. The information, including the methods and results, is based on the authors' experiences in the development of three research projects pertaining to 3D printing.

**Keywords:** Concrete; Cement; 3D Printing; Testing; Construction

## INTRODUCTION

The application of 3D printers has taken its place in the field of engineering, especially in the field of treatment and motorized. There have been developments in additive construction technology in layers with cement and various materials. This technology has developed as a joint product of resources discipline, mechanical coding and architectural design studies, using the advantages of shotcrete and self-compacting concrete. In this type of printing, the capability to pump, workability and construct of fresh concrete and the strength of hardened concrete are of great importance. The aim of this paper is to review 3D printing technology applications in the construction sector. The studies discuss the future of 3D printing technology in the field of construction and suggestions are made for possible uses in the construction industry.

Old-style industrial methods are based on the principle of deducting material from the raw material during the manufacture of parts. In additive manufacturing, which is one of the new production techniques that has become widespread today, unlike traditional manufacturing methods based on material reduction techniques from the part, the part is produced directly from the material. The device used in manufacturing manufactures the part layer by layer by following a tool path derived from the geometry of the part to be produced. It is possible to produce parts with complex geometries and the loss of material during manufacturing is at a minimum level due to this unique feature of additive manufacturing. Additive manufacturing is one of the modern manufacturing methods that has gained importance in recent years. It is a form of manufacturing in which the 3D model is obtained by adding layer by layer the powders to be built using geometric data. With additive manufacturing methods, parts with complex geometry can be obtained quickly. 3D printing technology, which has caused changes by breaking new ground in diverse sectors, has moreover affected the construction sector. Building production in construction contains of significant stages like design, projecting and implementation. With the improvement of innovation, digital manufacturing has been used for a long time in the design and projecting phase of buildings. The design and projection of the building is supported 2D drawings and scale models.



Today, 2D drawings and prototypes are replaced by 3D modelling techniques. Designers, architects and engineers have had the

advantage of making the necessary changes in their projects easily, seeing the problems that may arise before the implementation and making the changes that occur in unforeseen situations during the implementation phase with digital modelling methods. The implementation phase of building production, on the other hand, did not change as fast as the design process and remained dependent on the traditional method of building production.

### **3D CONCRETE PRINTING CONSTRUCTION TECHNOLOGY AND MATERIALS**

Dry mortar is commonly used as printer "ink" in 3D-printed buildings. The material requirements of 3D printing construction dry-mix mortar are similar to those of printing concrete, both of which require it to have good plasticity and other properties. Its performance requirements are very strict. Dry mixing mortar is cement, sand, mineral admixture, and functional additives according to the relevant proportion, by professional manufacturers in the dry state of well-proportioned mixing, mixing into a granular or powdery mixture. The next is to dry mix mortar with dry powder packaging or bulk transported to the site, according to the provisions of the ratio of water mixing can be directly used. Dry-mixed mortar is favored by engineering circles because of its convenience, flexibility, and other excellent properties, and has been more and more widely used in recent years.

### **REINFORCEMENT IN 3D CONCRETE PRINTING**

To ensure better structural performance of the building, it is often necessary to add suitable reinforcement to the concrete structure. 3D concrete printing process is a challenging task. Using current printing technology. The placement of vertical steel bars and the joining between steel bars are not simple. In order to support the structural strength of 3D concrete printing, we can try to introduce some alternative reinforcement methods. Examples include composite fibers in mixed concrete, carbon fibers, or fiber-reinforced polymers, but this requires thorough research and innovative adaptation of 3D concrete printing technology. Preliminary studies have shown that 3D prestressed concrete can significantly increase the load-bearing capacity of structures. We can try to develop a hybrid printing system that can respond to different needs and thus greatly enhance the structural strength. According to experiments, it is possible to manually place reinforcement bars, in the intermediate layers, or between the fiber layers or by directly extruding the concrete through the sides of the manually pre-tied reinforcement cage. The elimination of this intervention allows for a basic automation of the printing process, with the advantages of geometric accuracy, reduced manufacturing time, and reduced labor costs.

### **3D CONCRETE PRINTING TECHNOLOGY WILL LARGELY AUTOMATE THE CONSTRUCTION INDUSTRY**

3D printing technology is an important means to lead the development of future innovation in manufacturing. Furthermore, since the printer only prints where needed, contrary to the color-reducing method structure, the 3D printing principle of adding the structure can eliminate or significantly reduce the waste of materials. Concrete printing can improve current manufacturing methods by automating, thereby reducing dependence on labor and improving accuracy. However, considering these challenges, intelligent system design and advanced material development are needed to achieve environmentally friendly and affordable construction. Finally, the specific construction process may result in anisotropy, i.e. different performance in different directions. Therefore, this standard test method for layer by layer construction is also very important. In the case of assembled buildings, this technology has been around for many years in the construction industry. 3D concrete printing technology offers this alternative to prefabricated assemblies, which also suggests that prefabricated construction will expand from the factory to the construction site. In some areas of construction, particularly in underground buildings, the removal of formwork is both time consuming and costly. While innovative solutions have been developed for automated reinforcement with 3D concrete printing, a potential short-term application is 3D concrete printed permanent formwork. 3D concrete technology can provide an efficient automated production process for thin-walled formwork in which a reinforcement cage is placed and the internal concrete is subsequently poured in situ to form composite structural elements. Finally, each 3D concrete printing technology uses different materials and processing methods, so each has its own potential and direction for development.

### **BENEFITS OF 3D PRINTING**

- 3D printed products only use as far material as desired toward method. This means fewer resources are essential and a lesser amount of waste is produced.
- Condensed conveyance costs if products are printed on-site and possible to generate more effective and stimulating



plans as 3D printing can achieve shapes that conventional techniques. Lower labour costs.

- Decreased cost the customized design and also risks of health and safety is reduced.

### CONCLUDING REMARKS

This paper presents the current development of 3D printing technology in the construction industry. With gantry, robot and crane systems, 3D printing technology has been successfully applied in a number of exemplary construction projects that have received extremely high ratings. Options for improving shape retention and constructability of sub-layers include developing thixotropic concrete materials or using low-viscosity concrete that can be easily pumped and then chemically treated at the nozzle to speed up its setting rate. However, limited data on the structural properties, safety and economics of the materials do not allow for an in-depth presentation. However, through the comprehensive analysis, we believe that the future direction of 3D printing technology in the construction industry are as follows:

- (1) In order to achieve proper engineering design and construction, the mechanical properties of 3D of concrete printed elements must be characterized by standardized material testing.
- (2) In order to overcome the quasi-brittle damage of concrete materials, reinforcement is needed. As described in this paper, manual placement of steel bars or reinforcement assemblies provides a solution as interlayer or interline reinforcement. Rebar placement can be carried out automatically as part of the 3D concrete printing process or through other automatic equipment. A reasonable ratio of steel to concrete is important in building automation in order to provide sound design guidance for proper anchoring and reduction of reinforcement in 3D printed concrete structures and structural members.
- (3) The construction industry and government departments should accept 3D prestressed concrete as a construction technology and there needs to be strict standards in terms of materials, specifications, manufacturing, testing and structural design.

### REFERENCES

1. P M Dickens, Research Development in Rapid Prototyping, Proceedings of the Institution of Mechanical Engineers, 209(4), 1995, pp 261-266.
2. Dong Jie, Zhao Shengxiang and Tie Mei, 3D Printing Technology — A New Revolution in Manufacturing Technology. Science Think Tank, 05, 2013, pp 80-86.
3. Li Ran and Qi Xiangdong, Application and Research of 3D Printing Technology in Construction Industry, Electronic Technology and Software Engineering, 05, 2015, pp 102.
4. Luo Yi, Application and Development Prospect of 3d Printing Architecture, Journal of Shenzhen Vocational and Technical College, 01, 2020, pp 34-39.
5. Chen Jing, Current situation and Prospect of 3D printing construction Technology, Sichuan Cement, 10, 2015, pp 37+27.
6. Lei Sheng and Lei Wu, Review of 3D Printed Concrete Technology Research, China Concrete and Cement Products, 10, 2021, pp 7-11.
7. Ding Liyun, Xu Jie and Qin Yawei, A Review of the Research and Application of 3d Printing in Building Digital Construction Technology, Journal of civil engineering and management, 03, 2015, pp1-10.



# Experimental Investigations on the Performance of Sustainable Concrete Containing Plastic Waste Fibers

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**Abstract:** Utilization of waste materials in concrete plays a vital role in construction industry in order to achieve sustainable development. In this research work, plastic waste based sustainable concrete was investigated. Single-use type of plastic (i.e. Carry bags) was used in this study. Carry bag plastic waste was shredded into 5 mm to 20 mm long fibers. Plastic Waste Fibers (PWF) as reinforcing constituent for sustainable concrete was evaluated. PWF mixed in concrete from 0% to 2% with an increment of 0.5% by volume of concrete mixes. In this study, slump, compressive strength, splitting tensile strength and flexural strength were evaluated with and without addition of plastic waste fibers. Also, durability properties such as water absorption and resistance to chloride ion penetration were assessed. Ductile mode failure was observed in concrete specimen instead of brittle mode failure due to inclusion of plastic waste fibers. Concrete with addition of up to 1% plastic waste fibers does not affect the strength properties of concrete adversely.

**Keywords:** Plastic Waste; Concrete; Sustainability; Strength; Durability

## INTRODUCTION

In the past few decades generation of plastic waste is high. In India, average plastic waste generation is approximately 4060 tonnes per day. Four major cities such as Chennai, Mumbai, Kolkata and Delhi generating almost 40% (1670 tonnes) of plastic waste. Improper disposal of these generated plastic waste creates an environmental pollution [1]. State of generated plastic waste in India is shown in **Figure 1**. At the same time, production of concrete consumes valuable natural resources such as river sand and crushed stones. In this context, an attempt is to made utilization of plastic waste in the production of concrete. Ghernouti et al. investigated the fresh and hardened properties of self-compacting concrete containing plastic waste fibers. Length of fibers varied from 2 cm to 6 cm. Results indicated that the inclusion of plastic waste fibers does not affects the mechanical properties adversely.

Also, concrete containing plastic waste fibers delayed the initiation of micro cracks during compressive strength test[2]. Rao, et al investigated the post-cracking performance of fiber reinforced concrete containing high density polyethylene (HDPE). Addition of high density polyethylene fiber in concrete 0.3%, 0.4%, 0.5%, 0.6% and 0.7% by volume of concrete mixes. Incorporation of fiber in concrete significantly improved the ductility performance of concrete compared to the control mix concrete[3]. Masonry bricks prepared with polyethylene terephthalate (PET) performed well with high-ductility behavior, whereas brittle behavior was observed with the masonry bricks without PET[4]. Al-Hadithi and Hilal investigated the self-compacting concrete with waste plastic fibers. Waste plastic fibers obtained from beverage bottles. Waste plastic fibers were added from 0% to 2% by volume of concrete mixes with an increment of 0.25%. The results indicated that the mechanical properties of concrete were improved compared to conventional mix concrete[5]. Impact resistance and strength properties of concrete were investigated with metalized plastic waste fibers. Fibers content varying from 0% to 1.25% by volume of concrete mixes with the fiber length 20 mm. Test results indicated that the impact resistance improved with the metalized plastic waste fibers[6-14]. In this paper, mechanical and durability properties of concrete with plastic waste fiber were examined. Previous studies are same length of fiber were incorporated in the production of concrete. This study investigate the performance of concrete with varying length of plastic waste fibers.

## EXPERIMENTAL INVESTIGATION

### Materials

Ordinary Portland cement, manufactured sand and crushed stone was used for binding material, fine aggregate and coarse aggregate, respectively. Fine aggregate and coarse aggregate with a maximum size of 4.75 mm and 16 mm, respectively. Waste carrier bag plastic was used as a plastic fiber in this study. Plastic waste fiber obtained by cleaning,



Figure 1 State of waste plastic [1]

washing and shredding of carrier bag plastic. Plastic waste fiber is shown in **Figure 2**.

### Methodology

M30 grade of concrete was used in this study as per IS 10262:2019. Plastic waste fibers were added 0%, 1%, 1.5% and 2% by volume of concrete mixes. Slump test on fresh concrete mixes conducted as per IS 1199:1959 (R2004). Compressive strength of concrete specimens were carried out on concrete cubes of 100 mm × 100 mm × 100 mm size. Splitting tensile strength of concrete specimens were carried out on concrete cylinder of 100 mm × 200 mm size. Flexural strength of concrete specimens were carried out on concrete prism of 500 mm × 100 mm × 100 mm size. Mechanical properties of hardened concrete test conducted as per IS 516 (Part 1/Sec 1): 2021. Water absorption test was carried out on concrete disks 110 mm × 50 mm in the diameter and thickness respectively as per ASTM C 642:06. The concrete disks of 110 mm × 50 mm size were used for RCPT as per ASTM C1202:17a. To obtain the average results for all the test conducted in this study, triplicate specimens were cast and tested. Typical specimens used for this study is shown in **Figure 3**.

## RESULTS AND DISCUSSION

### Slump

**Figure 4** shows the variation of slump with the addition plastic waste fibers in concrete. Addition of plastic waste fibers



**Figure 2** Plastic waste fibers



**Figure 3** Typical concrete specimens

in concrete mixes reduced the workability of concrete compared to the conventional mix. Concrete containing plastic waste fibers showed slump reduction by 2%, 6%, 11% and 14% for the addition of 0.5%, 1%, 1.5% and 2% of plastic waste fibers, respectively compared to the conventional concrete mix. The addition of plastic waste fibers in concrete affects the consistency of concrete mix. Also due to the larger surface area of plastic waste fibers occupy a more volume of cementitious matrices[8].

#### Compressive Strength

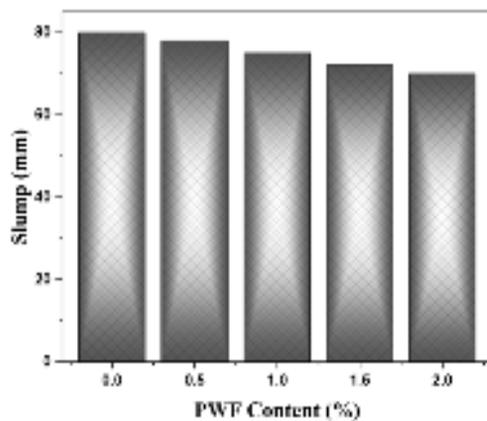
**Figure 5** shows the 28-day compressive strength variation with the addition of plastic waste fibers content in concrete.

Compressive strength of concrete decreased with increase in the percentage of plastic waste fiber content in concrete mixes. However, the reduction in compressive strength was very less compared to the conventional concrete mix. This indicates that the inclusion of plastic waste fibers up to 1% does not affect the compressive strength adversely. The reduction in compressive strength was 3%, 6%, 15% and 31% for the addition of 0.5%, 1%, 1.5% and 2% of plastic waste fibers, respectively compared to the conventional concrete mix. Similar trends were observed by the other researchers for the addition of plastic waste fibers[8].

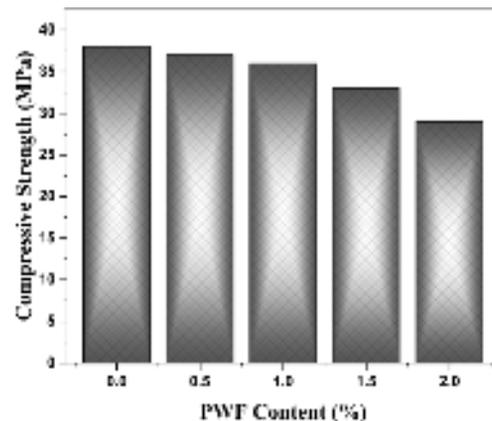
#### Flexural Strength

**Figure 6** shows the 28-day flexural strength variation with the addition of plastic waste fibers content in concrete.

Flexural strength of concrete decreased with increase in the percentage of plastic waste fiber content in concrete mixes.



**Figure 4** Slump vs PWF content



**Figure 5** 28-day Compressive strength vs PWF content

The reduction in flexural strength was 2%, 4%, 11% and 19% for the addition of 0.5%, 1%, 1.5% and 2% of plastic waste fibers, respectively compared to the conventional concrete mix. Plastic waste fibers did not affect the flexural strength of concrete significantly up to 1% addition by volume of concrete mixes. During flexural strength test, ductile mode failure was observed in concrete specimen instead of brittle mode failure due to inclusion of plastic waste fibers. Other researchers have reported a similar observation for flexural strength test with the addition of plastic waste fibers[18].

### Splitting Tensile Strength

Figure 7 shows the 28-day splitting tensile strength variation with the addition of plastic waste fibers content in concrete. Splitting tensile strength of concrete decreased with increase in the percentage of plastic waste fiber content in concrete mixes. The reduction in splitting tensile strength was 2%, 5%, 12% and 23% for the addition of 0.5%, 1%, 1.5% and 2% of plastic waste fibers, respectively compared to the conventional concrete mix. Plastic waste fibers did not affect the splitting tensile strength of concrete significantly up to 1% addition by volume of concrete mixes.

### Water Absorption

Figure 8 shows the percentage of water absorption with the addition of plastic waste fibers content in concrete.

Water absorption of concrete increased with increase in the percentage of plastic waste fiber content in concrete mixes. The increase in water absorption was 2%, 5%, 11% and 20% for the addition of 0.5%, 1%, 1.5% and 2% of plastic waste fibers, respectively compared to the conventional concrete mix. Low adhesion between the plastic waste fibers and cementitious matrix increased the voids in concrete mix. However, the increase in water absorption was negligible up to 1% inclusion of plastic waste fibers in concrete mixes.

### Resistance to Chloride Ion Penetration

Figure 9 shows the charge passed values with the addition of plastic waste fibers content in concrete.

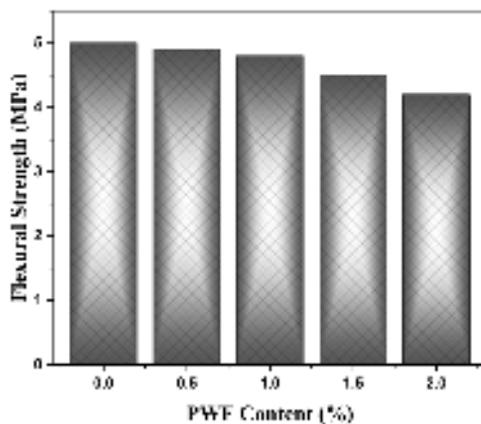


Figure 6 28-day Flexural strength vs PWF content

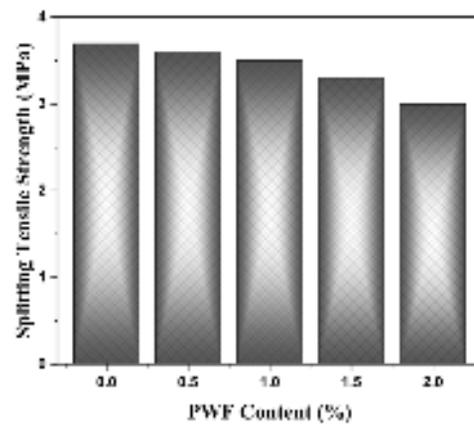


Figure 7 28-day splitting tensile strength vs PWF content

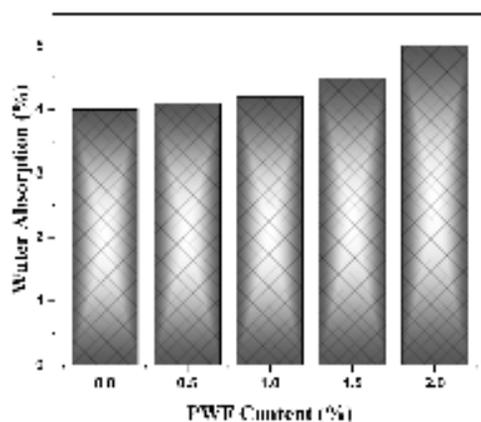


Figure 8 Water absorption vs PWF content

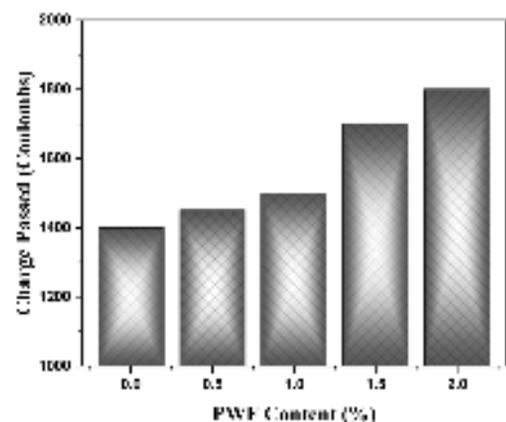


Figure 9 Charge passed vs PWF content



It was observed that conventional concrete mix and concrete containing plastic waste fibers fall under the low chloride ion penetrability category as per ASTM C1202-17a. Resistance to chloride ion penetration decreased by 3%, 7%, 18% and 22% for 0.5%, 1%, 1.5% and 2%, respectively. The reduction in resistance to chloride ion penetration of concrete containing plastic waste fibers was mainly due to the low adhesion between the plastic waste fibers and cementitious matrix, which increases the capillary pores in the concrete. Concrete containing 2% attained higher charge passed values (1800 coulombs) compared to the other concrete mixes studied.

## CONCLUSIONS

- Workability of concrete reduced with the inclusion of plastic waste fibers in concrete.
- Compressive strength, flexural strength and splitting tensile strength was not adversely affected by the addition of plastic waste fibers in concrete up to 1% by volume of concrete mixes.
- Increase in water absorption of concrete containing plastic waste fibers was negligible up to 1% dosage.
- All the concrete mixes studied fall under the low chloride ion penetrability category as per ASTM C1202-17a.

## REFERENCES

1. <https://www.downtoearth.org.in/factsheet/state-of-waste-plastic-60749>. Last accessed on 12.11.2022.
2. Y Ghernouti, B Rabehi, T Bouziani, H Ghezraoui and A Makhloufi, Fresh and Hardened Properties of Self-Compacting Concrete Containing Plastic Bag Waste Fibers (WFSCC), *Construction and Building Materials*, vol 82, 2015, pp 89–100.
3. M M Rao, K Sanjaya and S Basarkar, Mechanical and Post-Cracking Performance of Recycled High Density Polyethylene Fiber Reinforced Concrete, *J. Inst. Eng. India Ser. A*, vol 103(2), June 2022, pp 519–530.
4. A F Ikechukwu and A Naghizadeh, Valorization of Plastic Waste for Masonry Bricks Production: A Novel Construction Material for Sustainability, *J. Inst. Eng. India Ser. A*, vol 103(3), September 2022, pp 881–890.
5. A Al-Hadithi and N Hilal, The Possibility of Enhancing Some Properties of Self-compacting Concrete by Adding Waste Plastic Fibers, *Journal of Building Engineering*, vol 8, December 2016, pp 20-28.
6. H Mohammadhosseini, M Tahir and A Sam, The Feasibility of Improving Impact Resistance and Strength Properties of Sustainable Concrete Composites by Adding Waste Metalized Plastic Fibres, *Construction and Building Materials*, vol 169, 2018, pp 223–236
7. N Bui, T Satomi and H Takahashi, Recycling Woven Plastic Sack Waste and PET Bottle Waste as Fiber in Recycled Aggregate Concrete: An Experimental Study, *Waste Management*, vol 78, 2018, pp 79–93.
8. A C Bhogayata and N K Arora, Fresh and Strength Properties of Concrete Reinforced with Metalized Plastic Waste Fibers, *Construction and Building Materials*, vol 146, 2017, pp 455–463.
9. F S Khalid, J M Irwan, M H Ibrahim, N Othman and S Shahidan, Performance of Plastic Wastes in Fiber-reinforced Concrete Beams, *Construction and Building Materials*, vol 183, 2018, pp 451–464.
10. A Ahdal, et al. Mechanical Performance and Feasibility Analysis of Green Concrete Prepared with Local Natural Zeolite and Waste PET Plastic Fibers as Cement Replacements, *Case Studies in Construction Materials*, vol 17, 2022, e01256.
11. M Farooq, et al., Influence of Nylon Fibers Recycled from the Scrap Brushes on the Properties of Concrete: Valorization of Plastic Waste in Concrete, *Case Studies in Construction Materials*, vol 16, 2022, e01089.
12. A C Bhogayata and N K Arora, Impact Strength, Permeability and Chemical Resistance of Concrete Reinforced with Metalized Plastic Waste Fibers, *Construction and Building Materials*, vol 161, 2018, pp 254–266.
13. R Alyousef, H Mohammadhosseini, M Tahir and H Alabduljabbar, Green Concrete Composites Production Comprising Metalized Plastic Waste Fibers and Palm Oil Fuel Ash, *Materials Today: Proceedings*.
14. H Mohammadhosseini and M Tahir, Durability Performance of Concrete Incorporating Waste Metalized Plastic Fibres and Palm Oil Fuel Ash, *Construction and Building Materials*, vol 180, 2018, pp 92–102.
15. ASTM C642-13 Standard Test Method for Density, Absorption, and Voids in Hardened Concrete.



16. ASTM C1202-17a Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.
17. IS 10262:2019 Concrete Mix Proportioning - Guidelines.
18. IS 516:1959 (R2004) Methods of Tests for Strength of Concrete.
19. IS 1199:1959 (R2004) Methods of Sampling and Analysis of Concrete.



# Design Thinking: A Human Centred Approach for Sustainable Construction Management

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**Abstract:** After the agricultural sector, the construction sector is the second largest in the country. It has a significant contribution to the improvement of the gross national economy, nation-building and provides job opportunities to a large number of people. Construction projects play a pivotal role in the economic growth of any country. Investment in the construction sector in India has been growing consistently. 'Design Thinking is gaining momentum across construction industries, primarily due to the emphasis it places on a human-centred approach to problem-solving. Design Thinking has the potential to steer the construction industries towards more human centricity, re-imagining the business, balancing the organization, focusing on the human element of the market, harnessing appropriate technology, and fostering an innovative mindset.

Design Thinking offers a framework that, at a fundamental level, reorients the mindset from "what can I do next" to "where do users need help the most" approach. Its human-centric empathy-driven approach enables the construction industry to identify and understand potential contexts and problems from the perspective of the end user rather than from the point of view of the possibilities afforded by technology. Time and cost overrun are the hurdles that restrict the construction sector's potential support to achieve the desired growth and ensure productive capital expenditure. The article discusses several attributes that adversely affect the smooth execution of construction projects, which can be efficiently controlled and managed at the project level with proper planning and construction project management with the use of 'Design Thinking. This article attempts to identify these pertinent issues and also brings out how professional construction management practices can bring about a positive change in the completion of projects on time and within budget with desired quality to the satisfaction of all the stockholders.

**Keywords:** Design Thinking; Sustainable Construction Management; Infrastructure

## INTRODUCTION

Effective construction management involves activities pertaining to the project initiation, planning, building, coordinating, and supervising the construction project from the inception stage to the finish stage. The main purpose of construction management is to deliver the project with proper control over time, cost, and quality. It also includes the identification and effective controlling the productivity challenges in the construction industry.

Managing construction has become inexorably intertwined with sustainability. The requirement for construction managers to have expertise in environmental engineering, building physics, sustainable design, and the commissioning and testing of sustainable buildings is fundamental to problem-solving, professional judgments, and practical decision-making. The sustainable construction program emphasizes management techniques that are useful in organizing, planning, and controlling the activities of diverse specialists working within the unique project environment of the construction industry throughout all phases of development. Design thinking can help to transform the way of development of products, services, processes, and organizations.

## SUSTAINABLE CONSTRUCTION MANAGEMENT

By its nature, the construction industry is a big consumer of natural resources. Now the ever-growing and venerable issue of climate change and ever-diminishing natural resources creates pressure on the construction industry to reduce its carbon footprint. Sustainable construction management includes the following aspects in the site of work;

- ❑ Promoting the usage of renewable and recyclable materials;
- ❑ Initiative to reduce the embodied energy in construction materials;
- ❑ Initiative to reduce the energy consumption of the finished infrastructure;
- ❑ Putting the best effort into reducing on-site waste;



- ❑ Exploring the possibilities of protecting the natural habitats during and after the construction phase.

In addition to the above, effective, sustainable construction management demands the implementation of the following aspects;

- ❑ net zero operational carbon;
- ❑ net zero embodied carbon;
- ❑ sustainable water cycle;
- ❑ sustainable connectivity and transport;
- ❑ sustainable land use and biodiversity;
- ❑ good health and wellbeing;
- ❑ sustainable communities and social value;
- ❑ sustainable life cycle cost.

### **DESIGN THINKING**

In the 1960s, the concept of design thinking was developed by social scientist and Noble laureate Hebert A Simon, who argued that “Everything designed should be seen as artificial as opposed to natural. The engineer and, more generally, the designer should be concerned with how things ought to be in order to attain goals and how to function”.

Human-centred design evolved in the late 1990s when the development of methods described above shifted from a technology-driven focus to a humanized one. Design thinking, as a method of creative action and innovation, was considerably expanded by Rolf Faste at Stanford University between the 1980s and 1990s. In the business context, design thinking was adopted by Faste’s Colleague at Stanford, David Kailey, who started a new program for students from different backgrounds could nurture their creative talent and apply their newfound skills to tough challenges. The Institute came to be known as the Hasso Plattner Institute of Design. Plattner is the founder of SAP, and David Kelley is the founder of IDEO- a firm that pioneers teaching, consulting, and advocating Design Thinking.

Design thinking has a human-centered core. It encourages organizations to focus on the people they're creating for, which leads to better products, services, and processes. When you sit down to create a solution for a business need, the first question should always be -what the human need behind it is?

Design thinking fundamentally recognizes that design should achieve the purpose of desired business goal. It shifts the focus from a business-centered engineering solution( We develop some infrastructure based on some assumptions /commitment, and after development, we wait eagerly for the positive response of the users on the developed Infrastructure) to a customer-centric solution( study the requirement of the user, their lifestyle, behavior, culture, rituals, custom, etc. and developing the Infrastructure around it). Design thinking, therefore, solves the problem and redesign task by working from the viewpoint of the end user to come up with a new approach to processes that address common pain points.

### **DESIGN APPROACH FRAMEWORK**

The followings are some of the mindsets considered in the design approach framework;

- ❑ The show, don’t tell — communicating vision in an impactful and meaningful way by creating experiences, using illustrative visuals, and telling good stories;
- ❑ Focus on human value — empathy for the people you are designing for and feedback from these users is fundamental to good design;
- ❑ Craft clarity — produce a coherent vision out of the messy problem. Frame it in a way to inspire others and fuel ideation;
- ❑ Embrace experiment — prototyping is not simply a way to validate an Idea; it is an integral part of the innovation process;
- ❑ Be mindful of the process — know where one is in the design process, what methods to use in that stage, and what your goals are;
- ❑ Bias towards action — design thinking is a misnomer; it is more about doing than thinking. Bias towards doing and making over thinking and meeting;
- ❑ Radical collaboration — bring together innovators with varied backgrounds and viewpoints. Enable breakthrough



insights and solutions to emerge from diversity.

The design thinking framework comprises five modes- Empathize, Define, Ideate, Prototype, and Validate.

**Empathize:** Human-centric design is based on empathy. Understanding who we are designing for and what is important to them is a prerequisite for meaningful design.

**Define:** Define mode is about summarizing outcomes from empathizing stage into meaningful user requirements and the scope of the problem statement to be solved.

**Ideate:** The goal of the ideate stage is to explore various solutions and options that help address crucial user requirements. The focus here is to generate as many unique ideas as possible. These ideas are then utilized to build a prototype of the solution.

**Prototype:** Prototyping is about taking ideas into the real world. Prototypes are taken to the end users, who review the prototype and highlight its shortcomings if any. Prototyping is done in an iteration, and each iteration brings some improvements over the previous. In addition, if any prototype fails early, making the entire process is inexpensive.

**Validate:** Validate, or testing stage, is when the product is taken directly to the end user for evaluation in order to obtain feedback and make improvements. It is another opportunity to learn about the user and emphasize with them.

### APPLICATION OF DESIGN THEORY OVER THE SUSTAINABLE CONSTRUCTION MANAGEMENT

Design Thinking is considered as an emerging approach to achieve innovation, as appears from its very name it adapts the methods of design and designers to solve real life problems. It is also being referred to as the methods and processes of investigating challenges, acquiring information, analysing knowledge as well as putting the solutions in the design and planning field.

Following Case studies pertaining to the construction management in India are prepared with comparison of traditional thinking and design thinking approach.

**Case Study # 1:** In India, several festivals are celebrated around the year; during these festive periods, the progress and productivity of work at the construction site are hampered due to the non-availability of workers and other technical manpower. The worker desires to meet with their family and friend to celebrate the festival. It is a social requirement, and every organization respects the sentiment of workers. Several organization payout bonuses to the workers to facilitate the enjoyable celebration of the festival.

Solution

Traditional Approach

1. Postponing all the activity during the festive season.
2. The work schedule is revised keeping in view the festivals.

Design Thinking Approach

1. Classifying the workers based on the festival they celebrate.
2. Arranging entertainment activities at the site of work.
3. Paying per task executed during the vacation.
4. Paying extra incentive for the work done during the festive season.

**Case Study # 2 :** Effective management and optimal utilization of all resources in a construction site are very important. The building materials represent important resources, and managing them correctly will definitely lead to project success. For example, brick is one of the important materials in the construction site, and it is very difficult to handle, as it is required in massive numbers, which leads to a notable percentage of waste.

Solution

Traditional Approach

1. Monitoring block stacking process and insuring site preparation for easy maneuvering.
2. Insuring quality control on each phase of the process.
3. Making sub-contractor and supplier accountable for brick waste
4. Recycling bricks waste.

Design Thinking Approach

1. Studying orders history and observing waste ratios so we can control it.
2. Recycling in one of these activities: concrete works, underground cable protection or landscape works.
3. Applying QC plan that contains: monitoring delivery trucks to avoid bumps on roads, frequent visits to supplier factory and maintain site Cleaning.
4. Applying rewards and penalty system for the lowest



5. Verifying quantities before ordering
- and highest waste ratio team.
5. Exploring the possibilities of using large blocks instead of small bricks.

**Case Study #3:** Maintaining proper Health and Safety measures for the workers at the site is mandatory as per the law of the land. But compliance with the safety measures sometimes causes inconvenience to the workers, so they try to avoid it, putting their lives in danger. The organization is accountable & responsible for compliance with the health & safety protocols, and any breach invites legal complications.

#### Solution

##### Traditional Approach

1. Increase awareness and make training to project team.
2. Applying penalty and reward system
3. Monitoring system with team in uniform as policemen.
4. Spreading rumors that there will be law suits against who doesn't oblige to the regulations.

##### Design Thinking Approach

1. Increase awareness by showing videos of dangerous incidents and assuring workers are an important asset for the company.
2. Studying the nature of each trade to make sure that workers are comfortable while working, and noting that low quality supplies will affect the efficiency of work.
3. Gradually applying H&S regulation to set an example and benefiting from competition between different group of workers
4. Giving rewards and appreciation certificates to encourage the teams to excel
5. Making sure not to rotate workers too much until they settle on the new system so we can have better results.

## CONCLUSION

The holistic perspective introduced in construction management allowed the human-centered design to transform from a method to a mindset aiming to humanize the design process and empathize with stakeholders. Sustainable construction management with the application of design theory would promote reducing the negative impacts of the construction on the environment and improve the performance of the Infrastructure and the workforce and send a positive vibe among all the concerned stockholders. It will definitely mitigate the social and global stress on the environmental and natural systems and humanity. Sustainable construction management with a design thinking process, when applied in the construction industry, would help to create socioeconomic conditions conducive to promoting sustainability at all levels of society.

## REFERENCE

1. Mohan Kancharla, Design Thinking in Consulting, Notion Press Media Pvt Ltd.
2. James A Bent and Albert Thumann, Project Management for Engineering and Construction, The Fairmont Press, Inc.
3. P K Joy, Handbook of Construction Management, Macmillan India Ltd.
4. R C Newbold, Project Management in the Fast Lane: Applying the Theory of Constraints, St Lucie Press.
5. A Osterwalder, Y Pigneur, G Bernard and A Smith, Value Proposition Design, Willey India Pvt. Ltd.
6. D Norman, The Design of Everyday Things, Basic Books.
7. T Kelley, The Art of Innovation, Profile Books.

# Experimental Studies on Ground Granulated Blast Furnace Slag (GGBFS) as Supplementary Cementitious Material (SCM) in Concrete

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**Abstract:** Ground granulated blast furnace slag (GGBFS) is a by-product obtained from steel manufacturing industry hence the use of GGBFS as a direct replacement of Portland cement, helps in achieving the green environment. The study presents laboratory investigation results of 11 types of concrete mixes and aims to compare the strength and durability properties of OPC based concrete, fly ash based concrete and GGBFS based concrete for M-50, M-55 & M-60 grades at 7, 28, 56 and 90 days of concrete. Also, the behavior of GGBFS based concrete with varying percentage of GGBFS and at different ages of concrete is evaluated. It is observed that, the OPC concrete yields higher strength at 7 days whereas its strength development ceases after the age of 56 days. The concrete with GGBFS shows higher strength after 56 days when compared with OPC based concrete. It is found that, strength development phenomenon of concrete is increasing constantly with age of cube, for any percentage of GGBFS. The depth of water penetration and chloride ion penetration of GGBFS based concrete is significantly less as compared to OPC concrete and fly ash based concrete. Cost analysis of concrete with different SCM indicates GGBFS based concrete as economical solution.

**Keywords:** Ground Granulated Blast Furnace Slag (GGBFS); Supplementary Cementitious Material (SCM), GGBS in Concrete; Durability Properties of Concrete

## INTRODUCTION

These days concrete has been an indispensable, most liked and widely used construction material. Concrete, basically is a combination of specified proportions of cement, fine and coarse aggregates, water and admixture if required. The specified proportion of these components in concrete are designed so that the concrete produced is strong and durable enough to meet the requirements of its intended use. Practically, concrete is considered to be acceptable if the compressive strength requirements are met. However, this may not necessarily satisfy the durability aspects like water penetration depth, chloride penetration etc. In quest of making concrete economical for specified strength and durability requirements, use of Supplementary Cementitious Materials (SCM) or Mineral Admixture has gained importance now-a-days. These SCMs, as specified by BIS 456 : 2000 may be either Pozzolanic materials like fly ash, Silica fumes, Rice husk ash and metakaoline or Ground Granulated Blast Furnace Slag (GGBFS), are used as a partial replacement of cement in concrete, in order to reduce the cement content, thereby reducing CO<sub>2</sub> emissions associated with its production. Either of these SCMs along with cement are termed as Cementitious Material in concrete. Generally, the percentage of fly ash as part of the total cementitious materials in concrete ranges from 15% to 25% of cement, whereas that of GGBFS ranges from 25% to 50% of cement.

## Objective of Study

The present study aims to determine the strength & durability properties of different grades of concrete i.e. M-50, M-55 and M60 with GGBFS at 45% of cement, fly ash at 20% of cement and 100% OPC. The compressive strength of 150 mm concrete cube at age of 7, 28, 56 and 90 days and durability properties, like permeability, chloride penetration by Rapid Chloride Penetration Test (RCPT) at age of 56 days are obtained by laboratory experiments and are compared to understand the behavior of GGBFS based concrete. Also, the strength and durability properties of concrete using 25%, 35% and 45% percentage of GGBFS as replacement to OPC, for M-50 grade of concrete is evaluated to determine the best optimum proportion of GGBFS in concrete.

## LITERATURE REVIEW

Oner, et al (2007) have conducted laboratory investigations to determine the optimum proportion of GGBFS on



compressive strength of concrete. During investigation 32 mixes were prepared in four groups based on binder content. Tests were performed on concretes with GGBFS amounting to 0%, 15%, 30%, 50%, 70%, 90% and 110% of cement content and cured for 7, 14, 28, 63, 119, 180 and 365 days before conducting tests for compressive strength. The experimental investigations proved that, increase in percentage of GGBFS in concrete increases the compressive strength of concrete mixes, till an optimum point at around 55% of cementitious content. The quantity of GGBFS in concrete in excess of 55% of binder content remains unreacted and acts only as a filler material in the paste, rendering no improvement in compressive strength of concrete mixes.

Siddique, et al (2012) investigated the hydration reaction of GGBS in the cement paste. The GGBS particles get activated by the alkali present in the cement and form their own hydration products. Some of the hydration products of GGBS react with Portland cement again to form hydrates which tend to block the pores. This results in a cement paste with very fine gel pores. The hardened cement paste is more stable due to lesser free lime content. GGBS does not contain any Tri Calcium Aluminate (C3A) and its inclusion in concrete reduces the overall proportion of C3A in the concrete mix and increases the sulphate resistance.

Karri, et al (2015) performed laboratory studies on M-20 and M-40 grade of concrete with partial replacement of cement with GGBFS at 30%, 40% and 50%. The study is conducted on cubes, cylinders and prisms for compressive strength, split tensile strength, flexural strength respectively and for Durability studies, the cube specimen were cured with 1% sulphuric acid solution and 1% hydro chloric acid solution for 90 days and with 5% sulphuric acid solution and 5% hydro chloric acid solution for 28 days, before testing for compressive strength. It is observed that, the workability, compressive strength, flexural strength and split tensile strength of concrete increased with when cement is replaced with GGBFS and maximum increase of all these parameters was observed when GGBFS is replaced at 40% of cement. The study also revealed that compressive strength values of acid effected concrete decreased as compared to that normal concrete, however the effect of acid on concrete decreases with the increase of percentage of GGBS.

Suresh, et al (2015) concluded that, GGBFS based concrete offers high resistance to attack in aggressive environments probably due to dense and strong microstructure of interfacial aggregate – binder ratio and due to mineral composition of GGBFS – cement paste.

Saranya, et al. (2017) has observed that, the replacement of OPC with GGBFS to extent of 35-40% of cement produces a durable concrete with increased resistance to sulphate attack, increased resistance to alkali silica reaction, reduced chloride ion ingress which enhances corrosion resistance. The GGBFS based concrete can be used for any civil engineering application including building, bridges, prestress element etc.

Nanthagoplan (2017) has conducted laboratory experiment to obtain the optimum proportion of GGBFS. The study was conducted replacing GGBFS with cement for 0%, 40%, 50%, 60%, 70% and the concrete so produced was tested for properties of fresh and hardened concrete at age of 28 and 56 days. For hardened concrete, compressive strength, flexural strength, abrasion resistance and hardened density whereas durability properties like water absorption, water penetration, chloride migration, accelerated carbonation is investigated. The results of the study revealed that, the compressive strength and water penetration was higher for 40% replacement whereas, flexural strength and abrasion resistance was better at 50% replacement of GGBFS. The higher resistance to chloride penetration and lower carbonation depth was observed with increase in GGBFS content.

## EXPERIMENTAL INVESTIGATION PLAN

The laboratory investigation programme is planned in 5 steps elaborated as under:

1. Determine the properties of the materials such as cement, sand, coarse aggregate, water and GGBS.
2. Prepare Mix proportions of concrete for M-50, M-55 and M-60, using OPC, fly ash at 20% replacement and GGBFS at 45% replacement, as per guidelines recommended in BIS 10262 : 2019.
3. Casting trials of concrete mixes as per the Mix Proportions and casting cubes of every trial for 7, 28, 56 and 90 days of compressive strength testing and for 56 days of water penetration and chloride penetration (RCPT) testing. Curing the specimens for 7, 28, 56 and 90 days.
4. Determining compressive strength at 7, 28, 56 and 90 days and water penetration and chloride penetration (RCPT) testing on 56 days cured samples.
5. Collecting, processing and analyzing the test results and checking the economic viability of all mixes.



### Materials used in Study

The materials, along with their properties, used in the study are tabulated as under in **Table 1**. The sieve analysis, as per BIS 2386 (Part 1) : 1963 (RA 2016), of fine and coarse aggregates used in the study yielded results s graphically presented in **Figure 1**.

### Mix Proportioning and Test Methods Adopted

Based on the properties of materials as stated above, the mix design for various grade of concrete with different cementitious materials was performed as per guidelines specified in BIS 10262 : 2019 and BIS 456 : 2000 (RA 2021).

The concrete mix were designed considering following parameters:

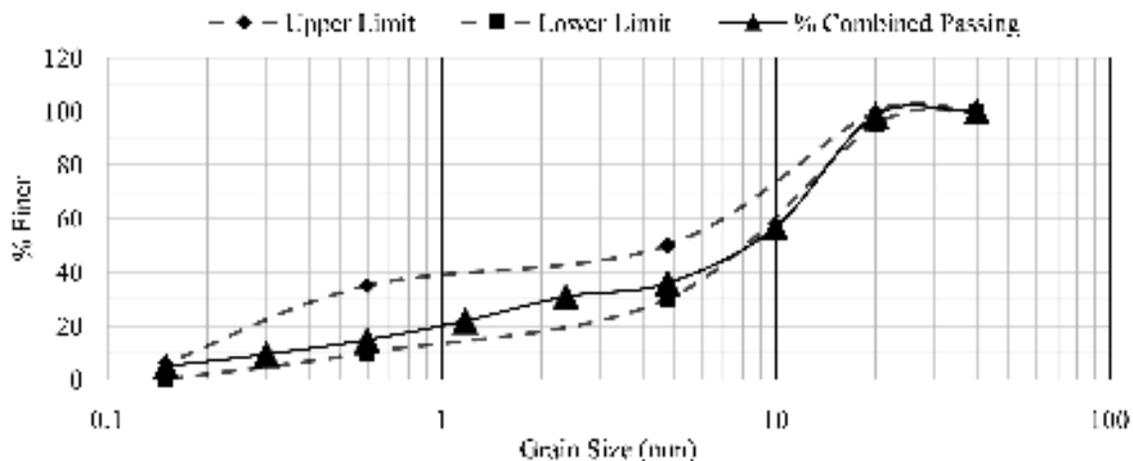
- (a) Nominal maximum size of aggregates (NMSA) as 20 mm;
- (b) Exposure— for severe conditions;
- (c) Workability— for collapse slump with retention time of 120 minutes;
- (d) The value of standard deviation for computing the design target strength was considered as 5.0 N/mm<sup>2</sup> and the design target strength for M-50, M-55 and M-60 is worked out as 58.25, 63.25 and 68.25 N/mm<sup>2</sup>, respectively.

The adopted proportions of cementitious material is tabulated in **Table 2**.

For all the above mentioned concrete grades, the compressive strength of 150 mm cubes at age of 7, 28, 56 and 90 days were tested in accordance with BIS 516: (Part 1/Sec 1) : 2021 whereas the depth of Water penetration test as per IS 516 (Part 2/ Sec 1) : 2018 and Rapid Chloride Ion permeability test as per ASTM C 1202 at 56 days were carried out.

**Table 1** Material used in study and their properties

Ingredients - Type & Grade of Material	Brand / Source of Material	Specific Gravity	Water Absorption (%)	Dry Loose Bulk Density
Cement - 53 grade OPC	JSW Cement	3.10		
Mineral Admix. 1 - GGBFS	JSW Cement Ltd	2.90		
Mineral Admix. 2 - Flyash	Adventures	-		
Chemical Admix. 1 - Superplasticizer	Cryso Delta G7325 (High PCE based)	1.106		
Coarse Aggregate	20 mm	2.84	1.20	1.50
	10 mm	2.72	1.20	1.40
Fine Aggregate	C Sand	2.67	3.40	1.78
Water	Laboratory Tap water	1.00	pH = 6.80	



**Figure 1** Grain size distribution curve for all-in-aggregates

**Table 2** Proportion of cementitious materials (at SSD condition) adopted

Sr. No.	Cementitious Material	Grade of Concrete	Cement (kg)	Fly Ash (kg)	GGBFS (kg)	Total Cementitious Material (kg)	w/cm Ratio
1.	100% OPC	M - 50	470	0	0	470	0.28
2.	100% OPC	M - 55	500	0	0	500	0.25
3.	100% OPC	M - 60	530	0	0	530	0.24
4.	OPC + 20% Fly Ash	M - 50	400	100	0	500	0.26
5.	OPC + 20% Fly Ash	M - 55	416	104	0	520	0.24
6.	OPC + 20% Fly Ash	M - 60	440	110	0	550	0.23
7.	OPC + 45% GGBFS	M - 50	286	0	234	520	0.25
8.	OPC + 45% GGBFS	M - 55	297	0	243	540	0.24
9.	OPC + 45% GGBFS	M - 60	308	0	252	560	0.22
10.	OPC + 35% GGBFS	M - 50	332	0	178	510	0.26
11.	OPC + 25% GGBFS	M - 50	375	0	125	500	0.26

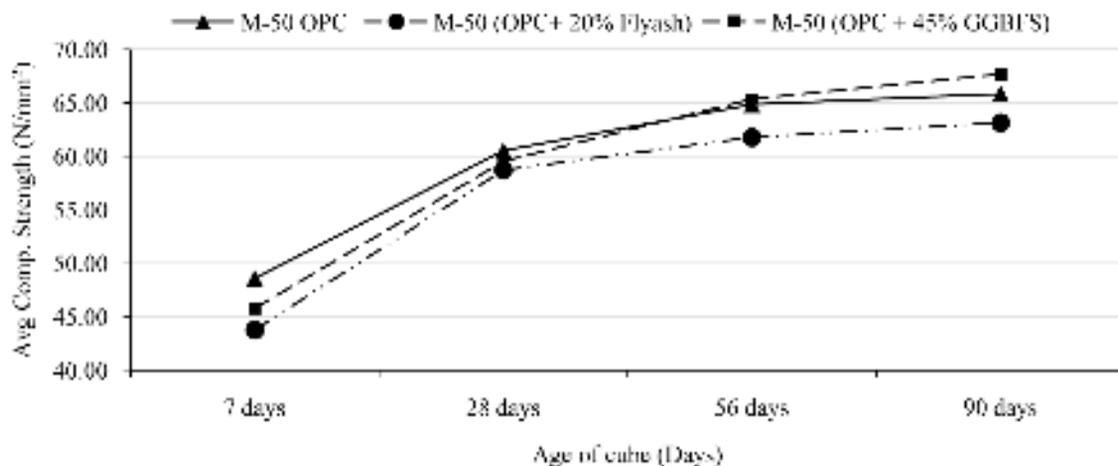
**RESULTS AND DISCUSSION:**

**Compressive Strength Studies**

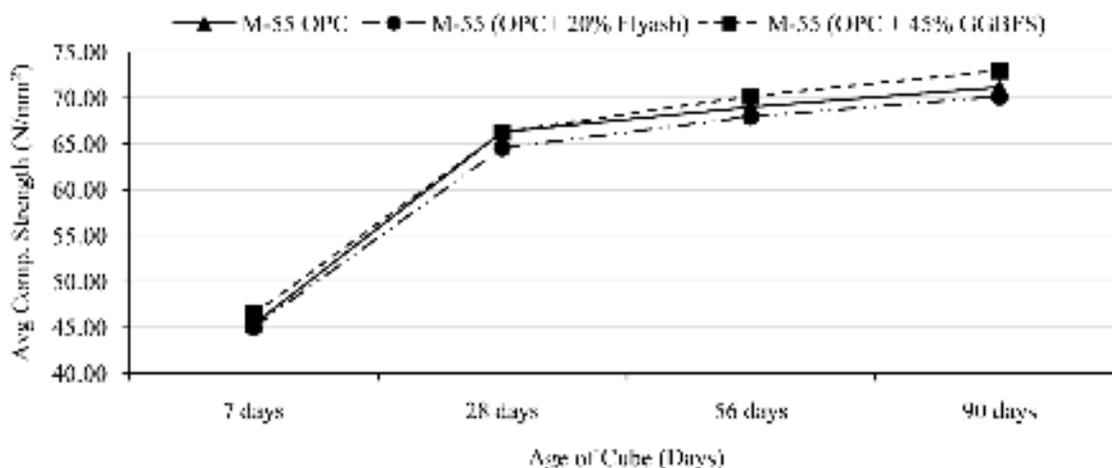
The development of compressive strength over 7, 28, 56 and 90 days for M-50, M-55 and M-60 grade of concrete, is depicted in graphs at **Figures 2 to 4**, respectively.

It can be seen from **Figure 2** that, for M-50 grade of concrete initially i.e. 7 days compressive strength of GGBFS based concrete is approx. 6% lesser than OPC based concrete. However, for higher ages the strength development of GGBFS surpassed the OPC based concrete. It is also observed that, the development of strength of OPC concrete has nearly ceased after 56 days, whereas for fly ash based concrete and GGBFS based concrete, the strength increases linearly with age till 90 days. At lower grade of concrete M-50, the compressive strength of fly ash based concrete is considerably lesser than GGBFS based concrete at any age of concrete.

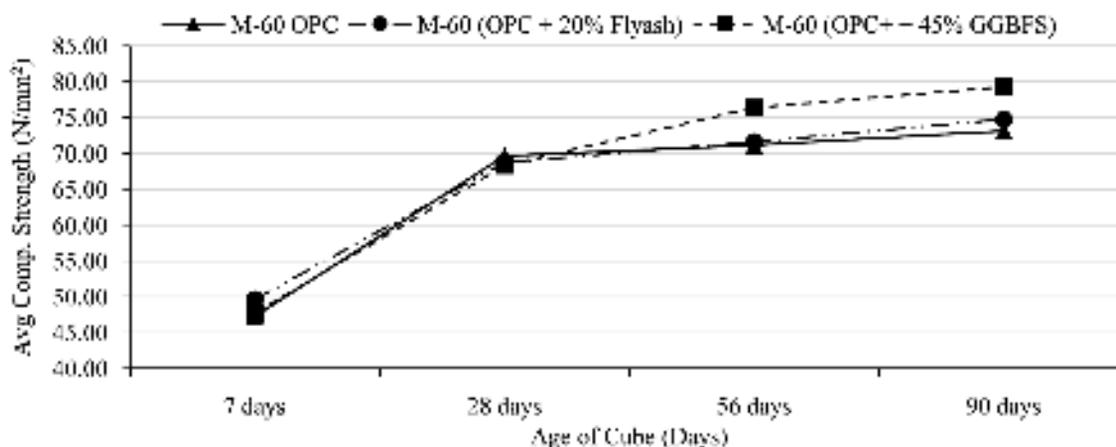
It can be seen from **Figure 3** for M-55 grade of concrete, the strength of all 3 type of concrete is marginally same at 7 days. However, at 28 days, the strength of GGBFS based concrete is almost same as that of OPC based concrete and in



**Figure 2** Development of strength over different ages of concrete for M-50 grade



**Figure 3** Development of strength over different ages of concrete for M-55 grade

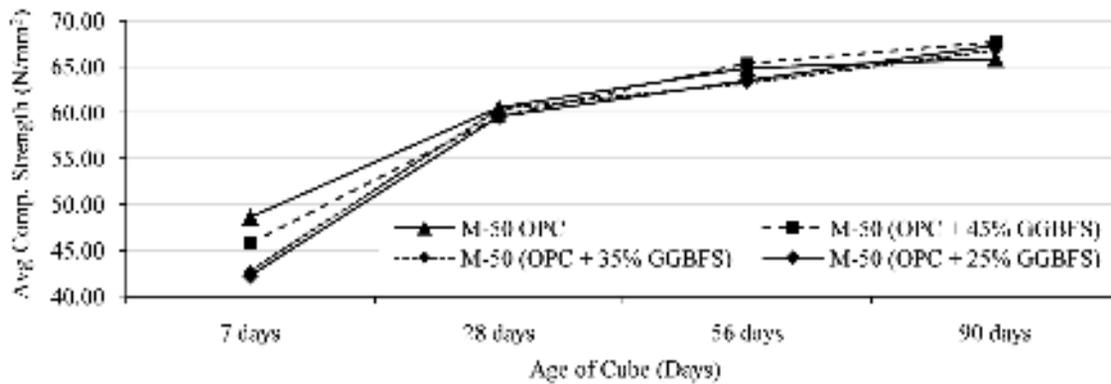


**Figure 4** Development of strength over different ages of concrete for M-60 grade

later ages, the strength of GGBFS based concrete is marginally better than OPC concrete. A similar pattern, like that of in M-50 grade, is observed, the development of strength of OPC concrete has nearly ceased after 56 days, whereas for flyash based concrete and GGBFS based concrete, the strength increases linearly with age till 90 days. For M-55 grade of concrete, the compressive strength of fly ash based concrete is still lesser than GGBFS based concrete at any age of concrete.

It is observed from **Figure 4** for M-60 grade of concrete, the strength of all 3 types of concrete is marginally the same at 7 days and at 28 days. However, at 56 days, the strength of fly ash based concrete is almost same as that of OPC based concrete and strength of GGBFS based concrete is 7.32% more than OPC concrete which increased to 8.43% at 90 days. A similar pattern, like that of in M-50 and M-55 grade, is observed, the development of strength of OPC concrete has nearly ceased after 56 days, whereas for fly ash based concrete and GGBFS based concrete, the strength increases linearly with age till 90 days. For M-60 grade of concrete, the compressive strength of fly ash based concrete is still lesser than GGBFS based concrete at any age of concrete.

**Figure 5** indicates that, the compressive strength at 7 days age of GGBFS based concrete is considerably less than that of OPC concrete. But, the strength of OPC concrete has ceased after 56 days, whereas the strength of GGBFS based concrete in any proportion of GGBFS gains strength even after 56 days. Therefore, it can be considered that, the strength development phenomenon is consistent with GGBFS based concrete, irrespective of proportion of GGBFS used. It is also observed that, strength of concrete with 35% GGBFS and that with 25% GGBFS is almost equal throughout the age, whereas strength of concrete with 45% GGBFS is considerably higher than other proportion, thereby indicating higher



**Figure 5** Development of strength over different ages of concrete for M-50 grade with different proportion of GGBFS and compared with OPC concrete

the proportion of GGBFS and higher grade of concrete, higher the strength at any age of concrete as compared to OPC cement.

#### Studies on Depth of Water Penetration

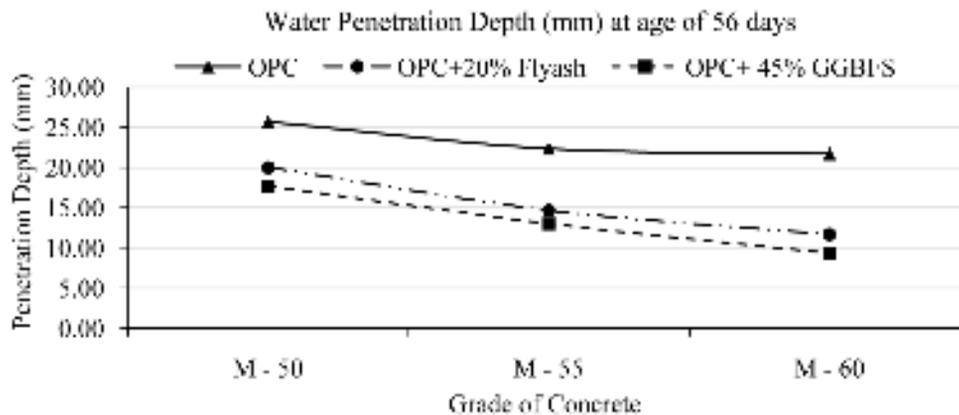
The concrete with OPC, 20% fly ash based concrete and 45% GGBFS based concrete is tested for depth of water penetration under pressure, as per IS 516 (Part 2): Sec 1, for M-50, M-55 and M-60 grade and the results are depicted in **Figure 6**. It is evident from **Figure 6** that, higher is the grade of concrete, lesser is water penetration. Also, it is clear that, the concrete with Mineral admixture, viz. fly ash and GGBFS, is more impermeable as compared to OPC concrete. Impermeability of GGBFS based concrete is higher than fly ash based concrete and much better than OPC concrete.

#### Studies on Durability of Concrete

In order to compare the durability aspect of concrete with different mineral admixture and OPC, Rapid Chloride Penetration Test, as per ASTM C1202-12 is conducted on 56 days cube sample of concrete with OPC, 20% fly ash based concrete and 45% GGBFS based concrete of M-50, M-55 and M-60 grade and the results are presented graphically in **Figure 7**. The results of chloride penetration of concrete are similar to that of water penetration. It is evident from **Figure 7** that, higher is the grade of concrete, more durable is the concrete. Also, the concrete with Mineral admixture is nearly two times durable as compared to OPC concrete. GGBFS based concrete is durable than fly ash based concrete and much durable when compared to that of OPC concrete.

#### Cost Analysis of Concrete with Different Cementitious Material

An attempt is made to compare the cost of cementitious material for concrete as indicated in **Table 2** and the results are shown in **Figures 8** and **9**. The base rate of cement and GGBFS is considered as Rs. 5600/- per MT and Rs. 4160/- per MT respectively, as per SSR 2021-22 whereas for fly ash is considered as Rs. 1000/- per MT, as per market rate.



**Figure 6** Water penetration depth of different grades of different concrete at 56 days

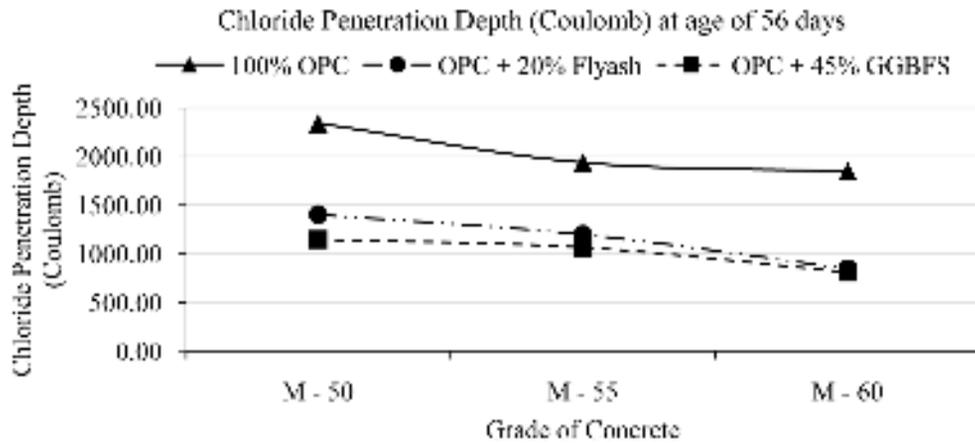


Figure 7 Chloride penetration of different grades of different concrete at 56 days

It can be seen from **Figure 8** that, for lower grade of concrete the cost of OPC and GGBFS is almost same, however for M-60 grade of GGBFS based concrete is almost 6.50% economical than that of OPC concrete and the percentage drops to 4.50% when compared for M-55 grade. Therefore, GGBFS based concrete is more economical as compared to OPC concrete for higher grades. It is observed from **Figure 9** that, the cost of 45% GGBFS concrete is lesser than other proportions of GGBFS based concrete. Hence, the greater is proportion of GGBFS, more economical is concrete.

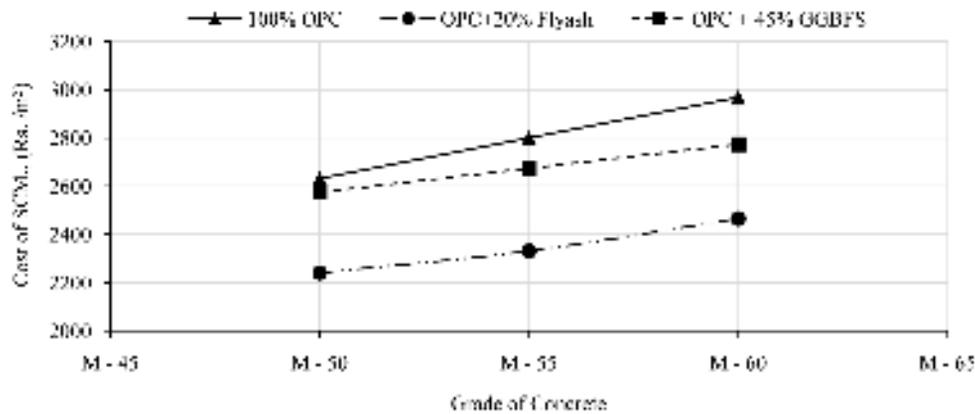


Figure 8 Comparison of cost of various grade concrete with different SCM

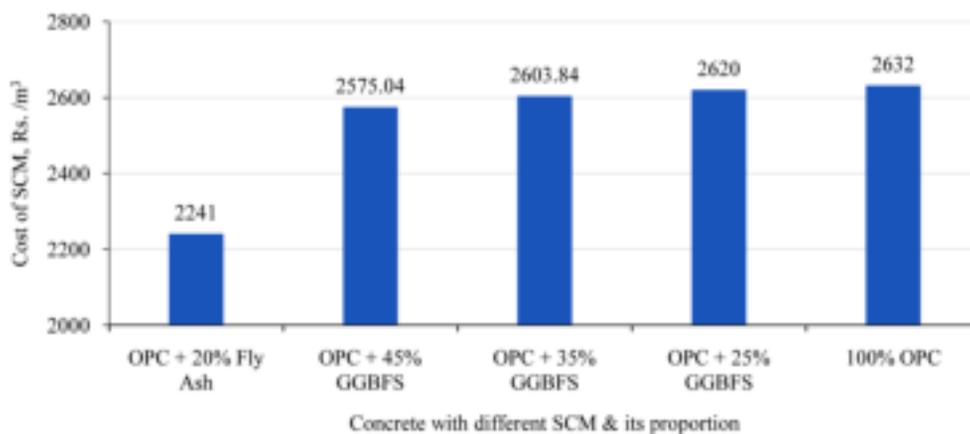


Figure 9 Comparison of cost of concrete of M-50 grade with different SCM



## CONCLUSION

Based on laboratory based experimental investigations on concrete produced using OPC, fly ash and GGBFS and relating the results of investigations with studies presented in literature, the following conclusions are drawn:

1. The strength development of OPC concrete ceases after 56 days, whereas that for fly ash based concrete and GGBFS based concrete, the strength increases linearly with age of concrete;
2. The early strength of GGBFS based concrete is less than OPC concrete of any grade, as the pozzolanic reaction starts after hydration of Portland cement and depends on availability of Calcium hydroxide from hydration of Portland cement. However, the strength of GGBFS based concrete increases gradually with increase in age of concrete, as pozzolanic reaction is slow, and surpasses the strength of OPC concrete approx. after 56 days;
3. The early strength of concrete with 25% and 35% proportions of GGBFS is less as compared to that of 45% proportion of GGBFS. Lesser content of GGBFS in concrete produces less hydrates of GGBFS and cement, which reduces heat of hydration, resulting in lower early strength, for lesser GGBFS content;
4. The strength of fly ash based concrete is lower than that of GGBFS based concrete, for any grade and at any age of concrete;
5. The percentage of GGBFS in concrete do not affect the strength development process in concrete, however, for high strength concrete it is recommended to obtain optimum percentage of GGBFS content, as excess GGBFS in concrete do not contribute to pozzolanic reaction and acts merely as aggregate or filler in concrete;
6. Depth of water penetration in GGBFS based concrete is significantly less than fly ash based concrete and much better than OPC concrete, thereby rendering concrete more impermeable. When GGBFS is used in concrete, the cement paste with very fine gel is formed which is more stable, thus making the concrete impermeable;
7. Chloride ion penetration in GGBFS based concrete is also significantly less than fly ash based concrete and much better than OPC concrete, as a result, making the concrete more durable. Since GGBFS does not contains Calcium Tri silicate, inclusion of GGBFS in concrete imparts chemical resistance property to the concrete;
8. For higher grade of concrete produced with GGBFS, the cost of cementitious material is less. Also, greater the proportions of GGBFS, the concrete produced is more economical.

Finally, it can be concluded that, the optimum proportion of GGBFS in concrete is key to the strength and durability properties of concrete. Different researchers have reported different optimum proportions of GGBFS in concrete, however, broadly the average range of GGBFS proportion in concrete varies from 40%-50% of total cementitious material. It is suggested to derive the optimum percentage of GGBFS based on requirement of the project.

## ACKNOWLEDGEMENT

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## REFERENCES

1. Binod Kumar, et al, Report Titled, Design and Evaluation of Pavement Quality Concrete Mixes using Ground Granulated Blast Furnace Slag as Partial Replacement of Cement, Rigid Pavement Division, CSIR Central Road Research Institute (CRRI), 2016.
2. Dr. Prakash Nanthagopalan, Report Titled, Potential use of Ground Granulated Blast Furnace Slag (GGBFS) as Supplementary Cementitious Materials in Concrete : Final Report, IIT Bombay, 2017.
3. P Saranya, et al., Eco-friendly GGBFS Concrete: A State-of-The-Art Review, IOP Conf. Series: Materials Science and Engineering, vol 330, 2018, 012057, doi:10.1088/1757-899X/330/1/012057.
4. A H L Swaroop, et al, Durability Studies on Concrete with Fly Ash & GGBFS, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, vol 3, issue 4, July-August 2013, pp 285-289.
5. D Suresh, K Nagaraju, Ground Granulated Blast Slag (GGBS) in Concrete : A Review, IOSR Journal of Mechanical



- and Civil Engineering, e-ISSN: 2278-1684, vol 12, issue 4, 2015, pp 76 – 82.
6. A Oner, S Akyuz, An Experimental Study on Optimum Usage of GGBS for the Compressive Strength of Concrete, Cement & Concrete Composites, vol 29, issue 6, 2007, pp 505–514.
  7. S K Karri, et al, Strength and Durability Studies on GGBS Concrete, SSRG International Journal of Civil Engineering, vol 2, issue 10, 2015, pp 34 – 41
  8. R Siddique, R Bennacer, Use of Iron and Steel Industry by-product (GGBS) in Cement Paste and Mortar, Resources, Conservation and Recycling, vol. 69, 2012, pp 29-34.
  9. BIS 456 (2005) Plain and Reinforced Concrete – Code of Practice, Bureau of Indian Standards.
  10. BIS 516 (Part 1 / Section 1) : 2021 – Hardened Concrete – Method of Test.
  11. BIS 516 (Part 2 / Section 1) : 2018 – Hardened Concrete – Method of Test.
  12. IS 10262 (2019) Concrete Mix Proportioning Guidelines. Bureau of Indian Standards.
  13. ASTM C 1202-12 - Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration, ASTM International.
  14. State Schedule of Rates, 2021-22, Govt. of Maharashtra.



# Stabilisation of Soil using Plastic Waste as a Reinforcing Material, as well as the Comparative Study of Egg Shells and Chir Pine Needle Leaves as a Binder: A Review

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**Abstract:** Soil stabilisation or reinforcement is a prominent and renowned method of enhancing soil properties, most notably shear strength in weak and poor-quality soil. Plastic waste has become a rising concern in recent years, and hence, a solution for its effective and proper disposal is necessary. As such, many researchers have proved plastic waste to be an effective reinforcing material for low strength soil through their laboratory investigations. The egg shell waste material is widely accessible and has the same composition and chemical qualities as lime, which is utilised for soil stabilisation. Also, chir-pine needle leaves have been discovered to be a suitable binding material. As a result, a research study on the utilisation of plastic waste, as a reinforcing material for soil reinforcement, as well as a comparative study between egg shell and chir pine needle leaves as a binder, is done in this paper. This has a great scope and potential for sustainability as waste produces are being reused and recycled. To provide an insight on the subject at hand and to derive conclusions, several sorts of journal publications were thoroughly analysed and evaluated.

**Keywords:** Soil Stabilisation; Plastic Waste; Pine Needle Leaves; Egg Shell

## INTRODUCTION

In geotechnical engineering practices, it is often necessary to examine soil characteristics in order to modify their qualities to fit various civil engineering projects. Soil is regarded as one of the most cost-effective building materials available. However, if the soil is weak and no thorough investigation and corrective measures are taken, the buildings may fail, resulting in a massive financial loss. There are several varieties of soil, and they respond differently under different situations. Under all situations, all soil types do not respond well. When locally accessible soil with poor qualities is discovered, it is either completely removed or modified with appropriate additives to suit the field requirements. In this case, soil stabilisation has proved to be favourable in almost every type of soil engineering problem. It is most commonly used to improve soil strength and reduce compressibility by binding the soil particles together. This technique makes the soil more stable and reduces volume change, making it suitable for use. Some admixtures need be added to improve their qualities for this purpose, but most of them are expensive and not economical. Hence, stabilisation of soil using naturally available and waste materials is the need of the hour. Thus, soil stabilisation with various forms of plastic waste is an effective alternate way for enhancing the subgrade and earth embankment stability.

As per statistics, India generates approximately about 3.46 lakh million tonnes plastic waste, out of which 50% of it is recycled. As per FICCI estimate, the average per capita plastic use in India is roughly 11 kg. According to the Ministry of Petroleum and Natural Gas, India's annual per capita consumption would be 20 kg by the end of 2022. Hence, this new soil stabilising approach may be utilised efficiently to fulfil societal concerns and minimise the amount of waste plastic, resulting in an eco-friendly safe environment. Experimental study done on reinforced plastic soil demonstrated that plastic may be utilised as an efficient stabiliser to address waste disposal issues as well as an economical alternative for stabilising unstable soils.

Eggshell Powder (ESP) has been used as a stabilizing material in soils in recent years to increase its strength behaviour. Because its chemical composition is comparable to that of lime, ESP might be a potential alternative for chemically manufactured lime. Its main components are calcium, magnesium carbonate (lime), and protein [15]. As per Economic Survey 2021-2022, India stands at the third position of egg produced globally, at 1.83 billion and one can imagine the amount of egg shell waste produced and disposed of. This must be managed efficiently in order to reduce the burden on the country's landfills. As a result, in the absence of a suitable waste disposal strategy, the use of eggshell in soil stabilisation will be an option.



According to statistics, India's annual gross pine needle production is estimated to be 1.9 million tons, with an annual net pine needle yield of 1.33 million tons. Pine needle is a bio-renewable resource that is available in abundance in India and may be manufactured at a minimal cost in a processed form. As a result, a lot of waste is produced and remains unused. Researchers have discovered that using fibres as a binder, has helped enhanced the strength of the soil and hence improved the overall stability of poor-quality soil.

### **MATERIALS USED AND SAMPLE PREPARATION**

The materials employed by various different researchers in their field of study in relation to the topic includes soil, plastic waste, egg shell (preferably derived from chicken) and chir pine needle leaves.

#### **Soil**

Soil is the main significant material used for any laboratory research project. The type of soil particle typically used includes sand [5], clay, such as Kuttanad clay where the mineral constituents are kaolinite and illite [3], black cotton soil [4], loamy soil containing silt, clay and sand [6], red mud [7], clayey-sand soil [8], dune sand [9], and so on, of different particle dimension like size (0.02mm, etc), shape (angular, spherical, flat, etc.) and colour (light coloured to dark coloured soil particle).

From several research studies, it was observed that the different types of soil samples used for research were first collected from their respective site of study and were oven-dried and sieved before performing any experimental procedure. The soil sample was then tested and once the results were obtained, the soil was then mixed with either plastic waste or egg shell powder or chir pine needle fibre individually, or combined together. The content of the materials to be added plays a significant role in achieving the desired result.

#### **Plastic Waste**

Plastics are defined as synthetic materials that contain polymers as a key component and are regularly produced using various machinery and has been used continuously in our day-to-day life. Plastic Waste are generally categorised into seven different types which includes Polyethylene Terephthalate (PET) waste, such as soda bottles, bakery products, and frozen food packaging; High Density Polyethylene (HDPE) waste, such as milk and shampoo bottles; Low Density Polyethylene (LDPE) waste, such as toys, lids, plastic bags, and computer components; Poly Vinyl Chloride (PVC) waste, such as blood bags, wire and cable insulation; Poly Propylene (PP) waste, such as bottle taps and Luggage; Polystyrene (PS) such as CD and DVD cases and egg cartons; and Miscellaneous plastics such acrylic, styrene, fibre-glass, and nylon.

As per journals reviewed, plastic wastes were collected from the place of study, washed clean and dried. They were either cut into strips of appropriate dimensions of length and width or shredded into smaller pieces with the help of a shredder machine. The amount of plastic waste used just with soil or in combination with egg shell and pine needle leaves determines its optimum result to be achieved.

#### **Egg Shells**

An eggshell has approximately 17,000 small holes and is bumpy and gritty in texture. Because it is a transparent membrane, air and moisture may pass through it. The shell also has a thin outer covering called the bloom or cuticle that serves to keep pathogens and dust out. A single eggshell weighs six grams and contains around 220 milligrams of calcium (228 gm).

The egg shells were collected from various different poultry farms, factories, restaurants and fast-food corners and properly cleaned of any unwanted substance. The inner membrane of the shell was carefully removed and then the shell was dried in the oven or in the sun. After a certain period of drying (two weeks or a month), the shells were crushed and grounded into powder form. They were then passed through a sieve (usually #200 sieve or 75-micron sieve) to attain uniformity of the material.

#### **Chir-Pine Needle Leaves**

Chir, commonly known as Chir Pine, is a species of pine in the Pinaceae family with the botanical name "Pinus Roxburghii Sarg". Chir pine leaves are needle-like, thin, and yellowish green. The plant grows best in well-drained light sandy or gravelly loamy soil. Chir pines normally do not let any vegetation to grow around them because their falling needles make the soil more acidic. Chir pines are most prevalent in Himachal Pradesh, Kashmir, Arunachal Pradesh, Sikkim and Uttarakhand.



**Table 1** CBR and UCS test results obtained from the study of various researchers

Sl. No	Author's Name	Title of Journal Paper	Year Published	The Type of Soil Sample used	Name of Tests done - Strength Parameter based	The Type of Plastic used	Percentage of Material used for optimum effect			Results obtained
							Plastic Waste (%)	ESP (%)	CPNLF (%)	
1	B. A. Katar and H. P. Vageesh [4]	Effect of Discarded Plastic Waste as Stabilizer on Engineering Properties of Cohesive Soil [4]	2017	Black Cotton soil	UCS  CBR	Shredded mixture of PET	1.25%,  0.4%	—  —	—  —	10.187 N/cm <sup>2</sup> .  1.54% at 5 mm (45.74% increase of AI) penetration (unsoaked)
2	H. J. A. Hassan & J. Rasol and M. Samin [10]	Effects of Plastic Waste Materials on Geotechnical Properties of Clayey Soil [10]	2021	Clayey-Silty	UCS  CBR	Fibre Strips of PET  PP	1% at 1cm and 2cm fibre length, 1cm and 2cm 6.2mm and 7.2 mm	—  —	—  —	261 kPa and 291 kPa  6.2 % and 7.2 % (unsoaked)  233 kPa and 256 kPa  5.7 % and 5.0 % (unsoaked)
3	S. Peddiah, A. Burman and S. Sneekap [6]	Experimental Study on Effect of Waste Plastic Bottle Strips in Soil Improvement [6]	2018	Loamy soil having depositions of clay, silt and sand	CBR	PET	0.4% of 15x15 mm strip size	—	—	16.5 mm penetration (unsoaked)
4	D. Garketa, R. Lucin, M. Nasser, S. Caravada and A. Simón [8]	Soil stabilization with waste plastic and waste tyre fibres [8]	2019	Clayey-Sand of reddish-brown colour, with fines	CBR	Shredded PET and PPE	1%	—	—	2.5 mm (36% increase of AI) and 5.0 mm (27% increase of AI) penetration (unsoaked)

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5	M. N. J. Alzaidy [13]	Experimental study for stabilizing clayey soil with eggshell powder and plastic wastes [13]	2019	Silty-Clay	UCS  CBR	Strips of PET	1%	5%	—	591 kPa  7.70 % (soaked) (2.8 times increase of A1) 9.20 % (unsoaked) (2.1 times increase of A1)
6	P. G. Sameer, S. N. Sanjay and D. S. Bhaskar [14]	Stabilization of Soil by the Composition of Eggshell Powder and Shredded PPE Kit [14]	August 2021	Soft Clay	UCS	Shredded Strips of PPE	Varying	2%	—	0.98 kg/cm <sup>2</sup>
7	K. Prasad, N. Mathachan, P. P. Junes and T. L. Justine [12]	Effect of Curing on Soil Stabilized with Egg Shell [12]	June 2016	Kumana d clay containing alluvial deposits [12]	UCS	—	—	15%	—	196.311 N/mm <sup>2</sup> (7 days)
8	P. Rani and Er. T. Gnyal [15]	Improvement of Engineering Properties of Soil Using Chir Pine Needles [15]	May 2019	Clay	UCS  CBR	—	—	—	1%  1%	5.61 kg/cm <sup>2</sup> at 3cm fibre length  2.66% at 2.5mm penetration (soaked) at 5cm fibre length
9	A. Kandel et al. [1]	Stabilization of Soft Soil with Pine Needles and Lime [1]	June 2020	Weak, Soft Clay	UCS	—	—	—	0.5% at 1cm fibre length	0.722 MPa (28 days curing)
10	V. Singh and A. Rani [16]	A laboratory study on pine needle reinforced soil [16]	May 2018	Silty	CBR	—	—	—	1% at 4cm fibre length	4% at 5 mm penetration (soaked)  22.5% at 5 mm penetration (unsoaked)



The Chir Pine Needle leaves were collected, cleaned and dried till brownish in colour. They were then burnt off as ash or cut into strips of required length. They were used in combination with soil to analyse their strength or in combination with other binders.

## RESULT AND DISCUSSION

From on the experimental results obtained from shear strength parameter tests of CBR and UCS, the following had been observed.

### CBR Test

The optimum value of the soil for CBR test was attained in a majority of the test results collected from different researchers' CBR experiments by adding plastic waste (PET and PPE) at a specified percentage or limit. In the instance of Black Cotton soil, the addition of plastic waste to the soil had resulted in just a slight rise in the CBR value of the soil, showing that the inclusion of plastic waste has no considerable effect on the CBR value of black cotton soil[4]. As was found for clayey-silty soil, the amount of plastic fibre content and fibre length had a substantial influence on CBR values. The presence of plastic fibre often causes an increase in the CBR value because it offers resistance to the penetration plunger, resulting in an increase in the CBR value[9]. The structure, form and type of surfaces of plastic strips is also essential in improving the strength qualities of soil plastic mass. When the plastic strips utilised have undulated surfaces, the cohesion and internal friction angle increases. If the surfaces of the plastic strips are plain/smooth, it may be impossible to raise both shear strength parameters[6]. When the eggshell powder concentration was increased, the curing period was shown to considerably enhance the engineering properties of stabilised soil samples. Based on the test results of the soaked CBR value, it was determined that the ideal value of Chir pine needles is 1% with a length of 5 cm[15].

### UCS Test

In the case of black cotton soil, a linear rise in UCS of soil was observed with increase in the concentration of plastic waste, as a result of increased internal friction with plastic waste addition [4]. The optimal fibre percentage for clayey-silty soil was determined to be 1% at 2 cm fibre length for PET and PPE. Increases in fibre over a certain proportion promote sliding of fibre panels over each other and cause soil particles to separate, reducing soil strength[9]. The curing period was also shown to have a considerable improvement in the strength of eggshell powder-plastic waste strips stabilised soil samples, which is due to the progressive development of cementitious compounds (calcium silicate hydrate) as a result of the reaction between the calcium carbonate present in the eggshell powder, soil, and water. When compared to the unstabilised soil sample, an increase in plastic waste strips content produces an increase in the residual strength value for the specified eggshell powder content. In other words, an increase in plastic waste strips content causes an increase in ductility behaviour and a decrease in peak loss [13].

It was discovered that solely the addition of pine fibres enhances the compressive strength of soil, but the addition of pine fibres with lime raises the compressive strength of soil much more. The addition of pine needles with shorter fibre lengths (1 cm) and lime significantly boosts the compressive strength over the parent soil. It has also been found that as curing time rises, so does the UCS. Thus, the value of UCS at 28 days is larger than the value of UCS attained at 14 and 7 days.

Where, A1 = % times increase against natural/ virgin/ un-stabilised soil without the addition of any plastic waste or egg shell powder or chir pine needle fibre; ESP = Egg Shell Powder; CHNLF = Chir Pine Needle Leaves Fibre; UCS = Unconfined Compression Strength Test; CBR = California Bearing Ratio Test.

## CONCLUSION

Therefore, as a result of what had been observed and analysed from numerous researchers' studies, it can be inferred that plastic trash may be used as a reinforcing material for soil with poor strength, as has been investigated by several researchers. Furthermore, both egg shell and chir pine needle fibres perform better together than separately, and so have the potential to be utilised as a binder for enhancing the engineering qualities and strength parameters of unstabilised soil.

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## REFERENCES

1. A Kandel, et al, Stabilization of Soft Soil with Pine Needles and Lime, Proceedings of 8th IOE Graduate Conference, vol 8, ISSN: 2350-8914, June 2020.
2. M H Nsaif, Behaviour of Soils Strengthened by Plastic Waste Materials, Journal of Engineering and Development, vol 17, no 4, ISSN:1813- 7822, October 2013.,
3. K Prasad, et al, Effect of Curing on Soil Stabilized with Egg Shell, International Journal of Science Technology & Engineering, vol 2, Issue 12, ISSN (online): 2349-784X, June 2016.
4. B G A Kumar and H P Vageesh, Effect of Discarded Plastic Waste as Stabilizer on Engineering Properties of Cohesive Soil, International Journal of Engineering Technology Science and Research, vol 4, Issue 12, ISSN 2394 – 3386, December 2017.
5. N C Consoli, J P Montardo, P D Marques, Prietto and G S Pasa, Engineering Behaviour of a Sand Reinforced with Plastic Waste, Journal of Geotechnical and Geo-environmental Engineering, ASCE:1090-0241, June 2002.
6. S Peddaiah, A Burman S Sreedeeep, Experimental Study on Effect of Waste Plastic Bottle Strips in Soil Improvement, Geotech Geol Engg, Springer International Publishing AG, vol 36, 17 March 2018, pp 2907–2920.
7. B R Paramkusam, A Prasad and C S Arya, A Study on CBR Behaviour of Waste Plastic (PET) on Stabilized Red Mud and Fly Ash, International Journal of Structural and Civil Engineering Research, vol 2, no 3, ISSN 2319 – 6009, August 2013.
8. D Gardete, R Luzia, M Sousa, S Carronda, A Simão, Soil stabilization with waste plastic and waste tyre fibres (Stabilisation des sols avec déchets de plastique et fibres de pneus usages),” Proceedings of the XVII ECSMGE-2019-Geotechnical Engineering foundation of the future, ISBN 978-9935-9436, pg. 1-3, 2019.
9. H. J. A. Hassan, J. Rasul and M. Samin, “Effects of Plastic Waste Materials on Geotechnical Properties of Clayey Soil,” Transportation Infrastructure Geotechnology (2021), vol8, pg. 390–413, January 2021.
10. A. Ashraf, et al, “Soil Stabilisation Using Raw Plastic Bottles,” Proceedings of Indian Geotechnical Conference, Paper No. H-304, December 2011.
11. K. Prasad, N Mathachan, P. P. James and T. L. Justine, “Effect of Curing on Soil Stabilized with Egg Shell,” International Journal of Science Technology & Engineering, vol 2, Issue 12, ISSN (online): 2349-784X, June 2016.
12. P. G. Sonar, S. N. Sanjay and D. S. Bhaskar, “Stabilization of Soil by the Composition of Eggshell Powder and Shredded PPE Kit,” International Journal of Scientific Research in Science, Engineering and Technology, vol 8, Issue 4, ISSN: 2395-1990, pg. 390-393, August 2021.
13. P. Rani and Er. T. Goyal, “Improvement of Engineering Properties of Soil using Chir Pine Needles,” International Research Journal of Engineering and Technology, vol 06, Issue: 05, ISSN: 2395-0072, May 2019.
14. V. Singh and A. Rani, “A laboratory study on pine needle reinforced soil,” International Research Journal of Engineering and Technology, vol 05, Issue: 05, ISSN: 2395-0072, May-2018.
15. M. N. J. Alzaidy, “Experimental study for stabilizing clayey soil with eggshell powder and plastic wastes,” IOP Conf. Series: Materials Science and Engineering 518, doi:10.1088/1757-899X/518/2/022008, June 2019

# Effect of Miscanthus Sinensis of Soil Strength Parameter and Flood Erosion Control

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**Abstract:** In this study, different types of ethnic plants of Arunachal Pradesh were examined for selecting as a soil stabiliser. Considering the geographical factors and plants properties, *Miscanthus Sinensis* plant was selected as a soil stabiliser. As an experimental study, 1 month old *Miscanthus Sinensis* plant was planted in grid pattern on the bank of Pare River for an area of about 200 sqm. The plants were allowed to develop naturally for a year. Thereafter the effect of *Miscanthus* plant on shear strength parameter of the soil was determined every month. It was determined using triaxial test (UU condition) in the laboratory. Further, the important parameters such as Root anchoring index (IRA), Root Binding Index (IRB) and tensile strength of the root were determined to check the bonding strength between the root and the soil. It was observed that

- The presence of *miscanthus* improved cohesion of soil up to 59 % to 90%;
- *Miscanthus* plant have very high IRA and IRB value;
- *Miscanthus* plant restricted the flood velocity and soil movement during flood.

**Keywords:** IRA/IRB; *Miscanthus*; Tensile Strength; Stabilisation; Erosion

## INTRODUCTION

In ancient times, vegetation was used to stabilise slopes. The contributions of vegetation to several particular geotechnical processes have recently come to light. In numerous ways, vegetation may impact the stability of a slope. Greenway (1987), Gray (1970), Gray and Leiser (1982), Coppin and Richards, and others have thorough reviews (1990). Load, the force that propels failure, and resistance, the fortitude of the soil-root system, are the two factors that determine the stability of slopes. The weight of trees that are present on a slope attribute to the burden, and the resistance is increased by the roots of the trees, which act as soil reinforcements. Additionally, vegetation indirectly affects slope stability by changing the soil moisture regime. By decreasing soil moisture and pore pressure and raising the soil's shear strength, the resistance is increased. Furthermore, using evapotranspiration, vegetation absorbs rainwater and pulls water from the soil.

According to several case studies (O'Loughlin, 1974; Riestenberg, 1987; Wu et al., 1979), the deprivation of tree roots as a soil reinforcement may be the cause of slope failures.

Research conducted in the field and in the laboratory has revealed that vegetation lowers soilwater content and enhances soil moisture suction (Greenway, 1987; Gray, 1970; Gray and Brenner, 1970; William and Pidgeon, 1983). Greenway (1987) provided a thorough description of the observations of how vegetation affects slope stability.

So, this paper tries to deal with one of the biggest environmental problems confronting the planet today i.e., soil erosion and landslides. Particularly, the North Eastern region of India is afflicted due to its high amount rainfall. Further the residents of Arunachal Pradesh are experiencing various difficulties such as landslides, soil erosion etc. Leading to pathetic road conditions, loss of lives and damages to properties. It is the absolute responsibility of Geotechnical engineers who live in this region of the country to find a solution to this enormous issue. The aforementioned issue can be solved using a variety of soil stabilisation approaches.

The following factors need to be taken into account when choosing a method for stabilising soil:

- i) Culture
- ii) Environment
- iii) Cost

Many hard engineering techniques has been tried to resolve the issue in past years but it has been ineffective while incurring large financial and environmental cost. With low budget and environmental sustainability in picture it seems imperative to find a solution. But one such technique which shows a promising result is Bioengineering.

Most common and prominent technique in bioengineering is Vetiver system. But Vetiver plant not being native to Arunachal Pradesh may cause harm to native flora and fauna. After researching and examining different types of plants in the state it has been found that Miscanthus Sinensis plant shows same type of behaviour as Vetiver plant

In the grass family Poaceae, Miscanthus sinensis, sometimes known as the eulalia or Chinese silver grass, is a species of flowering plant that is indigenous to eastern Asia and may be found in much of Arunachal Pradesh, China, Japan, Taiwan, and Korea. It is perennial grass, which can grow up to 0.8-2 m tall, while forming a dense root network and clump from an underground rhizome. The flowers are purplish, white and silver in colour. It is widely cultivated as ornamental flower in most part of the world. It has become an invasive species in most of the European and American country but it poses no threat in this part of the world since it is Aboriginal to Arunachal Pradesh.

The primary objective of this project is

1. To study the effect of Miscanthus Sinensis plant in the soil properties.
2. To evaluate its effectiveness in preventing soil erosion and landslides.

## METHODOLOGY

### Selection of Plant

To meet the objective of the study, the diverse plants available in the adjoining areas of Papum Pare, Arunachal Pradesh were explored and finally the Miscanthus plant has selected. While selecting the plant for this study, following criteria's have been considered:

1. It should have low shoot biomass
2. It should have large root biomass
3. It should be non-invasive to local ecosystem
4. It should exhibit xerophytic and hydrophytic characteristics if it is to survive the forces of nature.

**Table 1** shows the properties of different plants

### Selection of Site

Bank of Pare River was selected to carry out the experimental project work for the following reasons:

1. It gets eroded every year during monsoon season
2. Accessible distance for better monitoring

### Method of Plantation

One-month-old Miscanthus plant saplings were planted on the site in December, 2021. It was planted over an area of 20 m × 10 m sqm and 50 cm apart from each other.



**Figure 1** Miscanthus plant

**Table 1** Properties of native plants

Plant	Biomass Ratio	Nativity	Xerophytic	Hydrophytic
Amliso	Low	Native	Yes	Yes
Lemon Grass	Low	Native	No	Yes
Gooseneck	Low	Native	No	No
Rush	High	Native	No	Yes
Taro	Low	Native	No	Yes
Indian Goose Grass	Low	Native	Yes	Yes
Miscanthus	High	Native	Yes	Yes



### Shear Strength Parameter Tests

The shear strength parameter of the soil was determined using triaxial test (UU condition).

For undisturbed soil sample a custom-made mould of diameter 38 mm was made. Soil sample was collected from the site and brought to laboratory under air tight container carefully with great precaution so as not to disturb the soil sample. After sample was brought to laboratory the soil was

separated carefully from the mould and cut into the height of 76 mm. Then it was tested for the shear strength using triaxial machine. This process was repeated for the month of March, April, May and June. Where the age of plant was 4, 5, 6 and 7 months etc. A few of the soil samples served as a baseline (i.e., samples with no vegetation roots). Before the samples were analysed, the plants were allowed to develop for six to eight months.

### Root Anchoring and Binding Index

Root anchoring index (IRA) and Root Binding Index (IRB) are important root parameters. By using the above indices, we can determine the binding strength of the root and soil. If root IRA and IRB is greater than 1 then we can assume that the bond between soil and root is strong. And it may be able to withstand most of the overturning forces acting upon it.

### Tensile Strength of Root

For the determination of tensile strength of root, a root specimen from the plants were taken and testing was done under fresh condition (within 24 h) 0.30 cm length of roots of various thickness were collected and their diameter was measured. Then a root was secured with a clamp at one end and connected to a polyethylene bag at the other end. The polyethylene bag was progressively filled with sand and continued until the roots failed. The bag and sand's combined weight was measured to find the total load applied. This procedure was repeated for roots of various sizes.

### Root Length Density and Root Density

The root length density (total length of roots per unit of soil volume; RLD) is an important indicator of the amount of soil that a root system has explored and, as a result, the amount of soil it has anchored.

Root density is another parameter which can be used to determine the effect of root on the cohesion of soil.

To determine the values of RLD and RD, a whole plant was uprooted thereby creating a hole. The hole's volume was then calculated. The length of each root of the plant that was present within that hole was then measured.

$$RLD = \frac{\text{Total length of roots in the volume}}{\text{volume of pit}} = \text{m}^{-2}$$

$$RD = \frac{\text{mass of root}}{\text{volume of root}} = \text{mg/m}^3$$

$$C = 10.54 + 8.63 \log RD \quad (1)$$

where C is cohesion.

## TESTS AND RESULTS

### Sieve Analysis of the Soil

Sieve analysis of soil sample taken from the plantation site is shown in **Table 2**.

The soil is classified as SP i.e., Poorly Graded Sandy Soil (as per IS: 1498 -1970).

### Shear Strength Parameters of the Soil

Comparison of shear strength parameters of soil under different condition at different age of plant are shown in **Figures 2** and **3**.

It has been observed that the roots have increased the shear strength of soil by 59.72% in the month of March to 89.05% in the month of June.

But  $\phi$  value doesn't change much. Hence it can be determined that the change in shear strength of soil is mostly due to the increase of cohesion of soil due to the effect of plant's root.

### Root Anchoring and Binding Index

The Index of Root Anchoring (IRA) and the Index of Root Binding (IRB) were calculated using formula

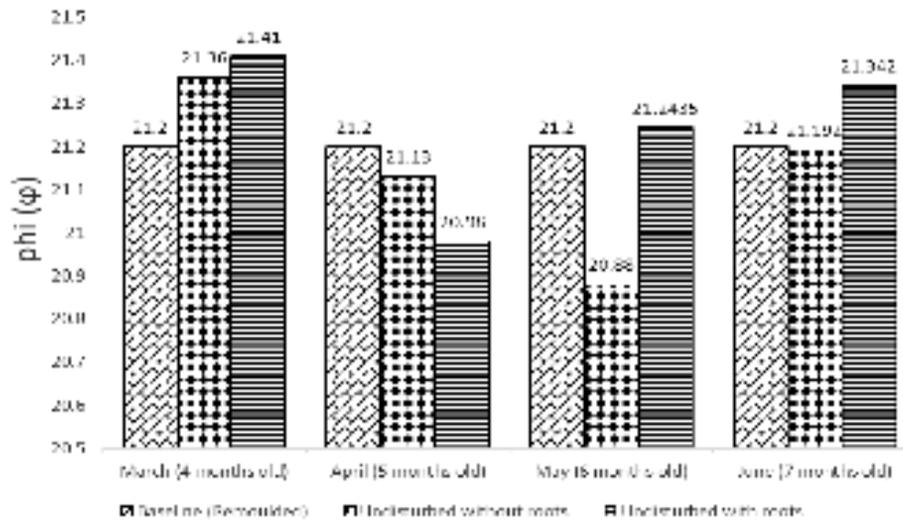


Figure 2 Comparison of phi (φ) value

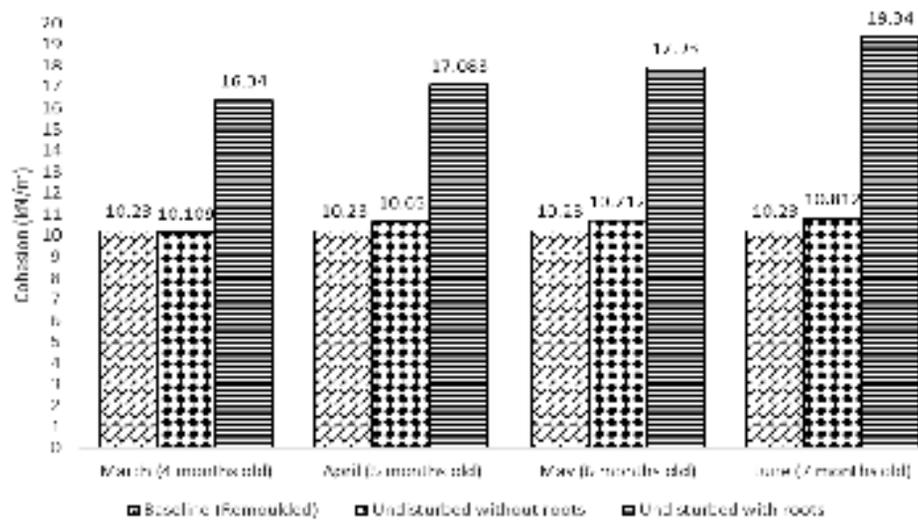


Figure 3 Comparison of Cohesion ©

Table 2 Grain size distribution

Type	Size Distribution
Gravel (20 - 4.75mm)	28.324%
Coarse Sand (4.75-2.0mm)	5.456%
Medium sand (2.0 – 0.425 mm)	29.048%
Fine sand (0.425 – 0.075 mm)	29.358%
Total sand fraction	63.862%



$$IRA = \sum D_v^2 / dbh^2 \quad (2)$$

$$IRB = D_h^2 / dbh^2 \quad (3)$$

where  $D_v$  and  $D_h$  are the diameters of vertical (angle  $> 45^\circ$ ) and horizontal (angle  $< 45^\circ$ ) proximal roots.

$D_{v1} = 981$  mm,  $D_{v2} = 678$  mm and  $D_{v3} = 781$  mm

$D_{h1} = 872$  mm,  $D_{h2} = 831$  mm and  $D_{h3} = 712$  mm

$dbh = 383$  mm

Index of Root Anchoring,  $IRA = 40.5865$

Index of Root Binding,  $IRB = 39.759$

### Tensile Strength Of Root

A weight of 1.5 kg to 2.2 kg, approximately 63.9–477.9 kPa (kg cm<sup>2</sup>) or 0.059–0.479 MPa of root tensile strength, was discovered to cause tree roots up to 2 mm in diameter (first-rated roots) to fail.

It was also observed that the tensile strength of the root decreased as the diameter of the root increased which concur with Wang Chenglong et al. (2020).

### Root Length Density and Root Density

Total length of root under within the volume = 79.83 m

Volume of Pit = 0.029 m<sup>3</sup>

$RLD = 79.83 / 0.029 = 2752.756$  m<sup>-2</sup>

$RD = 759.78$  kg/m<sup>3</sup>

Now,  $C = 10.54 + 8.63 \log RLD$ ;  $C = 18.1364$  kN/m<sup>2</sup>

It has been observed that the RLD of Miscanthus plant is higher compared to the plants available in our locality.

And the cohesion value we found using RD is almost equal to the cohesion value we found out using triaxial test.

### Site Result

One-month-old Miscanthus plant saplings were planted on the site in December. It was planted over a 20 m × 10 m space, 25 cm apart from each other.

Despite the fact that some of the vegetation was nibbled by animals. The majority of the plants survived, allowing the study to go on.

After the monsoon season the following were the situation of site.

It has been noted that during the monsoon season, the facility was entirely submerged beneath water. However, because of its high root biomass and low shoot biomass, the plant was able to withstand the effects of the water current. However, some of the weaker plants were uprooted as a result of the influence of the water current.

It was also observed that, within 8 months new plants germinating around the old plants which provided extra strength and support to the existing plants.

### CONCLUSION

There are many engineering methods available for the stabilisation and prevention of soil erosion. It would appear essential to develop a solution given the limited budget and the need for environmental sustainability. But bioengineering is one such method that has produced promising result.

In this study, Miscanthus plant were used to evaluate its effectiveness in controlling the soil erosion.

The following conclusions have been drawn from the study:

- 1) It was found that the RLD of Miscanthus plant is surplus compared to the other plants that are available in the locality.
- 2) It was observed that during monsoon period the plants were fully submerged under the water.



- 3) The effects of the river movement were observed to be endured by plants that were planted upstream. As the majority of the upstream plants were uprooted.
- 4) From the experimental study, it was found that IRA and IRB of the plant were sufficiently high.
- 5) It was also observed that the tensile strength of the root decreased as the diameter of the root increased. It might be due to the fact that the outer cover of root is weaker than the inner root.
- 6) The presence of *Miscanthus* plant improves the cohesion of the soil up to 59 % to 90%.

The scope of this study was strictly limited to determine, how the *Miscanthus* plant improved their in-situ shear strength parameters. Further, the effectiveness of the work can be explored by considering the crucial characteristics and experiments as follows:

- 1) To prevent submergence of plants, planting of more plants may be explored and proper monitoring of growth of plant may be maintain.
- 2) Assess effect of plant on surface run off.
- 3) Proper record of length of root, shoot of plant and planting methods may be examine.
- 4) Period of study may be increase to observe the effectiveness of the plant on erosion control.
- 5) Also checking of the cattle's is necessary to prevent grazing of the plants.

#### REFERENCES

1. R P Adams and M R Dafforn, Sunshine, The Vetiver Network Newsletter, no.18. Leesburg, Virginia USA, 1997.
2. O Babalola, J C Jimba, O Maduakolam and Dada, Use of Vetiver Grass for Soil and Water Conservation in Nigeria, Proc. Third Intern. Conf. on vetiver and Exhibition, Guangzhou, China, October 2003, pp 293-309.
3. Dalton, et al, Hydraulic Characteristics of Vetiver Hedges: An Engineering Design Approach to Flood Mitigation on a Cropped Floodplain, Proc. First Intern. Vetiver Conference. Chiang Rai, Thailand, October 1996, pp 65-73.
4. Dalton, et al, Vetiver Grass Hedges for Erosion Control on a Cropped Flood Plain: Hedge Hydraulics. Agric, Water Management, 31, 1996, pp 91-104.
5. Dalton et al, Vetiver Grass Hedges for Erosion Control on a Cropped Floodplain, Hedge Hydraulics Agric, Water Management: 31(1,2), 1996.
6. Goetz M Richter et al. Sequestration of C in Soils under *Miscanthus* can be Marginal and is affected by Genotype-Specific Root Distribution, volume 200, 1 February 2015, pp 169-177.
7. D Hengchaovanich and N S Nilaweera, An Assessment of Strength Properties of Vetiver Grass Roots in Relation to Slope Stabilisation. Proc. First Intern. Vetiver Conf, Chiang Rai, Thailand. October 1996, pp153-158.
8. Mulyono et al, The Hydromechanics of Vegetation for Slope Stabilization, IOP Conf. Ser.: Earth Environ. Sci. 118 012038, 2018.
9. Rossi C, Nimmo and J R, Modeling of Soil Water Retention from Saturation to Oven Dryness, Water Resources Research, 30(3), 1996, pp 701-708.
10. P Sapkota, Modeling Diffusion using an Agent-Based Approach, Master's Thesis, The University of Toledo. Advisor Dr Define Apul. 2010, 79 p.
11. Smeal, C, Truong P, "Effects of Vetiver Grass on Some Soil Physical Properties," Proc. ICV-4, Caracas, Venezuela, 2006.
12. Tscherning et al, Grass Barriers in Cassava Hillside Cultivation: Rooting Patterns and Root Growth Dynamics, Field Crops Research 43, 1995, pp131-140.
13. Truong P, Report on the International Vetiver Grass Field, 1993.

# Real-Time Analysis and Alert System for the Water Quality of River Ganga at Mehandi Ghat, Kannauj

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**Abstract:** One of the most crucial elements for human survival on this planet is water. The authorities have given thought to the water quality of the river Ganga over the past few years. They have found that the effects of using contaminated water are quite harmful if the quality of the water is not monitored. In this paper, we are providing real-time analysis and statistics on a variety of water quality parameters and introducing a system that can generate alerts when those values deviate from recommended levels. The IOT based system is capable of analyzing 12 different sensor data of samples collected from Mehandi Ghat, Ganga, including dissolved oxygen, electrical conductivity, pH value, etc. Authorities can utilize the analysis data to observe trends in water quality during different seasons and when industries dispose of large amounts of wastewater.

**Keywords:** Real time; IOT; Alert System; Mehandi Ghat; Sensor

## INTRODUCTION

After originating from Gaumukh in Himalayas to the Ganges Delta in the Bay of Bengal, Ganga runs for 2510 kms proving life to a major part of the country. In India the river flows through eleven states and is expected to provide water to over 40% population in the country. The Ganges valley provide a cultivated area in the canal system in the states of Uttar Pradesh and Bihar. At least 150 different animal and aquatic species call it home, and the basin alone irrigates more than 140 million acres of land. 54% of India's GDP is accounted for by this. The Ganges, which rises in the Himalayas and empties into the Bay of Bengal, has long been revered as the sacred river of India. Sadly, "The Holi Ganga" is now ranked as the fifth most polluted river in the world. Water-borne illnesses like cholera and thyroid diseases are brought on by water contamination. The waters in Ganga are expected to be fit for drinking as well as for aquatic life in the river. The Indian standards for drinking water are shown in the below **Table 1** [1].

To improve the Ganges' water quality, the Indian government is also moving forward. The National Mission for Clean Ganga, which includes of sewage treatment plants, pollution treatment plants, and steps to protect biodiversity in the holy river, as well as the Second National Ganga River Basin Project, both of which are being carried out with the help of the World Bank, are two schemes that are currently in operation. Ganga Quest 2020, Ganga-Utsav 2020, and Ganga Ceremony were all parts of this initiative. With a budget of about 10,000 crores, a dam rehabilitation and enhancement project was established to finish building dams and for upkeep. Additionally, the Central Water Commission started using Robust Satellite Techniques (RST) in April 2019 to monitor 23 reservoirs through satellite. For superior imaging, this project uses microwaves rather than optical fibre data. Prime Minister Narendra Modi opened two sewage treatment facilities (STPs) in Patna with capacities of 43 and 37 million litres in the middle of September. In addition, he dedicated STPs in Uttarakhand in late September 2020, along with STPs in a number of UK locations, including Chandreshwar

**Table 1**

Parameter	Acceptable limit	Permissible limit
Aluminium	0.03 mg/l	0.2 mg/l
Boron	0.5 mg/l	1.0 mg/l
Copper	0.05 mg/l	1.5 mg/l
Calcium	75 mg/l	200 mg/l
Total Hardness	200 mg/l	600 mg/l

Nagar, Haridwar, Sarai, Rishikesh, and Jagjeetpur. The largest projects with a capacity of more than 100 MLD are located in Haridwar and Rishikesh [2].

The quality of water can be observed using different parameters. By measuring the pH of water we can determine whether it is acidic or basic in nature. By measuring the TDS we can determine the concentration of salts that are dissolved in the water. Oxidation Reduction Potential of water tells about its ability of water to oxidise or reduce the other products inside it. ORP evaluates a lake's or river's capacity to eliminate or decompose waste, including contaminants, extinct plants and animals, and other waste products. Electrical Conductivity of water. The ability of water to transfer electrical current is determined by its conductivity. The quantity of conductive ions in the water has a direct impact on this parameter.

In this study we have collected some water samples and tested these parameters using different sensors like pH Sensor, ORP Sensor, DO Sensor, Water Sensor, Soil Moisture Sensor, Dust Sensor, Temperature and Humidity Sensor etc.

In the study the trends in Total Dissolved Salts (TDS) of water can be seen in the **Figure 1**.

From this figure we can see that the TDS readings are quite high in the post monsoon and winter season (Oct – Nov).

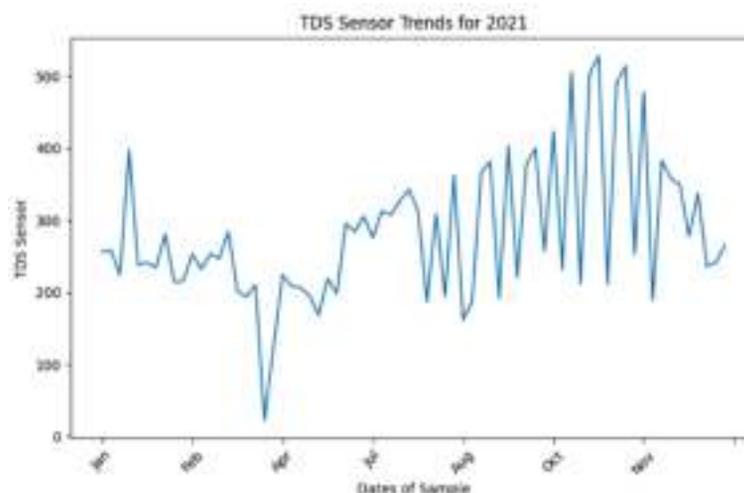
### LITERATURE SURVEY

A research was conducted on quality of water in river Ganga on 3 sites in Rishikesh. In the study, it was observed that the turbidity value was above WHO's permissible standards. This was attributed due to pollution from the organic matter, heavy rainfall and runoff. The water quality index (WQI) on some sites goes as high as 1714.6 in the monsoons i.e. July. While the highest 12.10 mg/L of dissolved oxygen was found to be in winter season (Jan 2007) with a minimum of 7.14 mg/L in monsoon during July 2008 [3].

Another study was performed for measuring the quality of water using machine learning and IOT sensors. The model contained multiple sensors connected to a NodeMCU to collect different parameters and also generate alert messages when these parameters go above the prescribed levels.

In the study the standard values were taken to be as shown in the **Table 2** [4].

A study on water quality indices was conducted in Haridwar, Uttarakhand. Assessment on quality of water in Ganga was made on the basis of 15 quality parameters for a period of 11 years. According to the River Ganga WQI, the research area's water quality was between good and medium. The river has a decent WQI according to the NSF, but according to the weighted Arithmetic approach, the river's water quality was subpar. Thus, it can be inferred that the 11-year study period saw a range in the water quality of the River Ganga from poor to good, which was consistent with other studies on the river's WQI. While bearing in mind the growing urbanisation and pollution loading of rivers, the proper actions should be taken to minimise future contamination loads from entering the river. The study found that the main causes of pollution were sewage, solid and liquid waste pollutants, or organic nature [5].



**Figure 1**



Table 2

S. No.	Parameters	Values
1.	pH	6.50 – 8.0
2.	Temperature	140 F
3.	Turbidity	5.0
4.	Dissolved Oxygen	5.0 mg/L
5.	Conductivity	0.05 S/cm
6.	Total Organic Carbon	55 mg/L
7.	Colour	Colourless

In another study of classification, the Chao Phraya River's numerous water parameters were identified and categorised in the research using river sensing processing actuators (rSPA), and a method for analysing water quality in Thailand's most important water resource was demonstrated. An experimental investigation on the conductivity, salinity, and total dissolved solid pollutants was conducted in the Chao Phraya River that had accumulated downstream (TDS). In particular for public consideration, the results have conveyed evaluations as comprehensible visuals. rSPA is regarded as an efficient method for implementing a alert system in river's water quality studies [6].

In another study in Bangladesh, they have proposed a Wireless Sensor Network (WSN). They showed the pH, temperature, turbidity, and ORP values that were as a result felt. The parameter values are continuously sensed, and the results are displayed in real-time on the LCD, PC, or mobile device. When the obtained value exceeds threshold value, "BAD" message is displayed in the interface [7].

A system was proposed in a study where an early warning system was proposed for the ungauged river basins of china. The system was named mobile device early warning system (MEWSUB). The system provides a web services model and browser based interface and makes use of risk response personnel and can use it any place, even if we have limited data [8].

At Kumaon district of Uttarakhand, a correlation in water quality parameters and water quality index (WQI). They discovered that the majority of the results from the examined water samples fell within the Bureau of Indian Standards' (BIS) recommended ranges for physico-chemical parameters. However, microbial pollution is the primary factor that has impacted the water quality in this region. In 96 villages, the WQI index based on the physicochemical and biological parameters was very low, but in 21 villages, it was excellent or good quality [9].

This study uses real-time data from the IoT model and applies the SVM model, which has an accuracy of about 94%. When 7 unique parameters are utilised, SVM performs best. Decision tree and ANN are also employed in addition to SVM [10].

Smart water monitoring system (SWMS) has been designed to monitor water quality and usage in real time. A smart quality and quantity metre has been devised to check the purity of potable water and record the consumption of water. Parameters that are taken into account include pH, conductivity, turbidity, and temperature. For remote access to data, an online monitoring system is used. A notification system is also devised to notify the customer and the authorities. The Raspberry PiTM is used to determine water potability, and after water consumption is checked, a bill is generated using a three-slab system [11].

Integration of SCADA and IoT has been implemented in the Tirunelveli Corporation, Tamil Nadu, for monitoring the quality of water in real time. Parameters added to the system include turbidity, color, and temperature. The GSM module is used for the generation, collection, transfer, and storage of sensor data over the web browser. This system performs more efficiently and shows better results than existing systems that produce better results [12].

## PROPOSED SYSTEM

### Material Used

As discussed above, the system consists of many components namely-

1. Arduino Uno: Arduino Uno is used to collect and convert all the Analog signals coming from all the 4 sensors to Digital signals for our interpretation. To expand the Arduino Uno to have an Ethernet port for transferring data over to cloud an

Ethernet W5100 Shield is used.

2. Raspberry pi: Raspberry pi is being used as the main computer with all the required software (like Arduino IDE) to execute all the code. Raspberry Pi is also being used to power the Arduino Uno and all the other sensors in the setup.

3. Sensors:

- a) pH Sensor: pH sensor helps to know how much acidic/ alkaline water is.
- b) TDS Sensor: TDS sensor helps to measuring the Hardness of water.
- c) ORP Sensor: ORP sensor helps to measuring the potential of water to oxidise or reduce any substance.
- d) Electrical Conductivity Sensor: Electrical conductivity sensor helps us in measuring the amount of salt concentration in the given water sample.

4. Other Components used:

- a) Bus bar / Mini Bread Board
- b) Raspberry Pi power adapter
- c) Jumper Wires
- d) Micro HDMI to HDMI Cable USB Type B to USB Type A Cable
- e) San Disk 16 GB Micro SD Card (Installed in Raspberry Pi)
- f) Ethernet Cable
- g) Enclosure Box

### Set up

For measuring water turbulence, pH, and temperature appropriately, turbidity sensors, pH sensors, and temperature sensors that are directly connected to the microcontroller are employed. Data is gathered by the microcontroller and processed with the system through LAN. Architecture of the system can be illustrated better in **Figure 2**.

A picture of the working model with all the sensors and other components is shown in the **Figure 3**.

### Working

Sensors send analog signals to the Arduino Uno microcontroller. The Arduino microcontroller convert this analog signals to digital data. Raspberry Pi is used as the main computer which receives all data from the Arduino microcontroller which sends data to the Cloud database. **Figure 4** shows the flow of data in the system and to the cloud network.

### Water Sampling

Water samples were collected over a period of months to determine the water's quality on Mehendi Ghat. Water samples are taken in accordance with ISO 5667-6. The samples were then examined using the pH, TDS, ORP, and EC sensors. **Table 3** displays the information from water samples.

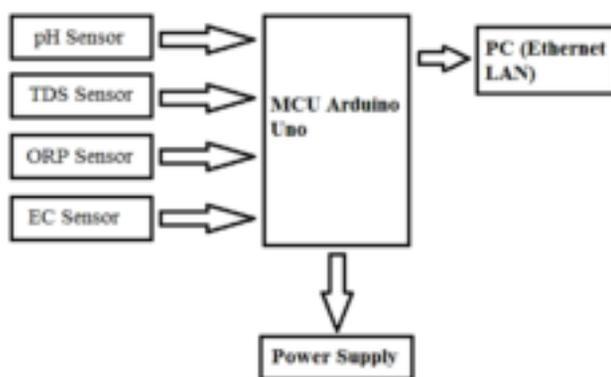


Figure 2



Figure 3

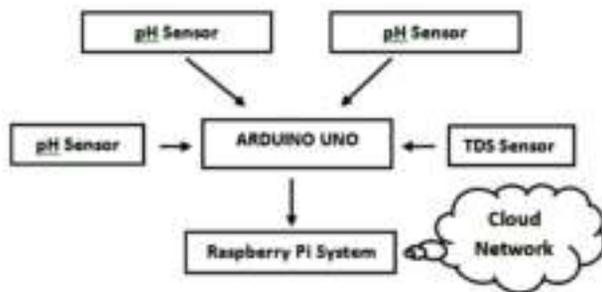


Figure 4

Table 3

Sample Date	TDS Sensor	pH Sensor	EC Sensor	ORP Sensor
04-05-20	206.69	7.51	0.74	77.6
07-08-20	186.09	7.32	0.71	68.22
14-08-20	194.33	7.1	0.74	85.44
21-08-20	161.7	6.68	0.71	106.9
28-08-20	187.84	7.94	0.71	78.25
11-09-20	191.58	6.82	0.71	97.52

### Analysis of Data

In this study, the river Sensing Processing Actuation (rSPA) served as a tool for the detailed classification of multi-parameter analysis and the detection of critical points. The steps taken to perform rSPA.

- For selecting the parameters of water quality, we are using parameters such as pH, oxidation reduction potential (ORP), electric reduction potential, total dissolved solid and turbidity.
- To create database of the common threshold values. We use the standard threshold value used were selected from the literature research and the worldwide organisation for standards in this database design. MySQL is used to process the knowledge databases and logic tests.
- To create the classification database. The reference of the impact range is taken from the literature review and worldwide organisation for standards in this database design. MySQL is used to process the knowledge databases and logic test.
- To design the actuation and alert or warning system base on trigger.

Figure 5 shows this process in a better way.

### Alert System

An alert or warning system can be achieved on applying trigger to rSPA. The system detects data value, if input value is more than predetermined threshold, classifies the data, and then sends output in terms of information about point, value, and effect class. A flow of the alert system is shown in Figure 6.

### RESULTS

The study found that the water quality parameters like TDS, pH, ORP tends to surge in early winter season (Oct – Nov). As we can see in Figure 7.

The most probable reason for this surge in the values of these parameters can be due to increase in concentration of microbial organisms in Ganga during the post monsoon season (Oct- Nov). The data saved in the cloud by the monitoring

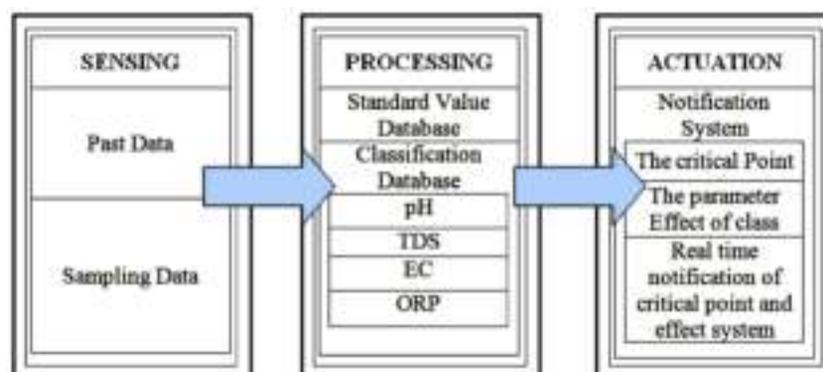


Figure 5

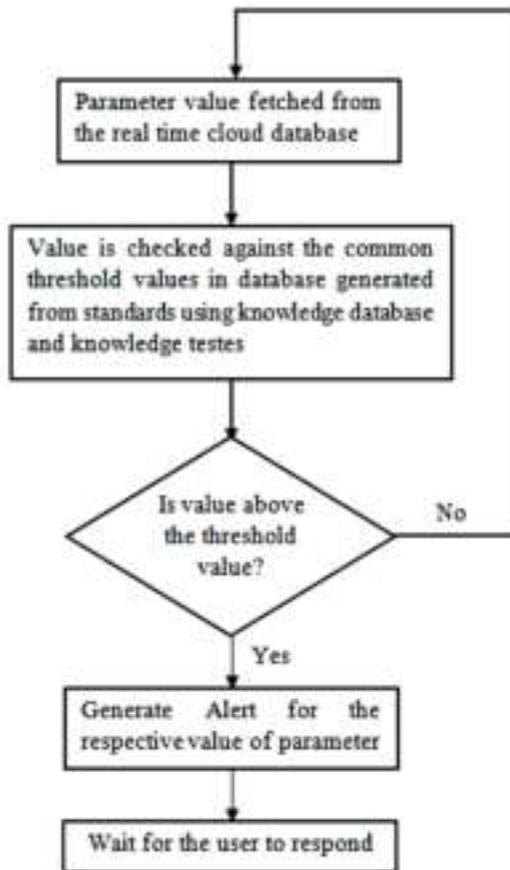


Figure 6

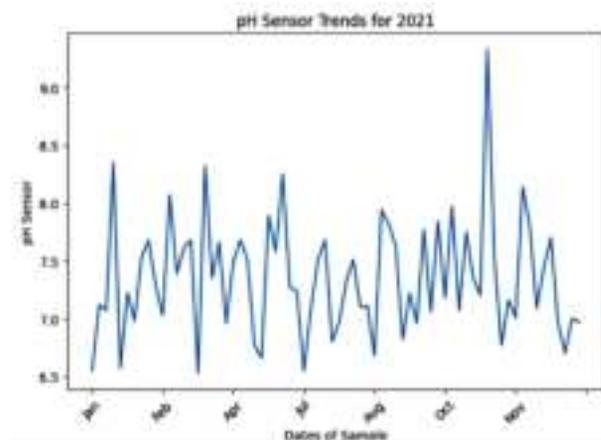


Figure 7



Figure 8

system can be accessed or displayed in real time using the interactive interface designed. This interface can be accessed remotely over the internet. The data found in the previous months can be visualized in graphical as well as numerical form. An instance of the interface can be seen in **Figure 8**.

The alert system thus achieved can be integrated with a mobile application. The application will generate timely alerts in the situations when the values of the parameters go beyond the recommended norms.

## CONCLUSIONS

The proposed system performs better than the existing systems and displays the results in a more intuitive and elaborated form. This system can be used by the concerned authorities to monitor the variations in the values of the parameters and the water quality taking place at Mehandi Ghat, Kannauj in the real time. Therefore this system can help in taking preventive measures in the early stage before the situation worsens. The data collected via this system can be used for further studies and advancements in this domain. The proposed system can be implemented at different locations for studying the water quality of various rivers worldwide by updating the standards defined accordingly at that particular geographical region.

## REFERENCES

1. B of Indian Standards, Drinking Water Specification (Second Revision) Amendment no.1, June 2015 to IS 10500:2012 Drinking Water Specification (04 2015). doi: <http://cgwb.gov.in/Documents/WQ-standards.pdf>.
2. V Rana, F Ahmad and A K Vidyarthi, Study of Water Quality of Ganga River and its Suitability for Mass Ritualistic Bathing before Kumbh Mela-2021 at Haridwar in Uttarakhand, India, April 2022, doi: <https://www.researchgate.net/publication/364278465>.



3. A Chauhan and S Singh, Evaluation of Ganga Water for Drinking Purpose by Water Quality Index at Rishikesh, Uttarakhand, India. doi: <https://www.researchgate.net/publication/270957974>.
4. C Ashwini, U Pratap Singh and E Pawar, Shristi, Water Quality Monitoring using Machine Learning and IoT, International Journal of Scientific & Technology Research, volume 8, issue 10, October 2019.
5. R Bhutiani, D R Khanna, D Bhaskar Kulkarni and M Ruhela, Assessment of Ganga River Ecosystem at Haridwar, Uttarakhand, India with Reference to Water Quality Indices, Appl Water Sci, 6, 2016, pp 107-113, doi: 10.1007/s13201-014-0206-6.
6. C Veesommai and Y Kiyoki, River Water-quality Analysis, "Critical Contaminate Detection", "Classification of Multiplewater-quality-parameters Values" and "Real-time Notification" by rSPA Processes, 2015 International Electronics Symposium (IES).
7. Mohd. Salah, U Chowdurya, T Bin Emranb, S Ghosha, A Pathaka, Mohd. Manjur Alama, N Absara, K Anderssonc and Mohd. S Hossaind, IoT Based Real-time River Water Quality Monitoring System, The 16th International Conference on Mobile Systems and Pervasive Computing (MobiSPC) August 19-21, 2019, Halifax, Canada.
8. Y Wang, W Zhang, B A Engel, H Peng, L Theller, Y Shi and S Hu, A Fast Mobile Warning System for Water Quality Emergency Risk in Ungauged River Basins, Environment Modelling & Software 73, 2015, pp 76-89.
9. V Kothari, S Vij, S K Sharma and Neha Gupta, Correlation of Various Water Quality Parameters and Water Quality Index of Disctricts of Uttarakhand, Environmental and Sustainability Indicators 9, 2021, 100093.
10. D Jalal and T Ezzedine, Toward a Smart Real Time Monitoring System for Drinking Water Based on Machine Learning, in: 2019 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), IEEE, 2019, pp. 1-5.
11. M K Jha, R Kumari Sah, R M S, Rupam Sinha, Sujatha B and Suma K V, Smart Water Monitoring System for Real-time Water Quality and Usage Monitoring, Proceedings of the International Conference on Inventive Research in Computing Applications (ICIRCA 2018) IEEE Xplore Compliant Part Number:CFP18N67-ART; ISBN:978-1-5386-2456-2.
12. K Saravanan, E Anusuya and Raghvendra Kumar, Le Hoang Son, Real-time Water Quality Monitoring using Internet of Things in SCADA, Environ Monit Assess, 190, 2018, p 556.



## Some Aspects on the use of Non-Recyclable Plastic Waste in Sustainable Pervious Concrete Production

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**Abstract:** Pervious concrete is a concrete produced without using fine aggregates and sometimes called as 'no-fines concrete'. Due to the absence of fine materials, the concrete achieves porous nature. Water can permeate in to pervious concrete and get drained. The ability to drain water has encouraged its usage in construction of parking lanes, low-traffic roads and pedestrian walkways for reducing storm water runoff on the road. Nowadays use of single-use plastic carrier bags has been increased and has caused huge volume of plastic non-recyclable plastic waste generation. In order to reduce the amount of plastic waste accumulated, the experimental study conducted in this paper investigates the possibilities of using non-recyclable plastic waste in the production of sustainable pervious concrete. The plastic waste was used in the form of fibers. Mechanical properties of pervious concrete such as compressive strength and flexural strength were determined. The influence of addition of fly ash as replacement for cement on the properties of pervious concrete containing the plastic waste fibers was also studied. Test results showed that use of plastic waste fibers in pervious concrete did not affect the hydraulic properties of pervious concrete. The results also showed that addition of plastic fibers in pervious concrete precluded brittle failure.

**Keywords:** Pervious Concrete; Plastic Waste Fibers; Sustainability; Experiment; Runoff

### INTRODUCTION

Pervious concrete is a type of concrete with no fines or less quantity of fines. Due to less fine particles, pervious concrete allows water to penetrate into it and get drained. This type of concrete is well suited for pavement applications especially in regions where storm water drains have not been installed properly or performed poorly. Due to poor drainage of storm water, there has always been flooding of pavements causing huge traffic. Flooding of rain water on platforms of residential housing systems like apartments and individual houses also could lead to increase in the mosquito population causing threat to health. A view of flooded road is shown in **Figure 1**. A typical view of pervious concrete is shown in **Figure 2**.

Together with water stagnation problem, it is also found that there is a continuous increase in the accumulation of plastic waste. The plastic wastes are mostly dumped on vacant lands causing threat to green environment. The generated plastic waste is dependent on the type of plastic such as thermoplastic or thermosetting. Thermoplastics do not undergo chemical change during heating and cooling, and hence can be moulded again and again (Example: Polyvinyl chloride



**Figure 1** View of flooded road1



**Figure 2** Pervious concrete



**Figure 3** Disposed plastic waste in compost yard

(PVC)). However, thermosetting plastics, if heated again undergo their chemical change and decompose (Example: Vulcanized rubber). It is important to note that Centre for Science and Environment CSE, 2020) report says that India generates about 9200 metric tonnes of plastic waste daily. Typical picture of plastic waste dumped in a compost yard is shown in **Figure 3**.

Several research studies have been conducted to investigate the mechanical and hydraulic performance of pervious concrete containing different wastes or materials like oyster shell aggregate [3], glass powder waste [4], municipal solid waste incineration bottom ash [5], coal fly ash [6], construction and demolition waste [7], recycled fibers [8] and sea shell waste [9]. Some case study has also been reported [10].

Horiguchi, et al. [3] have investigated the plant growing performance of pervious concrete produced using aggregates obtained from oyster shells. The aim of the study was to develop pervious concrete for urban greening. The size of the aggregates produced were chosen in order to retain maximum water in the pervious concrete so as to not require external agents to store water that will aid plant growth. Results showed that pervious concrete produced using oyster shell aggregates enhanced the plant growth than that produced using crushed stone aggregates. Moura, et al. [4] investigated the performance of pervious concrete containing glass powder waste. The study investigated the optimum percentage use of glass powder waste and the superplasticizer. Test results showed that characteristic compressive strength of 20MPa could be achieved with the use of glass powder waste. Inclusion of municipal solid waste incineration bottom ash in pervious concrete was studied by Shen, et al. [5]. Mechanical properties, water permeability, porosity, density and thermal conductivity were investigated. Results showed that due to internal curing of bottom ash, the mechanical properties of pervious concrete improved. However, excess content of bottom ash affected the behavior. Thermal studies indicated that there is potential for using pervious concrete for insulation purposes.

Hwang and Cortés [6] have studied the influenced of combined usage of coal fly ash and glass powder waste on the performance of pervious concrete. The mechanical characteristics of cement mortar and pervious concrete specimens were determined from the experiments. The authors concluded that sustainable production of green infrastructure is possible with combined usage of coal fly ash and glass powder waste. It has been stated that combined usage of the materials could reduce CO<sub>2</sub> emission. Another green pervious concrete was proposed by Ibrahim, et al. [7] by utilizing high volume of construction and demolition waste in pervious concrete production. About 72% volume of pervious concrete consisted of the waste. The target porosity considered was 15%. It was observed from the test results that water-cement ratio did not have any effect on the hydraulic properties of the pervious concrete. Recycled fine aggregates improved the mechanical properties. The authors observed that use of recycled fine aggregates improved the cement paste thickness and aggregate interlocking in concrete. Water-cement ratio of 0.35 achieved the best mechanical properties. Presence of fines caused divergence of the cracks and resulted in higher compressive strength. Togholi[8]



conducted studies on the performance of reinforced pervious concrete. Steel fibers and recycled plastic waste fibers were used. The fibers considered were based on plastic beverage bottles. The study showed that addition of fibers improved the compressive and flexural strength of pervious concrete.

In this study, non-recyclable plastic waste is used as fibers in the production of pervious concrete. Mechanical properties of concrete such as compressive strength and flexural strength were determined. The influence of addition of fly ash together with non-recyclable plastic waste fibers on the mechanical properties was determined.

## EXPERIMENTAL DETAILS

Experimental study consisted of casting pervious concrete specimens with the following variables.

- (i) Cement to coarse aggregate ratio,
- (ii) Presence/absence of 5% of fly ash as replacement for cement,
- (iii) Presence/absence of non-recyclable plastic waste fibres, and
- (iv) Presence/absence of fly ash and non-recyclable plastic waste fibres.

Concrete cube specimens of size 100mm was cast and cured for a period of 28 days. The compressive strength of the pervious concrete specimens was determined after the curing period. Portland pozzolana cement was used. Coarse aggregates with particles passing through 16mm sieve and retaining on 12mm sieve were only used in the production of pervious concrete. M-sand was used as the fine aggregate. The cement to coarse aggregate ratios considered varied in the range 1:3 to 1:6. The non-recyclable plastic waste fibers used was 5% of cement content. In order to determine the influence of fly ash addition on the strength of pervious concrete, 10% of PPC was replaced with fly ash. The specimen details are given in **Table 1**. Three specimens were considered for a specific configuration of the specimen.

Note: C – Control concrete; CP – Pervious concrete with plastic; CF – Pervious concrete with fly ash; CPF – Pervious concrete with plastic and fibers.

## RESULTS AND DISCUSSION

### 3.1 Compressive strength

The compressive strength of the tested pervious concrete specimens are given in **Table 2**. The compressive strength variation is shown graphically in **Figure 4**.

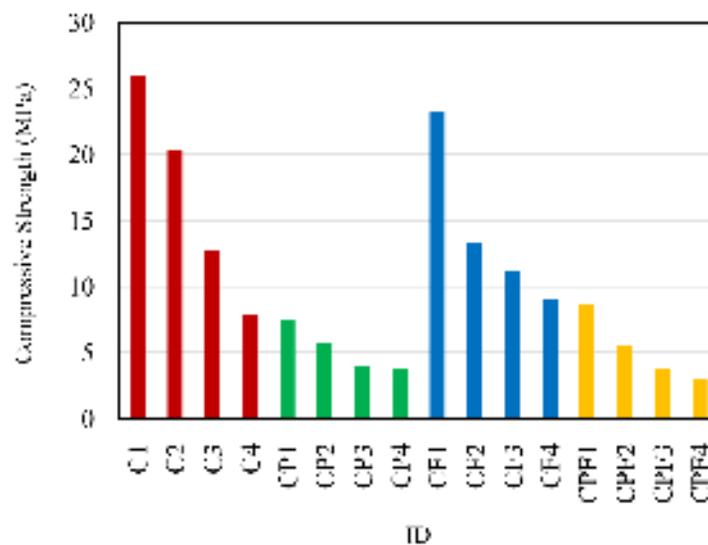
**Table 1** Specimen details

Sl. No.	ID	Cement-to-coarse Aggregate Ratio	Non-recyclable Plastic Waste Fibers	Fly Ash
1	C1	1:3		
2	C2	1:4		
3	C3	1:5	-	-
4	C4	1:6		
5	CP1	1:3		
6	CP2	1:4	5%	-
7	CP3	1:5		
8	CP4	1:6		
9	CF1	1:3		
10	CF2	1:4		10%
11	CF3	1:5	-	
12	CF4	1:6		
13	CPF1	1:3		
14	CPF2	1:4	5%	10%
15	CPF3	1:5		
16	CPF4	1:6		

Note: C – Control concrete; CP – Pervious concrete with plastic; CF – Pervious concrete with fly ash; CPF – Pervious concrete with plastic and fibers.

**Table 2** Test results

Sl. No.	ID	Compressive Strength (MPa)	Flexural Strength (MPa)
1	C1	25.9	3.7
2	C2	20.3	3.1
3	C3	12.7	1.8
4	C4	7.8	1.1
5	CP1	7.5	0.5
6	CP2	5.8	
7	CP3	3.9	< 0.5
8	CP4	3.7	
9	CF1	23.2	3.6
10	CF2	13.3	1.9
11	CF3	11.2	1.7
12	CF4	9.1	< 0.5
13	CPF1	8.7	0.6
14	CPF2	5.5	
15	CPF3	3.8	< 0.5
16	CPF4	3.0	



**Figure 4** Compressive strength variation

#### *Effect of Plastic Waste Fibers*

It was observed from **Table 2** and **Figure 4** that the compressive strength of pervious concrete generally decreased due to addition of non-recyclable plastic waste fibers. Examination of the tested specimens indicated that the plastic fibers were well distributed within the specimen. The strength decrease was attributed due to poor bonding of the plastic fibers with the cement matrix thus creating the weak links. The plastic fiber surface being smooth caused poor bonding with the cement matrix and decreased the strength.

#### *Effect of Cement to Coarse Aggregate Ratio*

The compressive strength of pervious concrete decreased with increase in the cement to coarse aggregate ratio for all the types of pervious concrete considered. The reason for this observation was attributed due to lesser volume of cement paste available for bonding the coarse aggregate particles. For control concrete, it was observed that increasing the cement to coarse aggregate ratio from 1:3 to 1:6 decreased the strength by 70%. The decrease in strength due to increase in cement to coarse aggregate ratio reduced due to the addition of plastic fibers. The strength reduction of 50% due to the



addition of plastic fibers. This observation indicated that the plastic fibers improved the performance at higher cement to coarse aggregate ratios. The plastic fibers provided binding or stitching effect when the less volume of cement matrix was available for holding the coarse aggregate particles.

#### *Effect of Fly Ash*

In general it was observed that, though inclusion of fly ash decreased the strength, fly ash addition did not decrease the strength significantly as that of plastic fibers.

#### **Flexural Strength**

With respect to the flexural strength it was observed that the flexural strength of pervious concrete decreased significantly due to the addition of plastic fibers. However, due to addition of plastic fibers it was observed that the prism specimens used for flexural strength did not break in two pieces and the failure of ductile in nature. The prism specimens without plastic fibers failed in brittle mode in to two pieces. This observation indicated that the plastic waste fibers can be used in pervious concrete where the flexural strength is not relied upon.

#### **CONCLUSIONS**

The conclusions arrived based on the study presented in this paper are given below.

- ❑ The strength of pervious concrete decreases due to addition of non-recyclable plastic fibers.
- ❑ The plastic fibers changed the brittle failure of prism specimens to ductile failure.
- ❑ Strength similar to control concrete can be obtained by replacing 5% of cement with fly ash.
- ❑ Use of non-recyclable plastic waste in pervious concrete applications in pedestrian walkways and less traffic roads could reduce the plastic waste accumulation and would result in improved environmental conditions.

#### **REFERENCES**

1. <https://timesofindia.indiatimes.com/city/chennai/chennai-receives-heaviest-rain-since-2015-showers-cause-flooding/articleshow/87563020.cms>. Last accessed 11.11.2022.
2. Centre for Science and Environment, Managing Plastic Waste in India – Challenges and Agenda, New Delhi, India, CSE, 2020.
3. I Horiguchi, Y Mimura and P J M Monteiro, Plant-growing Performance of Pervious Concrete Containing Crushed Oyster Shell Aggregate, Cleaner Materials, vol 2, 100027, 2021.
4. J M B M de Moura, I G Pinheiro, A Aguado and A B Rohden, Sustainable Pervious Concrete Containing Glass Powder Waste: Performance and Modeling, Journal of Cleaner Production, vol 316, 128213, 2021.
5. P Shen, H Zheng, J Lu and C S Poon, Utilization of Municipal Solid Waste Incineration Bottom Ash (IBA) Aggregates in High-strength Pervious Concrete, Resources, Conservation and Recycling, vol 174, 105736, 2021.
6. S S Hwang, C M Cortés, Properties of Mortar and Pervious Concrete with Co-utilization of Coal Fly Ash and Waste Glass Powder as Partial Cement Replacements, Construction and Building Materials, vol 270, 121415, 2021.
7. H A Ibrahim, Y Goh, Z A Ng, S P Yap, K H Mo, C W Yuen and F Abutaha, Hydraulic and Strength Characteristics of Pervious Concrete Containing a High Volume of Construction and Demolition Waste as Aggregates, Construction and Building Materials, vol 253, 119251, 2020.
8. A Toghroli, P Mehrabi, M Shariati, N T Trung, S Jahandari and H Rasekh, Evaluating the Use of Recycled Concrete Aggregate and Pozzolanic Additives in Fiber-reinforced Pervious Concrete with Industrial and Recycled Fibers, Construction and Building Materials, vol 252, 118997, 2020.
9. D Wang, Q Zhao, C Yang, Y Chi, W Qi and Z Teng, Study on Frost Resistance and Vegetation Performance of Seashell Waste Pervious Concrete in Cold Area, Construction and Building Materials, vol 265, 120758, 2020.
10. T Joshi and U Dave, Construction of Pervious Concrete Pavement Stretch, Ahmedabad, India – Case Study, Case Studies in Construction Materials, vol 16, e00622, 2021.



# Investigation of Low Cost Concrete using Paper Industry Waste

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**Abstract:** Concrete is strength and tough material but it is porous material also which interacts with the surrounding environment. The durability of concrete depends largely on the movement of water and gas enters and moves through it. To produce low cost concrete by blending various ratios of cement with hypo sludge and to reduce disposal and pollution problems due to hypo sludge it is most essential to develop profitable building materials from hypo sludge. This project presents result of an experimental investigation carried out to evaluate effects of replacing cement by hypo sludge which is an industrial waste by-product on concrete strength. The primary aim of this research was to evaluate the durability of concrete made with hypo sludge. The partial replacement by replacing cement via 10%, 20%, 30%, and 40%, of Hypo Sludge for mix design of M20, M25, M30. The Investigation was carried out for the following test like compressive strength and split tensile strength, Flexural strength. Paper making generally produces a large amount of solid waste. Paper fibers can be recycled only a limited number of times before they become too short or weak to make high quality paper. It means that the broken, low-quality paper fibers are separated out to become waste sludge. Keeping this in view, investigations were under taken to produce low cast concrete by blending various ratios of cement with hypo sludge.

**Keywords:** Hypo Sludge Concrete; Compressive Strength; Split Strength; Flexural Strength

## INTRODUCTION

Concrete, is most widely used man made construction material and is the largest production of all the materials used in construction industry. Concrete is basically made of cementitious materials which have to properly bind themselves together, as well as with other materials to form a solid mass. Concrete or mortar is made up of cement, water and aggregates (Coarse and Fine Aggregate) and sometimes with necessary admixtures. Concrete has attained the status of a major building material in all the branches of modern construction. It is difficult to point out another material of construction which is as variable as concrete. Concrete is the best material of choice where strength, durability, impermeability, fire resistance and absorption resistance are required. Compressive strength is considered as an index to assess the overall quality of concrete and it is generally assumed that an improvement in the compressive strength results in improvement of all other properties. Hence strength investigations are generally centred on compressive strength. Even though concrete mixes are proportioned on the basis of achieving the desired compressive strength at the specified age, flexural strength often play a vital role in concrete making. This hypo sludge consumes a large percentage of local landfill space for each and every year.

## LITERATURE REVIEW

**Experimental Investigations in Developing Low Cost Concrete from Paper Industry Waste R Srinivasan, \*K Sathiya and M Palanisamy, 2010**

Over 300 million tons of industrial wastes are being produced per annum by chemical and agricultural process in India. These materials pose problems of disposal and health hazards. The wastes like phosphogypsum, fluorogypsum and red mud contain obnoxious impurities which adversely affect the strength and other properties of building materials based on them.

**Utilization of Waste Paper Pulp by Partial Replacement of Cement in Concrete Sumit A Balwaik, S P Raut, ISSN: 2248-9622**

The use of paper-mill pulp in concrete formulations was investigated as an alternative to landfill disposal. The cement has been replaced by waste paper sludge accordingly in the range of 5% to 20% by weight for M20 and M30 mix. By using adequate amount of the waste paper pulp and water, concrete mixtures were produced and compared in terms of slump and strength with the conventional concrete.



## MATERIAL COLLECTION AND CHARACTERISATION SUPPLEMENTARY CEMENTITIOUS MATERIAL

- 1) Hypo Sludge,
- 2) Cement,
- 3) Coarse Aggregate,
- 4) Fine Aggregate,
- 5) Water.

### Hypo Sludge

Hypo sludge is also known as paper industry waste. It is the by-product of the paper waste. This hypo sludge contains low calcium and minimum amount of silica. Hypo sludge behaves like cement because of silica and magnesium properties. Hypo sludge may be used as part replacement of cement. It is usually used in proportion of per cent of cement content of the mix. Hypo sludge (paper industry waste) has a tremendous potential in this context and it is well documented that the use of hyposludge in concrete results in a significant improvement in the rheological properties. Hypo sludge is a recent arrival among cementitious materials. It was originally introduced as artificial pozzolana while producing paper. The various wastes that come out from the various processes in paper industries. From the preliminary waste named as hypo sludge due to its low calcium is taken out for our project to replace the cement utilization in concrete. Paper making industries generally produce a large amount of solid waste. Paper fibers can be recycled only a limited number of times before they become too short or weak to make high quality paper. From paper manufacturing process three types of sludge are obtained namely lime sludge (hypo sludge and De-Inking sludge). In my project I have utilized lime sludge as a replacement for cement. Lime sludge (hypo sludge) is a material obtained from the chemical recovery process of paper production. Hypo sludge is available abundantly worldwide, but its usage to date is very limited. Each Indian mill produces an average 40 over-dry tons of sludge per day. Where, this hypo sludge contains, low calcium and maximum calcium chloride and minimum amount of silica. Hypo sludge behaves like cement because of silica and magnesium properties. This silica and magnesium improve the setting of the concrete.

Specific Gravity	= 2.10
Fineness of Cement	= 91.25%
Consistency of cement	= 0.30%
Initial Setting Time	= 28 minutes
Final Setting Time	= 560 minutes

### Cement

Cement may be described as a material with adhesive and cohesive properties that make it capable of bonding mineral fragments ('aggregates') into a compact whole. In this process, it imparts strength and durability to the hardened mass called concrete. The cements used in the making of concrete are called hydraulic cements — so named, because they have the property of reacting chemically with water in an exothermic (heat generating) process called hydration that results in water-resistant products.

The products of hydration form a viscous cement paste, which coats the aggregate surfaces and fills some of the void spaces between the aggregate pieces. The cement paste loses consistency on account of gradual loss of free water, through adsorption and evaporation, and subsequently 'sets', transforming the mixture into a solid mass. If the consistency of the cement paste is either excessively 'harsh' or excessively 'wet', there is a danger of segregation, the aggregate tends to separate out of the mix.

Table 1 Physical properties of cement

S.No	Characteristics	Value Obtained Experimentally
1	Standard consistency	33%
2	Fineness of cement as retained on 90 micron sieve	3%
3	Initial setting time	30min
4	Specific gravity	3.0



**Table 2** Comparison of cement and hypo sludge

SL No	Constituent	Cement (in %)	Hypo Sludge (in %)
1.	Lime(CaO)	62	46.2
2.	Silica(SiO <sub>2</sub> )	22	9
3.	Alumina	5	3.6
4.	Magnesium	1	3.33
5.	Calcium sulphate	3	3.03
6.	Other	1	1.02

The most common type of hydraulic cement used in the manufacture of concrete is known as Portland cement, which is available in various forms. Portland cement is made by burning together, to about 1400 degree Celsius, intimate mixture (in the form of slurry) of limestone with alumina-, silica and iron oxide-bearing. The type of cement that could be made only by varying the relative proportion of the oxide compositions, were not found to be sufficient. Resources have been taken to add one or two more new materials, known as additives, to the clinkers at the time of grinding, or to the use of entirely different basic of raw materials in the manufacture of cement.

#### Fine Aggregate

Sand is an inert occurring material of size less than 4.75 mm. It is used as a material of construction not only as filling and as a porous foundation blanket (as for roads) but also to a wide extent as a filtering medium and as constituents of mortars and concrete position affect all of these leading characteristics.

Specifications for sand to be suitable for the concrete are that it should be free from all these injurious materials. Further the percentage of the clay and silt content are restricted to maximum 5% and it should be free from organic impurities such as tannin acid derived surface vegetation. Sand are classified according to the source such as river sand, pit sand, sea sand etc.

#### Coarse Aggregate

As explained aggregate used for concrete production is classified as fine aggregate and coarse aggregate depending on its particle size. Aggregate of size more than 4.75 mm, is called as coarse aggregate and is one of the most important ingredient of concrete. It gives strength to the concrete and constituents about 70 to 75% volume of concrete. Crushed stone in general used as coarse aggregate which is black in colour, angular and in local name known as black metal or 'Gitti'. Coarse aggregate are generally derived by crushing natural available.

#### Water

The quality of mixing water for concrete has a visual effect on the resulting hardened concrete. Impurities in water may

**Table 3** Particle size distribution for fine aggregate: weight of aggregate taken = 3000 grams

Sieve Size	Weight Retained (grams)	Cumulative Percentage Retained	Cumulative Percentage Passing
4.75 mm	420	14.00	100
2.36 mm	110	17.67	86.00
1.18 mm	400	30.97	82.33
600 micron	820	58.30	69.00
300 micron	980	90.97	41.67
150 micron	240	98.97	9.00
75 micron	20	99.64	1.00
Pan	10	100	0.33



**Table 4** Particle size distribution for coarse aggregate : weight of aggregate taken = 3000 grams

Sieve Size	Weight Retained (grams)	Cumulative Percentage Retained	Cumulative Percentage Passing
40 mm	0	0	100
20 mm	1618.00	53.93	46.07
16 mm	763.80	78.38	21.62
12.5 mm	345.80	90.92	9.08
10 mm	219.00	98.23	1.78

interfere with setting of cement and will adversely affect the strength and durability of concrete with steel slag. Fresh and clean water which is free from organic matter, silt, oil, and acid material as per standards is used for casting and curing the specimens. Water that is piped from the public supplies is used.

### DESIGN MIX

A mix M25 grade was designed as per Indian Standard method (IS 10262-1982) and the same was used to prepare the test samples.

### MIX PROPORTIONS FOR TRIAL NUMBER

Cement = 281.60 kg/m<sup>3</sup>

Hypo sludge = 70.4 kg/m<sup>3</sup>

Binding material = 352 kg/m<sup>3</sup>

Water = 140 kg/m<sup>3</sup>

Fine aggregate = 485.8 kg/m<sup>3</sup>

Coarse aggregate = 781.3 kg/m<sup>3</sup>

Water-cement ratio = 0.42

**Table 5** Properties of water

S.No	Parameter	Result	Limits IS : 456(12)
1	PH	6.92	6.5 -8.5
2	Chloride	52 mg/l	2000 mg/l (pec) 500 mg/l (rec)
3	Alkalinity	7 ml	< 25 ml
4	Sulphate	128 mg/l	400 mg/l
5	Fluorides	0.04 mg/l	1.5 mg/l
6	Organic solids	56 mg/l	200 mg/l
7	Inorganic solids	129 mg/l	3000 mg/l

**Table 6** Comparison of result

M25 mix No. of Days	Conventional Concrete N/mm <sup>2</sup>	10% Hypo Sludge Concrete N/mm <sup>2</sup>	20% Hypo Sludge Concrete N/mm <sup>2</sup>	30% Hypo Sludge Concrete N/mm <sup>2</sup>	40% Hypo Sludge Concrete N/mm <sup>2</sup>
7 days	14.22	11.55	13.11	10.66	10.44
14 days	17.56	17.11	17.55	14.22	12.88
21 days	23.33	22.00	24.44	18.88	17.11
28 days	24.88	24.22	24.66	22.00	21.11



## CASTING OF CONVENTIONAL CONCRETE AND HYPO SLUDGE CONCRETE

To understand the behavior of concrete in compression, split and flexure, cubes, cylinders and prisms are cast. The average values of three specimens are taken.

1. **Conventional Concrete (C):** The conventional concrete specimens are made up of M20 concrete with the mix ratio.
2. **Hypo Sludge Concrete:** Concrete specimens are made up of cement, hypo sludge, fine aggregate, coarse aggregate and water.

Concrete added Hypo Sludge 10%, 20%, 30% and 40% replacement of cement.

## CONCLUSION

Finally I conclude my project with full satisfaction. In my project casting of conventional cement concrete cubes, beams and cylinders has been done casting of concrete cube added with paper industrial waste (HYPO SLUDGE) has also been done comparison of results has been done testing of concrete cubes with various methods like compression, split tensile and flexural test has been done for both cubes. Up to 10% of hypo sludge concrete, the compression strength has been increased, so up to 10% cement has been replaced by hypo sludge. Compression, split tensile and flexural test of concrete with various mixes with different curing periods which are 7, 28 days by partial replacement of cement with hypo sludge that is 0%, 10%, 20%, 30% and 40% which are noted. The compressive strength increases as the curing period increasing for M20, M25 and M30 grade concrete, compressive strength, Split tensile strength and flexural strength is increase with 10% replacement finally hypo sludge 10% replaced in cement. Environment effects from wastes and maximum amount of cement manufacturing is reduced through this project.

## REFERENCES

1. Andrew M Dunster, Paper Sludge and 23. Ergun, 2011. Effects of Usage of Diatomite and Paper Sludge Ash in Portland Cement Manufacture, Waste Marble Powder as Partial Replacement of Cement WRT 117/WR0115. on the Mechanical Properties of Concrete, 2007
2. Binal P Lad, Aayush R Sharda, Investigation of Low Cost Concrete using Paper Industry Waste- Lime Sludge, Gujarat Technology University, May 2014.
3. R Balamurugan, R Karthickraja, An Experimental Investigation of Partial Replacement of Cement by Industrial Waste (Hypo Sludge), International Journal of Engineering Research and Applications (IJERA), ISSN: 2248 9622, vol 4, iIssue 4 (Version 1), April 2014, pp 430-435.
4. Gabriel Fava, Maria Letizia Ruello and Valeria Corinaldesi, Paper Mill Sludge Ash as Supplementary Cementitious Material, Journal of Materials in Civil Engineering, ASCE, 23(6), 2011, pp 772- 776.
5. Jayesh Kumar Pitroda, L B Zala, F S Umrigar, Durability of Concrete with Partial Replacement of Cement by Paper Industry Waste (Hypo Sludge), International Journal of Innovative Technology and Exploring Engineering (IJITEE) February 2013.
6. Jayraj Vinodsinh Solanki, Jayeshkumar Pitroda, Investigation of Low Cost Concrete Using Industrial Waste as Supplementary Cementitious Materials, International Journal of Engineering Science and Innovative Technology (IJESIT), vol 2, issue 1, January 2013, ISSN:2319-5.



# Mud Mortar, the Earth Concrete Material —— Case Study and Overview

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**Abstract:** Earth is the most primitive and traditional construction material which was used effectively with natural additives as admixtures from the ancient construction period. The zero-carbon footprint of this construction material makes it environment-friendly, economical, and sustainable. The overview on utilizing mud mortar in its best form is given by; the choice of local mud material and the role of fine aggregate to mud ratio to fulfill the strength & durability parameters. This research has been carried out by reviewing the past researchers throughout the world who have utilized mud mortar as a construction material with various natural admixtures were studied and it ensures a promising future to use these materials for sustainable construction for the people who would like to lead a life with nature without disturbing its ecological balance. A characterization case study on the Chakrapani temple compound wall made of mud mortar from an ancient site situated in Kaatumanarkoil (Komaratchi village), Kadalur district was studied with the samples collected to investigate the secret of their everlasting strength and durability properties that have withstood many man-made and natural disasters. The mineralogical characterization study on the mortar sample was performed with SEM-EDAX, FT-IR, and DSC-TGA to identify ingredients that made this construction material reach its stable form. From the SEM analysis, it is inferred that the samples have dense and minute pore structures and the presence of Calcium oxalate crystals, a stable form of calcium carbonate (lime) were present. It indicates the use of lime as a stabilizer in the mud mortar to improve its properties. The EDAX summarizes the constituents of the mortar matrix with a major percentage of silica and secondly calcium, nitrogen, and alumina. The presence of oxygen confirms the breathable character of mud mortar. The sepiolite material formed by mud and air lime composition was profoundly found from the intense bands of FTIR analysis. The characterization study resulted in stable morphological details of the composition. These vernacular construction methods give way to the utilization of locally available materials that fulfill a comfort zone for the people living in it. Making use of local resources plays a vital role in preserving natural resources with numerous benefits in all aspects.

**Keywords:** Earthen Constructions; Mud Mortar; Mud Testing Methods; Sustainable Constructions

## INTRODUCTION

The Earth provides every basic need required for a healthy living. The three basic needs of humans are food, water, and shelter, which are available in the surrounding, with a little effort they can be converted to utilizable form. Raw food is cooked, water is purified and the shelter needs to be constructed with the most readily available local materials like soil, sand, and water the universal solvent to make them plastic enough to give the desired shape for the structure of the shelter. The construction era started with these vernacular construction materials that satisfied the people with structures of safety from natural calamities and dangerous predators. As the evolution of humans began, the evolution of the three basic needs for living too evolved, and shelter was the most evolved for emerging aesthetic needs in living trends. In India, as many as 80 million earth constructions[1] while Africa and China have plenty more compared to India. **Figure 1** denotes the number of lively use of Vernacular mud constructions all over the world.

Globally, these constructions made with locally available materials[12-14] in their most minimally processed form played a vital role in keeping the carbon footprint minimum to zero. The higher levels of processing of natural resources lead to higher emissions of carbon dioxide, known as the carbon footprint of any resource production. The use of locally available materials reduces the need for transportation and intensive processing and wastage which contributes to lesser embodied energy [15-17]. Higher embodied energy in rapidly increases carbon footprint[19]. An increase in carbon dioxide in the atmosphere causes Global warming, a major threat to the ozone depletion and melting of Arctic and Antarctic glaciers. Ozone is a protective layer that filters unwanted rations from the Sun, depletion of this layer causes the inlet of various unfiltered UV radiations that lead to cancerous diseases in living beings and genetic changes to prolonged exposure. Whereas the melting of glaciers increases the sea levels, leading to the submerging of land area.



**Figure 1** Number of vernacular mud mortar constructions [2-11]

Carbon dioxide, a major greenhouse gas, has to be minimized by following vernacular construction methods[20].

In India, 55% of the Rural population still makes use of earthen materials for their domestic construction works[21,22]. Being a tropical country, India makes use of a huge amount of power in stabilizing the indoor temperature which means overutilization of natural resources for power generation whereas the olden construction methods made use of unprocessed and minimally processed construction materials like mud, and lime gave very good thermal comfort in all the seasons of the year [23]. The Indian construction technology has always made use of natural ingredients that were locally available in the surrounding environment, for example, plant extracts like Aloe vera, spinach extract, jaggery, kadukkai, animal products like egg albumin, and natural fibers like hay, straws, coconut shells/coir the construction was done efficiently.

The aim of this paper is to enhance the knowledge of earthen construction methods followed by people from the earlier era of construction all over the world, which has been stable and strong with timely maintenance. The practice of natural building construction in its vernacular form gives sustainable growth to the environment around it. This paper is concerned with spreading knowledge on vernacular construction methods for healthy living.

### INDIAN CONSTRUCTION PATTERN

India is a versatile country known for its various natural resources, climate, people, and traditions that stay united. The evolution of construction can clearly be seen as the people used their locally available construction material (soil) for their needs and it provided the needed indoor comfort (**Figure 2**). Nature itself provides what is needed for every particular area according to its temperature and climate. Vernacular construction has evolved by facing various obstacles to the climatic conditions today, which has provided sustainable structures that have stayed strong over many years[24].

The six different temperature zones, numerous types of soils (red, black, laterite, alluvial, forest, desert, marshy, saline, etc.), and numerous micro and macro climates cannot be fulfilled with the same type of concrete construction all over the country. The soil naturally gives the comfort needed for that particular area for construction, every type of soil is hence suitable for construction in the proper ratio. Concrete constructions increase Carbon dioxide emission, it is known that the building sector produces 11% of the total carbon emission in the world[25]. The higher the embodied energy higher will be the pollution created by these materials' production and throughout their time. The type of soil used in various parts of India is shown in **Figure 1** and **Table 1** depicts the various types of construction techniques used by using locally available materials in that

The use of natural ingredients in the mud/lime materials was predominantly seen in almost all of the ancient construction techniques. Cow dung is said to have improved the consistency of the mortar, egg improves the smoothness for plastering, the addition of neem, and turmeric improves the termite resistivity of the mortar matrix, the addition of paddy



**Table 1** Construction techniques in various parts of India[20,24,29,32,34,48]

States	Highly Prone Seasons	Beam Materials	Mortar Materials	The Common Term for Buildings
Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh,	Snow	Indian cedar tree trunk	Mud mixed with cow dung and burra grass	Kachha House
Uttar Pradesh, Bihar, Punjab, Haryana	Northern Plains- Continental Climate	Timber	Mud mixed with paddy straw	Haveli
Rajasthan, Gujarat	Desert	Brushwood	Mud and dung, Elephant Grass, Murat Grass	Jat, Bhunga, Haveli
Gujarat, Daman & Diu	Towards the Arabian Sea	Teak	Mud and dung, Lime plaster	Haveli, Delo
Gujarat, Maharashtra, Madhya Pradesh, Orissa	Central India	Bamboo, Timber	Wattle & Daub, Mud mixed with paddy straw, cow dung with mud, Teak leaves	Kaccha, Pukka
Andhra Pradesh, Karnataka, Goa, Kerala, Tamil Nadu	South India	Coconut tree trunks, Bamboo	Mud with dung, plant & animal byproducts, crop waste, Palm leaves, Paddy, Wattle, Rubbles, pebbles	Arsh, Pukka
Bengal, Orissa, Assam, Meghalaya, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura	Ganga Delta to Eastern Delta	Bamboo	Mud & dung, Wattle, cane, Jackwood	Moring

straws, grass, and leaves improves the resistance, adds strength, and improves the thermal performance of the structure[26,27]

**Mud Mortar Constructions in India**

It is seen that various parts of the country with various climate and temperature zones are satisfied with their own locally available materials by vernacular construction methods followed traditionally. Some of the traditionally constructed structures with mud mortar are shown here.



**Figure 2** Indian map showing various types of soil and the annual temperature zones of India (source: Maps of India.com)

### Mud Selection and Testing

Mud is a composition of the following constituents in it as shown in the **Figure 3** from the top to the bottom layer of the Soil.

The selection of soil for mud mortar construction plays a crucial role in its strength and durability properties [29]. Organic soil will be the worst choice of material since it contains more percentage of degrading organic waste and the soil content is less.

The use of a higher percentage of clay leads to earlier shrinkage since the temperature reaches more than 30 degrees Celsius during the summer and sand individually cannot hold a shape or give good strength. **Figure 4** represents the importance of choosing the best combination of materials for mud mortar. Hence a proper combination of clay and sand gives the best mud mortar for construction purposes by avoiding the various shrinkage occurrences while using mud mortar as a construction material.

### Preliminary Testing of Mud Quality

The composition of the clay used in the mud mortar plays a vital role in strengthening the matrix to be used, the Composition of the Mix, Liquid limit, plastic limit, water content, and dry density are known as Atterberg limits [28,30,31,34,41], and various on-site on hand testing is made by the constructors [50] and from the Handbook for Cob, Laurie baker mud as shown in **Table 2**.

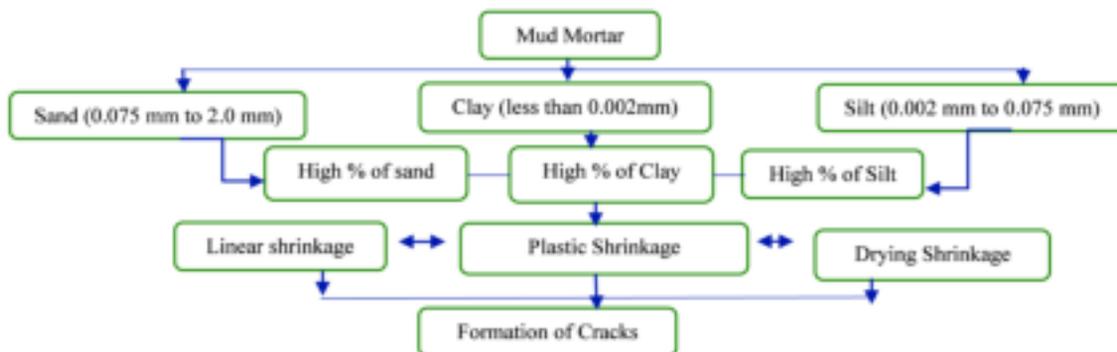
The tests mentioned in **Table 2** are the most commonly used on-site with hands that have resulted in efficient results so far. The Auroville Earth institute located in Auroville Pondicherry successfully executes the use of earth as a construction material utilizing these techniques in their construction practices and over 3+ floors have been constructed and utilized using compressed and stabilized earth material. The stabilizer utilized was mostly 5% of cement material in 95% of the mud chosen from the above techniques.

### VARIOUS COMPOSITIONS OF MUD MORTAR

The use of mud/clay mortar with various ingredients was seen throughout the country, and some of the research papers that have given out the best mechanical properties of these mud mortars are compared with various compositions. The



**Figure 3** The soil layers on earth (source: Freepik), the mud mortar combination (source: Laurie Baker Mud, [28])



**Figure 4** Consequences of improper composition of mud mortar [36,37]



**Table 2** Vernacular soil testing for construction [50]

Various methods of testing	Sand	Clay
Senses test	Super grainy, crunchy sound while rubbing	Clay is super soft, sticks in hand
Bottle test	The proportion of different components of soils	
Cigar test	Rolling a cigar of soil, and checking the length of rollability of the soil. If it breaks soon, it is weak.	
Biscuit test	Making a ball out of the mud and drying it in the sun and breaking it. It should break into two halves rather than get crushed.	
Handwashing test	Rub your hands in the soil and wash them in water to check how easily it is washable. More clay content tougher the hand-cleaning process	
Ball/palan test	Make a ball and hit it on the ground. Instant segregation is not recommendable, the soil should stay together.	

shrinkage properties of this mix have also been tested to give the durable mortar matrix with natural ingredients to improve the strength and durability properties. The below table denotes the compositions that have been experimented with promising results on improved properties of mud mortar.

**Table 3** details the use of mud mortar used efficiently in various combinations all over the world, the use of locally available raw materials like straw, rice husk ash, plants, herbs, coconut coir, and cow dung as admixtures have given the best results and the stabilizers lime and cement in mud mortar drastically improved the properties of mud mortar by constraining the formation of cracks a major problem faced while using mud mortar construction.

The strength, thermal performance, and life cycle assessment on utilizing mud mortar in constructions have been a great research interest to bring in minimal carbon foot printed construction materials from the past to the present in an updated form using stabilizers for needed strength and durability achievement.

### CASE STUDY ON ANCIENT MUD MORTAR CONSTRUCTION WALL

A case study on mud mortar constructed temple structure was taken to know in depth the materials utilized for a stable mud-mortared wall structure of a heritage structure located in Tamil Nadu. Tamil Nadu being rich in heritage and culture holds an end number of ancient structures depicting the utilization of locally available materials as vernacular constructions. These heritage sites are found by the government of Tamil Nadu under

#### Location of the Sample Collected

The magnificent 2000+ years old temple is located in Ma.arasur a village panchayat located in the Cuddalore district of Tamil-Nadu state, India. The latitude 11.7482289 and longitude 79.7481573 are the geocoordinates of the Ma.arasur (Wikiedit.org). The temple has been highly damaged due to no maintenance and by the calamities of nature and vegetation growth all over the temple hiding its chariot look on which temple resides in **Figure 4**. The main structure of the temple is intact and with maintenance can be stable and strong for the forthcoming many years. The renovation works were started by the government to protect this ancient structure recently. The mud-mortared outer layers and the compound walls were studied and samples were collected to know the main ingredients of the mortar material.

#### Mineralogical Characterization Study

##### SEM-EDAX

The internal morphological changes and formations for the ancient mud mortar sample taken from the heritage site have been studied using the SEM and the EDAX gives the constituents present in the material. The SEM-EDAX analysis was done using a Hitachi S-3400N model with a magnification of 5X to 300,000X and a resolution of 3.0 nm.

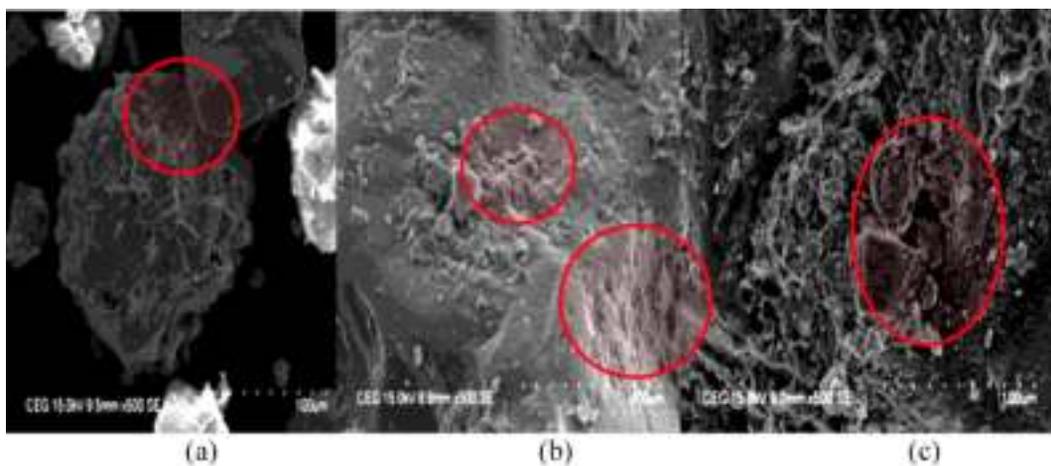
**Figure 5** depicts the C-S-H and CH formations that have led to the form of stable construction material[48]. The rigid nature of these ancient materials can be identified by the formation of quartz and sepiolites[49]in all three SEM images (a),(b), and (c). The uniformly blended mortar mix implies the minute pore structures, fibers, and globules of bonded particles by the activity of admixtures that have been added for the formation of calcium oxalate[49]. The highly denser microstructure[50]of the ancient mortar has made it resistant to various climatic conditions. Mud mortar constructions are a highly healthy version of construction, and these SEM images show they gain strength by the usual C-S-H gel

Table 3 Compositions of mud mortar that have been experimented

Author	Various types of Composition	Specimen	Strength Parameter Tests	Testing	Important Points & Codes used	Research Findings
[30]	Neolithic clay with cement stabilizers	Case study	Energy use of the building		The utilisation of clay of the building materials	Recycling of materials in the utilization of building materials at the heart of the occupants. Social and economic aspects related to the utilization of clay in the building materials. The utilization of clay in the building materials.
[31]	Soil + Fly ash + cement + straw	Cubes, Cylinder, Prism	0.56 to 1.75 MPa (With slope compression test) (0.45 and 1.5) MPa (Size independent values)	Non-linear structural analysis		
[32]	Mud, industrial residues, human fibres, GGBS, Fly ash, Lime, and sand	Cubes, Beams	Strikingly parameters. Water absorption. Dimensional tolerance test. Workability	IS: 675-1972, IS: 5495 (Part 1)-1992, IS: 1077-1972	Chemical composition of the soil, IS: 457-1972-1	Fines improved compression strength, shrinkage, and density. Self-compacting mortar. % of the content of admixtures
[33]	Clay, lime, and sand	Prismatic specimens	Water absorption test. Workability			
[34]	Clay, lime, and sand	Rammed earth wall, sub wall	Swelling test, cohesion strength test - surface color test, water retention test, Gasberg erosion test, water absorption test, permeability test	IS: 675-1972, IS: 5495 (Part 1)-1992, IS: 1077-1972	Chemical composition of the soil, IS: 457-1972-1	Each water treated with silane-siloxane admixture gives improved properties
[35]	Straw or animal hair, Palm fibres, human fibres, sugarcane plantain peonon stem, rice or pig bristles	Cubes	5 MPa to 2.6 MPa Compressive strength	Code used: DIN: 15976		Importance of aspect ratio of sand, Addition of sand, natural air entrainment and air trap
[36]	Sandy soil, stabilizer (Cement) and animal fibres (Cashew nut, and paddy straw)	Striking spars	Linear shrinkage	IS: 457-1972 Part 20		Fiber spars in shrinkage reduction & density reduction, the Effect of the paddy plantain peonon stem in the strengthening process (Crack) Straw fibers in the soil-stabilizing process (Crack)
[37]	Composite Adobe with fibres (Cement, animal fibres)	Compressive, Diagonal Tensile Test	4.04 MPa (1) Just strength for compressive failure	CEX, Euro code 6 and Technical Building Standard EN: 12600		Straw fibers improved the stress-strain, fiber spars improved the ultimate strain strength and
[38]	Mud mortar with stabilized (fly ash, lime, and sodium silicate) with Type II soil	Compressive strength and water absorption	Striking parameters	IS: 457-1972		The use of cement as stabilizer and earthen adhesives in masonry
[39]	Adobe with fibrous cancellable fiber	Cubes, Beams	Spray test, Lateral conductivity	Lesson learnt evolution and stress on soil fabric versus the content and the length of fibers		Pressed Adobe blocks were improved thermal comfort. High % of fibers reduced the strength required
[40]	Concrete, lime, and sodium silicate with Type II soil	Blocks	Paired shear strength test, Direct strength, Displacement compression test	Numerical simulations		4-block triplet shear strength test is recommended as the standard assessment for earth block masonry
[41]	Red mud + Rice husk ash + cement	Cubes, Beams	Compression, tensile, flexure	IS: 12269-1988,		To suggest alternatives for cement use
[42]	Cement-stabilized soil, cow dung	Rammed earth wall	Compressive, tensile, flexure	Linear study	IS: 12269-1988,	Potential for the use of stabilized rammed earth
[43]	Soil, animal hair, poultry manure, cement, bamboo and metal bars	Cylindrical	Flexural strength	Flexure study	IS: 12269-1988,	Barbed wire and steel fiber reinforcement enhances the ductility property of masonry
[44]	Clay, straw, cow dung	Case study	Pullout test, Lateral study	IS: 12269-1988,		Importance of surface area to volume ratio, Orientation of the fibers, Ventilation, Building envelope materials
[45]	Clayey soil, vegetable and animal fibre, cow dung, rice husk, cow dung, red wine	Randomized clay blocks, cube (Compression)	Moisture content	The optimum clay: sand ratio was below 0.43 and 0.36		Effect of the clay: sand ratio on the performance envelope materials
[46]	Sand, clay, straw, and rubble	Case study	The failure of the structure is caused by the settling of the mud mortar layer	Decreased change in the ground-water level		Reliable strengthening
[47]	Compost, glue binders (polymer Acrylic (PVA) and Polyvinyl Alcohol (PVA))	Thermal insulation measurement in 30 minutes, hour	Life cycle assessment	ISO 14040 and ISO 14041		Organic waste as thermal content in earth construction: evaluation for agricultural wastes and by-products as potential eco-friendly building materials



**Figure 4** Temple image and the walls of the temple



**Figure 5** SEM image of the mud mortar sample

formation that leads to the strengthening of the construction material and the role of bio-additives or bio-admixtures had a major role in improving the properties of the mortar.

**Figure 6** summarizes the constituents present in the mud mortar sample as 35% of silica, alumina 5%, and the presence of higher oxygen content of 52% showing the lively air movement in the particles and the presence of nitrogen confirming the organic content in the mortar. This organic content inclusion has led to an improved version of air entrainers that gives the “breathable construction material” quality. From the study of the mortar sample, the presence of calcium denotes that for the stabilization of mud mortar a certain percentage of lime would have been used for improved strength properties of the ancient mortar samples collected at the temple site.

#### DSC-TGA

The Differential scanning calorimetry (DSC)-Thermo-gravimetry for the ancient mud mortar sample taken from the heritage site was performed with the temperature range of RT 1700 degrees Celsius with a TG resolution of 0.1  $\mu$ g and DSC resolution of <math>1 \mu\text{W}</math> to the thermal transition of materials at higher temperatures by identifying the mineral that as reacted to that particular increase in temperature.

The loss of mass is seen gradually high in the TGA curve in **Figure 7**. The calcium oxalate present in the mud mortar material had decomposed to form its finer versions of calcium carbonate and calcium oxide[51]. The transition of kaolinite a clay material present in the mud mortar was noted from 400 degrees Celsius to 500-degree Celsius [52]. And the DSC-TGA signifies the major disintegration happens above 500 degrees Celsius in the clay content of the mud mortar material sample, with the change in kaolinite to meta kaolinite happening from above 500 degrees Celsius as mentioned in the DSC curve.

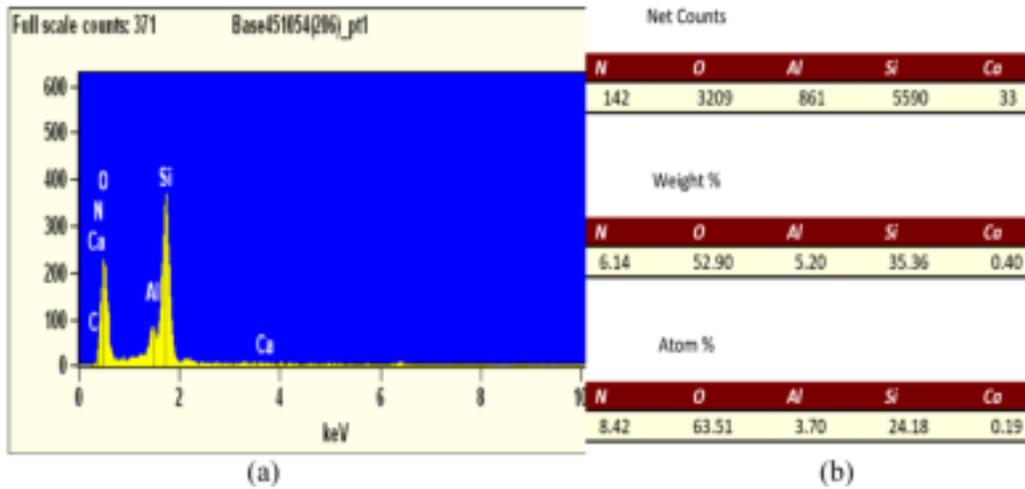


Figure 6 (a)SEM with EDAX image (b) Quantification of the constituents of the mud mortar sample

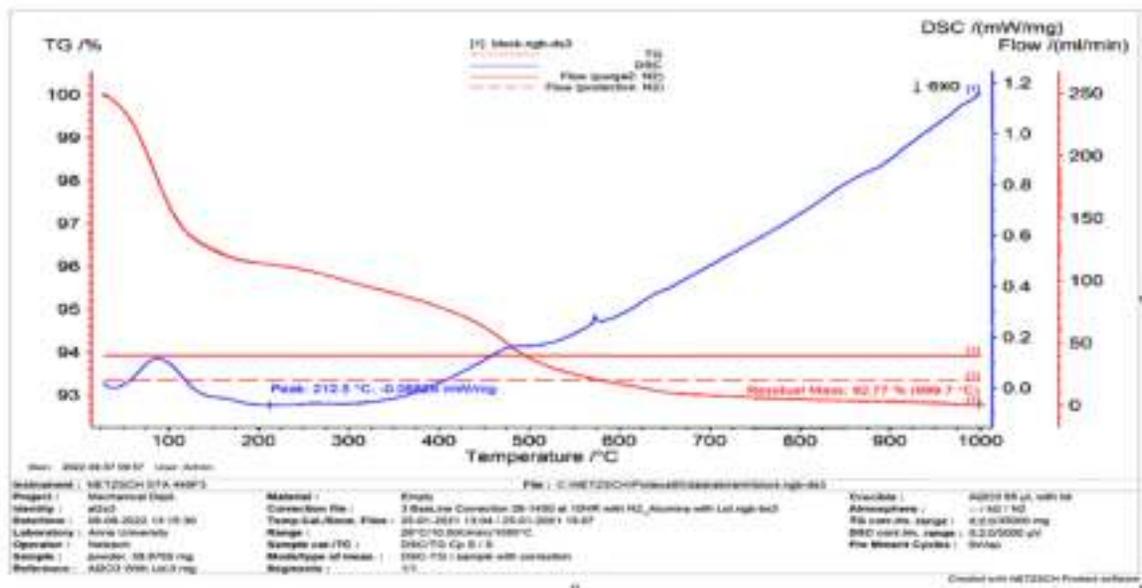


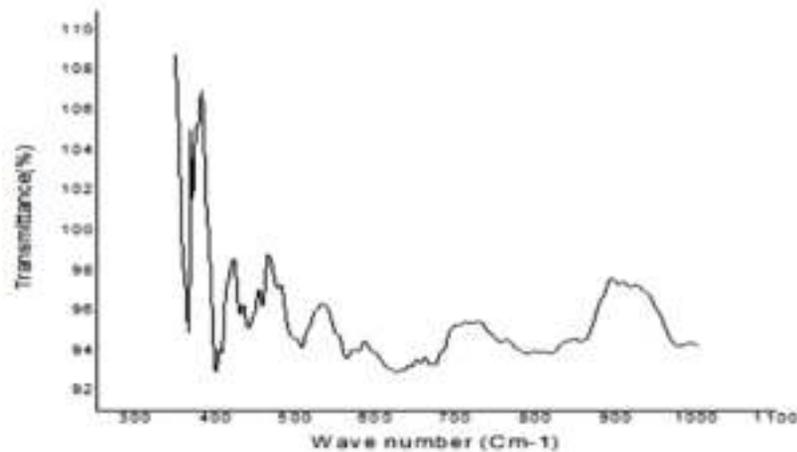
Figure 7 DSC-TGA image of the mud mortar sample

### FT-IR

The spectrums produced in the spectroscopy identify the presence of organic content and minerals; the FT-IR analysis was carried out on the ancient mud mortar samples taken from the heritage site using JASCO-Fourier-Transform Infrared Spectroscopy of the wave number range, with a standard DLaTGS detector 7800 to 350  $\text{cm}^{-1}$ .

The intense bands in **Figure 8** FT-IR analysis spectrum show the presence of calcium carbonate, silica, kaolin (clay material), and calcium oxalate in the mud mortar sample. The spectrums from 300  $\text{cm}^{-1}$  to 500 $\text{cm}^{-1}$  show the presence of sepiolite material which is a soft clay material that was profoundly seen in these ancient mud mortars and plays a vital role in improving the properties of mud mortar stabilized with air lime[53].

Air lime materials stabilizers use in mud mortar make them stable and strong and let the mortar absorb carbon dioxide present in the atmosphere to achieve its strength. The SEM analysis and FTIR confirm the presence of sepiolite in the



**Figure 8** FT-IR analysis of the mud mortar sample

composition. Air lime materials hence can be seen as the most compatible material with the mud mortar that acts as a catalyst in improving the properties of mud mortar. The presence of bio-additives was seen in the nitrogen content of the mortar from the EDAX analysis of the composition of the material, lime being a boon to the environment[54], and the abundantly available bio-additives/admixtures contribute a major part to sustainable construction materials that have been used in the past with the most minimum carbon footprint can be used in present-day construction materials by utilizing the stabilizers like air lime with bio-additives[55].

## CONCLUSION

“We shape our buildings- thereafter, they shape us.”– Winston Churchill.

The Earth provides every need of the living being, in such a way that no pollution occurs, a healthy construction gives way to healthy living. It is always the overutilization/over-extraction and over-processing that lead to the ecological imbalance. The overview on mud mortar utilization as a construction material have been studied from various researches and a case study on a heritage structure that made use of mud mortar as the basic construction material in compound wall construction was investigated and the findings are given below;

- ❑ The use of mud mortar with locally available organic materials as admixtures has been profoundly seen in all countries. These admixtures acted as strength and durability enhancers.
- ❑ The use of natural fibers prohibits the formation of cracks which was identified and used from the past to till today.
- ❑ The mud mortar structures have exhibited efficient thermal performance and a perfect mix gives a stable structure by avoiding the hindrance caused by crack formation, the locally available hand test methods give way to the selection of viable material.
- ❑ The choice of material in construction in any particular area fulfills its own living comfort with improved air quality and thermal performance.
- ❑ The case study reveals the ingredients utilized in the mud mortar material construction and the stabilizer used in the mud mortar was identified to be air lime.
- ❑ From the mineralogical characterization study of the ancient mud mortar sample it is found that the stable C-S-H formation, the calcium oxalate compound formed in the mud mortar confirming the reasons for a stronger construction material; The presence of higher oxygen content proving the “breathable nature” of the construction material for efficient air movement in a structure.
- ❑ The DSC-TGA and FTIR go hand in hand proving the presence of minerals identified from the SEM-EDS analysis for the formation of stable compounds. The presence of sepiolite material and forms of clay prove various mix proportions that have been used to achieve stableness in mud mortar material.

Knowledge shared by experienced constructors who have been in natural building construction for years should be



encouraged so that the methodology of this construction travels through time to the forthcoming generations. More research on improving the properties of these eco-friendly economical materials should be encouraged and funded with good lab facilities.

The high increase in pollution produced by various industries in the environment has led to the protective ozone layer that protects from the inlet of harmful radiation from the sun. Depletion in this protective layer leads to major health threats to all living beings, ozone reacts with the various chemicals produced in the environment and makes the air unhealthy which may lead to major health issues related to the lungs [56-59]. The use of earthen materials is much more economical when planned properly compared to conventional pollution-causing construction methods [60]. The Life cycle of these feasible eco-friendly construction materials gives way to lesser greenhouse gas emissions on longer terms that lead to global warming of the world [61].

## CONSENT FOR PUBLICATION

### Availability of Data & Materials

All the data and materials are available within the paper.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## REFERENCES

1. C Williams, S Goodhew, R Griffiths and L Watson, The Feasibility of Earth Block Masonry for Building Sustainable Walling in the United Kingdom, *Journal of Building Appraisal*, vol. 6, no. 2, September 2010, pp 99–108, doi: 10.1057/jba.2010.15.
2. L Keefe, *Earth Building e Methods and Materials, Repair and Conservation*, Taylor & Francis Group, Abingdon (UK), 2005.
3. C Ziegert, *Analysis of Material, Construction and Damage in Historical Cob Buildings in Central Germany*, Terra 2000 8th Int. Conf. Study an Conserv. Earthen Archit., English Heritage, Torquay, Devon (UK), 2000, pp 182–186.
4. J C Loudon, *Encyclopaedia of Cottage, Farm, and Villa Architecture and Furniture*, Cambridge University Press, 2014.
5. T J Joce, *Cob Cottages for the Twentieth Century*, 1919, pp. 169–174.
6. J McCann, Ed., *Clay and Cob Buildings*. Shire Publications, 1995.
7. M Rouault and *Geographie, habitat rural traditionnel du Bassin de Rennes etredecouverte des maisons en terre*, Bull. R eg. Tiez Breiz Maison Paysannes Betagne , 1984, pp 18–22.
8. M Ford, H E Kadi and L Watson, *The Relevance of GIS in the Evaluation of Vernacular Architecture*, *Journal of Architectural Conservation*, 1999.
9. E P Mora, *Life Cycle, Sustainability and the Transcendent Quality of Building Materials*, *Materials Science*, March 2007.
10. *Traditional Earthen Building Techniques in Central Asia*, *International Journal of Architectural Heritage Conservation, Analysis, and Restoration*, vol. 3, no. 2, September 2009.
11. F Pacheco-Torgal and S Jalali, *Earth Construction: Lessons from the Past for Future Eco-Efficient Construction*, *Construction and Building Materials*, vol 29. April 2012, pp 512–519, doi: 10.1016/j.conbuildmat.2011.10.054.
12. C Hange, *United Nations Environmental Program, Buildings and Climate*, 2009.



13. J C Morel, Ali Mesbah, M Oggero and P Walker, Building Houses with Local Materials: Means to Drastically Reduce the Environmental Impact of Construction, *Build Environ*, vol. 36, no. 10, December 2001, pp 1119–1126.
14. MK Dixit and CH Fernández-Solís, Identification of Parameters for Embodied Energy, 2010
15. E Hamard, B Cazacliu, A Razakamanantsoa and J C Morel, Cob, a Vernacular Earth Construction Process in the Context of Modern Sustainable Building, *Building and Environment*, vol. 106. Elsevier Ltd, pp. 103–119, September 01, 2016. doi: 10.1016/j.buildenv.2016.06.009.
16. B Rosselló-Batle, C Ribas, A Moià-Pol and V Martínez-Moll, An Assessment of the Relationship Between Embodied and Thermal Energy Demands in Dwellings in a Mediterranean Climate, *Energy Build*, vol. 109, December 2015, pp 230–244, doi: 10.1016/j.enbuild.2015.10.007.
17. S Mandley, R Harmsen and E Worrell, Identifying the Potential for Resource and Embodied Energy Savings within the UK Building Sector, *Energy Build*. 86, 2015 841e851, <http://dx.doi.org/10.1016/j.enbuild.2014.10.044>,” DOI:10.1016/J.ENBUILD.2014.10.044, 2015.
18. P J Godwin, Building Conservation and Sustainability in the United Kingdom, *Procedia Engineering*, vol. 20, 2011, pp 12–21. doi: 10.1016/j.proeng.2011.11.135.
19. J Giesekam, J Barrett, P Taylor and A Owen, The Greenhouse Gas Emissions and Mitigation Options for Materials used in UK Construction, *Energy Build*, vol 78, 2014, pp 202–214, doi: 10.1016/j.enbuild.2014.04.035.
20. J Gupta, M Chakraborty, S Mathew and A Jharia, Mud as a Construction Material in Rural Dwellings: Study of Thermal Performance in Composite Climate, *International Journal of Advanced Science and Technology*, vol 29, no 03, 2020, pp 12481–12498.
21. R Illampas, I Ioannou and D C Charmpis, Adobe Bricks under Compression: Experimental Investigation and Derivation of Stress-Strain Equation, *Constr Build Mater*, vol 53, February 2014, pp 83–90, doi: 10.1016/j.conbuildmat.2013.11.103.
22. J Gupta, M Chakraborty, S Mathew and A Jharia, Mud as a Construction Material in Rural Dwellings: Study of Thermal Performance in Composite Climate, *International Journal of Advanced Science and Technology*, vol 29, no 03, 2020, pp 12481–12498.
23. Baruch Givoni, *Man, Climate and Architecture*. Applied Science Publishers, 1976.
24. I Cooper, *Traditional buildings of India*. 1998.
25. T Abergel, B Dean and J Dulac, Towards A Zero-Emission, Efficient, and Resilient Buildings and Construction Sector. Online available: [www.globalabc.org](http://www.globalabc.org)
26. S Thirumalini, R Ravi, S K Sekar and M Nambirajan, Knowing from the Past - Ingredients and Technology of Ancient Mortar used in Vadakumnathan tTemple, Tirussur, Kerala, India, *Journal of Building Engineering*, vol 4, December 2015, pp 101–112, doi: 10.1016/j.jobee.2015.09.004.
27. Arvind Krishan, *Climate Responsive Architecture: A Design Handbook for Energy Efficient Buildings*. Tata McGraw-Hill Pub. Co, 2001.
28. S Sangma and D D Tripura, Experimental Study on Shrinkage Behaviour of Earth Walling Materials with Fibers and Stabilizer for Cob Building, *Constr Build Mater*, vol 256, September 2020, doi: 10.1016/j.conbuildmat.2020.119449.
29. M Pedergnana and S T Elias-Ozkan, Impact of Various Sands and Fibres on the Physical and Mechanical Properties of Earth Mortars for Plasters and Renders, *Constr Build Mater*, vol 308, November 2021, doi: 10.1016/j.conbuildmat.2021.125013.
30. J C Morel, A Mesbah, M Oggero and P Walker, Building Houses with Local Materials: Means to Drastically Reduce the Environmental Impact of Construction, 2001. Online Available: [www.elsevier.com/locate/buildenv](http://www.elsevier.com/locate/buildenv)
31. R Illampas, I Ioannou, and D C Charmpis, Adobe Bricks under Compression: Experimental Investigation and Derivation of Stress-Strain Equation, *Constr Build Mater*, vol 53, February 2014, pp 83–90, doi: 10.1016/j.conbuildmat.2013.11.103.



32. M S Lekshmi, S Vishnudas and D G Nair, Strength, Sorptivity and Shrinkage Characteristics of Cow Dung Stabilized Mud Mortar, *Materials Today: Proceedings*, vol 32, January 2020, pp 782–787. doi: 10.1016/j.matpr.2020.03.715.
33. C Udawattha and R Halwatura, Geopolymerized Self-Compacting Mud Concrete Masonry Units, *Case Studies in Construction Materials*, December 2018, vol 9, doi: 10.1016/j.cscm.2018.e00177.
34. F Stazi, A Nacci, F Tittarelli, E Pasqualini and P Munafò, An Experimental Study on Earth Plasters for Earthen Building Protection: The Effects of Different Admixtures and Surface Treatments, *J Cult Herit*, vol 17, January 2016, pp 27–41, doi: 10.1016/j.culher.2015.07.009.
35. M Pedergnana and S T Elias-Ozkan, Impact of Various Sands and Fibres on the Physical and Mechanical Properties of Earth Mortars for Plasters and Renders, *Constr Build Mater*, vol 308, November 2021, doi: 10.1016/j.conbuildmat.2021.125013.
36. S Sangma and D D Tripura, Experimental Study on Shrinkage Behaviour of Earth Walling Materials with Fibers and Stabilizer for Cob Building, *Constr Build Mater*, vol 256, September 2020, doi: 10.1016/j.conbuildmat.2020.119449.
37. F F Khorasani and M Z Kabir, Experimental Study on the Effectiveness of Short Fiber Reinforced Clay Mortars and Plasters on the Mechanical Behavior of Adobe Masonry Walls, *Case Studies in Construction Materials*, vol 16, Jun.e 2022, doi: 10.1016/j.cscm.2022.e00918.
38. L M S, Experimental Study on the Physical Properties of Mud Mortar in Comparison with the Conventional Mortars, *Civil Engineering and Urban Planning: An International Journal (CIVEJ)*, vol 3, no 2, June 2016, pp 127–135, doi: 10.5121/civej.2016.3211.
39. Y Millogo, J C Morel, J E Aubert and K Ghavami, Experimental Analysis of Pressed Adobe Blocks Reinforced with Hibiscus Cannabinus Fibers, *Constr Build Mater*, vol 52, February 2014, pp 71–78, doi: 10.1016/j.conbuildmat.2013.10.094.
40. G Lan, Y Wang, L Xin and Y Liu, Shear Test Method Analysis of Earth Block Masonry Mortar Joints, *Constr Build Mater*, vol 264, December 2020, doi: 10.1016/j.conbuildmat.2020.119997.
41. K S Shinge, B B Warad, S B Rathod and S S Pendhari, Partial Replacement of Cement in Mortar by using Red Mud and Rice Husk Ash, *Int J Sci Eng Res*, 2015, vol 6, no 9, online available: <http://www.ijser.org>
42. Q B Bui, J C Morel, B V Venkatarama Reddy and W Ghayad, Durability of Rammed Earth Walls Exposed for 20 Years to Natural Weathering, *Build Environ*, vol 44, no 5, May 2009, pp 912–919, doi: 10.1016/j.buildenv.2008.07.001.
43. S Sangma and D D Tripura, Flexural Strength of Cob Wallethes Reinforced with Bamboo and Steel Mesh, *Constr Build Mater*, vol 272, February 2021, doi: 10.1016/j.conbuildmat.2020.121662.
44. A Madhumathi, J Vishnupriya and S Vignesh, Sustainability of Traditional Rural Mud Houses in Tamilnadu, India: An Analysis Related to Thermal Comfort, 2014, Online available: [www.jmest.org](http://www.jmest.org)
45. E Hamard, J C Morel, F Salgado, A Marcom and N Meunier, A Procedure to Assess the Suitability of Plaster to Protect Vernacular Earthen Architecture, *J Cult Herit*, vol 14, no 2, 2013, pp. 109–115, doi: 10.1016/j.culher.2012.04.005.
46. S Szabó, A Kövesdi, Z Vasáros, Á Csicsely and D Hegyi, The Cause of Damage and Failure of the Mud-Brick Vault of the Khan in New-Gourna, *Eng Fail Anal*, vol 128, October 2021, doi: 10.1016/j.engfailanal.2021.105567.
47. A Ramos et al., “Thermal Performance and Life Cycle Assessment of Corn Cob Particleboards, *Journal of Building Engineering*, vol 44, December 2021, doi: 10.1016/j.jobbe.2021.102998.
48. M Anirudh, K S Rekha, C Venkatesh and R Nerella, Characterization of red mud based cement mortar; Mechanical and microstructure studies,” in *Materials Today: Proceedings*, 2020, vol. 43, pp. 1587–1591. doi: 10.1016/j.matpr.2020.09.504.
49. M Singh and B R Arbad, Scientific Studies on Decorated Mud Mortar of Ajanta, *Case Studies in Construction Materials*, vol 1, December 2014, pp 138–143, doi: 10.1016/j.cscm.2014.07.001.
50. S Song, N Zhang, J Yuan and Y Zhang, New Attempt to Produce Red Mud-Iron Tailing based Alkali-Activated



- Mortar: Performance and Microstructural Characteristics, *Journal of Building Engineering*, November 2021, vol 43, doi: 10.1016/j.jobbe.2021.103222.
51. D Banerjee, Experimental Techniques in Thermal Analysis Thermogravimetry (TG) & Differential Scanning Calorimetry (DSC).
  52. L Laoufi, Y Senhadji and A Benazzouk, Valorization of Mud from Fergoug Dam in Manufacturing Mortars, *Case Studies in Construction Materials*, vol 5, December 2016, pp 26–38, doi: 10.1016/j.cscm.2016.06.002.
  53. S Tunç, O Duman and R Uysal, Electrokinetic and Rheological Behaviors of Sepiolite Suspensions in the Presence of Poly (Acrylic Acid Sodium Salt) S, Polyacrylamides, and Poly (Ethylene Glycol) S of Different Molecular Weights, *J Appl Polym Sci*, vol 109, no 3, August 2008, pp 1850–1860, doi: 10.1002/app.28245.
  54. A Manoharan and C Umarani, Lime Mortar, a Boon to the Environment: Characterization Case Study and Overview, *Sustainability*, vol 14, no 11, May 2022, p 6481, doi: 10.3390/su14116481.
  55. A Manoharan and C Umarani, Properties of Air Lime Mortar with Bio-Additives, *Sustainability*, vol 14, no 14, July 2022, p 8355, doi: 10.3390/su14148355.
  56. E K Darling, C J Cros, P Wargocki, J Kolarik, G C Morrison and R L Corsi, Impacts of a Clay Plaster on Indoor Air Quality Assessed using Chemical and Sensory Measurements, *Build Environ*, vol 57, November 2012, pp 370–376, doi: 10.1016/j.buildenv.2012.06.004.
  57. workingsci1 \_ Enhanced Reader.
  58. J C Morel, A Mesbah, M Oggero and P Walker, Building Houses with Local Materials: Means to Drastically Reduce the Environmental Impact of Construction, *Build Environ*, vol 36, no 10, December 2001, pp 1119–1126, doi: 10.1016/S0360-1323(00)00054-8.
  59. P C Kreijger, *Ecological Properties of Building Materials*, Mater Struct, July 1987.
  60. C Williams, S Goodhew, R Griffiths and L. Watson, The Feasibility of Earth Block Masonry for Building Sustainable Walling in the United Kingdom, *Journal of Building Appraisal*, vol 6, no 2, September 2010, pp 99–108, doi: 10.1057/jba.2010.15.
  61. L Ben-Alon, V Loftness, K A Harries, G DiPietro and E C Hameen, Cradle to Site Life Cycle Assessment (LCA) of Natural vs Conventional Building Materials: A Case Study on Cob Earthen Material, *Build Environ*, vol. 160, August 2019, doi: 10.1016/j.buildenv.2019.05.028.
  62. M Gehlot and S Shrivastava, Sustainable Construction Practices: A Perspective View of Indian Construction Industry Professionals, *Mater Today Proc*, vol 61, Januray 2022, pp 315–319, doi: 10.1016/j.matpr.2021.09.493.
  63. M. Srivastava and V. Kumar, The Methods of using Low Cost Housing Techniques in India, *Journal of Building Engineering*, vol 15, January 2018, pp 102–108, doi: 10.1016/j.jobbe.2017.11.001.
  64. Gernot Minke, *Building with Earth: Design and Technology of a Sustainable Architecture*.



# River Basin Management — an Integrated Approach for Sustainable use

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**Abstract:** Sustainable use of water as a resource for humanity is imperative. The impact of climate change on availability, spatial distribution, floods, drought and growing needs make the judicious and equitable use of water all the more important. The basin management of Mississippi (USA), Murray-Darling (Australia) and Ganga (India) are studied in respect of management, policies and strategies, participation of stake holders in the decision process and resources used. Comparative analysis on these and their sub aspects was made. Review of two publications was made and the practices suggested therein are summarized. On the basis of the comparative analysis and the practices summarized in the two publications reviewed, conclusions were drawn for adaptation in India. Indian Engineers can play a proactive role in the management and process for Sustainable use of Water in the Indian context. The study is limited to the information available through public access only.

**Keywords:** River Basin; Sustainable use; Integrated management; Practices

## INTRODUCTION

Sustainable use of water is imperative. Water is to be used on the principles of equity for societal needs. In global warming scenario and climate change, there are uncertainties in availability, spatial and temporal distribution, floods and drought. An integrated approach is required to assess availability, allocation for competing needs and provide assured supplies and quality. Floods and drought conditions are also to be managed. The ill effect of drought on the navigation in Mississippi in October 2022 brings out the need for integrated and proactive approach in the river basin management. The objective of this study on the aspects of Management and Policies of Basin Management of Mississippi (USA) Murray-Darling Basin (Australia) rivers is to identify the areas for emulation and adaptation to meet India's needs. Ganga River Basin is taken up for comparison, this being the largest effecting maximum percentage of Indian Population.

## METHODOLOGY

Mining of information available for public access through web by organizations involved in the domain of Water Resources management of the three rivers in their annual reports, journal articles, study reports and publications is done. Comparison is made in respect of Management structures, Policies, Strategies, Processes and resources.

## BASIN MANAGEMENT

### Mississippi River Basin, USA

Watershed area of 2,980,000 sq-km (1,151,000 sq-mile) of the river drains 41% of USA. US Army Corps of Engineers, serves the Mississippi Valley through Mississippi Valley Division (MVD) and Mississippi River Commission (MRC)[1]. Mississippi River Commission, established in 1879, has seven members, each nominated by US President of which three are from US Army Corps of Engineers, one from National Oceanic and Atmospheric Administration (NOAA) and three civilians. The President of MRC serves as Commanding Officer of the Mississippi Valley Division (MVD). The basin management is executed through MVD.

Mississippi Watershed Management Organization (MWMO)[2] is governed by a Board of seven Commissioners, one from each of the MWMO member communities appointed by the respective urban bodies/communities according to State Law. The Mission of the MWMO is:

*“Mission Statement: to lead and to foster stewardship of the watershed with actions that promote civic ownership and responsibility and through measures that achieve diverse and functional ecosystems.”*



### **Murray-Darling River Basin, Australia**

The Murray-Darling River Basin, across the four states of Queensland, New South Wales, Victoria, South Australia and Australian Capital Territory, is managed by Murray-Darling Basin Authority (MDBA)[3]. The watershed of this Basin is 1,000,000 sq-km (14% of land mass), an inter connected system of 22 flattest catchments, 7700 km of rivers and 2.3 million people. 40% of farming in Australia is in the basin. 40 First Nations people live in the basin. MDBA, an expertise based statutory agency, is set up under “The Water Act 2007” with responsibility to prepare basin plans, oversee implementation and manage the infrastructure in the basin. Basin states and Capital Territory Government manage the water in their own area in line with nationally agreed principles and plans.

### **POLICIES AND STRATEGIES**

#### **Mississippi River Basin**

With the floods and devastation in the lower Mississippi basin in 1927, it was recognized that the levee protection system by local bodies with limited resources is inadequate. US Federal Government, under Mississippi River and Tributaries (MR & T) Project, focused on strengthening of structures (like levees), improvement of flood ways as navigable water ways combined with strengthening of tributary reservoirs as flood management and mitigation strategy.

Over the years, this evolved into integrated River Basin Management by US Army Corps of Engineers, US Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), Federal Emergency Management Agency (FEMA) and Basin States’ agencies for zoning and land planning. National Flood Control Act, 1936 encouraged development of comprehensive water shed plans. The technologies of Geographical Information System (GIS), weather and floods forecasting, Data storage and analysis are making the integrated water resources management of the river possible with multi disciplinary approach. The roles of each of the agencies are defined and coordinated[4, 5].

#### **Murray-Darling River Basin**

The 1914 River Murray Agreement, 1995 cap on river diversion, 2004 National Water Initiative and formation of Murray-Darling Basin Authority in 2007 as a statutory body under “The Water Act 2007” are the fore-runners of the present policy of Murray-Darling River Basin Management Authority (MDBA). Basin Plan 2012 is under implementation and compliance reviewed periodically.

National Water initiative ordains the policy of “fixing water entitlement, making water resource plans, support for structural adjustments and capabilities”. Implementation and compliance with the Basin Plan and operating the river system for the stake holders in the basin in a transparent manner are the primary duties of MDBA. Adaptive water planning policy, communication and engagement with the stake holders are the strategies.

### **SCOPE OF MANAGEMENT AND RESOURCES**

#### **Mississippi River Basin**

Mississippi River Commission (MRC) works in conjunction with US Army Corps of Engineers, Mississippi Valley Division (MVD) for an integrated and holistic approach[5]. US Army Corps of Engineers main role is flood management and ensuring navigability of the river. It works in conjunction with Federal Management Agency (FEMA) and parallel State Agencies in the basin for flood control and relief measures. National Oceanic and Atmospheric Administration (NOAA) gives support of weather and flood forecasts.

Building and maintenance of assets for flood management and navigation are in the scope of the MVD. It co-ordinates preparation of Natural Resources Plans for the Watersheds of Tributaries with co-option of departments of land use planning and local communities of basin states. Mississippi Watershed Management Organization (MWMO) leads and fosters stewardship for promotion of civic ownership and participation of local communities in tune with its mission statement quoted in earlier. Monitoring the quality of water flows and environment norms are in the scope of statutory agencies under respective state laws.

#### **Murray-Darling River Basin**

Murray-Darling River Basin Authority (MDBA) is the statutory authority for integrated River Basin Management implementing the agreed Basin Plan, annual water resource allocations and ensure sustainable diversion limits fixed in 2019. Operation of the river system and assets efficiently and effectively are in the scope. Five goals are set and performance monitored in respect of eight key performance indicators [6]. Compliance with Basin Plan 2012 is evaluated in 2017 and 2020. Next review is due in 2025 in time for Basin Plan 2026. In December 2020, statutory



compliance role is separated from MDBA to Inspector General of Water Compliance (IGWC). Communication and engagement with partner states, GIS, Remote sensing, Project Management and Governance, Hydrological Data analytics are the resources for the river basin management.

## **GANGA RIVER BASIN**

Ganga River Basin is the largest in India with catchment area (watershed) of 861,452 sq-km within India and 1,086,000 sq-km including areas outside India [7]. The river is of 2525 km length, traversing eleven states. Water resource potential is 525,020 million cubic meters (MCM). 65.57% of the basin area is agricultural land. 28% of net irrigated area is catered by several major systems of canals. 631 km length of the river is navigable.

### **Basin Management**

Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India (DoWR) is vested with the role of preparation of policy guidelines, programmes for development, conservation and management of water as a national resource with an overall national perspective[8]. National Mission for clean Ganga (NMCG) is the implementation arm of National Council for Rejuvenation, Protection and Management of River Ganga (referred as National Ganga Council in the notification dated 7th October, 2016 issued under Environmental Protection Act, 1986).

National Ganga Council is the apex body of Government of India under the Chairmanship of Hon'ble Prime Minister of India and Chief Ministers of Bihar, Jharkhand, Uttarakhand, Uttar Pradesh, West Bengal as members apart from other agencies and functionaries[9]. National Ganga Council was formerly National Ganga River Basin Authority. NMCG is a society registered under Societies Registration Act, 1860. The policies and directions of National Ganga Council are implemented through Empowered Task Force (ETF) on River Ganga under the Chairmanship of Hon'ble Union Minister of Jal Shakti, GOI through Director General, NMCG as coordinator. DG, NMCG is Ex-officio Member Secretary of National Ganga Council.

DoWR has two attached offices, seven subordinate offices, twelve Regd. Societies, Autonomous Bodies or Statutory Bodies. The department has two PSUs as well.

Central Water Commission (CWC) is an attached office of Department of Water Resources, Ministry of Jal Shakti, Government of India [10]. CWC is the technical organization with three wings viz., Design and Research Wing, Water Planning and Projects Wing and River Management Wing. Flood forecasting services are provided by CWC.

### **Policies and Strategies**

The State Governments are vested with the power of management of Water Resources in respective jurisdictions. The Government of India (GOI) assists them with technical and financial resources under various central schemes. GOI coordinates use of water of inter-state rivers, flood management, mitigation of water pollution and supply of pure drinking water to the communities.

The policy and strategies of flood risk management and development of infrastructure to protect life and assets from floods, changes in river course evolved into a National Water Policy (NWP). National Water Policy, 2002 focused on treatment of industrial waste water through regulations like Environmental Protection Act and recycling. It encouraged water conservation and implementation of new technologies to consume less water for industrial use. The National Water Policy, 2012, which is presently operative, took cognizance of water availability, demand, competing needs and laid a plan of action with a unified national perspective. Actions and interventions at local, regional and sub basin levels are evolving into Integrated Water Resource Management (IWRM).

Taking cognizance of effects of Climate change on availability, spatial and temporal variations and the experiences of implementation of NWP 2012, new National Water Policy 2020 is on the anvil [11]. New National Water Policy 2020 is being developed on four pillars/concepts of Aviral Dhara (Continuous flow), Nirmal Dhara (Un polluted flow), Geological entity and Ecological entity. The objectives of Aviral Dhara, Nirmal Dhara and Swachh Kinara are to be achieved by implementing "The Wet lands (Conservative & Management) Rules 2017" and meet Sustainable Development Goals Indicator 6.5.1 by the year 2030.

### **Scope of Management and Resources**

"Namami Gange" is the Ganga River Basin Management Plan being implemented under the National Mission for Clean Ganga (NMCG) [11]. Ganga Action Plan I, laid emphasis on Water Quality by preventing pollution load. This is being enhanced under Phase II as National Conservation Plan. Technical support is provided by CWC through its River



Management Wing and various subordinate offices Upper Ganga Basin Organization, Lucknow, Lower Ganga Basin Organisation, Patna and Yamuna Basin Organization, New Delhi. Namami Gange programme is adopting Integrated River Basin Management (IRBM) approach.

National Mission for Clean Ganga (NMCG) and the Center for Ganga River Basin Management and Studies (cGanga) at Indian Institute of Technology, Kanpur prepared the Draft for “River Restoration and Conservation – A concise Manual and Guide” (December 2019) and kept the same in public domain for wider consultation and participation [12].

CWC provides technical support for flood management and forecast, Hydrological Information System, India Water Resources Information System along with NRSC and India Meteorological Department (IMD) to the respective departments of State Governments in the Ganga River Basin.

## **PRACTICES FOR INTEGRATED RIVER BASIN MANAGEMENT**

### **Water Global Practice – Water Resources Management (WRM)**

World Bank Group, Global Water Security and Sanitation Partnership (GWSP) in its Learning Note (February 2022)[13] brought out the key lessons on the case study – Malawi Shire River Basin Management Program (Ph I) Project. The Learning Note presented “What to do” and “How to do it”. The report observed that Integrated Water Resources Management (IWRM) approach offers viable planning and management decisions to meet the challenges of climate change. The key lessons brought out are,

- \*Integrated cross-sectoral policies and programs are vital;
- \*Climate-informed approach to WRM improves chances for positive results;
- \*Manage climate related environmental and social safe guards;
- \*Coordination mechanisms based on incentives with all relevant stake holders.

### **Integrated Watershed Management: Evolution, Development and Emerging Trends**

Authors, Wang et al, in the Review Article ‘Integrated water shed management: evolution, development and emerging trends’ [14], presented three case studies of Poyang Lake Basin, China, Rhine River Basin, Europe, and Fraser River Basin, Canada.

From the study, the need for ‘An Unified Organization for Management’; ‘Appropriate Big Data and Sharing Mechanism’; and ‘Long Term Perspective and Quantitative Goals’ are identified. The scope for use of adaptive management techniques and traditional ecological knowledge was established. It has also been brought out that, holistic sustainable watershed management using latest science and technologies, tools and public participation and interagency communication, as the need of the hour to meet the challenges of climate change and sustainable use of Water as a Resource.

The lessons drawn from the literature review in earlier affirm that the best practices are,

- \*Integrated River Basin Management
- \*Need for long term perspective and quantitative goals
- \*Adaptive management and cross-sector policy
- \*Use of multiple and latest technology
- \*Community participation.

## **COMPARATIVE ANALYSIS**

The study on Mississippi, Murray-Darling and Ganga River Basins in para 3 to 6 is summarized in **Table 1**.

## **CONCLUSIONS**

The lessons from the literature review mentioned earlier are kept in focus and conclusions are drawn from the comparative analysis made in previous.

The Murray-Darling River Basin Management is of the highest maturity with dynamic plans and measuring performance for the goals set with key performance indicators. Compliance monitoring is done as a statutory function by an agency independent from MDBA.

The Mississippi River Basin Management, though comprehensive with clarity of roles of each of the organizations



Table 1 Comparative analysis

S.No. (1)	Aspect (2)	Sub Aspect (3)	Mississippi River Basin (4)	Murray-Darling River Basin (5)	Ganga River Basin (6)
1.	Basin Management	Authority	Mississippi River Commission (MRC)	Murray-Darling Basin Authority(MDBA) Basin States Queensland, New South Wales, Victoria, South Australia and Australian Capital Territory	National Ganga Council, Basin States
		Statutory support Implementing Agency	US Presidential appointments & State Laws Mississippi Valley Division (MVD), US Army Corps of Engineers, Basin State Agencies & Mississippi Watershed Management Organization (MWMO)	MDBA according to agreed Basin plans with infrastructure management maintaining statutory sustainable diversion limits. Compliance with Water Resource plans by Basin states and Capital Territory.	GOI Gazette Notification National Mission for Clean Ganga (NMCG) & Basin State agencies
2.	Policies and Strategies	Evolution	Flood management and Navigation (MRC)1879) activity evolved into Basin Management jointly with Basin States, preparation of Natural Resource plans for Territories. MWMO promotes civic ownership and participation.	Murray River Agreement (1934) evolved into a statutory MDBA (2007) making dynamic agreed Basin Plans, maintain statutory sustainable diversion limits and Water Resource Plans.	National Water Policy 2002 (NWP) for industrial water treatment and recycling, under EPA evolved into NWP (2012) with national perspective. IWRM evolving into IRBM. (Policy 2020 in draft stage)
		Role clarity	Yes	Yes	Multiple agencies with DG,NMCG as coordinator on interstate issues "Namami Gange" IWRM Plan
3.	Scope of Management & Resources	Strategy	Integrated and holistic approach. Involvement and ownership of stake holders.	Adaptive Management strategy, compliance monitoring, communication and engagement with stake holders, Goals setting and review with Key Performance Indicators.	
		Scope	Comprehensive with role clarity of functionaries. Monitoring quality of water flows and environment, metrics by respective statutory agencies. Flood Management, Navigation, Asset maintenance and improvements, interstate coordination, preparation of National Resource plans	Comprehensive management of infrastructure, maintain sustainable water diversion limits.	DoW – Policy guides lines and programmes, NMCG-Implementation arm of "Namami Gange" Plan Basin States-Water management within their zones
	Activities		Assess maintenance and improvements, interstate coordination, preparation of National Resource plans	Preparation of basin plans, water resource plans, effective and efficient use of assets, improvements of assets, coordination with stake holders, compliance monitoring, periodical review of plans	GDI-Interstate coordinator, DG,NMCG Plan implementation coordination. States-Water use, flood management, water pollution mitigation, drinking water supply
		Tech support	MVD and National Oceanic and Atmospheric Administration (NOAA) Hydrological data collection, analysis, usage monitoring Multi technology	MDBA	Central Water Commission (CWC), IMD, NRSC (ISRO) and respective State Dep.s.
	Resources		GIS, Remote sensing, Project Management and Governance, Hydrological Data analytics		IWRM, Hydrology, Weather forecast, Flow forecast, monitoring, Disaster relief



involved, statutory backing is divided amongst the Federal and State Governments. The study could not bring out any information on the measurements of performance. However it can be gain said that with active involvement of local bodies and communities in decision process and implementation, the satisfaction levels meet their expectations. The navigability of Mississippi River got a hit in October 2022 and remedial measures are being taken. This type of situation demonstrates the need for integrated basin management.

Ganga River Basin Management is moving towards Integrated River Basin Management (IRBM) mode under the guidance of National Ganga Council, with National Water Policy 2020 on the anvil. While coordinated approach is adopted in implementing the policies, the development of Basin Plans, Water Resource Plans and policy for measurements of performance and compliances need to be done. The Indian Engineers can play a proactive role in establishing these plans and processes to enable an IRBM approach.

### LIMITATIONS

The study is limited to the information available for public access on the web and focused on Mississippi (USA), Murray-Darling (Australia), and Ganga (India) river basins only.

### ACKNOWLEDGMENT

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### REFERENCES

1. URL:<https://mvd.usace.army.mil>
2. URL:<https://www.mwmo.org>
3. URL:<https://www.mdba.gov.au>
4. cs\_usa\_mississippi\_sum.pdf
5. World Bank Document 103353 Revised (2016)
6. MDBA Annual Report 2020-21
7. Ganga Basin, Ver 2.0, Central Water Commission (CWC) and National Remote Sensing Center, (ISRO), Hyderabad, India, March 2014, URL:<https://indiawris.gov.in>.
8. Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti, GOI, Annual Report 2021-22, URL:<http://jalshakti-dowr.gov.in>.
9. River Ganga, Rejuvenation, Protection and Management, Authorities Order, 2016, Gazette Notification No. 2458 dated 7th October, 2016 and amendment order dated 2nd September, 2019.
10. Central Water Commission (CWC), GOI, Annual Report 2020-21, URL:<http://www.cwc.gov.in>.
11. New National Water Policy, Press Information Bureau Note, 16th December 2021.
12. River Restoration and Conservation – A Concise Manual and Guide Draft jointly by NMCG and Center for Ganga River Basin Management and Studies (cGanga), Indian Institute of Technology, Kanpur, December 2019, URL:<https://nmcg.nic.in>.
13. Water Global Practice – Water Resources Management (WRM) – Strengthening Climate Informed Project Design – Learning Note – World Bank Group, Global Water Security & Sanitation (GWSP), February 2022, URL:<https://openknowledge.worldbank.org>.
14. G Wang, S Mang, H Cai, et al. Integrated Watershed Management: Evolution, Development and Emerging Trends. J. For. Res. 27(5), 2016, pp 967-994, <https://doi.org/10.1007/s11676-016-0293-3>.

# Comparative Study on the Behaviour of Reinforced Cement Concrete Poles Added with Different Admixtures

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**Abstract:** In India, the use of R.C.C. poles is gaining importance day by day. The main reason is the non-availability of the good timber for the construction of the poles. As the R.C.C. poles are widely used in the construction of the overhead transmission lines, they are subjected to dynamic and static loads. Hence it is necessary to design them to withstand the loads. The paper discusses the influence of different admixtures on the compressive strength of reinforced concrete poles. The research was carried out for the reinforced concrete poles made of M25 concrete grade with a length of 1830 mm. The purpose of the research was to determine the influence of the selected admixtures used in concrete according to the selected Indian standards on the compressive strength of reinforced concrete poles. The research showed that the use of concrete admixtures significantly affects the compressive strength of reinforced concrete poles. The compressive strength of reinforced concrete poles is significantly influenced by the use of a high range of water reducer and a super plasticizer which allows for the production of concrete with a higher compressive strength.

**Keyword:** RCC poles – Reinforced Cement Concrete Poles; Admixtures – Chemical Admixtures Added to concrete to increase the Additional Workability of the Concrete

## INTRODUCTION

The electric poles act as the main element for transmission and distribution of power supply to each and every house or commercial establishments. These poles are also called as line supports and manufactured by the State Electricity Boards based on the design of Rural Electrification Corporation (REC). All these poles have to withstand attacks due to chemicals, gases, moisture and other harmful substances as well. When such is the case, the same type of pole is used in all these environments without any addition of mineral or chemical admixtures. The concrete poles are also to be used in marine environments and coastal zones too, where excellent corrosion resistance is required to reduce the impact of sea water, salts, fog, and corrosive soil conditions. In order to overcome all these problems, and to make the poles stronger and more durable, the design mix has to be changed with the addition of certain suitable mineral admixtures in specified proportions.

## LITERATURE REVIEW

Abeles (1966) have investigated and shown that the load deflection curve is almost a straight line up to the stage of visible cracking and beyond that, the deflections increase at a faster rate which is attributed to the stiffness reduction of the beam. In the post cracking stage, the behaviour of the beam is almost same as that of reinforced concrete members.

Adbdelkarim, et al (2013) have done a study to quantify the variability of concrete properties to allow for a probabilistic performance based approach regarding the service life time predication of concrete structures. The mechanical behaviour, chloride migration, accelerated carbonation, gas permeability, desorption isotherms, porosity have been discussed and a statistical analysis was performed to characterize the results through appropriate density functions. It is found out from the research that the chloride migration coefficient should be selected as a relevant parameter for chloride induced corrosion.

Haiyan, et al (2013) have found out that high performance concrete with 50% of mineral admixtures and 10 % of Aluminate expansion agent (AEA) by mass of the total cementitious material, steel fibres will improve the freeze-thaw durability.

Okedu and UmaziUka (2014) have asserted that the concrete poles are resilient since the shear forces are small when compared to the bending moments. The poles tested did not develop any hair crack up to 40 % of the ultimate load and the permanent set after the removal of 60 % of the ultimate load did not exceed 10 % of the deflection shown for the same load.



ShahidIqbal, et al (2017) have found out from their study that the modulus of elasticity increases with increase in fly ash content while it decreases slightly when the quantity of fly ash is more than 125 kg/m<sup>3</sup>. The compressive strength gets increased by 13.5 % when the fly ash content increases from 100 kg/m<sup>3</sup> to 125 kg/m<sup>3</sup>. At the same time, the strength is decreased by 4.5 % when the amount of fly ash is increased to 150 kg/m<sup>3</sup>.

## MATERIALS USED

**Cement:** Ordinary Portland cement has been used for the present experimental study.

**Fine Aggregate:** Natural river sand conforming to zone-II as per IS: 383(1970) has been used.

**Coarse Aggregate:** Crushed aggregates of size 12 mm to 16 mm conforming to IS: 383 (1970) have been used for making of RCC poles while 10 mm and below have been used for PSC poles.

**Water:** Potable water has been used for both mixing and curing of concrete.

**Reinforcements:** TMT rebars (Fe 415) of 12 mm and 6 mm diameter have been used as main rods while 6 mm diameter rod and 3 mm diameter wire have been used as stirrups in the prototype (7.32 m long) and model (1.83 m long) respectively.

**HTS Wires:** High tensile steel (HTS) wires of 4 mm diameter with ultimate tensile strength of 1750 N/mm<sup>2</sup> has been used in the making of prestressed concrete poles. 8 nos. of tensioned wires and 2 nos. of un-tensioned wires have been provided.

**Mineral Admixtures:** Fly ash, classified as class 'F' low calcium fly ash, obtained from Mettur Thermal Power Station has been used in this investigation. Also, quartz powder of snow white colour (a free flowing granular solid) with low iron content, obtained from Erode has been used even as silica fume procured from Karur has been used.

**Chemical Admixtures:** Conplast SP 430, having properties as laid down in IS: 9103-1999 with a quantity ranging from 0.6 % to 0.8 % by weight of cement has been used.

## CASTING OF POLES

In order to study the behaviour of 7.32 m (24') long RCC pole, a scale model has been cast and comparison of the load-deflection behaviour of the scale model with different admixtures has been made. This will help us study further if there will be any improvement in terms of strength of the poles by casting and testing the models alone. The model (one fourth scale model) pole of length 1830 mm with bottom size of 115 mm × 75 mm and top size as 75 mm × 55 mm has been cast with M25 grade concrete to assess the structural behaviour of pole under monotonic loading.

## TESTING OF POLES

The bottom of the pole is tightened by rigid devices in such a manner that the clamped length is equal to the minimum depth of planting (i.e. 1.5 m for prototype and 0.38 m for model). The load is applied at a point 600 mm (150 mm for model) from the top of the pole.

The load applied and the deflection of the pole is noted down simultaneously at different stages of loading. The measurement of deflection at the tip of the pole is made in a direction perpendicular to the position of the initial pole axis.

## BEHAVIOUR OF MODEL POLE WITH ADMIXTURES

### Replacement with Admixtures

An attempt has been made to replace cement by certain percentages of fly ash and to replace the fine aggregate with quartz powder. Also, the performance of these admixtures has been studied by conducting experimental tests. In order to impart additional workability, a super plasticizer (Conplast Sp430) 0.6% to 0.8% by weight of cement conforming to IS: 9103 -1999 has been used.

### Mix Proportions

The mix proportion as shown in **Table 6.8** is adopted in this study. The Mix-1 is conventional M25 grade of concrete, while the Mix-2 has only the replacement of fine aggregate with quartz powder of 20%. Mix-3 involves the replacement of cement with fly ash of 20% and replacement of fine aggregate with quartz powder of 20%. The mix design has been done as per the Indian standard codes, IS: 10262-2009 and IS:456-2000. The mix proportions of CC, QR and QF are furnished in **Table 1**.



Figure 1 Test setup in the casting yard

Table 1 Mix proportions

Mix Notation	Cement (kg/m <sup>3</sup> )	Fine aggregate (kg/m <sup>3</sup> )	Coarse aggregate (kg/m <sup>3</sup> ) (3mm to 16mm)	w/b Fly ash ratio (kg/m <sup>3</sup> )	Quartz powder (kg/m <sup>3</sup> )
1 CC	340	740	1200	0.47	-
2 QR	340	562	1200	0.47	144 (20% of F.F)
3 QF	272	740	1200	0.47 + 88 (20% of cement)	144 (20% of F.F)

### Compressive Strength Test

The results showed that the conventional M25 concrete has attained the compressive strength of 41 N/mm<sup>2</sup>, while the strength of the concrete mix, quartz replacing fine aggregate by 20% (QR), attained strength of 47 N/mm<sup>2</sup>. The strength of the mix, quartz replacing fine aggregate by 20% and fly ash replacing cement by 20% (QF), has attained only strength of 39 N/mm<sup>2</sup>. It is seen that the compressive strength has increased at 14.63% for QR mix, while strength of the QF mix is reduced by 4.88%. It is evident that fly ash in concrete will increase the strength only with increase in duration. The compressive strength values of CC, QR and QF are shown in **Table 2**.

### Casting of Concrete Model Poles

Three poles namely CC, QR and QF poles of length 1.83 m were cast to find out the structural behaviour of poles under the monotonic loading. Totally six poles were cast for this study, out of which, two poles are made of conventional concrete, two poles with 20% of fine aggregates replaced by quartz powder and the other two poles with fly ash replacing 20% of cement and quartz powder replacing 20% of fine aggregate. The reinforcement placed inside the form box is shown in **Figure 6.17**.

### Experimental Test Set Up

Two days before testing, the specimens were taken out from curing tank and were allowed to dry. specimens were white washed and the grid lines were drawn to facilitate easy marking of the crack pattern.

The schematic representation of test setup is shown in the **Figure 4**. A measuring tape is placed perpendicular to the initial longitudinal axis of the pole to measure the deflection.

The load was applied gradually by a screw jack at a distance of 150 mm from the top of the specimen. The bottom end was fixed for a length of 380 mm. The deflection readings are taken for the each monotonic loading. The load at which the crack was formed is noted down as first crack load. As the load level increased, further cracks propagated and the widening of crack took place. The monotonic loading was applied up to the ultimate load level and the failure pattern was observed. The test set up is shown in **Figure 3**.

Table 2 Compressive strength values

S. No.	Notation	Compressive strength(N/mm <sup>2</sup> )
1	CC	41
2	QR	47
3	QF	39

Figure 2 Reinforcement grill inside form box of model pole





**Figure 3** Schematic representation of test set up for model pole



**Figure 4** Actual test set up for model pole

### Load-Deflection Behaviour of CC Pole

The pole was tested under single point monotonic loading. The load was applied gradually until the failure of the pole occurred. The deflection was noted down for corresponding load and it is measured with the help of a measuring tape. The deflection value of the first crack load was noted down. Then, the loading was continued until the ultimate failure occurred and the crack pattern was marked. Load-deflection behaviour of the conventional RC pole is shown in **Figure 5**.

The load-deflection values of Conventional Concrete pole (CC) are shown in **Table 3**.

### Load-Deflection Behaviour of QR Pole

The pole was tested under single point load by giving the monotonic loading. The instrumentation for load measurement is shown in **Figure 6**. The load was applied gradually until the failure of the pole happened. The value of the first crack load was noted down and the loading was continued until the ultimate failure occurred and the crack pattern was marked. The parameters like load deflection behaviour, ductility factor, energy absorption capacity and stiffness have been found out.

The load-deflection values of quartz powder added pole (QR) are shown in **Table 4**.

The first crack load was observed at the load level of 800 N. As the load increased, further cracks were developed in the other portions and also the crack width of the first appeared cracks increased. The ultimate load carrying capacity of the QR pole was 1700 N and the corresponding deflection was 80 mm.

### Load-Deflection Behaviour of QF Pole

The load-deflection (**Figure 7**) values of quartz powder and fly ash added pole (QF) are shown in **Table 4**.

The first crack load was observed at the load level of 400 N. As the load increased, further cracks were developed in the other portions and also the first appeared cracks were widened. The ultimate load carrying capacity of the QF pole was 1400 N.

The pictorial representation of the load-deflection behaviour of all the three poles namely CC, QR and QF have been furnished in **Figure 8**.



**Figure 5** Deflection of the pole

**Table 3** Load-deflection values of conventional concrete pole (CC)

Load (Newton)	Deflection (mm)
0	0
200	3
400	8
600	13
800	20
1000	28
1200	38
1400	51
1500	64



Figure 6 Instrumentation for load measurement

Table 4 Load-deflection values of quartz powder added pole (QR)

Load(Newton)	Deflection (mm)
0	0
200	4
400	9
600	14
800	19
1000	24
1200	29
1400	35
1600	44
1700	54
1700	66
1700	80



Figure 7 Deflection of QF pole

## RESULTS AND DISCUSSION

### Strength Properties of Concrete

It is seen that the compressive strength of M25 grade concrete at the end of the 28 days of the cube specimen has increased by 14.6 % for QR (quartz replacing 20 % by weight of fine aggregate), while strength of the QF (quartz replacing 20 % by weight of fine aggregate and fly ash replacing 20 % by weight of cement) is reduced by 5 %.

### Load - Deflection Behaviour of RCC Poles

Three poles namely CC, QR and QF poles of length 1830 mm, bottom size (115 mm × 75 mm) and tapered with dimensions at top as 75 mm × 55 were cast to find out the structural behaviour of poles under the monotonic loading.

Table 5 Load-Deflection values of quartz powder and fly ash added pole (QF)

Load (Newton)	Deflection (mm)
0	0
200	4
400	9
600	15
800	22
1000	29
1200	39
1400	47
1400	58
1400	72

Table 6 Load-Deflection values of CC, QR and QF poles

CC POLE		QR POLE		QF POLE	
Load (New ton)	Deflecti on (mm)	Load(N ewton)	Delle ction (mm)	Load (New ton)	Delle ction (mm)
0	0	0	0	0	0
200	3	200	4	200	4
400	8	400	9	400	9
600	13	600	17	600	15
800	20	800	19	800	22
1000	28	1000	24	1000	29
1200	38	1200	29	1200	39
1400	51	1400	35	1400	47
1500	64	1600	44	1400	58
		1700	54	1400	72
		1700	66		
		1700	80		

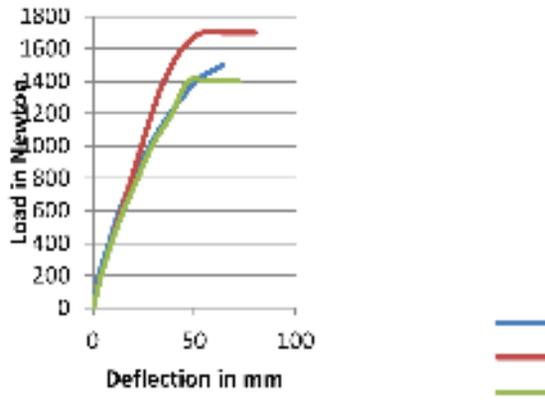


Figure 8 Load-deflection behaviour of CC, QR and QF poles

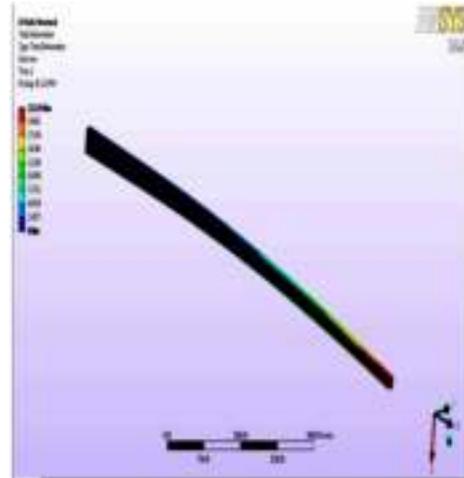


Figure 9 Total deformation of 8.0 m PSC pole

It is found out from the study that the first crack load of QR pole is 33.33% more than that of CC pole. The QR pole takes up more ultimate load than the control pole as well, which is 13.3 % more. Also, the load-deflection behaviour of QR pole is better than the other poles.

The performance of QR pole is better than the conventional pole with an increase of 34.4 % in the deflection at the ultimate load while the ultimate load itself gets increased by 8.5%.

## NUMERICAL INVESTIGATION

### General

A study on numerical investigation on the Reinforced Cement Concrete (RCC) and Pre-Stressed Concrete (PSC) poles will be very much useful in studying the behavior of the poles under different conditions. A comparison has been made with the values obtained in the actual and analytical method to check whether they are in good agreement.

### Results of PSC Pole

The three-dimensional model of 8.0 m PSC pole has been developed in ANSYS 14.0 with dedicated solid bricks (SOLID65) representing the concrete. The embedded three dimensional spar elements (LINK8) have been used as pre-stressing wires. For a load of 500 N, the deformation, equivalent (von-Mises) stress and elastic strain have been found out and they are presented in Figures 9 to 11.

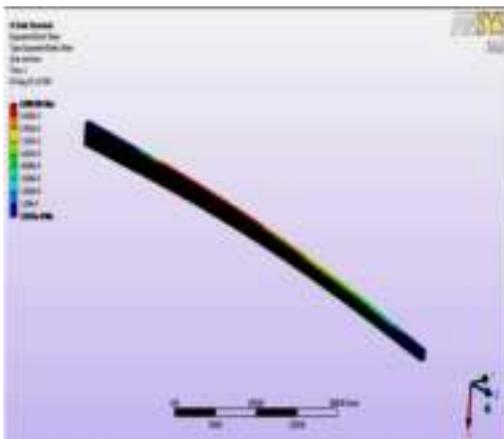


Figure 10 Equivalent elastic strain of 8.0 m PSC pole

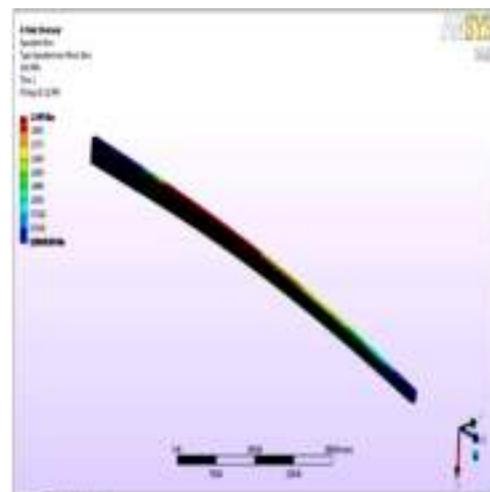


Figure 11 Equivalent (von-Mises) stress of 8.0 m PSC pole

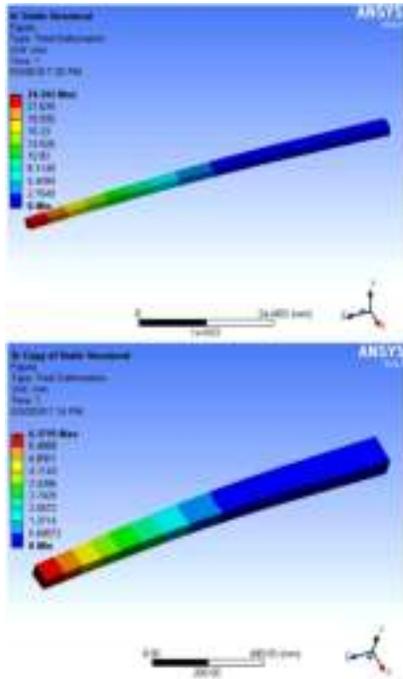


Figure 12 Total deformation of Prototype and Model pole

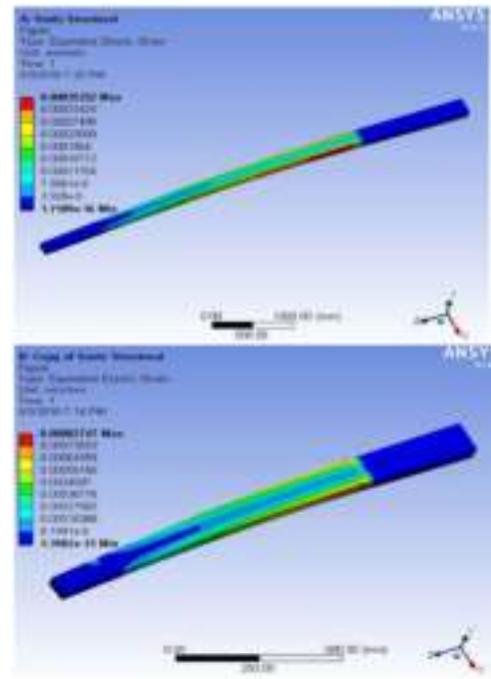


Figure 13 Equivalent elastic strain of Prototype and Model pole

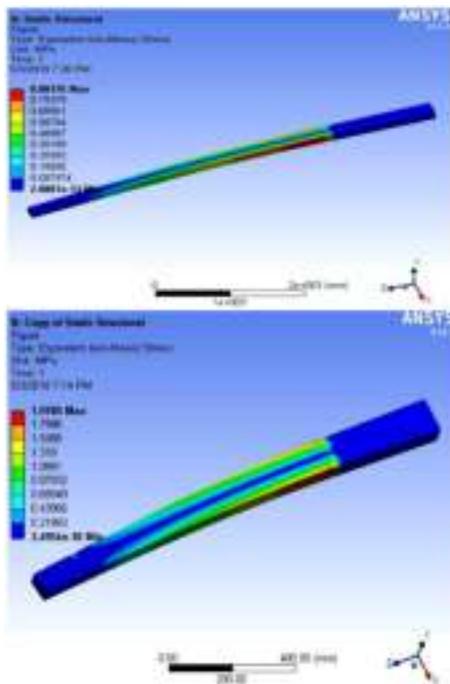


Figure 13 Equivalent elastic strain of Prototype and Model pole

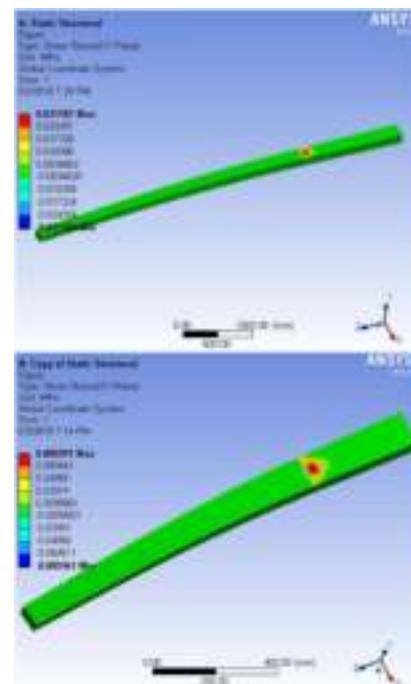


Figure 16 Shear stress of Prototype and Model pole



### Results of RCC Prototype and Model Pole

The three dimensional models of physical model and prototype of 7.32 m pole have been developed using ANSYS R14.5(work bench) to verify whether the scaled physical model and prototype behave in a similar manner. The total deformation, von-Mises stress, elastic strain and shear stress images are presented below in **Figures 12 to 16**.

It is observed from the patterns of above figures that the scaled physical model and the prototype have behaved similarly, from which it is evident that the physical modeling is perfect.

### SUMMARY AND CONCLUSIONS

The compressive strength and the ultimate load have been enhanced by nearly 14% with the replacement of quartz (replacing 20% of fine aggregate), while the first crack load is increased by one third of the first crack load of conventional concrete pole. The QR pole takes up more ultimate load than the control pole as well, which is nearly 13% more. Also, the performance of QR pole is better than the conventional pole with an increase of 34.4 % in the deflection at the ultimate load while the ultimate load itself gets increased by 8.5%. This can also be checked with the prototype pole of 7.32 m that are used in the field.

In general, it is concluded that the performance of power line supports which are abundantly used in the field can be very much improved by suitably modifying the concrete with the admixtures.

### REFERENCES

1. P W Abeles, Introduction to Prestressed Concrete, Concrete Publications, Ltd., London, vol II, 1966, pp 542-554.
2. Adbdelkarim Ait Mokhtar, Rafik Belarbi, Farid Benboudjema, Nicolas Burlion and H Y Godoy, Experimental investigation of the variability of concrete durability properties, Cement and Concrete Research, vol 45, no 1, 2013, pp 21-36.Ma
3. Haiyan, Yu Hongfa and Sun Wei, Freezing-Thawing durability and its improvement of high strength shrinkage compensation concrete with high volume mineral admixtures, Construction and Building Materials, vol 39, 2013, pp 124-128.
4. Roland Uhunwangho, Kenneth Okedu and Mong Umazi Uka, Improved performance of electric transmission concrete poles for national integrated power project (NIPP) in Nigeria, Journal of Engineering Technologies and Policy, vol 4, no 9, 2014, pp 52-57.
5. K Gurunaathan and G S Thirugnanam, Effect of mineral admixtures on durability properties of concrete, International Journal of Advanced Structures and Geotechnical Engineering, vol 03, no 01, 2014, pp 65-68.
6. K Gurunaathan and G S Thirugnanam, Upshot of fly ash and silica fume on durability properties of pre-stressed concrete, International Journal of Engineering and Innovative Technology, vol 15, no 03, 2015, pp 59-64.
7. K Gurunaathan and G S Thirugnanam, Investigation on the behavior of prestressed concrete poles of different lengths', International Journal of Earth Sciences and Engineering, vol 09, no 01, 2016, pp 32-36.
8. ShahidIqbal, Ahsan Ali, Klaus Holschemacher, Yuri Ribakov and Thomas AB, Effect of fly ash on properties of self compacting high strength light weight concrete, Periodica Polytechnica Civil Engineering, vol 61, no 1, 2017, pp 81-87.

# Environmental Analysis of Air Quality Levels by Modelling Studies – A Case Study

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**Abstract:** Air pollution is a major concern for the earth, and it should not impact their development. Current Scenario, Air pollution is a gas flowing in atmosphere to impairment the health of public, also tear down plants or pull down its healthy growing. The rapid growth of the industrial sector and urban development has led to significant quantities of substances and harm materials, having effects on human health and environmental imbalance. Also, the vehicle emits high gases of sulphur dioxide to the environment and pollutes the healthy sustainability. In the place, Alandur Chennai during the month of December 2017 and January 2018, the maximum concentration Nitrogen Dioxide exceeded to 44.8  $\mu\text{g}/\text{m}^3$  concentrations; Sulphur Dioxide exceeded to 100.62  $\mu\text{g}/\text{m}^3$  concentrations; Ozone level to 121.28  $\mu\text{g}/\text{m}^3$  concentrations; Benzene to 15.1  $\mu\text{g}/\text{m}^3$  concentrations; Toluene to 11.94  $\mu\text{g}/\text{m}^3$  concentrations. For all these parameters, the threat zone Mapping and Marplot is plotted to represent in graphical form for further planning and operational benefits. This paper gives awareness to the public to save and protect our society, keep clean from major ill effects.

**Keywords:** Environmental Awareness; Air Pollution; Health Effects; Marplot

## INTRODUCTION

Air deliveries us by way of the fresh air, oxygen to survive which is vital for our bodies to animate. Fresh breathing is the prime requirement of the human existence in this planet earth. Air contains 99.9% oxygen, nitrogen, water vapour and the gases. Humanoid activities and the industries develop huge emissions into air make the air gets polluted. Many vehicles emissions and the oil refining and resource of fuel, carbon emission is the major causes of air pollution all through the world. India's carbon dioxide emissions are occurring chiefly from warming, reheating, domestic conventions and power segments. Some percentage of emissions impart from the vehicle emissions. India's all type of thermal power stations such as coal fired, oil fired and natural normal gas fired plants are incompetent besides pollute substantial amount for carbon dioxide, CO<sub>2</sub> emissions. This CO<sub>2</sub> emission reduction has to be sorted for the betterment of Environmental issues as global warming. India is growing efficiently on CO<sub>2</sub> emissions and it's taken measures to reduce the emissions over the past years. A substantial cause of greenhouse gas radiations and emissions as of India is after dark black carbon, NO<sub>x</sub> emissions and added further air pollutants. Pollutants are released in huge extents of level in India every single day from unfinished and incompetent combustion of treatment in biomass. India's ailing managed solid waste management, insufficient treatment of sewage plants, surface and sub-surface water pollution, emissions from vehicles and industry, agriculture are other causes of greenhouse gas releases. Fossil fuels combustion and industry effluents, NO<sub>x</sub> from vehicles, burning of fossil fuels from coal, oil etc, harmful productions etc are source of pollutants in the air. The air pollution study helps to analyze the need of the hour in that particular zone. This paper gives the analysis of the study area and gives awareness to maintain the clean environment also insisting to the public to protect the surrounding clean, which it should not to get polluted. In environmental pollution early-warning and forecasting systems artificial Intelligence methods and machine learning algorithms are used (Subramaniam, et al, 2022). This kind of study also guides in retort at time of necessitate to chemical catches in mapping (Sheena, et al, 2022).

## LITERATURE REVIEW

Very few literatures are focused at this point of view:

The principal influence to NO<sub>x</sub> derives since vehicular reasons and to particulate matters arises from the road traffic dust emissions. The emissions per capita of each parameter are also dogged to allow a fair reasonable assessment through

cities. The pollution factors were found for the years 2012 and 2017 (Ramanathan, et al, 2011). Long extended distance transportation of aerosol has remarkable impacts (Ramanathan, et al 2001; Lawrence and Lelieveld 2010). The profit of any research stands in the view of results. The anticipated structure brings exceptional results. The required concern was the suggested system over existing system. The numerical calculations and techniques in the anticipated system as stated mounted up visualising the downside of existing system. The Matlab analysis tool verified exceptional results for execution of numerical calculations, their simulating outcomes and graphical show. This tool results helped in investigation and analysis of the precise two scenarios (Talokar and Bakal 2014). Pollution observing and resistor is a wide spread intensive field and this study project is an effort to minimize the problem. A real time attainment and monitoring system centred. The network has magnificently met the objective of giving real time attainment of concentration, level of temperature and the level of humidity (Sami 2015). Health based setting of Air Quality Standards (Hester, et al, 1998). The effective study of saturated atmospheric concentrations were discussed (Kalabokas and Hatzianestris, et al, 2000).

### STUDY AREA AND SOFTWARE USED

The study area is chosen to be Alandur Bus Depot in Chennai (**Figure 1**) near hot of the city at the Latitude of 12°59' 49.6104" N and Longitude of 80° 11' 29.4612" E Point.

The ALOHA open source software is used here to find the extent of parameter levels in the atmosphere of the selected site. It helps to plot in the pictorial form of representation of the harmful levels by threat zone mapping and marplot mapping.

### METHODOLOGY

The stages of work are shown in the flowchart as shown in **Figure 2**. The parameters are given as input and analyze using the software for getting the results.

#### The Introduction of Areal Locations of Hazardous Atmospheres (ALOHA)

The ALOHA software is intended to use in the environment with hazardous atmosphere to evaluate the area which is affected in that zone. It has issued three levels of ERPG values in evaluating the effects of accidental chemical releases on the general public based on toxic effect of the chemical for use with respect to these (AIHA, 2002 and classified as ERPG-1, ERPG-2, and ERPG-3 to estimate the concentrations of specific chemicals above which acute exposure in terms of toxic effects (up to 1 hour (AIHA, 2002).

### THREAT ZONE

A threat zone is the study of area inside which ALOHA foresees the level of hazard to surpass the concern level at some time afterward a release initiates. ALOHA can model multiple hazards like, toxicity, thermal radiation, flammability and overpressure), and also type of LOC that you choose will vary based on the hazard.



**Figure 1** Study Area Map of Alandur Bus Depot



**Figure 2** Flowchart showing the Air Pollution Mapping

### THREAT ZONE MAPPING

The inferior the speed of wind, the extra the wind diverge its direction, so as speed of wind declines, thus the wind direction assurance lines develop beyond to farther side apart. Thus, the threat zone mapping is done for Alandur study area for the month December 2017 and shown below in **Figures 3 to 6**.

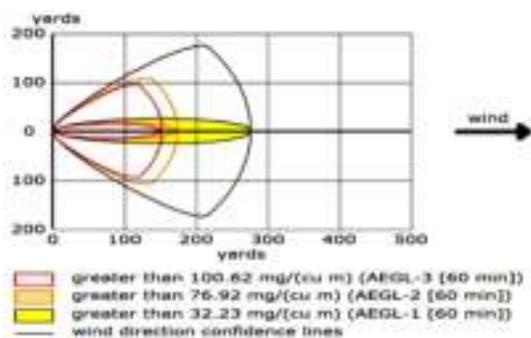
### MARPLOT

The mapping with the Mapping Application for Response, Planning, and Local Operational Tasks, MARPLOT is a mapping program used in this study for analyzing the air pollution effects. MARPLOT mapping helps to plot with Geo-reference information in exact coordinates and GIS interface, helps to visualize the location and its effects of threat zone geospatially. Access several different online base maps or download base map tiles for offline use. Draw objects on top of the base map or import objects from many common file types. Manage database information associated with the objects on the map. Choose from hundreds of symbols included in MARPLOT to use for symbol (point) objects or add your own custom symbols. Customize your map by adding Web Mapping Services (WMSs), raster maps and annotations. Easily display ALOHA threat zone estimates.

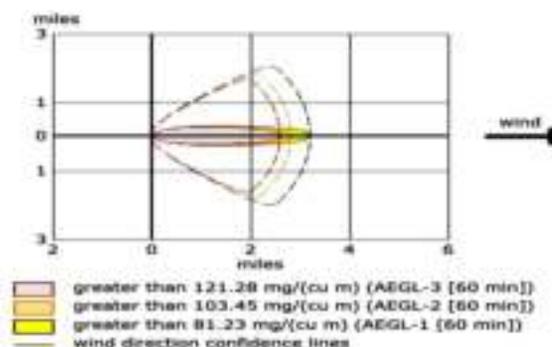
Green infrastructure effectiveness for air quality improvement in urban street is examined (MacKenzie, et al, 2012).

### MARPLOT Mapping

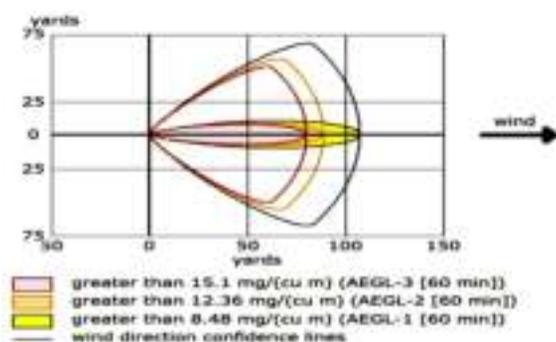
Marplot mapping is drawn for the Alandur study area and the threat zone for each chemical parameters present in atmosphere which imparts air pollution and ill-effects. The three zones which are indicated are yellow, orange and red zone. These Marplot mapping is an efficient tool to visualize the real-time scenario of the threat zones of any affected region. In this study, the Alandur region threat zone is mapped using Marplot. **Figures 7 to 12** represents the plotted threat zone mapping in the Alandur study area.



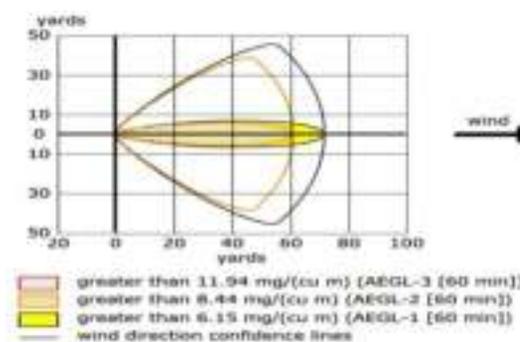
**Figure 3** Sulphur Dioxide – Alandur Threat Zone in December 2017



**Figure 4** Ozone – Alandur Threat Zone in December 2017



**Figure 5** Benzene – Alandur Threat Zone in December 2017



**Figure 6** Toluene – Alandur Threat Zone in December 2017



Figure 7 Nitric oxide – Marplot at Alandur for December 2017



Figure 8 Nitrogen Dioxide – Marplot at Alandur for December 2017



Figure 9 Sulphur Dioxide – Marplot at Alandur for December 2017



Figure 10 Ozone – Marplot at Alandur for December 2017



Figure 11 Benzene – Marplot at Alandur for December 2017



Figure 12 Toluene – Marplot at Alandur for December 2017



## SUMMARY

Today's pollution is high in the environment and it leads to disaster in the worldwide and Chennai is also facing major impacts on air pollution in the recent decades. The analyzed values on Alandur area implies that the pollution is very much high in both the areas. The sulphur dioxide is very much high in both the areas and it is mainly due to the vehicular emission and industrial areas. The ozone and benzene values are also determined and it is analyzed from the Aloha software. The software gives the output of the threat zones and the marplot of the zone which is analyzed for the two months and the value is observed. The values show that the environment should be protected.

## CONCLUSIONS

The concentration observed during December 2017 and January 2018 were studied and analyzed using ALOHA software and the results of threat zone mapping and marplot is plotted Alandur. This analysis study is the chief principal one in different way used as an extensive research projecting the real cases in an around the zone, thus paving way to help in a clean society. In this study where in a comprehensive analysis was accompanied to decide the sources of pollution using a thorough emission analysis. The excellence of air quality was dogged to represent the study areas. This paper gives an analysis to maintain the quality of air for the better safe India. This promotes awareness to keep the society clean. This research work can be examined in elsewhere any part of the globe.

## REFERENCES

1. V Ramanathan, Paul Crutzen, Jeffrey Kiehl and Daniel Rosenfeld, *Aerosols, Climate, and the Hydrological Cycle*. Science, New York, 2002, 294. 2119-24. 10.1126/science.1064034.
2. Sonal Talokar and Jagdish Bakal, *Air Pollution Monitoring System*, International Journal of Recent Advances in Engg & Technology. 2, 2014, p 25.
3. S Bedoui, S Gomri, H Samet and A Kachouri, *Air Pollution Monitoring System using LabVIEW*, IEEE 12th International Multi-Conference on Systems, Signals & Devices (SSD15), 2015, pp 1-6, doi: 10.1109/SSD.2015.7348259.
4. S Subramaniam, et al, *Artificial Intelligence Technologies for Forecasting Air Pollution and Human Health: A Narrative Review*, Sustain., 14(16), 2022, pp 1–36, doi: 10.3390/su14169951.
5. A R MacKenzie, R M Harrison, I Colbeck, C N Hewitt, *The role Of Biogenic Hydrocarbons in the Production of Ozone in Urban Plumes in Southeast England*, Atmos. Environ. 25(2), 1991, pp 351-359.
6. E Brancaleonia, M Scovaventib, M Frattonia, R Mabiliaa and P Ciccioli, *Novel Family of Multi-layer Cartridges Filled with a New Carbon Adsorbent for the Quantitative Determination of Volatile Organic Compounds in the Atmosphere*, J Chromatogr. A. 845(1-2), 1999, pp 317–328.
7. J Dewulf and H V Iagenhove, *Anthropogenic Volatile Organic Compounds in Ambient Air and Natural Waters: A Review on Recent Developments of Analytical Methodology, Performance and Interpretation of Field Measurements*, J. Chromatogr. A., 843(1-3), 1999, pp 163-177.
8. R M Harrison, *Setting Health-based Air Quality Standards*, Air Pollution and Health, Issues in Environmental Sciences and Technology, 10, Cambridge: The Royal Society of Chemistry, 1998, pp 57-73.
9. P D Kalabokas, J Hatziaianestris, J G Bartzis and P Papagiannakopoulos, *Atmospheric concentrations of saturated and aromatic hydrocarbons around a Greek refinery*, Atmos. Environ. 3(14), 2000, pp 2545-2555.
10. H A Waxman, *Oil Refineries Fail to Report Millions of Pounds of Harmful Emissions*, Minority Staff Special Investigations Division, Committee on Government Reform U.S. House of Representatives, 1999.
11. AD Sheena, B Anuradha and S Packialakshmi, *Integration of ALOHA- MARPLOT in the Real Study of Monitoring Air Quality Measures*, selected for ICDSAAI2022 and IEEE Xplore, 2022.



# Expanded Polystyrene in Construction

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**Abstract:** Expanded polystyrene (EPS) is one of the most important building material which has the ability to enhance the design and structural component of the building. The word “Styrofoam” is often used to describe expanded polystyrene (EPS) foam; however, ‘Styrofoam’ is actually a trademarked term for closed-cell extruded polystyrene foam made for thermal insulation and craft applications. Since its recognition as conventional insulating material in 1950. Expanded polystyrene is performed in three stages are Pre-expansion, Stabilization and Molding Polystyrene. In this study, it is explained about the properties of light weight, Durability, Water and Moisture absorption, Thermal Efficiency. EPS foam material used in road building as an embankment construction material for earth and also in personal protection equipment. Although this foam material has established itself today in many applications sectors, its development potential is still very popular. This paper also explains about the decorative molding material, vaccum insulated panel (VIP) which is an evacuated porous material inserted within multilayer envelope also alternative to conventional building insulation method.

**Keywords:** Expanded Polystyrene; Vaccum Insulated Panel; Expansion; Thermal Efficiency; Durability

## INTRODUCTION

Polystyrene was first discovered by a German apothecary Eduard Simon in the year 1939. In the recent times, there is an increase in interest in the application of expanded polystyrene (EPS) for construction industry. EPS is a well-established insulation material used widely in the construction field as it has a light yet rigid foam with good thermal insulation and high impact resistance. In order to this, it can possess high load-bearing capacity at low weight, absolute water and vapor barrier, air tightness for controlled environments, long life, low maintenance, fast, and economic construction. The lightweight cellular plastic foam in EPS consists of small spherical-shaped particles containing about 98% of air. This microcellular closed cell construction provides an excellent insulating and shock absorbing characteristics for EPS. EPS consists of small polystyrene beads which are derived from styrene through the process of polymerization

The foam quality of EPS can be affected by the size distribution of the beads[1]. After the polymerization process, EPS is infused with blowing agent such as pentane and hexane.

## STRUCTURE OF POLYSTYRENE

(C<sub>8</sub>H<sub>8</sub>)<sub>n</sub> is a synthetic aromatic hydrocarbon polymer with the chemical name Polystyrene.

## FORMATION OF EPS

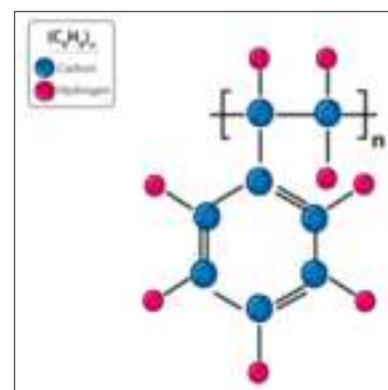
Polystyrene is produced from crude oil refinery product styrene. For manufacturing expanded polystyrene, the polystyrene beads are impregnated with the foaming agent pentane. Polystyrene granulate is pre foamed at temperatures above 90°C. This temperature causes the foaming agent to evaporate and hence inflating the thermoplastic base material to 20-50 times its original size.

## MANUFACTURING PROCESS OF EPS

The conversion of polystyrene to EPS is carried out in three stages. They are: (1) pre-expansion, (2) intermediate maturing and stabilization, and (3) expansion and final molding.

### Pre-Expansion

In the first stage, the raw material is heated in pre-expanders with steam at temperature between 80°C and 100°C to





create a uniform cellular structure with small closed cells that hold air in the interior region. The density of the material falls from some  $630 \text{ kg/m}^3$  to values ranging between 10 and  $35 \text{ kg/m}^3$ . According to Doroudiani and Omidian[2] during this process, the internal gas of the beads will experience volume expansion which generates air-penetrable cellular structure.

### **Intermediate Maturing and Stabilization**

On cooling, the recently expanded particles from a vacuum in their interior and this must be compensated for by air diffusion. This process is carried out in aerated silos. The beads are dried at the same time. The beads getting improved expansion capacity and greater mechanical elasticity.

### **Expansion and Final Moulding**

During The final stage, the stabilized pre-expanded beads are transported into moulds where they are again subjected to steam so that the beads bind together. The moulded shapes or large blocks are obtained by this way (which are later sectioned to the required shape like boards, panels, cylinders etc). Blocks created using this process is further enhanced in terms of dimensional stability prior to separation into required shape. **Figure 1** shows the three main forms of EPS.

Moreover, solid-state polystyrene foam can be made. In extrusion process, carbon dioxide or nitrogen is used during suspension polymerization as blowing agent[3–6]. EPS starts to melt at temperature about  $100^\circ\text{C}$ [7]. During flashover, EPS self-ignites instantaneously at temperature about  $490^\circ\text{C}$ . Ignition of combustible gases released from the decomposition of EPS may occur when they are exposed to air at these lowest initial temperatures or due to self-heating properties of the EPS[12]. The porous structure of EPS allows more storage of air which intensifies the fire spread during combustion.

## **THE EXPANDING ROLE OF EPS IN CONSTRUCTION**

EPS has grown into one of the most versatile insulating materials in construction today. The first expanded polystyrene (EPS) block molding plant was established in Grand Rapids, Michigan in the year 1965. It manufactured blocks measuring from 0.6 m to 4.9 m (2 ft to 16 ft) in thickness, but nowadays EPS blocks can be cut into any required shape. They are generally cut with hot wires into sheets for use as thermal insulation, but other uses for the large 'billets' include flotation, 'geofoam' landfill applications, and other large-scale uses.

In construction industry, it is mandatory to use a flame-retardant grade of EPS to reduce the flammability and spread of flame on the surface of EPS products. Since EPS has restricted function in terms of fire protection, EPS is applied in construction sector only when it is used in tandem with other suitable material capable of resisting fire. Due to its flexibility and versatility nature, it can be cut into sheets, slabs, or any desired design to meet specific building code requirements, as well as customized designs. EPS is used as insulation in walls, roofs, and foundations, and serves as an integral component of structural insulated panels (SIPs), insulated concrete forms (ICFs), and exterior insulation and finish systems (EIFS).

Sheathing is one of the most basic and widely used applications for EPS insulation in residential and commercial construction. It helps create an envelope around the structure, covering wall cavities and studs to increase their resistance to heat transfer and moisture penetration. EPS foam- insulating sheathing has become an industry standard. The sheathing is non-structural, and is primarily used as an exterior insulator, both below and above grade (though it can be used throughout the structure in roof, floors, and ceilings). Different densities help provide the R-value required to meet local building energy codes.

EPS sheathing is used in renovations as well as new construction because of its compatibility with wood and steel framing, and masonry. The boards are installed vertically over the exterior sides of the studs, with the vapor retarder facing the heated side of the structure. It can be fastened with nails, screws, and/or staples (depending on the framing surface), while spot adhesive is the norm for masonry substrates.

Generic EPS blocks can be molded within a range of densities. In theory, final product density affects all material properties, both thermal and, especially, 'mechanical' (stress-strain-time temperature) although density turns out to be an imperfect metric in practice. There is no standard EPS block size and the same molder with different plants might produce blocks of different size depending on the plant. Block-molded EPS (referred to as EPS-block in the remainder of this presentation) is the most common form of EPS-geofoam and is properly referred to as EPS-block geofoam as shown in the **Figure 2**.

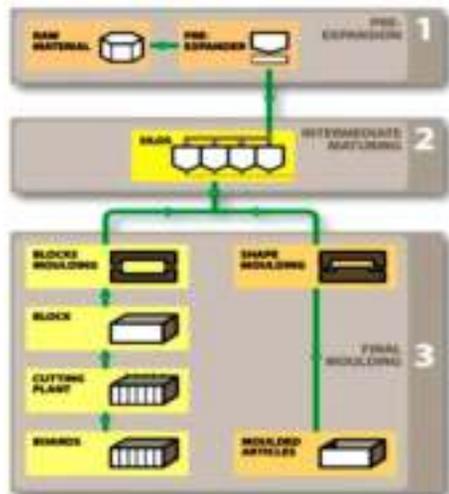


Figure 1 Three stages of EPS



Figure 2 EPS Geo foam

EPS-block geofoam is the EPS product of choice for all small-strain functional applications such as lightweight fill, thermal insulation, and small-strain vibration and noise damping.

### BENEFITS OF EPS CONSTRUCTION

#### Stable R-Value

When comparing the different merits and benefits of various insulation products for construction, there is usually a focus on cost, environmental impact and versatility, but the top concern is almost always the performance factors.

EPS has a high R-value per inch and is closely comparable to other insulation materials. EPS insulation offers excellent thermal resistance, and its consistency and stability set it apart from other insulation materials like Extruded polystyrene (XPS). The stability and consistency of EPS products mean they have a longer life than other insulation products and will not need replacement as often, leading to long-term savings.

Products made of XPS contain a trapped blowing agent that diminishes over time. So, while they may have a slightly higher initial R-value than EPS insulation products, their effectiveness depreciates over time.

EPS is made up of only air and polystyrene there are no added blowing agents or chemicals. This means that its R-value does not reduce over time and will remain as effective in fifty years as it was on day one.

#### Dimensional Stability

Many plastic polymers either shrink or expand when exposed to humidity or temperature change. But EPS has incredible dimensional stability and remains unaffected by varying environmental conditions.

The maximum dimensional change of EPS is less than 2%, and the predictable material performance means it delivers consistently for the entirety of its lifetime.

#### Compressive Resistance

One of the most significant mechanical properties of EPS is its resistance to compressive stresses — and the strength and resistance capabilities increase with higher density. EPS is a closed-cell foam, meaning there are no holes or spaces between the cells. Because of this make-up, EPS is highly resistant to bending and compression, so it works well in load-bearing situations. EPS is an extremely strong material for construction projects that is not subject to degradation over time.

#### Other Benefits

##### *Versatility*

EPS is used in a variety of construction projects. It works as a fill material for road and bridge construction and is



commonly used by the Department of Transportation. It is a great insulation material for homes and commercial structures. Also, EPS is used in several applications within the building from the roof to the walls to the foundation.

The list of applications continues on, making EPS one of the most versatile materials in any industry.

#### *Sustainable Life Cycle*

Contrary to popular belief, EPS is actually environmentally friendly. The manufacturing of EPS is a much cleaner process than the manufacturing of other insulation alternatives. No toxic substances are used to make EPS, and no ozone-depleting gases are used or created as a byproduct when manufacturing EPS.

EPS has low global warming potential, low water consumption during manufacturing and no generated waste. EPS has a lower environmental impact than other construction materials including fiberboard, wood and paper. It neither possesses nor creates any water or air pollutants, and EPS is 100% reusable or recyclable at the end of its life.

### **PROPERTIES OF EPS**

#### **Light Weight**

EPS is an extremely lightweight material which is not surprising considering it is comprised of ~98% air. This characteristic makes it ideal for use in packaging as it does not significantly add to the weight of the total product thereby reducing transportation costs. Energy consumption for transport fuel is also reduced and vehicle emissions minimised — all contributing to lower global warming.

#### **Durability**

The exceptional durability of EPS makes it an effective and reliable protective packaging for a wide range of goods. The cellular structure of EPS makes it dimensionally stable and therefore does not deteriorate with age. EPS is also odourless and non-toxic.

#### **Water and Moisture Absorption**

EPS is a closed cell material and does not readily absorb water. There is no loss of strength in damp conditions, making EPS ideal for cool-chain products. The material is moisture resistant, so the highest hygiene requirements are met. The ability of EPS to resist moisture also lends itself for use in fishing floats and marina buoys. Even when subjected to prolonged saturation in water, Percentage of water absorption of EPS products is listed in the **Table 1**.

EPS will still maintain its shape, size, structure and physical appearance with only a slight reduction to its thermal performance. EPS with 9-12 years of usage period has 8-9% of its volume filled underground table. EPS Geofoam is prone to moisture absorption which causes deterioration of thermal properties. Less than 10% of geofoam is absorbed during its lifetime usage.

#### **Thermal Efficiency**

The superior thermal efficiency of EPS makes it ideal for packaging any product that is sensitive to temperature change. Products enclosed in EPS containers can be maintained for long periods at temperature above or below ambient conditions and can be protected from sudden temperature changes that can occur in the transport through different climatic zones. Examples include fresh produce and seafood as well as pharmaceutical and medical products.

#### **Mechanical Strength**

The EPS product is classified based on compressive strength and compressive stress. Compressive strength is maximum

**Table 1**

<b>DENSITY</b>	<b>AFTER 7 DAYS</b>	<b>AFTER 1 YEAR</b>
15	3.0	5.0
20	2.3	4.0
25	2.2	3.8
30	2.0	3.5
35	1.9	3.3



uniaxial compressive stress that material can bear before fracturing. Number is assigned to each EPS product based on its compressive stress. Jablite is one of the many brands of EPS.

## APPLICATIONS OF EPS

### Lightweight Concrete

Expanded polystyrene (EPS) concrete (also known as EPScrete, EPS concrete or lightweight concrete) is a form of concrete known for its light weight made from cement and EPS. It is a popular material for use in environmentally "green" homes. It has been used as road bedding, in soil or geo-stabilization projects and as sub-grading for railroad trackage. Before 1980, EPS as the aggregate of concrete has been studied in detail .It is created by using small lightweight EPS balls (sometimes called Styrofoam) as an aggregate instead of the crushed stone that is used in regular concrete. It is not as strong as stone-based concrete mixes, but has other advantages such as increased thermal and sound insulation properties, easy shaping and ability to be formed by hand with sculpturing and construction tools. After many years of exploration and attempt, EPS lightweight concrete can be used in many building structures, such as EPS insulation coating, EPS mortar, EPS sealing putty, EPS lightweight mortar, EPS concrete inner and outer wall panels, etc

In addition, EPS lightweight aggregate concrete is also used in the fields of pavement backfill, antifreeze subgrade, thermal insulation roof, floor sound insulation and marine floating structure. In particular, it has a strong energy absorption function, so it can also be used as a structural impact protection layer.

EPS concrete combines the construction ease of concrete with the thermal and hydro insulation properties of EPS and can be used for a very wide range of application where lighter loads or thermal insulation or both are desired. Lightweight concretes have been successfully used in the construction, thanks to its low density. To produce lightweight concrete, we can use several types of inorganic lightweight aggregates, like expanded clay, agropolite, or organic lightweight aggregates like expanded polystyrene (EPS).

### Vacuum Insulated Panel

Vacuum insulated panel (VIP) is an evacuated open porous material inserted within multilayer envelope. VIP consists of inner core, barrier envelope, and desiccant. The envelope protects the panel against external stress. VIP is categorized based on the type of material used as envelope; either thick metal sheet or metallized polymer film. EPS foam is used as core to maintain the vacuum condition as well as to provide support for the envelope. The desiccant is placed in the core as adsorbent in order to avoid infiltration by external gas or water vapor. Therefore, VIP is an alternative to conventional building insulation material. It creates vacuum inside the core which is effective in inhibiting the heat transfer. The schematic diagram of VIP is shown in **Figure 3**.

### Backfilling

EPS geofoam is used as backfilling to reduce the weight of embankment especially when it is erected on top of soft soil. EPS geofoam is also used as backfilling material for bridge abutment and road widening. As lightweight fill, EPS is suitable for construction of ground embankment with low-bearing capability. Furthermore, it reduces the lateral forces on the back of bridge abutment's structure. In a case study conducted in Thanet Way, England, EPS lightweight blocks were used to eliminate the lateral loading on bridge abutment and stabilized the weak foundation formed on chalk ground. The lightweight property of EPS block allows it to be carried and positioned easily without requiring any lifting equipment thus reducing transportation cost. The blocks were arranged in staggered conformation and steel bars were embedded to further strengthen the structure.

### Embellish Tiles and Moldings

The purpose of decorative molding is to improve the overall aesthetic aspects of a building by concealing transition and gaps between surfaces. Currently, EPS has replaced stone as material for decorative molding as observed in North America and other Countries where EPS is embedded with reinforcing mesh before Polyurethane (PUR) or polymer modified cement coatings is applied. Polymer foams are popular materials for decorative tiles and molding.

## MARKET OVERVIEW OF EPS

The total market overview of EPS is illustrated in the **Figure 4**. The Global Expanded Polystyrene Market Size accounted for USD 18,194 Million in 2021 and is estimated to achieve a market size of USD 27,592 Million by 2030 growing at a Compound Annual Growth Rate (CAGR) of 4.9% from 2022 to 2030.

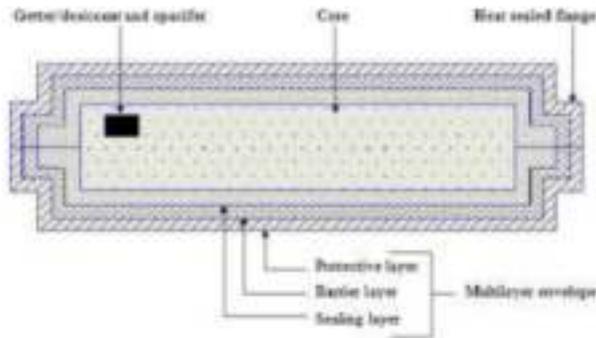


Figure 3 Vacuum Insulated Panel



Figure 4 Market overview of EPS

## CONCLUSION

The EPS can be produced with a wide range of properties, shapes and sizes, used in many other constructive applications - such as filler material, such as roof tile in civil engineering projects, as a fill light in construction of roads and railways and as a floating material to build floating pontoons in sea areas from shipping.

## REFERENCES

1. J A Brydson, *Plastics Materials*; Butterworth-Heinemann: Oxford, 1999. p 425.
2. S Doroudiani and H Omidian, *Build. Sci.* 45(3), 2010, p 647.
3. J M Martini-Vvedenski, N P Suh and F A U S Waldman, *Pat.* 4,473, 1984, p 665.
4. S Doroudiani and M T J Kortschot, *Appl. Polym. Sci.* 90(5), 2003, 14215.
- [5] Doroudiani and M T J Kortschot, *Appl. Polym. Sci.* 90(5), 2003, 1427.
6. S Doroudiani and M T J Kortschot, *Appl. Polym. Sci.* 90(5), 2003, 1412.
7. X Han, K W K oelling, D L Tomasko and L J Lee, *Polym. Eng. Sci.* 42(11), 2002, 2094.
8. S Doroudiani, C E Chaffey and M T J Kortschot, *Polym. Sci. Part B: Polym. Phys.* 40(8), 2002, p 723.
9. *Concrete Wall Building System-the Innovative Concrete System*, www.cbs-ibs.com.wall building [M2]
10. *Prospects of Expanded Polystyrene Sheet as Green Building Material*, *International Journal of Civil Engineering Research*, 5(2).



# Role of Modern Materials in the Construction Field

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**Abstract:** This paper looks into the way in which materials and components were selected and incorporated in ancient periods and the adaptation of number of new building materials in modern period. Technology is getting more modernized day by day. With this there has been a great development in the construction technique which depends upon the modern materials used. In ancient days there were no consideration related to eco-friendly and recycled materials. But these two key words are playing major vital role in modern world. Without compromising, strength, durability and other climatic changes problem advanced modern construction materials solve the above problem. The modern construction materials used in the construction industry shows good aesthetic appearance. In this paper discuss with important of modern materials in the construction field, to focus on. Temperature resistance, acoustic arrestor, firefighting materials and handling hazardous waste materials in the industries.

**Keywords:** Eco-friendly Materials; Recycled Materials; Aesthetic Appearance; Construction Techniques

## INTRODUCTION

Every day, new materials are discovered or invented, but how did it begin? When did they first come to use?

Construction or building construction techniques must now meet industrial standards or human living standards, but that has not always been the case. Construction is an ancient human activity that dates as far back as 400 BC. It started from using constructed materials to produce shelters for regulating the effect of climates on humans. Soon, the advent of agriculture paved the way for various construction materials such as timber and animal skin. In Egypt and the Middle East, timbers were used to construct dwellings for humans and as storage facilities for plants.

During the late Stone Age, hunter-gatherers used circular rings of stones to form the foundations of shelters. Then animal skins were used, along with crude huts made of wooden poles to shed snow or rain and reduce sunlight penetration. Primitive builders soon developed tholoi – a construction material made of dry-laid stone to build dwellings with domed roofs. The tholoi were the beginning of masonry construction because of their durability. Wood remains a common material in building development

throughout the world. This ancient material has been serving the construction industry for time immemorial. With expansive forests, Europe and North America are the havens of wood.

Many homes in these nations are mainly timber-framed homes. Timber comes with a lot of benefits and some drawbacks. It is inexpensive and can be carved into any shape. On the downside, the integrity of the building becomes compromised when the woods used are exposed to moisture.

Due to its ability to absorb moisture, wood also creates a conducive environment for moisture growth in homes. However, researchers have been able to develop various treatments for timber to ensure their safety.

Wood remains essential for the industry even if modern materials and construction techniques seem to outshine more prominently. Lime is a calcium-containing inorganic material composed primarily of oxides and hydroxide, usually calcium oxide and/or calcium hydroxide. It is also the name for calcium oxide which occurs as a product of coal-seam fires and in altered limestone xenoliths in volcanic ejecta. The origin of ready mix concrete as a construction material can be traced back to the Romans. They used cement to form concrete, which is incredibly versatile and used to make constructing gladiator arenas, museums, theatres, and so on.

Concrete is a mix of cement, water, fine/coarse aggregates. In North America, concrete is widely used to lay foundations during residential construction. Concrete is primarily used to lay foundations in North American residential construction to support the rest of the structure.

Introduction of new building materials with the introduction of new building materials, innovative construction methods



were developed. Especially with the breakthrough of Portland Cement (1824), the steel pro (1849) and in the glass (1866); all were formative for the construction industry. These materials opened up design possibilities not previously known, but at the same time, also increased the demands on the structural understanding of the planner and construction workers. In general, until about the middle of the 19th century, traditional building construction (i.e. technical solutions in conjunction with local experience and a small number of different materials) had been used. However, from about 1850, this changes to a universal construction approach. From the multitude of scriptures and quotes that take a position on this issue, the following examples will be singled out. In his work, it is above all Otto Wagner (1841-1918) in Vienna, the pioneer constructive aesthetics and a new architecturally technically determined way of thinking in Europe (Moravánszky,1988). He formulated his principles, as follows: “Every new style gradually results from the previous, that new designs, new materials, new human tasks and views required a change or reconstitution of the existing forms. ... It is to assume well proven that art and artists always represent their own epoch. ... The purpose of art, even so, the modern, has remained but the same, which was at all times. The art of our time must be modern ... All modern created must comply with the new material that corresponds with the requirements of the subject ... on behalf of the colossal technical and scientific achievements and the practical benefit ..... This new style, the Modern, ... must in all our work clearly express the emergence of fulfillment of purpose. ....” (Wagner, 1896).

### BASIC MATERIALS USED IN CONSTRUCTION

The crux for your building and construction projects rely on essential ingredients called “construction materials”.

#### Stone

Without construction materials, maintain the structural strength of a building while reducing environmental hazards. The first and foremost basic construction material is stones.

Types of stone:

- Igneous rocks,
- Sedimentary rocks,
- Metamorphic rocks.

Stones have been consider as one of the popular building material from the olden days due to their availability in abundance from the natural rocks. Some of its types is used as a major building materials they are, granite, lime stone, slate etc..

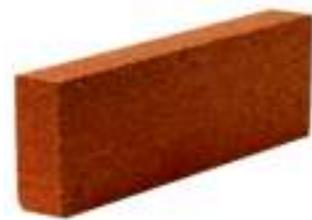
#### Bricks

Next to stones, the uses of bricks is increased in construction field because their life span and limited environment impact make bricks unbeatable if you want to build a durable building. Bricks make it possible to create beautiful buildings with limited spending and a long life span.

Types of bricks

- Conventional bricks

The size of bricks over time has changed considerably. Some early medieval bricks were 13 inches by 6 inches by 2 inches. By the late 15th century a brick 9.5 inches by 4.5 inches by 2 inches became the norm and a charter in 1571 stipulated bricks by the measurement of 9 inches by 4.5 inches by 2.25 inches. By the 18th century, 8.25 inches by 4





inches by 2.5 inches brick was introduced. Modern bricks are 8.5 inches by 4 inches by 2.5 inches which is following metrication translated to 215mm by 102.5mm by 65mm. Modern bricks are the bricks that are most used in buildings nowadays.

#### ➤ Refractory bricks

Refractory materials are those that can withstand high temperatures without the heat damaging their structure, resistance, or thermal conductivity. In the case of bricks, the chemical composition of refractories is different from that of regular bricks, which also influences their color and thermal conductivity.

#### Lime

Lime is a calcium-containing inorganic material composed primarily of oxides and hydroxide, usually calcium oxide and/or calcium hydroxide. It is also the name for calcium oxide which occurs as a product of coal-seam fires and in altered limestone xenoliths in volcanic ejecta. The International Mineralogical Association recognizes lime as a mineral with the chemical formula of CaO. The word lime originates with its earliest use as building mortar and has the sense of sticking or adhering. Different types of limes used in construction are Quick Lime, Slaked Lime, Fat Lime and Hydraulic Lime. They are obtained by the process of calcination of natural limestone over a temperature of 900°C.

#### Cement

Cement is a binder, a substance that sets and hardens and can bind other materials together. Cements used in construction can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to be used in the presence of water. Non-hydraulic cement will not set in wet conditions or underwater, rather it sets as it dries and reacts with carbon dioxide in the air. It can be attacked by some aggressive chemicals after setting. Hydraulic cement is made by replacing some of the cement in a mix with activated aluminium silicates, pozzolanas, such as fly ash. The chemical reaction results in hydrates that are not very water-soluble and so are quite durable in water and safe from chemical attack. This allows setting in wet condition or underwater and further protects the hardened material from chemical attack (e.g., Portland cement).

#### Ordinary Portland Cement

Ordinary Portland cement is the most common type of cement in general use around the world. This cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450°C in a kiln, in a process known as calcination, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement' (often referred to as OPC).

Portland cement is a basic ingredient of concrete, mortar and most non-specialty grout. The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element. Portland cement may be grey or white.

- This type of cement use in construction when there is no exposure to sulphates in the soil or ground water.
- Lime saturation Factor is limited between i.e. 0.66 to 1.02.
- Free lime-cause the Cement to be unsound.





- Percentage of  $(\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3)$  is not less than 0.66.
- Insoluble residue not more than 1.5%.
- Percentage of  $\text{SO}_3$  limited by 2.5% when  $\text{C}_3\text{A} < 7\%$  and not more than 3% when  $\text{C}_3\text{A} > 7\%$

#### White Portland Cement

- Grey colour of OP cement is due to presence of Iron Oxide. Hence in White Cement. Sodium Alumina Ferrite (Crinoline)  $\text{NaAlF}_6$  is added to act as flux in the absence of Iron-Oxide.
- It is quick drying, possesses high strength and has superior aesthetic values and it also cost less than ordinary Cement because of specific requirements imposed upon the raw materials and the manufacturing process.
- White Cement are used in swimming pools, for painting garden furniture, moulding sculptures and statues etc.

#### Coloured Portland

- The Cement of desired colour may be obtained by mixing mineral pigments with ordinary Cement.
- The amount of colouring material may vary from 5 to 10%. If this percentage exceeds 10%, the strength of cements is affected.
- The iron Oxide in different proportions gives brown, red or yellow colour. The coloured Cement are widely used for finishing of floors, window sill slabs, stair treads etc. garden seats, artistically designed wens, flower posts, etc.
- Preparation of foundation, water tight floors, footpaths, etc.

### MODERN MATERIALS IN CONSTRUCTION

#### Concrete

Concrete is a composite material composed mainly of water, aggregate, and cement. Often, additives and reinforcements are included in the mixture to achieve the desired physical properties of the finished material. When these ingredients are mixed together, they form a fluid mass that is easily molded into shape. Over time, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone-like material with many uses. The aim is to mix these materials in measured amounts to make concrete that is easy to: Transport, place, compact, finish and which will set, and harden, to give a strong and durable product. The amount of each material (ie cement, water and aggregates) affects the properties of hardened concrete.

#### Types of concrete

- Reinforced concrete;
- High performance concrete;
- High strength concrete.

#### Timber

Timber has many important attributes. It has a warm texture and attractive appearance and is often used for internal finishing as well for the main structure. It is easy to work with and can be produced in a wide range of shapes and sizes. It





has a high strength-to-weight ratio and has good thermal insulation properties. Timber can be used compositely with concrete and steel. It is the only construction material that does not contribute to greenhouse emissions and is a fully renewable and largely recyclable material. Because it is a naturally grown material, timber is a complex building material. Its properties are highly variable and are sensitive to environmental and loading conditions. It is a highly anisotropic material with high strength and stiffness parallel to the grain but low properties perpendicular to the grain. These factors must be taken into account in the design of timber structures

## INNOVATIVE CONSTRUCTION MATERIAL USED AROUND THE WORLD

### Cross Laminated Timber

CLT is a sustainable and resilient form of engineered wood which does not require burning of any fossil fuels during its construction. It is made by gluing layers of solid-sawn lumber together and layers lay perpendicular to each other making it more tensile and greater compressive strength. Originated in Europe, CLT is now worldily used, plays to be an excellent building material due to faster production, great quality and flexibility in design. The initial costs of the material are higher but when taken an account on the complete building costs, it saves up. Due to its natural-looking aesthetics and strength, designers and builders are now coming up with building CLT based skyscrapers. One of the eye-catchy examples of CLT used in a building.

### Modular bamboo

Modular Bamboo fits for the most versatile building construction material. Being light weight, availability in abundance and stronger than steel, this material can take any shape in construction and also act as a major earthquake resistant structure in various parts of the world. Bamboo can grow up to 4 feet in a couple of hours and is majorly used in low-cost housing in Philippines, Indonesia and other low-lying islands.

### Translucent concrete

Translucent concrete is mixed with glass fiber optical strands, which create a solid but shear block. It can be used in flooring and pavement.

### Self-repairing concrete

It may seem that most of the materials have been designed to replace concrete, but cement is itself still evolving. A new self-healing cement is currently being developed which has the ability to repair its own cracks.

### Plastic Wood

It is made primarily from high-density polyethylene(HDPE), recovered from the waste stream mainly in the form of used milk containers or recovered plastic bags, and from wood wastes that have been ground to fine powder.





## CONCLUSION

The demand for building materials has been continuously rising with the increasing need for housing both in rural and urban areas. A review of the recent trends indicates that the growth in the area of building materials covers emerging trends and latest developments in the use of wastes, mineral mixtures in cement and concrete, substitutes to conventional timber, composite materials and recycling of waste and the same time ensuring desired response of material to fire, long term performance and durability.

The most important feature governing the choice of material and form of construction for any component is its structural integrity.

## REFERENCES

1. C J Kulkarni, A Text Book of Building Material.
2. P C Varghese, PHI, Pvt Ltd., Building Materials.
3. S K Duggal, Building Materials, 3rd Edition.

# Water-Cement Ratio and Curing: Simple Approach for Durable Rural Roads

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**Abstract:** Concrete pavements have been constructed on many rural roads in India under various schemes. They are also being widely used on internal areas of villages carrying very low volume of traffic because of their durability even under poor drainage conditions. However, it has been observed that concrete rural roads in India deteriorate early due to improper construction technique or methodologies primarily due to improper curing or water-cement ratio. This paper presents relationship between curing and water cement ratio and using this relationship to construct strong and durable roads in India.

**Keywords:** Curing; Durable; Concrete

## INTRODUCTION

In India more than 70% of the population lives in villages and their main source of livelihood is agriculture. Because of stringent environmental rules industries are now shifting towards villages. Both of these activities require a better mode of transportation which can be provided by good conditioned roads. Earlier village roads had low volume of traffic, consisting mostly of rural transport vehicles, like agricultural tractors/trailers, light goods vehicles, buses, animal drawn vehicles, motorized two-wheelers and cycles. Some of the rural roads used to have light and medium trucks carrying sugarcane, timber, quarry materials, etc. As of now flexible pavements are preferred for village connectivity because of the type of traffic and low initial cost of construction. But due to high cost of maintenance, sensitivity to water logging and lack of institutional set up for the maintenance, village roads deteriorate very fast[2]. Moreover, the nature of traffic is also changing due to industrial growth in the nearby areas. Rigid pavement (Cement-Concrete Road) is an alternative to flexible pavement where the soil strength is poor, aggregate are costly and the drainage conditions are bad (as in portions of the roads passing through villages and water logged areas). However, they demand a high degree of expertise at the design stage, construction and maintenance besides high initial cost.

## CONCRETE ROADS IN RURAL INDIA

According to [1], roads having daily traffic less than 450 commercial vehicles per day are known as low-volume roads or village/ rural roads. Cement concrete village roads in India are designed and constructed in accordance with the provision of [1] as well as Ministry of Rural Development handbooks (MoRD). These roads are constructed in villages by various agencies such as Zila Panchayat, Block Panchayat, Village Panchayat, MPLADs funds etc.

## DEFECTS IN CONCRETE ROADS IN VILLAGES

It has been observed that concrete roads in villages get damaged / deteriorated very early as compared to their design period. Since traffic volume is very low, settlement cracks are very less, the major problems are in the preparation and improper curing of cement concrete which give rise to shrinkage cracks. Usually in village roads, design grade of concrete does not exceed more than M30 with water cement ratio usually between 0.47-0.50[3]. Generally no superplasticiser or admixture or any types of fibres are added in village concrete roads construction. Therefore strong and durable concrete road can only be made by proper mix design and curing.

## SHRINKAGE CRACKS IN CONCRETE

Shrinkage is one of the most detrimental properties of concrete, which affects the long-term strength and durability[4]. Shrinkage is larger in village roads because of the high water-cement ratio as the latter determines the amount of evaporable water in the cement paste and the rate at which water can move towards the surface of concrete[5]. Major types of shrinkages in concrete are Plastic, Drying, Autogenous, Carbonation and Thermal. However, only Plastic and Drying shrinkage are discussed in this paper.



**Figure 1** A typical plastic shrinkage crack [6]

Plastic Shrinkage manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic form. Loss of water by evaporation from the surface of concrete or by the absorption of aggregates or subgrade is believed to be the reason of plastic shrinkage causing cracks. These are cracks that start to form before the concrete has set (i.e. is still 'plastic'), but which may not become parallel to each other. They are typically 300 to 600 mm long and up to 3 mm wide [5]. Although often quite small and shallow initially, subsequent loading can cause the cracks to increase in size.

Withdrawal of water from concrete placed in unsaturated air causes drying shrinkage. When concrete is exposed to its service environment it tends to reach equilibrium with that environment. If the environment is a dry atmosphere the exposed surface of the concrete loses water by evaporation. The first water to be lost is that held in the large capillary pores of the hardened concrete. The loss of this water does not cause significant volume change. However as drying continues, loss of water from small capillary pores and later from gel pores takes place. With the reduction in the vapour pressure in the capillary pores, tensile stress in the residual water increases. Tensile stresses in the capillary water are balanced by compressive stresses in the surrounding concrete and a result concrete shrinks. Evaporation of gel water changes the surface energy of the solid phase and causes further shrinkage [4]

#### **RELATIONSHIP BETWEEN WATER – CEMENT RATIO AND CURING**

The hydration of cement depends upon the water-cement ratio of the concrete [4]. It is to be noted that full hydration of cement is very much necessary for the strength development, shrinkage prevention and thus durability of the concrete. Curing is the best procedure to reduce the effects of plastic and drying shrinkages. Curing prevents the loss of moisture from concrete and, when needed, supply additional moisture and maintain favourable concrete temperature for sufficient period of time. However while choosing the best curing procedures for any concrete structures, the water-cement ratio must be considered, as follows:

##### **When Water-cement Ratio is Greater than 0.42**

According to [7], 0.42 is a critical w/c ratio. Concrete having w/c ratio more than 0.42, contain sufficient water to fully hydrate the Portland cement. Thus, in order to take all the binding potential of this cement, it is necessary to keep this water inside the concrete as long as possible. Preventing the evaporation of this water is the best means of providing good curing conditions for such concretes [4].

##### **When Water-cement Ratio is between 0.36-0.42**

According [8], if some additional water is introduced into a hardening cement paste of w/c between 0.36 and 0.42, full hydration can be achieved. To properly cure concrete having w/c ratio between 0.36 and 0.42, it is necessary to provide



**Figure 2** Good quality village concrete road in Amethi district prepared with conventional curing technique for 7 days

some additional water within the hardening paste of concrete to fully hydrate the cement and prevent the shrinkages. This can be achieved through Internal Curing [4]

#### **When Water-cement Ratio is less than 0.36**

Concrete having water-cement ratio less than 0.36 must be water cured. If these are not water cured, at the end of hydration process they contain a very fine porosity filled with air and water vapour due to chemical contraction of the paste [7]. Thus concrete having a water-cement ratio less than 0.36 must be water cured not to improve the hydration condition but rather to mitigate and counteract the effect of plastic and drying shrinkages.

#### **CURING OF CONCRETE IN VILLAGE ROADS**

Village roads in India are designed and constructed as per the provisions laid in [1] and [8]. Grade of concrete in this road is always less than 30 with water-cement ratio vary between 0.47-0.50. Since these roads are very small in length and low cost, admixtures, fibres, etc are generally not used. Therefore, curing is the best and economical approach to make these roads strong and durable. Strong emphasis must be laid on curing and curing technique.

Plastic shrinkage occurs due to loss of water contained in the fresh concrete. In village roads, it can be prevented by covering the concrete with an impervious layer, provided mix design is as per the specifications. Village concrete roads can be cured by membrane curing. Wet curing is not required. Evaporation reducers, covering concrete with polyethylene sheets or gunny bags can be used. Drying shrinkage cracking is only concern with concretes having a w/c ratio greater than 0.42[10]. These concretes contain more water than necessary to fully hydrate the cement and they have well-connected capillary porosity; the greater the w/c, the larger and better connected this porosity is. So when these concretes dry, water evaporates and due to the resulting tensile forces menisci increases. Water curing only delays the time at which  $w/c > 0.42$  concrete will begin to shrink due to drying[11]. Drying shrinkage can be mitigated using shrinkage reducing admixtures that reduces the surface tension in the menisci. Drying shrinkage of the concrete can also be reduced by increasing the content of coarse aggregate. According to[5], an aggregate volume of 30% reduces by half the shrinkage of the mixture.

#### **EFFECT OF CURING TIME ON SHRINKAGE**

The duration of curing is very much essential to prevent the shrinkage effects on concrete. The duration of curing is sensitive to the w/c of the pastes because a lower w/c results in closer initial spacing of the cement particles, requiring less hydration to fill inter particle spaces with hydration products (ACI 308R- 01). For concrete with and without pozzolonas and chemical admixtures, a 7-day minimum curing is required to attain the desirable characteristics and prevention of shrinkages.



## REFERENCES

1. IRC SP:62-2014, Guidelines for Design and Construction of Cement Concrete Pavement for Low Volume Roads.
2. A Singh, M Nigam and R Srivastava, Study of Durability for Cement Concrete Pavement and Flexible Pavement in Expansive Soil Region, JETIR , 8(6), 2021.
3. IRC 44:2017, Guidelines for Cement Concrete Mix Design for Pavements.
4. V Krishna and R Kumar, Water Cement Ratio : Simple and Effective Approach to Control Plastic and Drying Shrinkage in Concrete, SCMT4, Las Vegas, 2016.
5. A M Neville, Properties of Concrete, Cement Concrete and Aggregate, Australia, 4, 2012, pp 423-435.
6. Cement Concrete & Aggregate, 2002, [http://www.astm.org/DIGITAL\\_LIBRARY/JOURNALS/CEMENT/TOC/2412002.htm](http://www.astm.org/DIGITAL_LIBRARY/JOURNALS/CEMENT/TOC/2412002.htm)
7. Pierre-Claude Aitcin, Sidney Mindness, Sustainability of Concrete.1, 2011, pp 212-223.
8. O Jensen and E Hansen, A Model for the Microstructure of Calcium Silicate Hydrate in Cement Paste, Cement and Concrete Research, 30(1), 2001, pp 101-116.
9. Ministry of rural Development, Specification for Rural Roads, 2014.
10. N Singh, Design Aspect of Cement Concrete Pavement for Rural Roads in India, International Journal of Engineering Research and General Science, 3(4), 2015.
11. Pierre-Claude Aitcin, Sidney Mindness, Sustainability of Concrete.1, 2011, pp 212-223.
12. Drying shrinkage of Cement and Concrete, Cement Concrete and Aggregate, Australia, <http://59.167.233.142/publications/pdf/DryingShrinkage.pdf>.
13. ACI 308R. Guide to Curing Concrete, American Concrete Institute, 2001.

# Characterization of Strength and Durability Properties of Concrete using M-Sand Residue

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**Abstract:** There is a high demand for coarse and fine aggregates in the construction industry. As a result, an alternate material like Manufactured Sand (M-Sand), can be employed as new building material. Manufactured sand residue is not properly disposed of from the site, majority of stone crushing units encounter a major problem in the disposal. When the residue has been dried to a fine powder, then as a result it is necessary to discover a solution for consumption of residue in the form of an alternate material used in construction field. This research focuses on substituting M-Sand with M-Sand residue in the production of concrete. For M30 grade concrete mix, fine aggregates are substituted with M-Sand residue up to 20% with equally divided four proportions. Where the Strength test are conducted for conventional concrete with the comparison of durability Properties including Acid resistance and Alkali Attack Tests are experimented on Hardened Concrete. The strength properties of concrete for partial replacement of M-Sand residue are found to be greater than or approximately equal up to 10% replacement and observed the reduction with additional replacement.

**Keywords:** Manufactured Sand Residue; Strength Property; Acid Attack; Alkali Attack; Eco-friendly Product

## INTRODUCTION

River sand is being totally replaced in the construction sector by manufactured sand (M-Sand). As the usage of M-Sand grows, one key issue that requires consideration is the waste generated during its production. Manufacturers are having difficulty disposing of this massive amount of sludge. It appears as a M-Sand residue after the dust has been cleaned to separate M-Sand accounts for 30-40% of all dust [16]. Though landfills are dumped by M-Sand residue, the large amount produced makes total disposal difficult for producers. Even in the hot season, waste formed and piled on all of days takes approximately 3-4 days for the state of transporting for dumping. Furthermore, difficult to transport because of its sticky nature [3,4]. A sustainable and feasible solution has to be followed to use of this waste production at the manufacturing stage itself, so that the time consumption for evaporation and transportation of residue can be avoided [5,6]. Given the difficulty in keeping it, the manufacturing unit normally sold it at a tenth of the price of M-Sand, or even at free of cost. M-Sand Residue can be used as a substitute for M-Sand in concrete.

Few research has been conducted in this field with positive outcomes. It has been demonstrated to be more efficient in the high-performance concrete. Various studies show that partial substitution of fine aggregate increases compressive strength by up to 30%. When compared to granite stone dust, dust demonstrated greater strength [9]. Dust has also been discovered to be efficient in self-compacting concrete [2]. Improvement in the strength properties when dust was added to high performance concrete. Because of their increased water absorption, these materials have a negative impact on the workability of concrete. Most prior research examined strength criteria by performing tests on samples such as splitting tensile strength, flexural strength, and compressive strength. From the references, that there is an enormous need for fine aggregates in the construction industry and due to the depletion of natural resources, a replacement is mandatory for the future and it should be a waste by-product so that can be a double benefited[1,17]. Also, very fine particles can be replaced so that the density of the concrete can be increased, without affecting the workability[12,13]. Evidenced replacement up to 20% based on the experimental results.

The primary goal is to determine the characteristics of M-Sand residue in the manufacturing of concrete effectively as an alternative material. The parameters of strength and durability of concrete made with M-Sand residue will be evaluated in comparison with traditional concrete by considering M-Sand residue as an Eco-Friendly Product [8].

## MATERIALS USED

Cement is a well-known building material that has characteristics of adhesion and cohesion, Ordinary Portland Cement



(OPC)-53 grade may combine the ingredients of concrete into a compact and durable mass[10]. During transportation of concrete, to improve the workability and minimize the bleeding and segregation of the concrete, fine aggregate is added. M-Sand is a type of artificial sand made by crushing hard stones into small sized angular shaped fine particles, which are then washed and carefully graded for used as construction fine aggregate.

Before usage of coarse aggregates, adequate screening needs to be done and if necessary, washed and cleaned. Coarse aggregates with flat, elongated, or pieces of flaky, or mica should be avoided. Properly graded 20 mm sized coarse aggregate used as per IS specifications[11]. The ultimate by-product of stone crusher is M-sand residue, which is a fine powder[7]. Stones crushed to get coarse aggregate (gravel) and fine aggregate (M-Sand). When this M-sand is washed to remove tiny particles of about less than 150 microns, a residue is formed. The water used for mixing and curing must be pure and free of salts, acids, alkalis, and other contaminants.

## EXPERIMENTAL WORK

### Mix Proportion

In accordance with IS 10262:2019 the mix design was developed [15]. In this work, five mixes were developed one of which was a reference mix. The other four mixes were developed by replacing fine aggregate (M-Sand) with M-Sand Residue.

**Table 1** illustrates the amount of residue-based concrete calculated using the proposed mix proportioning approach.

### Test Properties

The workability of concrete can be investigated to assure uniformity for varied loads of concrete, which determines homogeneity with which the concrete can ease to mix, place, consolidate and complete the finishing. The slump cone and compaction factor test were carried out in accordance with IS 1199 to establish the workability of fresh concrete[14].

One of the objectives of hardened concrete testing is to ensure that the concrete used has attained the necessary strength. In order to monitor and validate the caliber of cement concrete operations, testing of hardened concrete is essential[18]. Any concrete quality control must include systematic testing of the raw materials, newly-poured concrete and cured concrete.

Tests for hardened concrete (compressive strength) and concrete durability tests (acid resistance and alkali attack test) are conducted after the controlled and residue replaced concrete has been cast and allowed to cure for 28 days. Acid resistance and alkali attack on concrete is measured in order to lose weight and strength in concrete specimens. Five percent of sodium hydroxide and hydrochloric acid diluted by volume of water were used for the acid resistance and alkali attack tests, respectively.

## RESULTS AND DISCUSSION

Slump cone and compaction factor tests were performed as a quick course of action for workability of fresh cement concrete mixes in order to predict the fresh concrete property satisfies the standards. To investigate the quality of properties of concrete using M-Sand Residue with varying amounts of M-sand residue as fine aggregate were tested for optimal strength qualities.

**Table 2** presents the compressive strength parameter of harden concrete, for which the three sample specimens were examined to determine the mean of each age.

M-Sand residue for various curing periods

**Table 1** Mix proportions with fractions of M-Sand residue

Mix	Cement %	Coarse Aggregate %	Fine Aggregate %	Residue%
CC1	100	100	100	0
CC2	100	100	95	5
CC3	100	100	90	10
CC4	100	100	85	15
CC5	100	100	80	20



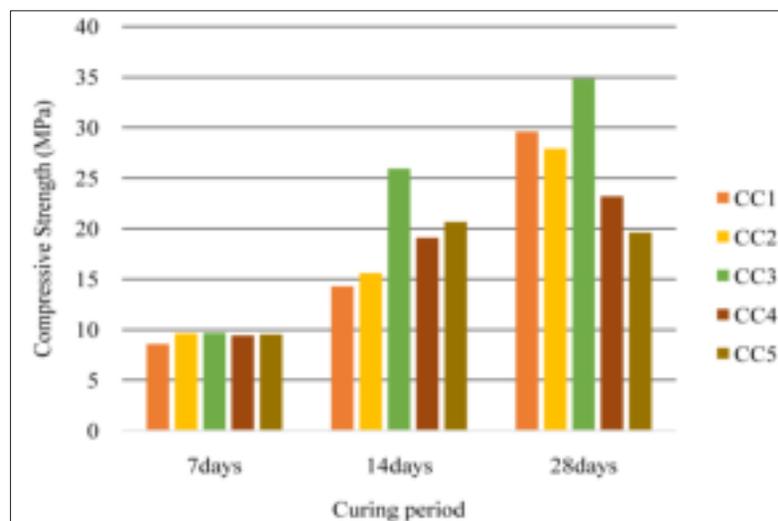
**Table 2** Compressive strengths of concrete using

Mix	Compressive Strength (MPa) of Concrete using M-Sand Residue		
	7 Days	14 Days	28 Days
CC1	8.56	14.28	29.6
CC2	9.6	15.6	27.9
CC3	9.68	25.92	34.8
CC4	9.4	19.08	23.2
CC5	9.52	20.66	19.6

**Figure 1** show the results for strength parameters at three distinct ages of 7,14 and 28 days for the concrete specimens. According to the findings, the compressive strength of concrete, which increases from 19.6 to 34.8 N/mm<sup>2</sup> when M-Sand residue is substituted for fine aggregate, varies by 0% to 20%.

When it reaches 20% of replacement in fine aggregate, as shown in fig, it is reduced to 19.6 N/mm<sup>2</sup>. When compared to a concrete mixture made entirely of M-sand, showed a peripheral increase in compressive strength. By increasing the amount of residue used in place of M-sand in the mixes that contained 10% of M-Sand residue gives the optimal compressive strength.

**Table 3** illustrated durability properties such as acid attack and alkali attack test of concrete using M-Sand residue studied. The acid resistance test resulted in weight reduction of 6.6% and in the concrete using M-Sand residue alkali attack testing, the loss of weight was found to be as low as 0.4% in CC3 mix.



**Figure 1** Compressive strength of M-Sand residue concrete with respect to curing periods

**Table 3** Durability Properties of concrete using

Mix	Percentage of Weight Loss of the Specimen (%)		Loss of Compressive Strength (%)	
	Acid Resistance Test	Alkali Attack Test	Acid Resistance Test	Alkali Attack Test
CC1	10.9	1.6	11.15	4.05
CC2	10.4	0.8	11.47	3.94
CC3	6.6	0.4	7.18	2.59
CC4	10.7	0.8	9.91	4.74
CC5	12.2	1.2	16.84	5.61



## M-Sand Residue

Loss of compressive strength from acid resistance test and alkali attack test as similar like loss of weight reduction found in CC3 mix as 7.18% and 2.59%.

### SUMMARY

The results of an experimental examination into the characteristics of concrete are presented here as summary.

- The improved microstructure of concrete caused by the filling of voids in concrete with residue accounts for the increase in workability, it can be evidenced by the fresh property test of concrete. According to the findings, the ideal replacement of residue with M-Sand about 10% when its workability is maintained to be average in terms of slump value and compaction factor.
- When compared to other mixes, the partial replacement of 10% M-Sand residue concrete in Acid Attack exhibited less weight and strength loss, but in Alkali Attack showed very little weight loss about 0.4%. Loss of compressive strength due to alkali attack found as 2.59% as like the weight loss. It is possible to deduce that there is a considerable change in strength attributes up to a partial replacement of 10% with residue and a sudden decrease from 15% of M-Sand residue concrete.
- The increase in various attributes caused by the addition of residue should be mostly owing to the close packing caused by its fine nature. Even though the weight increases slightly when residue is added, their superior characteristics outweigh it. The findings will help to solve the problems caused by residue at stone crushing operations.

### REFERENCES

1. Khalifa S Al-Jabri, Makoto Hisada, Salem K Al-Oraimi, Abdullah H Al-Saidy, Copper Slag as Sand Replacement for High Performance Concrete, *Cement & Concrete Composites*, 31, 2009, pp 483-488.
2. Anayat Ali and Shamshad Alam, Partial Replacement of Fine Aggregate with Brick Dust: A Review, *Advancements in Engineering, Science, Management, and Technology*, 5(4), April 2019
3. Ansu John and Elson John, Study on the Partial Replacement of Fine Aggregate using Induction Furnace Slag, *American Journal of Engineering Research (AJER)*, vol. 4, pp. 1-5, 2013
4. Dinesh Kumar R and Suchithra S, Properties of Concrete with Partial Replacement of Steel Slag with Fine Aggregate, *International Conference on Energy, Communication, Data Analytics and Soft Computing*, August 2017, pp 3850-3852,
5. Jnyanendra Kumar, Prusty Sanjaya Kumar Patro and S S Basarkar, Concrete using Agro-waste As Fine Aggregate for Sustainable Built Environment – A Review, *International Journal of Sustainable Built Environment*, 5, pp 312–333, 2016
6. A B M A Kaish, Temple Chimuanya Odimegwu, Ideris Zakaria, Manal Mohsen Abood and Lutfun Nahar, Properties of Concrete Incorporating Alum Sludge in Different Conditions as Partial Replacement of Fine Aggregate, *Construction and Building Materials*, 284, 2021
7. El-Sayed Sedek Abu Seif and Abdullah R Sonbul, Engineering Properties of Concrete Made with Crushed Aggregates of Diorite, *Acta Montanistica Slovaca*, 22(3), 2017, pp 225-237
8. S K Kirthika, S K Singh and Ajay Chourasia, Alternative Fine Aggregates in Production of Sustainable Concrete- A Review, *Journal of Cleaner Production*, 268, 2020
9. Ahmed O Mashaly, Basel N Shalaby and Mohammed A Rashwan, Performance of Mortar and Concrete Incorporating Granite Sludge as Cement Replacement, *Construction and Building Materials*, 169, 2018, pp 800–818.
10. IS 12269, 53 Grade Ordinary Portland Cement, Bureau of Indian Standards, New Delhi, India, 2013.
11. IS 383, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standards, New Delhi, India, 2016.
12. S K Kirthika, M Surya and S K Singh, Effect of Clay in Alternative Fine Aggregates on Performance of Concrete,



- Construction and Building Materials, 228, 2019
13. Manasseh Joel, Use of Crushed Granite Fine as Replacement to River Sand in Concrete Production, Leonardo Electronic Journal of Practices and Technologies, 17, 2010, pp 85-96.
  14. IS 1199, Methods of Sampling and Analysis of Concrete, Bureau of India Standard, New Delhi, India, 2004.
  15. IS 10262, Guidelines for Concrete Mix Design Proportioning, (Second Revision), Bureau of India Standard, New Delhi, India, 2019.
  16. Sarvesh P S Rajput, An Experimental Study on Crushed Stone Dust as Fine Aggregate in Cement Concrete, Materials Today: Proceedings, 5(9), 2018, pp 17540-17547.
  17. V Saravana Karthika, A Mohan, R Dinesh Kumar and Chippymol James, Sustainable Consideration by Characterization of Concrete through Partial Replacement of Fine Aggregate using Granite Powder and Iron Powder, Journal of Green Engineering, 9(4), 2019, pp 514–525.
  18. IS 516, Method of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi, India, 1959.





# Waste Management by Replacement of Construction and Demolition Waste in Geo-polymer Concrete

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**Abstract:** This paper is all about the physical tests of Construction and Demolition Waste (C&D) which has been used as partial replacement and fully replacement in both fine-aggregate and coarse aggregate. This test is carried out to bring out a sustainable building material by using the 100% of wastes from industry. Concrete cubes and cylinders casted and test for 25%, 50%, 75% and 100% replacement of C&D waste in concrete from the results, Geopolymer concrete showed promising results and thus promotes to manage the waste by replacing them as fillers in concrete. Finally, the produced concrete is generated using waste materials, and a compressive strength test has been done for the same making the Geopolymer concrete an alternative to the demanding conventional concrete.

**Keywords:** C&D Waste; Geopolymer; Construction and Demolition Waste; Waste Management

## INTRODUCTION

The consumption of natural resources is widely increasing day by day unless we limit the usage of virgin materials there will be a day where we wouldn't be able to access them. The limiting of virgin products can be accomplished by promoting the recycling process. According to the Building Material Promotion Council, In India, Every year it is estimated that Construction and Demolition (C&D) Waste of 150 million tons is generated but the official recycling capacity is 6,500 tons per day which is about 1%.

The recycling process not only helps to prevent the natural resources from depleting but also for waste management. As we all know about the heat of demand for the virgin materials for concrete production such as natural aggregate (fine and coarse) and sand. On the contrary, the amount of C&D waste is increasing which will lead to some environmental problems. One of the ways to initiate the recycling process in the industry of construction is by making concrete with recycled products known to be Recycled Concrete. The recycled materials were made available for the appropriate size by crushing them with the help of crushing equipment and screening tools.

Concrete is one of the most important products for raising a structure in modern times but cement is the major component in it, which is also the highest consumed product on the Earth besides water. Cement contributes around 4 billion tons of Carbon dioxide annually due to this industry and In India; it generates about 7% of carbon dioxide (CO<sub>2</sub>) emissions globally. Moreover, the raw materials such as clay, limestone and other minerals are used in manufacturing of cement but the raw materials are obtained by quarrying which leads to cause environmental degradation. Furthermore, the use of raw materials for the production cement is more than the quantity of cement available such that 1.6 tons of raw materials are used to produce 1 ton of cement which is found not at all feasible and the time is taken for the formation of natural raw materials is longer than the rate which we use. To minimize the usage for the production of cement, an alternate way called "Geopolymer concrete" was introduced.

In this paper, a numerous test cases were performed by altering both the coarse and fine aggregate as to infer the behavior of the generated concrete. The cubes were tested in load conditions and they were replaced by 0%, 30%, 50% and 100% of recycled coarse and fine aggregates.

## EXPERIMENTAL PROGRAM

The recycled fine and coarse aggregate were taken from a nearby locality and they were pre-treated and used in the generation of Geopolymer concrete. The mechanical behavior of the each and every mixture was tested in compression during three different days like at 1 day, 7 days and 28 days. There were 4 different types of mixture CC, MR30, MR50 AND MR100. CC refers to conventional concrete, MR30 refers to the 30% replacement of fine and coarse recycled

**Table 1** Mix proportions of CC, MR30, MR50 and Mr100

Mixtures	GGBS	Fly Ash	Fine Aggregate			Coarse aggregate		
			Brick Waste	Copper Slag	M-sand	RCA	Natural Coarse	Brick Coarse
MR30	0.320	0.270	0.200	-	0.660	0.320	0.120	1.290
MR50	0.320	0.270	0.320	-	0.446	0.630	0.120	0.92
MR100	0.320	0.270	0.320	0.465	-	1.40	0.120	-

aggregate, MR50 refers to the 50% replacement of fine and coarse recycled aggregate and MR100 refers to the 100% replacement of coarse recycled aggregate along with 50% replacement of copper slag and 50% replacement of brick powder. For a detail clarification the mix proportion has been given in **Table 1**.

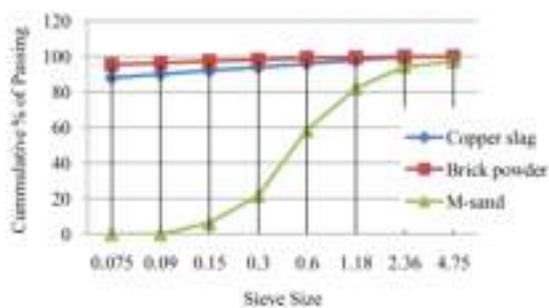
**MATERIALS USED**

The materials used in this study are Fly ash, Ground granulated Blast Furnace (GGBS), as cementitious materials which are byproducts from industries. The fine aggregates are used by three different substances namely recycled brick powder, copper slag and M-sand. The recycled brick powder is obtained by crushing the bricks which have been collected from the site where the construction and demolition waste got collected. The sieve analysis test also been conducted according to the IS 2386 (part 3):1963 which is given in **Figure 1**. The coarse aggregate were also of three different substances namely recycled brick coarse aggregate, recycled coarse aggregate and natural coarse aggregate.

In this study, the alkaline solutions are used as sodium hydroxide and sodium silicate where the sodium silicate is used in the form of solution while the sodium hydroxide is used in the form of flakes though there were various forms available in the market as flakes, pellets and powder. By using sodium silicate we may prepare a solution of the required molarities. To increase the workability of fresh concrete, Super plasticizer Cornplast SP 430, of color brown based on sulfonated naphthalene polymers, complies with IS 9103-1999, BS: 5075 part 3 and ASTM C-494, Type F was used.

**Recycled Coarse Aggregate**

The recycled brick coarse aggregate obtained by crushing the used bricks was collected from the construction and demolition waste site. The recycled coarse aggregate obtained by crushing them. They were sieved between the sieves from 4.75 mm above and 20 mm below. There was a specific gravity test conducted according to IS 2386 (part 3):1963 and found that the specific gravity of RCA is comparatively less than the natural aggregates. They cannot be used directly in the production of geo-polymer concrete as they have high water absorption property. The water absorption test was also conducted according to the IS 2386 (part 3):1963. The specific gravity test and the water absorption test results are shown in **Table 2** and **Table 3**.



**Figure 1** Sieve analysis for fine aggregate

**Table 2** Specific gravity test.

Materials	Specific Gravity
Fly ash	2.28
GGBS	2.625
M-sand	2.79
Copper slag	2.91
Brick powder	2
RCA	2.25
Natural aggregate	2.68
Brick Coarse	1.79

**Table 3** Water absorption test

Material	Recycled Coarse Aggregate	Brick Powder
Water absorption	10%	20%



**Figure 2** Mechanical treatment of RCA

**Table 4** Adapted mix proportion

Fly ash	215
CGGBS	215
Fine aggregate	580
Course aggregate	1250
Water content	30.67
NaOH flakes	17.33
Sodium silicate	120
Super plasticizer	6% of 430

\*The proportion is in kg/m<sup>3</sup>.

### Mechanical Treatment Method

The Mechanical Treatment of RA is going to be done by the procedure reported by Babu et al is adopted in this work. The RCA is treated in a Los angles abrasion machine for 300 revolutions with 12 charges. **Figure 2** shows how the treatment got executed.

### Pre-soaking in Nano-silica Slurry

Though mechanical treatment is done to RA, the attached mortar will be present in it and it is very hard to remove them. The presence of attached mortar in RA will lead the RA to have high water absorption which is quite not good for concrete characteristics.

To make the RA for optimum utility, the attached mortar can be strengthened. The reason for strengthening the attached mortar in RA is to close the micro pores as best as possible to avoid cracks. The idea behind strengthening the attached mortar in RA is to develop a strong

ITZ by filling the weak ITZ. The method for making the slurry is prepared by the procedure reported by Hossein Sasanipour and Farhad Aslani is adapted.

- (a) RCA being immersed in slurry
- (b) Nano-silica slurry
- (b) Brick coarse being immersed in slurry
- (d) Brick coarse after treatment
- (e) RCA after treatment

### MIX DESIGN

The mix design of Geopolymer concrete is based on conventional concrete with some modifications. In the case of conventional concrete, the material proportion can be found out for the required strength using the code, but in the case of Geopolymer concrete, there is no design method which made to follow the trial and error method. **Table 4** gives the mix proportion.

### Preparation of Alkaline Solution

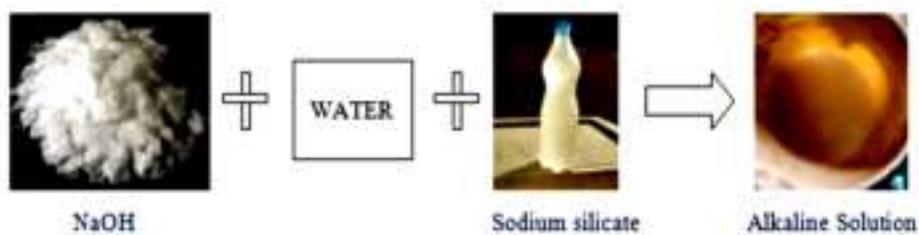
In this project, the compressive strength of geo-polymer concrete is examined for the mixes of fastened concentration of hydroxide (12M). The mass of hydroxide is 40 and to attain 12M i.e. 12 molar hydroxide solutions, 480 g of hydroxide flakes are weighed and that they will be dissolved in water to make a 1-liter solution. For this, a volumetric flask of 1-liter capability is taken; hydroxide flakes are further added slowly to water to attain 1 liter solution.

### Mixing Procedure

A Two-Stage-Mixing-Approach (TSMA) is adopted for mixing. The adopted TSMA improves durability properties of RAC, C-S-H gel at ITZ is increased. This method also reduces pore in ITZ which is a reason for better properties. The mixing procedure is done as per the method suggested by Panda[14]. There is a modification done from the method suggested by Panda. **Figure 5** gives a pictorial representation of the mixing procedure to be carried out.



**Figure 3** Pre-soaking in nano-silica slurry for recycled aggregate and brick aggregate



**Figure 4** Preparation of alkaline solution

### Mechanical Properties

Compressive strength is the capacity of a material or structure to withstand an axially directed load. Hence, to know about the mechanical properties certain number of cubes of size 100 mm × 100 mm × 100 mm were cast and a compressive strength test was conducted on specimens. To conduct the test the specimens are placed in a Universal Testing Machine (UTM) the load is applied to the cube and the load at failure is referred to as failure load. Table 5 gives the test results and the test was carried out as per Indian standards.

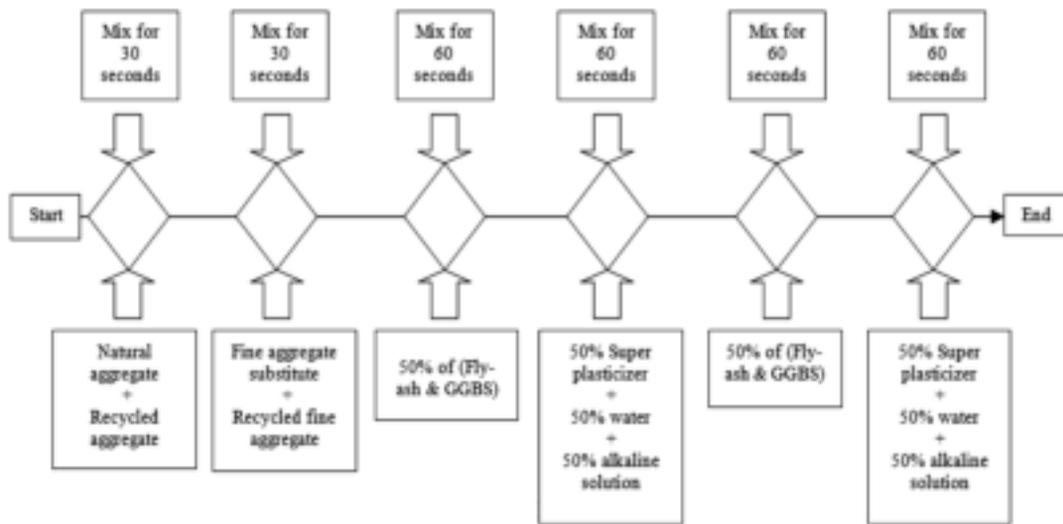


Figure 5 Two step mixing approach

Table 5 Compressive strength test

Mix no	Compressive strength in N/mm <sup>2</sup>		
	1 day	14 days	28 days
CC	22	24.8	27
MR30%	25.8	28.68	38.3
MR50%	24.4	25.24	28.5
MR100%	20	23.5	25.6

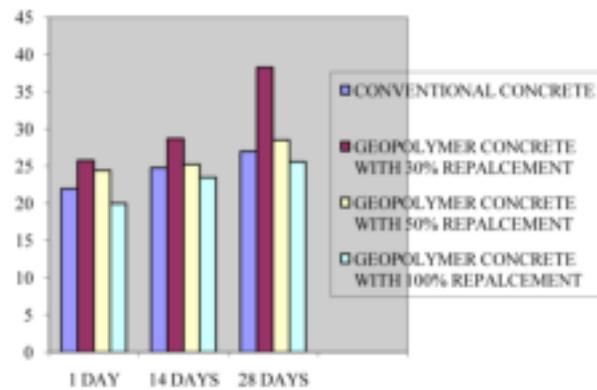


Figure 6 Compressive test

The 100% replacement of the combination gave the strength of 25.6 N/mm<sup>2</sup> that may be a satisfying price for M25. The elaborated description is as follows:

- 50% of brick waste and 50% of copper scum in fine mixture are replaced and 100% of brick coarse and 90% of recycled mixture has been used.

This method of exploitation secondary raw materials, derived from construction and demolition activities, within the manufacturing technique of property materials to acquaint into the building market represents associate degree intelligent and environmentally friendly resolution to the many environmental problems close the disposal of this wide offered waste.

## RESULTS AND CONCLUSIONS

From the results we can come to know about various properties of geopolymer concrete:

1. For the Geopolymer concrete with 30% replacement it has a great strength development as the composition of the mix is taken to be:

- 30% and 70% of Fine aggregate as Brick waste and M-sand.
- 10%, 20% and 70% of coarse aggregate as Brick coarse, RCA and Natural coarse aggregate.



We can conclude that this mix attained the maximum strength compared to all other mix composition as the proportion of natural content of the substance is relatively higher which led to greater ITZ between the particles present, less porous and great bond strength.

2. For the Geopolymer concrete with 50% replacement it has a great strength development as the composition of the mix is taken to be:

- 50% and 50% of Fine aggregate as Brick waste and M-sand.
- 10%, 40% and 50% of coarse aggregate as Brick coarse, RCA and Natural coarse aggregate.

We can conclude that this mix attained the second maximum strength compared to all other mix composition as the proportion of natural content of the substance is relatively equal to the proportion of recycled content which produced quite suitable strength.

3. For the Geopolymer concrete with 100% replacement it has a great strength development as the composition of the mix is taken to be:

- 50% and 50% of Fine aggregate as Brick waste and copper slag.
- 10% and 90% of coarse aggregate as Brick coarse, RCA.

Though the 100% replacement of the geopolymer concrete gave a low strength compared to all other mixes, the target strength has been achieved which made this study successful. The highest bending strength obtained in this study is 25.6 N/mm<sup>2</sup>. This research therefore concludes that geopolymer concrete are an environmentally friendly alternative to conventional concrete.

4. We also found that the modified Two Step Mixing Approach (TSMA) gave an advantage to the mixing process as the strength gained by the concrete is relatively higher than the conventional mixing approach.

5. The Pre-treatment method made the concrete to be more rigid thereby closing the pores of the Recycled material effectively which thereby enhances the strength of the developed geopolymer concrete efficiently.

## REFERENCES

1. Zhu Pan, Jay G Sanjayan, B V Rangan, An Investigation of the Mechanisms for Strength Gain or Loss of Geopolymer Mortar After Exposure to Elevated Temperature, *J Matera Science*, 2009, 44, 2007, pp 1873–1880.
2. Mohan, A, Prabha, G, Balapriya, B, Deepika, M, Hemanthimekala, B. Tribological Investigations on the Properties of Concrete Containing Recycled Plastic Aggregate, *Journal of Balkan Tribological Association* 2021, 27(6), pp. 1010–1020.
3. K Pandurangan, A Dayanithy, S Om Prakash, The Effects of the Influence of Treatment Method on Bond Strength of Recycled Aggregates, March 2020 *Journal of Cleaner Production* 259(1), 120920.
4. Hossein Sasanipour, Farhad Aslani, The Durability of Assessment of Concrete Containing Surface Pre-treated Coarse Recycled Concrete Aggregate, <https://doi.org/10.1016/j.conbuildmat.2020.120203>.
5. G Velraj Kumar, R Muralikrishnan, A Mohan, R Bala Thirumal, P Naveen John, Performance of GGBFS and Silica Fume on Self Compacting Geopolymer Concrete using Partial Replacements of R-Sand, *Materials Today : Proceedings*, Volume 59, Part 1, 2022, pp 909-917.
6. Prabha, S L, Surendar, M, Neelamegam, M, Experimental Investigation of Eco-friendly Mortar using Industrial Wastes, *Journal of Green Engineering*, 9(4), 2019, pp 626–637.
7. Xiaolu Guo, Huisheng Shi, Warren A Dick, Compressive strength and Microstructural Characteristics of Class C Fly Ash Geopolymer, Elsevier Ltd, *Cement and Concrete Composites* 32, 2010, 142–147 [www.elsevier.com/locate/cemconcomp](http://www.elsevier.com/locate/cemconcomp).
8. Christina K, Yip, Grant C, Lukey, John L, Provis, Jannie S J, van Deventer, Effect of calcium silicate sources on polymerization” published in Elsevier.Ltd, *Cement, and Concrete Research* 38, 2008, 554–564
9. Xiaolu Guo, Huisheng Shi, Warren A Dick (2009) Compressive strength and microstructural characteristics of class C fly ash Geopolymer, Elsevier Ltd, *Cement & Concrete Composites* 32, 2010, 142–147 [www.elsevier.com/locate/cemconcomp](http://www.elsevier.com/locate/cemconcomp).



10. Abhijith Mistri, Sriman Kumar Bhattacharya, Navdeep Dhami, Abhijit Mukherjee, Sudhir Kumar V.Barai, The different treatment methods for enhancing the properties of recycled aggregates for sustainable construction materials, *Construction and Building Materials* 233, 2020, 117894
11. P Pavithra, M Srinivasula Reddy, Pasla Dinakar, B Hanumantha Rao, B K Satpathy, A N Mohanty, The mix design for geopolymer concrete with fly-ash, *Journal of Cleaner Production* JCLP 7223.
12. P Saiz Martinez, M Gonzalez Cortina, F Fernandez, Martinez, A Rodriguez Sanchez, The study of three types of fine recycled aggregate from construction and demolition waste (CDW) and their use in masonry mortar fabrication, <http://dx.doi.org/10.1016/j.jclepro.2016.01.059>.
13. Abhishek Verma , V S Babu, S, Arunachalam Characterization of recycled aggregate by the combined method: Acid soaking and mechanical grinding technique, <https://doi.org/10.1016/j.matpr.2021.01.842>.
14. Nishikant Kiskua, Puja Rajhans, S K Panda, Vikrama Pandey, Sanket Nayak, Microstructural investigation of recycled aggregate concrete produced by adopting equal mortar volume method along with two-stage mixing approach <https://doi.org/10.1016/j.istruc.2020.01.044>.
15. Zarina Yahya 1, Mohd Mustafa Al Bakri Abdullah, Kamarudin Hussin, Khairul Nizar Ismail, Rafiza Abd Razak and Andrei Victor Sandu. Effect of Solids-to-Liquids,  $\text{Na}_2\text{SiO}_3$ -To- $\text{NaOH}$  and Curing Temperature on the Palm Oil Boiler Ash (Si + Ca) Geo-polymerisation System *Materials* 2015, 8, 2227-2242, doi:10.3390/ma8052227.



# Evaluation of Sustainable Self Compacting Concrete with Replacement of Fine and Coarse Aggregate

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**Abstract:** A high-performance concrete known as Self-Compacting Concrete (SCC) can flow despite carrying its own weight without any mechanical vibrations, totally fill the formwork, and self-consolidate. The adoption of SCC will increase the quality, dependability, and long life of concrete structures while lowering the technical expenses of in-situ cast concrete constructions. This work includes an experimental analysis on SCC by substituting M-sand and treated Construction & Demolition (C&D) waste for both fine and coarse aggregate, respectively, in varied quantities of 0%, 10%, 20%, and 30%. The mix design for M40 grade Self-Compacting Concrete will be designed in accordance with the guidelines of European Federation of National Association Representing for Concrete (EFNARC). After each mix, specimens of cubes, cylinders, and prisms are cast and given varying curing intervals of 3, 7, and 28 days in water. Fresh concrete is inspected for SCC using methods like passing, filling, and segregation resistance, whereas hardened concrete is inspected using methods like compression, tension, and flexure values. It was observed that 1% of a super plasticizer was utilised in the study. According to the test results, SCC's fresh properties and hardened properties complied with EFNARC standards.

**Keywords:** SCC; Fly ash; M-sand; C&D Waste; Super Plasticizer

## INTRODUCTION

Modern concrete, known as self-compacting concrete, can be placed without compaction or vibration because it can flow under its own weight, completely fill formwork, and achieve full compaction even in steel structures that are closely spaced. The hardened SCC has the same endurance and engineering qualities as conventional vibrated concrete [3]. Additionally, it is environmentally friendly. The high powder content, Super Plasticizers (SP), and Viscosity Modifying Admixtures (VMA) used for making this type of concrete are necessary to produce SCC of high fluidity without bleeding or segregation during the transportation or placing [13]. There is currently a need for natural coarse aggregates (NCA) and fine aggregate in different regions of the nation. C&D waste in place of NCA and M-Sand in place of fine aggregate gives potential importance in construction industry [1]. By decreasing the use of natural resources and the disposal of construction waste, the considerable potential expansion of C&D waste in the place of NCA offers an appropriate green alternative for sustainable development [2,14]. Here C&D waste is first treated by silica fume impregnation method to reduce its water absorption ability and to improve its overall strength [5,15]. Consuming waste materials helps to make use of them, but it also has a number of unintended advantages like protecting the environment from pollution and saving on energy and money [11,12]. This study is mainly focuses on the characteristics of SCC produced with C&D waste and M-sand [16-18].

## MATERIAL PROPERTIES

In this experimental study, Ordinary Portland Cement conforming to IS codes was used [6]. Cement has specific gravity of 3.15 and normal consistency of 28%. In order to increase the flow ability, mineral admixtures such as fly ash (class 'F') has been used, with physical properties of colour grey (blackish) and specific gravity of 2.12 [10]. Locally available natural sand with 4.75 mm maximum size was used as fine aggregate, having specific gravity 2.65 and grading zone (II) [9]. M-sand used as replacement of fine aggregate which has specific gravity of 2.57 and grading to zone II. Master Glenium sky 8233 superplasticizers used which has reddish brown liquid and confined to specific gravity of 1.08. Construction & Demolition (C&D) waste which is confined to grade zone II and specific gravity of 2.64 is used. Water with total hardness 105Mg/L and pH value of 6 to 8.5 used as per IS code.

## EXPERIMENTAL WORK

### SCC Mix Design

The mix design was developed with target strength of 40 MPa as per codal provision IS:10262 – 2019 with water cement



ratio as 0.38 [8]. This mix proportions are designed as per EFNARC guidelines [4]. In this experiment, seven different mixes were created. Cement, water, superplasticizer, and fly ash are all retained at the same volume in those seven mixtures. Coarse and fine aggregates were replaced in the proportion of 0%, 10%, 20% and 30% by C&D waste and M-sand respectively. **Table 1** displays the SCC designed mix compositions.

### Silica Fume Treatment Process

First the C&D waste dried in an oven for 48 hours under 105°C, cooled back to room temperature and soaked in a tray for 24 hours. The tray consists of Silica fume solution and 1% of SP. After this process the aggregates allowed to dry. In replacement of normal coarse aggregate with 30% of C & D waste, we can able to achieve 27.2 MPa as a compressive strength for 7 days and 42.3 MPa as a compressive strength for 28 days.

### TESTING METHODS

The testing procedures for SCC in this experimental investigation are broken down into two categories: (a) SCC's fresh properties; and (b) SCC's strength characteristics.

#### (a) Fresh Properties of SCC

SCC differs from regular conventional concrete in that the fundamental criterion in determining whether it can be installed successfully or not is its fresh qualities. To ensure that its ability to must be acceptable, the many workability characteristics that affect its segregation resistance, filling ability, and passing ability should all be properly managed.

SCC fresh properties test methods for filling ability, passing ability and segregation resistance has been achieved through test methods like slump-flow, T50 cm slump flow, V-funnel, V-funnel at T5minutes and L-box test.

#### (b) Strength Characteristics of SCC

Hardened concrete needs to be strong enough to support all of the loads that will be placed on it and durable enough to withstand the environmental risks that it is designed to withstand [7]. Concrete will be the most firmly grounded, powerful, and long-lasting material if it is created with high-quality materials and is treated and proportioned properly. All SCC mixes are tested for various curing periods to determine the strength characteristics for cubes, cylinders, and prisms.

### RESULTS AND DISCUSSION

Results are tabulated for the two SCC test methods, and discussions are made.

#### Fresh Properties of SCC

To study the effects on fresh properties of SCC when different proportion of C&D waste is used as a replacement of coarse aggregate for various tests like slump flow, V-funnel, L-box.

**Table 2** included the results of all SCC mixes' fresh concrete properties.

All of the new SCC concrete's property values fell within the range set forth by Standards.

#### Strength Characteristics of SCC

In order to examine the strength properties of SCC including different amounts of recycled aggregates as coarse

**Table 1** Design Mixes of SCC

Mix	Fine Aggregate %	M-sand %	Coarse Aggregate%	C & D %
CC	100	-	100	-
M1	90	10	100	-
M2	80	20	100	-
M3	70	30	100	-
M4	100	-	90	10
M5	100	-	80	20
M6	100	-	70	30
M7	Optimum value		Optimum value	



**Table 2** Test for fresh properties of SCC

Mix	Slump Flow (mm)	T <sub>50</sub> cms Slump (Sec)	V-funnel (Sec)	V-funnel T <sub>5</sub> min (Sec)	L-Box (H <sub>2</sub> /H <sub>1</sub> )
CC	680	6.2	8.4	14.2	0.85
M1	670	5.9	8	13.5	0.81
M2	660	5.4	8.5	13	0.80
M3	665	5.5	9	14	0.82
M4	690	6	10.2	14.2	0.89
M5	710	6.2	11	14.5	0.91
M6	700	6.1	11.2	14.6	0.93
M7	705	6.15	11.1	14.3	0.9
EFNARC	650-800	5-7	6-12	6-15	0.8-1

aggregate replacement, tensile strength, compressive strength, and flexural strength tests were conducted. For cubes, cylinders, and prisms, the results for compressive strength, tensile strength, and flexural strength were discovered for different curing ages, respectively.

The outcomes for tensile strength, compressive strength, and flexural strength for three specimens that were crushed for the average of each age are shown in the **Table 3**.

#### Durability Test

Numerous physical phenomena, including alternate wetting and drying, freezing and thawing, heating and cooling, have an impact on the durability of concrete. Concrete's durability can be tested using a number of different techniques, and the progression of damage can be quantified in a number of different ways.

#### Rapid Chloride Penetration Test

The RCP test is the industry-standard procedure for determining electrically how well concrete can withstand chloride ion penetration. This test involves measuring the electrical current flow rate through cylindrical test specimens during a six-hour period. Following that, the total charge passed immediately correlates with the sample specimen's resistance to chloride ion penetration. Rapid chloride permeability test result of Mix M7 (28 days) shows charge passed (mAh) 1154 with low chloride ion penetrability.

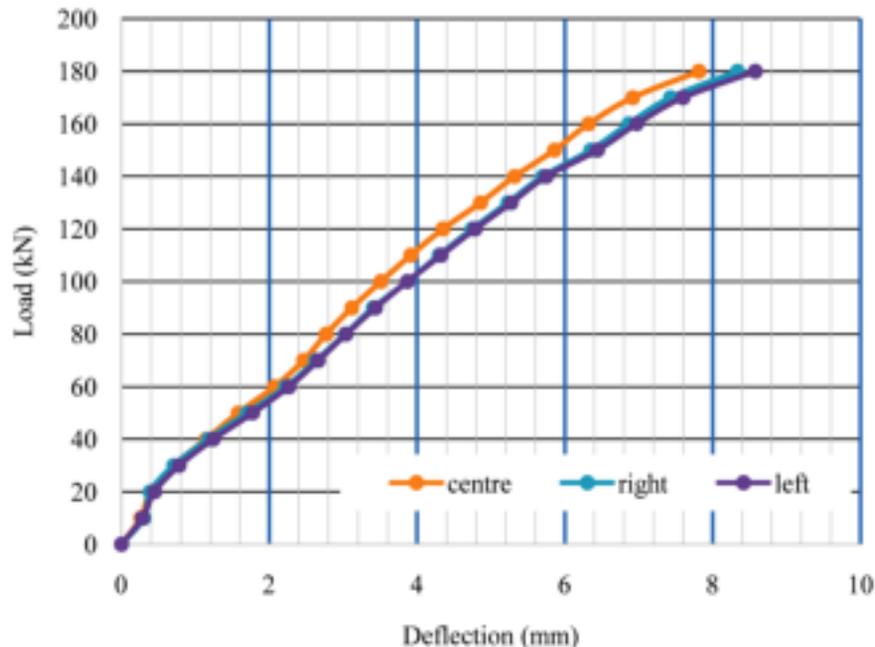
#### STRUCTURAL BEHAVIOUR ON BEAM

The beam of span 1.2 m length has been casted by replacing both fine and coarse aggregates in that fine aggregate is replaced with 30% of M- sand and coarse aggregate is replaced with 20% of C&D waste.

Here in this beam LVDT has been connected to right, left and to the centre of the beam to find out its deflection. **Figure 1** plotted with the graph for load vs deflection.

**Table 3** Strength characteristics of SCC for various curing periods

Mix	Compressive Strength (MPa)			Tensile Strength (MPa)		Flexure Strength (MPa)	
	3 days	7 days	28 days	7 days	28 days	7 days	28 days
CC	16.7	26.6	39.4	2.2	2.68	2.7	4.03
M1	15.4	23.2	35.2	1.58	2.16	2.3	3.45
M2	18.6	25.9	39.5	1.8	2.44	2.5	3.82
M3	21.2	27.4	40.8	1.95	2.77	2.61	4.09
M4	14.9	25.2	36.7	1.72	2.32	2.50	3.81
M5	18.88	30.7	40.2	2.37	2.8	2.76	4.10
M6	16.8	26.8	39.1	1.95	2.54	2.42	3.89
M7	19.07	28.01	48.02	2.12	2.83	2.67	4.12



**Figure 1** Graphical representation of load vs Deflection for M7-SCC Mix

## CONCLUSION

The SCC mixes that included M-sand as the fine aggregate and C&D waste as the coarse aggregate passed the SCC acceptance requirements after being tested for the qualities of both fresh and hardened concrete according to EFNARC Standards. There is an improvement in the fresh properties of SCC by using fly ash. At 28 days, SCC's maximum compressive, tensile, and flexural strengths were determined to be 40.8 MPa, 2.77 MPa, and 4.09 MPa for 30% replacement of M-sand by fine aggregate and 40.2 MPa, 2.8 MPa and 4.10 MPa at 28 days for 20% replacement of C&D waste by coarse aggregate respectively. The pulse velocity test results of cube shows that the concrete quality was excellent. Thus, the concrete mix exhibits an extreme resistance against chloride attacks and therefore can be used for construction works in coastal regions and other chloride attack prone areas. Thus, from the structural behaviour of SCC beam, we can able to see that ultimate critical load is 180 kN and it suddenly drops, i.e., the breaking load is 140 kN According to the experimental findings, the maximum strength is obtained by replacing M-sand with 30% and C&D waste with 20%.

## REFERENCES

1. Aurelian Joan D'mello and R Prabhakaran, Study on Mechanical Properties of Self-compacting Concrete with C&D Waste as Coarse Aggregate, International Journal of Engineering Research & Technology, IJERT, 4(7), 2011, pp 01-06.
2. Dinesh Kumar R, Ravichandran P T and Divya Krishnank, Evaluation of Self-compacting Concrete with Partial Replacement of Recycled Aggregates, Jour of Adv Research in Dynamical & Control systems, 10(4), 2018, pp 01-07.
3. Dinesh A and Harini S, Experimental Study on Self-compacting Concrete, International Journal of Engineering Sciences & Research Technology, IJESRT, 3(7), 2017, pp 01-09.
4. EFNARC, Specifications and guidelines for self-compacting concrete, EFNARC, UK, www.efnarc.org, 2002.
5. Gowtham S K, Narandiran P B and Karvendhan A, Durability Study on Self-compacting Concrete, South Asian Journal of Engineering and Technology, SAJET, 2(13), 2015, pp 44-50.
6. IS: 12269, Specifications for 53 Grade Ordinary Portland Cement, Bureau of Indian Standards, New Delhi, 1987.
7. IS: 516, Method of Tests for Strength of Concrete, Bureau of Indian Standards, New Delhi, 1959.



8. IS: 10262, Guidelines for Concrete Mix Design Proportioning, Second Revision, Bureau of India Standard, New Delhi, 2019
9. IS 383, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standards, New Delhi, 2002
10. IS: 9103, Specification for Concrete Admixtures, Bureau of India Standard, New Delhi, 1999
11. Praveen Kumar K and Radhakrishnan, Characteristics of SCC with fly ash and manufactured sand', International Journal of Innovative Research in Advanced Engineering, IJIRAE, 2(10), 2015, pp 45-52.
12. Prashant O Modani and Vinod M Mohitkar, Self-compacting Concrete with Recycled Aggregate: A Solution for Sustainable Development, International Journal of Civil and Structural Engineering, IJCSE, 4(3), 2014, pp 430-440.
13. Rajasekaran D and Aravind Prabu S, Comparison of the Performance of Self-compacting Concrete, International Journal of Chem Tech Research, IJCR, 10(11), 2017, pp 95-101.
14. Sandeep Nasier, Ifrah, Mushtaq, Self Compacting Concrete Design and Performance using Flyash, International Journal of Civil Engineering and Technology, IJCIET, 9(4), 2018, pp 436-445.
15. Sakthi Ganesh G, Mechanical and Durability Properties of Self-compacting Concrete, International Journal of Engineering Trends and Technology, IJETT, 48(4), 2017, pp 01-06.
16. Suresh S and Revathi J, An Experimental Investigation on Effect of High strength Concrete using M-Sand, International Journal of Innovative Research in Science, Engineering and Technology, 5(2), February 2016.
17. Shanmugavadivu P M and Malathy R, Durability Properties of Concrete with Natural sand and M-sand, Proc. of the International Conference on Science and Engineering, 2011.
18. Tuljaramsa B K and Gundakallea D, Study on Strength Properties of SCC with M-sand, Proceeding of NCRIET-2015 and Indian J.Sci.Res., 12(1), 2015, pp 370-374.



# Experimental Investigation on Mechanical and Thermal Properties of Fibre Reinforced Concrete

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**Abstract:** The benefits of fibre used for concrete have attracted increasing attention in the building industry over the last few decades. Basalt fibre is regarded as the most promising of the various types of fibres that are currently accessible. It is a renewable and sustainable resource and also greatly increases concrete toughness, flexural strength, and tensile strength. Although basalt has a comparable impact on the characteristics of concrete as glass does, basalt fibre is superior to other fibres in terms of thermal resistance (low thermal conductivity), strong resilience to an alkaline environment, and cost, making it a great material to reinforce concrete. The volume fraction of basalt fibre (1%, 1.5%, and 2% depending on the volume of the entire mix) has been used. Alternative cementitious materials with effective thermal insulation were used, including 40% GGBS and 20% fly ash. The compressive strength, split tensile strength, thermal conductivity test, thermal diffusivity, and specific heat of all specimens with varying amounts of basalt fibres were evaluated. The results revealed that the use of 2% fibre gave the highest values in mechanical properties and thermal conductivity decreased with an increase in basalt fibre content.

**Keywords:** Basalt Fiber; Thermal Conductivity; Mechanical Properties

## INTRODUCTION

Concrete is the most dependable, long-lasting, and adaptable building material in the world. However, due to severe weather or other local conditions, the heating and cooling system is affected by the outside temperature. A variety of different experimental techniques have been developed to measure the thermal conductivity for various experimental conditions and for various materials in concrete, which are used in building construction. Thermal insulation is crucial in a wide range of scientific and industrial applications. Alternative building materials, such as thermally insulated concrete, can increase the thermal efficiency of building construction. According to previous studies and publications, concrete's thermal conductivity is a crucial factor in determining how hot or cold a huge structure like pier stems or footers will be. Because different building materials have varying thermal insulation qualities, they are suitable for different environments in different ways. Of order to lower the temperature in fibre reinforced concrete compared to ordinary concrete, a variety of materials with thermal insulation properties can be utilized in place of materials with high thermal conductivity. It can be used to extend the life of important concrete structures such as nuclear power plants, highways, bridges, and runways. Basalt fibre in concrete is still an exploratory area due to limited studies for thermal properties. The key thermal property affecting the transfer of heat by conduction through concrete is thermal conductivity. According to [1], the thermal conductivity for various types of concrete ranged from 2.24 to 3.85 (W/m.K). Thermal conductivity is measured using the k-value, specific heat capacity, and thermal diffusivity units. Concrete conducts heat through molecular vibrations and the movement of free electrons, which transports energy. The rate of heat transfer through concrete under temporary heat transfer conditions is indicated by thermal diffusivity. Specific heat, thermal conductivity, thermal diffusivity, and thermal expansion are typically used to determine the qualities of thermal insulation. Depending on the types of coarse aggregate, moisture level, and temperature, the thermal conductivity value of typical concrete varies by more than five orders of magnitude from 0.62 to 3.3 W/m.K. However, the thermal conductivity of the lightweight insulating concrete ranges from 0.07 to 0.33 W/m.K. The amount of heat per unit mass needed to raise a material's temperature by one degree is known as specific heat, and it is typically stated in terms of thermal (heat) capacity, which is created by multiplying specific heat by density. By adjusting the ratios of components with various specific heat (cp) and thermal conductivity (k) values, it is possible to change the total thermal properties of concrete. The amount of heat that may be stored in a material and its rate of heat transport into and out of it are both determined by these two qualities. The purpose of this paper is to examine important studies on thermal insulation performance in applications involving concrete. In order to improve thermal insulation characteristics as a passive energy saving concrete material, researchers are increasingly interested in the thermal insulation properties of different types of insulated concrete. This study reviews those properties. Improvements in thermal insulation also affect the



sustainability of the concrete with the least amount of energy use, according to research published in volume 4 of the World Academy of Science, Engineering, and Technology International Journal of Civil and Environmental Engineering. Using GGBS and Fly Ash is more environmentally friendly and less expensive than using cement. The heat of hydration associated with Delayed Ettringite Formation is similarly decreased by GGBS (DEF). The previous journals came to the conclusion that increasing the replacement of regular Portland cement with fly ash and GGBS, respectively, resulted in a decrease in the influence of binder type on thermal conductivity of concrete at ambient temperature. The modern building and construction business is focused on providing high thermal insulation concrete to improve the operational energy efficiency of structures. The use of materials with high thermal insulation, which may store heat and delay the transmission of heat through structural elements, as well as insulated concrete construction are utilized to prevent heat losses or gains.

## MATERIALS USED

### A. Cement

In accordance with IS 12269-1987, ordinary Portland cement of grade 53 with a 40% partial was employed in this study. Cement has a specific gravity of 3.15.

75 minutes and 315 minutes, respectively, were discovered to be the initial and final setting time. Cement had a standard 31% consistency.

### B. Fine aggregates

According to the specifications, the manufactured sand is used as fine aggregate. The fine aggregate employed in this investigation has a specific gravity of 2.52 and a fineness modulus of 2.86.

### C. Coarse Aggregate

For this study, coarse aggregate that complies with IS: 383-1970 was collected from nearby quarry units. The largest aggregate size that can be used has a specific gravity of 2.64 and is 20 mm.

### D. Fly Ash

About 20 % of the cement has been replaced with fly ash. We employed Class F fly ash, which has a reduced CaO level and demonstrates pozzolonic properties. According to the Specific gravity Test, IS: 2386 Part III, 1963, fly ash has a specific gravity of 2.2. (ASTMC 618).

### E. Ground Granulated Blast Furnace Slag (GGBS)

By 40%, GGBS was employed in partial replacement of cement. Ground Granulated Blast Furnace Slag (GGBS), is a by-product of the simultaneous production of iron and molten blast furnace slag.

### F. Basalt Fibre

Basalt fibre of 12 mm length has been used with Specific gravity of 2.9. This natural fibre has high insulation property and tensile strength. Basalt fibre used are 1%, 1.5% 2% of the whole volume of mix added to the M30 grade concrete.

### G. Super Plasticizer

CONPLAST SP 430 which helps in reducing water content up to 25% has been used in the mix and its Specific gravity is 1.2.

**Table 1** Chemical composition of GGBS

Chemicals	Fly Ash %	GGBS%
SiO <sub>2</sub>	54.4	29.2
Al <sub>2</sub> O <sub>3</sub>	28.6	13.8
CaO	1.6	44.9
MgO	1.4	6.2
Fe <sub>2</sub> O <sub>3</sub>	3.2	5.5
Na <sub>2</sub> O	0.3	0.3
K <sub>2</sub> O	1.7	1
TiO <sub>2</sub>	1.8	2.1
LOI	5	-
CaO/SiO <sub>2</sub>	0.03	1.54

**Table 2** Mix design proportion

Materials	Proportions	Volume
Cement	1	2.11
GGBs	1	2.11
Fly Ash	0.5	1.05
Fine Aggregate	3.3	7
Coarse Aggregate	6.2	13.1
W/C Ratio	0.4	1800 ml



## METHODOLOGY

### Mixing and Curing Details

Concrete mix design: M30 concrete grading mix design was developed with a water-to-cement ratio of 0.40. According to IS 10264:2019 and IS 10262:2009.

Cylinder with a 150 mm diameter and 300 mm height was cast as a specimen, as was a cube with dimensions of 150 × 150 × 150 mm. On the 7th, 14th, and 28th days, the Cubes' compressive strength and the Cylinder's split tensile strength were evaluated. After a 7-day test, the concrete steadily gets stronger for a 14-day and 28-day test.

### TEST METHODS

#### Test on Fresh Concrete

To examine the characteristics of concrete, tests on fresh concrete such as the slump cone, impact, compaction factor, and VEE-BEE test were carried out. In order to ensure that concrete is of a consistent quality during construction, concrete slump tests are performed from batch to batch. Concrete's actual slump value is determined to be 280 mm (TRUE SLUMP).

Aggregates' capacity to withstand unexpected impact or shock loads is known as resistance. It can also be described as the aggregate's resistance to failure from an impact load. This impact load has the potential to fracture aggregate, leading to the failure of roads and pavements. The compaction factor test is used to gauge how workable new concrete is in relation to the amount of internal energy needed to compact it completely. The compacting factor test is used to determine whether concrete has a low workability. Concrete has a compaction value of 0.92, according to the research.

#### Test on Hardened Concrete

##### A. Compression Test

On a compression testing machine, the test was conducted using 150mm concrete cubes. Steel cube moulds measuring 150 mm × 150 mm × 150 mm or cylinders with a diameter of 150mm and a length of 300mm were used for the IS: 516-1959 Compression Testing Machine (2000 kN).

##### B. Split Tensile Test

To assess the tensile strength of hardened concrete, a splitting tensile strength test is used. The intended concrete strength is affected by little adjustments in the water to cement ratio, component proportioning, and increase in slump, etc. This in turn has an impact on the stability and strength of structures.

Split tensile strength of concrete =  $0.7 \times F_{ck}$

The splitting tensile strength,  $T_{sp} = 2P / \pi DL$

##### C. Thermal Conductivity Test

Because it depends on the makeup of concrete, thermal conductivity (TC) has drawn a lot of attention. In order to gauge a material's capacity to transfer heat, thermal conductivity is crucial in building insulation. The conductivity of saturated

**Table 3** Comparison between conventional and fibre reinforced concrete

Materials	1% Fibre (kg)	1.5% Fibre (kg)	2% Fibre (kg)	Conventional (kg)
Cement	2.116	2.116	2.116	4.485
GGBS	2.116	2.116	2.116	-
Fly Ash	1.055	1.055	1.055	-
20mm Aggregate	13.09	13.09	13.09	12.108
M sand	6.97	6.97	6.97	6.7
Basalt Fibre	50g	100g	150g	-
Super Plasticizer	20mL	40mL	60mL	-
Water Weight	1,230L	1L	980mL	1,89L
No. Of Cubes	6	6	6	6



Figure 1 Compression test

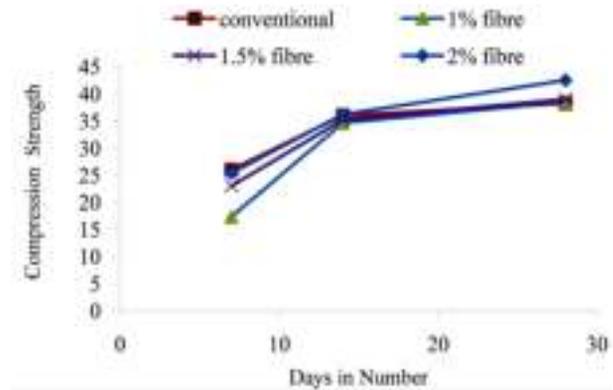


Figure 2 Graph for compression strength

Table 4 Compressive strength of standard concrete and with varying fibre percentages at days 7, 14, and 28

Days	7 <sup>th</sup> day	14 <sup>th</sup> day	28 <sup>th</sup> day
Conventional Concrete — Compressive Strength (N/mm <sup>2</sup> )	26	36	38.25
Fibre Reinforced Concrete (N/mm <sup>2</sup> ) 1%	17.3	34.6	38.5
Fibre Reinforced Concrete (N/mm <sup>2</sup> ) 0.5%	23	35.2	39
Fibre Reinforced Concrete (N/mm <sup>2</sup> ) 2%	25	36	42.5

concrete typically ranges from 1.4 to 3.4 J/S/m<sup>2</sup>.

The two primary methods for measuring thermal conductivity are thought to be steady state and plane transient. The thermal conductivity of concrete is influenced by its moisture content, temperature, type of aggregate, type of cementitious material, and density.

#### D. Thermal Diffusivity

The rate at which temperature varies inside the bulk of concrete is represented by diffusivity. The following equation directly connects conductivity and diffusivity:

$$\text{Diffusivity} = \text{Conductivity} / \rho C$$

where  $\rho$  denotes concrete density and  $C$  denotes specific heat. Concrete's diffusivity ranges from 0.002 to 0.006 m<sup>2</sup>/h.

#### E. Specific Heat

It is described as the amount of heat needed to increase a unit mass of a material's temperature by one degree Celsius.

840 to 1170 J/kg<sup>3</sup>/C is the typical range of values for concrete.

The thermal characteristics test for fibre reinforced concrete has revealed variations in thermal conductivity with basalt fibre usage at varying percentages for 7, 14, and 28 days for concrete of the M30 grade.

Table 5 Tensile strength of concrete was found for 7th, 14th and 28th days respectively

Days	7 <sup>th</sup> day	14 <sup>th</sup> day	28 <sup>th</sup> day
Conventional Concrete — Compressive Strength (N/mm <sup>2</sup> )	1.56	3.27	3.56
Fibre Reinforced Concrete (N/mm <sup>2</sup> ) 1%	1.63	3.46	4.02
Fibre Reinforced Concrete (N/mm <sup>2</sup> ) 1.5%	2.1	3.53	4.79
Fibre Reinforced Concrete (N/mm <sup>2</sup> ) 2%	2.35	4.13	5.1



Figure 3 Split tensile test

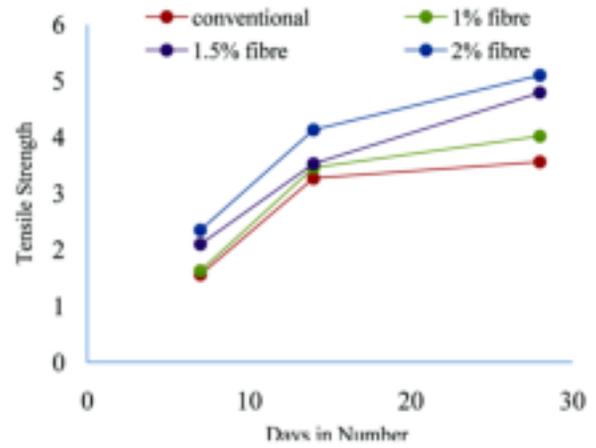


Figure 4 Graph for tensile strength

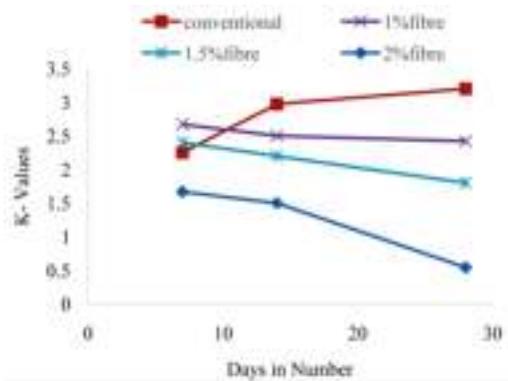


Figure 5 Graph for thermal conductivity

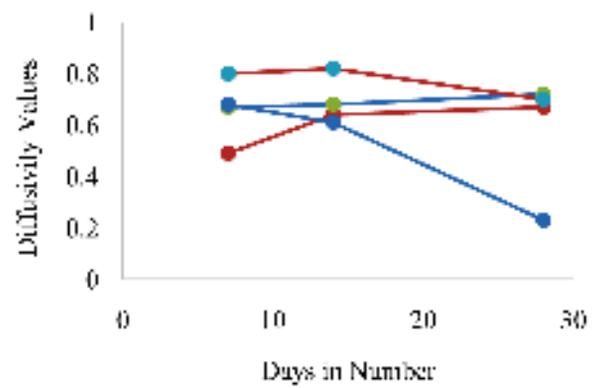


Figure 6 Graph for thermal diffusivity

Table 6 Thermal conductivity of concrete

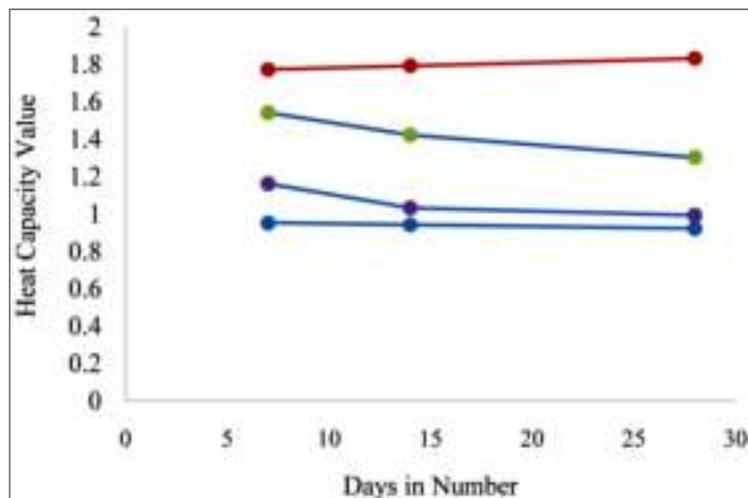
Days	7 <sup>th</sup> day	14 <sup>th</sup> day	28 <sup>th</sup> day
Conventional Concrete	2.25	2.97	3.2
Fibre Reinforced Concrete (1% basalt fibre)	2.67	2.5	2.42
Fibre Reinforced Concrete (1.5% basalt fibre)	2.4	2.2	1.8
Fibre Reinforced Concrete (2% basalt fibre)	1.67	1.5	0.54

Table 7 Thermal diffusivity of concrete

Days	7 <sup>th</sup> day	14 <sup>th</sup> day	28 <sup>th</sup> day
Conventional Concrete	0.49	0.64	0.67
Fibre Reinforced Concrete (1% basalt fibre)	0.67	0.68	0.72
Fibre Reinforced Concrete (1.5% basalt fibre)	0.8	0.82	0.7
Fibre Reinforced Concrete (2% basalt fibre)	0.68	0.61	0.23

**Table 8** Specific heat capacity of concrete

Days	7 <sup>th</sup> day	14 <sup>th</sup> day	28 <sup>th</sup> day
Conventional Concrete	1.77	1.79	1.83
Fibre Reinforced Concrete (1% basalt fibre)	1.54	1.42	1.3
Fibre Reinforced Concrete (1.5% basalt fibre)	1.16	1.03	0.99
Fibre Reinforced Concrete (2% basalt fibre)	0.95	0.94	0.92



**Figure 7** Graph for specific heat capacity

## CONCLUSION

Basalt fiber's superior thermal insulation has been demonstrated via use. According to the results, basalt fibre reinforcement is applied in the field to runways at airports, industrial floors, industrial shops, and industrial floors where heavy equipment is utilized, internal reinforcement of tunnels and channels, and military installations. The thermal conductivity is directly proportional to thermal diffusivity and indirectly proportional to heat capacity, so the thermal conductivity decreases with increase in basalt fibre content and decrease in cement thus exhibiting insulation property. The thermal and mechanical properties for fibre reinforced and conventional concrete have also been studied. The findings and outcomes showed that a material's resistance to heat increases as its thermal conductivity decreases.

## REFERENCES

1. Aarti Kamble, Virendra Desale, Palash Borwal, Akshay Ingole and Sudhanshu Pathak, Experimental Analysis of Partial Replacement of Cement by Ggbs and Fly Ash in Concrete, 7, 2018.
2. Azmat Ali Phul, Muhammad Jaffar Memon, Syed Naveed Raza Shah and Abdul Razzaque Sandhu, GGBS and Fly Ash Effects on Compressive Strength by Partial Replacement of Cement Concrete, 5, 2019.
3. B K Varun and Harish B A, Effect of Addition of Fly Ash and GGBs on Cement Concrete in Fresh and Hardened State, 5, 2018.
4. Basim Abu Jdayil, Abdel Hamid Mourad, Waseem Hittini, Muzamil Hassan and Suhaib Hameedi, Traditional, State-of-the-art and Renewable Thermal Building Insulation Materials: An Overview, 214, 2019.
5. Bin, An Investigation on Strength Characteristics of Basalt Fiber Reinforced Concrete, International Journal of Engineering Research, 2(5), 2011, pp 64-67.
6. Daniel J Pickel, Jeffrey S West and Abdulaziz Alaskar, Use of Basalt Fibers in Fiber-Reinforced Concrete, 115,



- 2018.
7. Dilip Patidar and Ankit Panjwani, Effect of Different Chemical Admixture on Fresh and Harden Concrete, 2, 2019.
  8. Mohammad, Al-Homoud Performance Characteristics and Practical Applications of Common Building Thermal Insulation Materials, 40, 2005.
  9. S Elshafie and G S Whittleston, A Review of the Effect of Basalt Fibre Lengths and Proportions on the Mechanical Properties of Concrete, International Journal, 2019.
  10. G K Geethanjali, Mohinder R, Chandraraj R, Venkateshwaran M and Vijayaprabu M, Deformation Characteristics of Basalt Reinforced Concrete with Superplasticizer.
  11. Giyeol Lee and Okpin Na, Assessment of Mechanical, Thermal and Durability Properties of High-Volume GGBS Blended Concrete Exposed to Cryogenic Conditions.
  12. Gokhan Kaplan and Osman Jencil, Basalt fibre Reinforced Foamed Concrete with Waste Marble Powder and Slag, Physico-Mechanical, Durability and Thermal Properties, 288, 2021.
  13. Hafsa Jamshaid and Rajesh Mishra, A Green Material From Rock: Basalt Fiber – A Review, 2015.
  14. S M Han, Y C Song, D H Lee, K S Ark and T Miura, Property and Applied Technology of Concrete at Very Low Temperature. Mag. KCI, 17, 2005, pp 10–17.
  15. Hao Ding, Bo Li and Qianli Gu , Effect of Fiber Characteristic Parameters on the High and Low Temperature Rheological Properties of Basalt Fiber Modified Asphalt Mortar, 2022
  16. Hassani Niaki, Fereidoon, Experimental Study on the Mechanical and Thermal Properties of Basalt Fiber and Nanoclay Reinforced Polymer Concrete, 91, 2018.
  17. Hong Li and Xiaobao Lei, Compressive Strength Prediction of Basalt Fiber Reinforced Concrete via Random Forest Algorithm, 30, 2022.
  18. Iman Asadi, Payam Shafigh, Zahiruddin Fitri Bin Abu Hassan, Norhayati Binti Mahyuddin, Thermal Conductivity of Concrete - A Review.
  19. JiapingliuabWenyangabyingyingwanga, Optimization of the Thermal Conductivity Test for Building Insulation Materials under Multifactor Influence, 332, 2022.
  20. Jongsung Sim, Cheolwoo Park and Do Young Moon, Sa-1-dong and Ansan, Kyunggi, Characteristics of Basalt Fiber as a Strengthening Material for Concrete Structures, 66, 2005, pp 425-791
  21. Juan Shi Zhenqian Chen, Shuai, Shao and Jiayi Zheng, Experimental and Numerical Study on Effective Thermal Conductivity of Novel form Stable Basalt Fiber Composite Concrete with PCMS for Thermal Storage, 66, 2014.
  22. Kirthika Subramaian and S K Singh, Experimental Investigations on Basalt Fibre-Reinforced Concrete, 2018.
  23. Le Duong Hung Anh and Zoltán Pásztoryc, A Summary of the Variables Affecting the Thermal Conductivity of Building Insulation Materials, 44, 2021.
  24. X Li, Study on Thermal Resistance of Basalt Filament Yarn. Advanced Materials Research, 146, 2011, pp 666-669.
  25. Liminlu, Feihan, Experimental Study of the Mechanical Properties of Basalt Fibre-reinforced Concrete at Elevated Temperatures, 2021.
  26. Mathias Pahn and Andreas Clinger, Mechanical and Thermal Properties of Basalt Fibre Reinforced Polymer Lamellas for Renovation of Concrete Structures, 2022
  27. Mr. Navnath Raut and Urmila Kawade, Conventional Concrete by using Basalt Fiber, 4, 2017.
  28. Naraindas Bheel, Basalt Fibre-reinforced Concrete: Review of Fresh and Mechanical Properties, 2021.
  29. Noor FifinatashaShahedan, Mohd Mustafa Al Bakri Abdullah, NorsuriaMahmed, et al “Review on thermal insulation performance in various type of concrete “on 26 April 2017
  30. O G Akana l, O C Nwadike and O P Dike, Effects of Superplasticer (Conplast SP430) on Some Properties of Quarry



Dust Concrete, 2020

31. PL Meyyappan and Jemimah Carmichael, Studies on Strength Properties of Basalt Fibre Reinforced Concrete, 43, 2020.
32. Ramiz Delpak, Albinas Gailius and Dangyras Žukauskas, Determination of Thermal-mechanical Properties of Concrete, 2012.
33. Robert Jansson, Measurement of Concrete Thermal Properties at High Temperature, 2004.
34. Salvatore, Compressive behavior of Basalt Fiber Reinforced Composite., International Journal of Structural Analysis & Design, 1(1), 2011, pp 50-53.
35. Sami Elshafie and Gareth Whittleston, A Review of the Effect of Basalt Fibre Lengths and Proportions on the Mechanical Properties of Concrete, 4, 2015.

# Carbon Dioxide Capture by Green Concrete Wall with Microalgae for Industrial Buildings

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**Abstract:** This paper presents a study on CO<sub>2</sub> capture by porous green concrete slab. CO<sub>2</sub> imprint has been steadily increasing in the industrial sector due to uninterrupted growth according to global needs. Among the varied CO<sub>2</sub> capture techniques, microalgae integrated application established a credible progress. This paper details a construction-based CO<sub>2</sub> sequestration technique, where a green lightweight slab with microalgae can be employed as a prefabricated compound wall to sequester CO<sub>2</sub> from the atmosphere. It was also proved that about 27g of algal biomass has been imbibed on the porous slab with microalgae and 14 g on non-porous slab. Microalgae employed as green walls give a luscious bright green aesthetic look. The lightweight porous slab was characterized by self-weight, compressive strength, water absorption ratio, and void volume. It was found that porous geopolymer lightweight slab with microalgae had absorbed 0.3g of CO<sub>2</sub> per sq. cm than the slab without microalgae. It is one of the most promising strategies for reducing the carbon dioxide footprint in the atmosphere using microalgae. Thus, using this technique, CO<sub>2</sub> sequestered can be a good way to reduce global warming, thus illustrating the need for this study.

**Keywords:** Lightweight Geopolymer; Microalgae; Porous Slab; Aluminium Powder; CO<sub>2</sub> Sequestration

## INTRODUCTION

As even the population keeps expanding and livelihoods rise, the world's pollution also is constantly rising significantly. Annual increases in CO<sub>2</sub> emissions are expanding. Carbon sequestration is an important strategy in combating rising carbon dioxide concentrations in the atmosphere. Because of their capacity to absorb carbon dioxide, microalgae have received tremendous interest in recent years. Carbon dioxide is eventually sequestered by algae and trees. As a result of gathering carbon into their trunks and roots and leaving oxygen back into the atmosphere, trees consume it as a phase of the photosynthetic process. This very same technique is simulated by algae, except they contain the carbon by producing new algae. Algae can absorb more carbon dioxide than plants because, given their relative size, they can make up more surface area, develop fast, and be more easily assessed by bioreactors. The two environments thought to be the most usual for growing phototrophic microalgae were open ponds and photobioreactors. This paper aims to provide a real-time application of the current state of microalgal CO<sub>2</sub> fixation, encompassing culture, and handling. Industrial environments lack an adequate footprint to promote the growth of microalgae for CO<sub>2</sub> sequestration despite its potential application. There has been extensive research on the cultivation of microalgae onto the concrete matrix. However, there are very few reports or perhaps nil on the cultivation of microalgae in porous concrete matrix. The focal theme of the present investigation was to develop a porous constructional concrete matrix and the same could be used for cultivation of microalgae and thereby CO<sub>2</sub> sequestration.

## OBJECTIVE OF THE STUDY

To identify the microalgae species that sequester the CO<sub>2</sub>;

- To develop a smart concrete matrix for microalgae growth on screed concrete for exposed areas of the building;
- To calculate the CO<sub>2</sub> absorption and effectiveness of the microalgae selected;
- To measure the amount of microalgae growth on the matrix.
- To compare the amount of growth on porous slab seeded with microalgae vs. non-porous slab.

## A. Methodology

The present investigation was basically rooted in developing a smart concrete matrix of porous ability to accommodate maximum microalgae on it, aiding maximum CO<sub>2</sub> absorption. It in turn is an important tool to reduce global warming to a greater extent.

## B. Method

- 1) Selection and Finalization of Microalgae: Out of six types of microalgae, based on their employability, optimized growth rates, etc, *Chorella vulgaris* was chosen to be a suitable microalga for our project.
- 2) Preparation of Growth Medium: Microalgae *Chorella vulgaris* was identified in treated water from sewage treatment plant (STP), SRM Ramapuram campus, Chennai.
- 3) Preparation of Substrate: Sodium hydroxide pellets were dissolved in distilled water to achieve the concentration of 8 M. To effectively utilize industrial byproducts, Class fly ash, from Ennore Power Plant, Tamil Nadu, India, has been adopted as the base material to acquire geopolymer. Copper slag (as a replacement for fine aggregate) was collected from Sterlite industries. Aluminium powder was used to introduce voids in the geopolymer mix. Lightweight concrete was achieved. **Table 1** depicts the mix design for the porous geopolymer concrete, which was already developed and is used for further study.
- 4) Mechanical Property: Geopolymer lightweight bricks were tested for easy feasibility and conforming to IS Code 6441. Brick size of  $200 \times 100 \times 100$  mm was cast and tested. The same mix mortar was used to cast a slab that can be used as a prefabricated compound wall sequestering  $\text{CO}_2$  from the  $\text{CO}_2$  gas cylinder.

**Table 2** shows the maximum compressive strength, maximum bulk density, and maximum water absorption.

- 5) Casting of Specimen (Porous and Non-porous Slab): Slab mould of size  $300 \times 300 \times 40$  mm was cast. The aluminium powder reacted with alkaline water to generate hydrogen bubbles. It produced a very lightweight concrete. The same mortar mix excluding the aluminium powder gives a non-porous slab.
- 6) Seeding of *Chorella Vulgaris* on Substrate: The slabs were transferred into the tray containing treated STP water inoculated with microalgae. In between days, the tray was refilled with STP final water to avoid the loss of water due to evaporation.
- 7) Monitoring the Rate of Growth of Microalgae: Daily growth of microalgae on the cubes of porous slab was inspected as shown in **Figure 1**.

Comparatively slower growth of *Chorella vulgaris* on the non-porous slab was observed. Day-wise images of the growth pattern of microalgae on the non-porous slab were recorded. The profile of microalgal growth in non-porous slab is shown in **Figure 2**.

## EXPERIMENTAL ANALYSIS

### Test for Dry Weight of Biomass

From this study, it was found that there was commendable growth in the 1st week. **Table 3** indicates the results obtained. It is found that porous geopolymer slab consists of more algal mass and more water removal than the non-porous slab.

**Table 1** Mix design

Fly ash	1155 kg/m <sup>3</sup>
Copper slag	840 kg/m <sup>3</sup>
Fly ash/copper slag ratio	1: 1.5
Na <sub>2</sub> SiO <sub>3</sub> /NaOH ratio [AAS]	2.5
Mass of alkaline liquid	405 kg/m <sup>3</sup>
Mass of NaOH	115 kg/m <sup>3</sup>
Mass of Na <sub>2</sub> SiO <sub>3</sub>	290 kg/m <sup>3</sup>
AAS/fly ash ratio	0.35
Distilled water	246.95 g



**Figure 1** Progressive growth of microalgae on porous slab (Day 25)



**Figure 2** Progressive growth of microalgae on non-porous slab (Day 25)

**Table 2** Bulk density, water absorption, and compressive strength test results

SL No	Weight of Brick (kg)	Weight of Wet Brick (kg)	Moisture Content (%)	Bulk Density of Brick (g/cm <sup>3</sup> )	Max. Load (N)	Comp. Strength as per IS 6441 Part V (kN/m <sup>2</sup> )
1	2.6	2.66	37.06	1691	67.2	3.95
2	1.89	2.12	15.79	960	87.5	4.58
3	1.98	2.36	31.84	977	66.7	3.92

**Table 3** Comparison between the amount of microalgae on porous slab seeded with microalgae vs. Non-porous slab

Porous slab S.L. No	Description	Weight (g)
1.	Weight of empty dish	40
2.	Weight of dish + microalgae	80
3.	Weight of dish + microalgae after oven curing	67
<b>Non-porous slab</b>		
1.	Weight of empty dish	40
2.	Weight of dish + microalgae	66
3.	Weight of dish + microalgae after oven curing	54

For a 100 sq. cm slab, about 27g of algal biomass has been grown on the porous slab with microalgae and 14 g on non-porous slab.

### CO<sub>2</sub> Absorption Test

CO<sub>2</sub> absorption test is undertaken using a chamber attached to CO<sub>2</sub> cylinder and pump as shown in **Figure 3**. The goal of this test was to identify the amount of CO<sub>2</sub> absorbed by the slabs. Comparison between the amount of CO<sub>2</sub> absorbed by porous slab seeded with microalgae vs. porous slab without microalgae is done. The slab with microalgae weighed 300 g initially. After taking it out of the CO<sub>2</sub> chamber, it weighed 330 g. It is concluded that porous geopolymer slab with microalgae had absorbed 30g of CO<sub>2</sub> than the slab without microalgae. Therefore, about 21.21% CO<sub>2</sub> is absorbed by the slab with microalgae. This thereby confirms that microalgae are best in CO<sub>2</sub> sequestration.

### Microstructural Analysis

(i) Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Analysis:

The surface morphological analysis was studied. The aluminium powder has played an important role in creating pores inside the slab. The fly ash particles in the cross-section reveal a typical spherical morphology. The round-shaped particles denote ideal fly ash for concrete in terms of workability. Visible pores could be identified by the porosity of the geopolymer concrete slab. In **Figure 4**, the flower petal-shaped configuration indicated the massive growth of microalgae on the porous slab.

(ii) Fourier Transform Infrared Spectroscopy (FTIR):

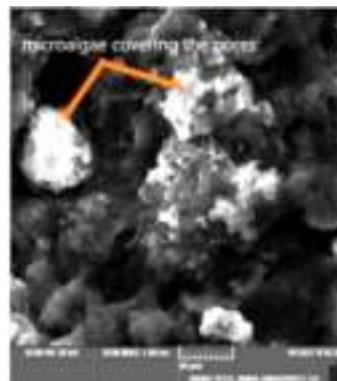
FTIR analysis is used to ascertain the molecular geometry and properties of the material. There are two regions (4000–2200 cm<sup>-1</sup> and 2200–500 cm<sup>-1</sup>) for the samples. In the region of 2200-400 cm<sup>-1</sup>, well-resolved sharper bands were observed.

(iii) Thermogravimetry/differential Thermal Analysis (TG/DTA):

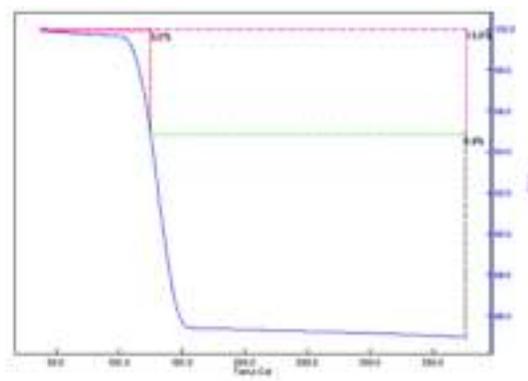
The thermal behavior of the porous geopolymer slab with microalgae is obtained. It can be seen from **Figure 5** that TG1



**Figure 3** Experimental setup to measure CO<sub>2</sub> sequestration



**Figure 4** Pores filled with microalgae



**Figure 5** TGA curves of the specimen



= 125°C and TG2 = 150°C. Main transactions occur in these two regions only. Heating the pan with 6.218 g of the sample, water molecules are removed and a major weight loss of 15% occurs at TG1. When the temperature is further increased, after attaining TG2, weight loss becomes very less and the material moves to a crystalline state.

## RESULT DISCUSSIONS

- ⊙ A porous lightweight concrete slab was developed to suit the growth of microalgae (*Chlorella vulgaris*).
- ⊙ The porosity of the slab was highly beneficial for the microalgae to thrive.
- ⊙ The porous slab showed better uniform growth of microalgae than the non-porous slab.
- ⊙ The microalgae growth was progressing up to 2.5 weeks and it was found that there was full growth of microalgae covering the entire slab.
- ⊙ The study found that sewage/STP water works incredibly well for microalgae's quick development.
- ⊙ Being porous, the geopolymer lightweight slab with microalgae absorbed 1.8 g per day of CO<sub>2</sub> per sq.cm.
- ⊙ SEM analysis of the slab confirmed the growth of microalgae over the pores of the slab, aiding better adherence.
- ⊙ The slab's absorbency of infrared light at different wavelengths showing the absorption peak was identified using FTIR.
- ⊙ Major amount of water removal occurred at 125°C, which was confirmed by TG/DTA analysis.
- ⊙ Hence this idea of using microalgae on a lightweight porous slab can be made as a prefabricated slab for compound walls, other open areas, rooftops, etc. to sequester CO<sub>2</sub> emissions from industrial areas.

## CONCLUSION

- ⊙ Our goal of achieving microalgal growth inside the pores of the geopolymer slab was achieved.
- ⊙ SEM analysis proved that the microalgae were embedded inside the porous of the slab which will aid better CO<sub>2</sub> sequestration.
- ⊙ Comparison between the amount of microalgae on porous slab seeded with microalgae vs. non-porous slab proved that porous slab contains comparatively more algal mass than the non-porous slab due to better integration.
- ⊙ The geopolymer lightweight porous slab with microalgae can sequester approximately 6570 kg/cm<sup>2</sup> of CO<sub>2</sub> per year.
- ⊙ In the future, the porous geopolymer slab can be integrated as a prefabricated compound wall where CO<sub>2</sub> from the atmosphere is sequestered, thereby providing a healthy and safe environment, and reducing harmful GHG.

## REFERENCES

1. M Anjos, B D Fernandes, A A Vicente, J A Teixeira and G Dragone, Optimization of CO<sub>2</sub> Bio-mitigation by *Chlorella Vulgaris*, *Bioresource Technology*, 139, 2013, pp 149-154.
2. B Barati, K Zeng, J Baeyens, S Wang, M Addy, S Y Gan and A E Abomohra, Recent Progress In Genetically Modified Microalgae for Enhanced Carbon Dioxide Sequestration, *Biomass and Bioenergy*, 145, February 2021, p 105927.
3. B Behera, N Aly and P Balasubramanian, Biophysical Model and Techno-economic Assessment of Carbon Sequestration by Microalgal Ponds in Indian Coal Based Power Plants, *Journal of Cleaner Production*, 221, June 2019, pp 587-97.
4. M E Boot-Handford, J C Abanades, E J Anthony, M J Blunt, S Brandani, N Mac Dowell, J R Fernández, M C Ferrari, R Gross, J P Hallett and R S Haszeldine, Carbon Capture And Storage Update, *Energy & Environmental Science*, 7, 2014, pp 130-89.
5. C S Comstock and B F Dodge, Rate of Carbon Dioxide Absorption by Carbonate Solutions in a Packed Tower, *Industrial & Engineering Chemistry*, 29, May 1937, pp 520-9.
6. E Daneshvar, R J Wicker, P L Show and A Bhatnagar, Biologically-mediated Carbon Capture and Utilization by Microalgae towards Sustainable CO<sub>2</sub> Biofixation and Biomass Valorization – a Review, *Chemical Engineering Journal*, 427, January 2022, p 130884.



7. R Dineshkumar, R Narendran, P Jayasingam and P Sampathkumar, Cultivation and Chemical Composition of Microalgae *Chlorella Vulgaris* and its Antibacterial Activity against Human Pathogens, *J Aquac Mar Biol*, 5, 2017, p 00119.
8. D J Farrelly, C D Everard, C C Fagan and K P McDonnell, Carbon Sequestration and the Role of Biological Carbon Mitigation: A Review, *Renewable and Sustainable Energy Reviews*, 21, May 2013, pp 712-27.
9. R W Gaikwad, M D Gudadhe, and S L Bhagat, Carbon Dioxide Capture, Tolerance and Sequestration using Microalgae-a review, *Int J Pharm Chem Biol Sci [Internet]*, 6, 345-9, September 2016.
10. A L Gonçalves, M Simões and J C Pires, The Effect of Light Supply on Microalgal Growth, CO<sub>2</sub> uptake and Nutrient Removal from Wastewater, *Energy Conversion and Management*, 85, September 2014, pp 530-6.
11. W Han, C Li, X Miao and G Yu, A Novel Miniature Culture System to Screen CO<sub>2</sub>-sequestering Microalgae, *Energies*, 5, November 2012, pp 4372-89.
12. H J Herzog and E M Drake, Carbon Dioxide Recovery and Disposal from Large Energy Systems, *Annual Review of Energy and the Environment*, 21, November 1996, pp 145-66.
13. C Kiruthika, S L Prabha and M Neelamegam, Different Aspects of Polyester Polymer Concrete for Sustainable Construction, *Materials Today: Proceedings*, 43, January 2021, pp 1622-5.
14. K Chandrasekaran, L P Srinivasan and N Meyappan, Characterisation of Fibre Reinforced Resin Concrete, *Materiale Plastice*, 58, December 2021, pp 158-70.
15. W Klinthong, Y H Yang, C H Huang, and C S Tan, A Review: Microalgae and their Applications in CO<sub>2</sub> Capture and Renewable Energy, *Aerosol and Air Quality Research*, 15, February 2015, pp 712-42.
16. Y Li, M Horsman, N Wu, C Q Lan and N Dubois-Calero, Biofuels from Microalgae, *Biotechnology Progress*, 24, July 2008, pp 815-20.
17. K Maliutina, A Tahmasebi, J Yu, and S N Saltykov, Comparative Study on Flash Pyrolysis Characteristics of Microalgal and Lignocellulosic Biomass in Entrained-flow Reactor, *Energy Conversion and Management*, 151, November 2017, pp 426-38.
18. S S Oncel, A Kose and D S Oncel, Carbon Sequestration in Microalgae Photobioreactors Building integrated, *Start-Up Creation*, Woodhead Publishing, January 2020, pp 161-200.
19. E Ono and J L Cuello, Selection of Optimal Microalgae Species for CO<sub>2</sub> Sequestration, *Proceedings of Second Annual Conference on Carbon Sequestration*, Alexandria, VA, May 2003.
20. V Patil, K I Reitan, G Knutsen, L M Mortensen, T Källqvist, E Olsen, G Vogt and H R Gislerød, Microalgae as source of Polyunsaturated Fatty Acids for Aquaculture, *Plant Biol*, 6, 2005, pp 57-65.
21. D Pavlik, Y Zhong, C Daiek, W Liao, R Morgan, W Clary and Y Liu, Microalgae Cultivation for Carbon Dioxide Sequestration and Protein Production using a High-efficiency Photobioreactor System, *Algal Research*, 25, July 2017, pp 413-20.
22. J C Pires, M C Alvim-Ferraz, F G Martins and M Simões, Carbon Dioxide Capture from Flue Gases using Microalgae: Engineering Aspects and Biorefinery Concept, *Renewable and Sustainable Energy Reviews*, 16, June 2012, pp 3043-53.
23. R Prasad, S K Gupta, N Shabnam, C Y Oliveira, A K Nema, F A Ansari and F Bux, Role of Microalgae in Global CO<sub>2</sub> Sequestration: Physiological Mechanism, Recent Development, Challenges, and Future Prospective, *Sustainability*, 13, 13061, November 2021.
24. J Pruvost, B Le Gouic, O Lepine, J Legrand and F Le Borgne, Microalgae Culture in Building-integrated Photobioreactors: Biomass Production Modelling and Energetic Analysis, *Chemical Engineering Journal*, 284, January 2016, pp 850-61.
25. R Rajamma, L Senff, M J Ribeiro, J A Labrincha, R J Ball, G C Allen, and V M Ferreira, Biomass Fly Ash Effect on Fresh and Hardened State Properties of Cement based Materials, *Composites Part B: Engineering*, 77, August 2015, pp 1-9.



26. R Ramanan, K Kannan, A Deshkar, R Yadav and T Chakrabarti, Enhanced Algal CO<sub>2</sub> Sequestration through Calcite Deposition by *Chlorella* sp. and *Spirulina Platensis* in a Mini-raceway Pond, *Bioresource Technology*, 101, April 2010, pp 2616-22.
27. A Rinanti, E Kardena, D I Astuti, and K Dewi, Integrated Vertical Photobioreactor System for Carbon Dioxide Removal using Phototrophic Microalgae, *Nigerian Journal of Technology*, 32, July 2013, pp 225-32.
28. J Singh, and D W Dhar, Overview of Carbon Capture Technology: Microalgal Biorefinery Concept and State-of-the-art, *Frontiers in Marine Science*, 6, 29, February 2019.
29. R G Smith, I J Smith and B D Smith, A Novel Strategy for Sequestering Atmospheric CO<sub>2</sub>: The Use of Sealed Microalgal Cultures Located in the Open-oceans, *Renewable and Sustainable Energy Reviews*, 83, March 2018, pp 85-9.
30. D J Stepan, R E Shockey, T A Moe and R Dorn, Carbon Dioxide Sequestering using Microalgal Systems, Univ. of North Dakota, Grand Forks, ND (United States), February 2002.
31. C Stewart, and M A Hessami, A Study of Methods of Carbon Dioxide Capture and Sequestration — the Sustainability of a Photosynthetic Bioreactor Approach, *Energy Conversion and Management*, 46, February 2005, pp 403-20.
32. M Tabatabaei, M Tohidfar, G S Jouzani, M Safarnejad and M Pazouki, Biodiesel Production from Genetically Engineered Microalgae: Future of Bioenergy in Iran, *Renewable and Sustainable Energy Reviews*, 15, May 2011, pp 1918-27.
33. D M Thomas, J Mechery, and S V Paulose, Carbon Dioxide Capture Strategies from Flue Gas using Microalgae: A Review, *Environmental Science and Pollution Research*, 23, September 2016, pp 16926-40.
34. E M Valdovinos-García, J Barajas-Fernández, M D Olán-Acosta, M A Petriz-Prieto, A Guzmán-López, and M G. Bravo-Sánchez, Techno-economic Study of CO<sub>2</sub> Capture of a Thermoelectric Plant using Microalgae (*Chlorella Vulgaris*) for Production of Feedstock for Bioenergy, *Energies*, 13, 413, January 2020.
35. B Wang, Y Li, N Wu, and C Q Lan, CO<sub>2</sub> Bio-mitigation using Microalgae, *Applied Microbiology and Biotechnology*, 79, July 2008, pp 707-18.

# Study on the Performance of High Strength Concrete using Basalt Fiber with Metakaolin

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**Abstract:** Exploring new materials for construction field lead us to utilizing new material. For several decades, concrete is a versatile material due to casting in any shape and provides good workability. This study presents the effect of incorporating Basalt fiber metakaolin and fly ash on the high strength concrete. For this project, the mix design is carried out for M60 grade. The basalt fiber used in the present study has a diameter of 13  $\mu\text{m}$  and a length of 12 mm. This investigation carried to show that the metakaolin has the potential to produce high strength concretes. Construction has been most important human activity since early ages. The main aim is to study strength characteristics and flexural behavior of metakaolin with basalt fiber. In this study, basalt fiber with metakaolin concrete is produced with fly ash, silica fumes, super plasticizer and water is used as a binder. The specimen of size 100  $\times$  100  $\times$  100 mm cubes 100  $\times$  200 mm cylinders and 100  $\times$  100  $\times$  500 mm beam were casted and the specimens of metakaolin base concrete are cured at ambient temperature for 7 days, 14 days and 28 days. The cured specimens were then tested for compressive strength, split tensile strength and flexural strength, respectively.

**Keywords:** Basalt Fiber; Metakaolin; Compressive Strength; Split Tensile Strength; Flexural Strength

## INTRODUCTION

The construction sector is expanding quickly in many countries. Fibers and pozzolanic materials reduce the cost of concrete while enhancing its mechanical and chemical qualities [1]. The presence of basalt fibre in concrete modifies the behavior of failure from delicate failure mode to flexible failure mode when it is compressed, tilted, and affected. Cement is substituted for the superior pozzolanic substance metakaolin in order to increase the durability of concrete. The basalt fibre utilized in this investigation has a 13  $\mu\text{m}$  diameter and a 12 mm length. The use of high strength concrete (HSC) has grown significantly during the past few years. However, the danger to the environment posed by the manufacture of concrete has encouraged efforts to develop eco-friendly materials for construction. In India, dry process technology, which is good to the environment, is used in 93% of cement production [2]. Research has been done in the cement industry to collect the most recent materials and to upgrade the technology. The  $\text{CO}_2$  varies depending upon methods and type of mix design. In India 93% of the cement industry uses dry process technology which is environment friendly [3]. In cement industry, research has been carried out in collection of latest material and up gradation of technology. The cement industry is not suitable for sustainable industry since it causes high pollution to the environment. So, there is necessity for alternate material for cement in the concrete which should be eco-friendly, should satisfy mechanical properties and durability characteristics. This new material should be more superior, preferable compared to conventional concrete based on cement. It is found that metakaolin, fly ash and basalt fiber are best source material to get satisfactory high strength concrete. This research investigation studies the results of an experimental work on strength characteristics of concrete produced with the blending of Basalt fiber and metakaolin.

## EXPERIMENTAL PROGRAM

### Materials Used

The Class F fly ash, according to ASTM C618-99 [13], obtained from Ennore power plant, basalt fiber from fiber zone and metakaolin obtained from Chennai were used for this investigation. The chemical properties of basalt fiber and fly ash and metakaolin were studied and the results are shown in **Table 1**. The coarse aggregate of downgraded size 20 mm and a specific gravity of 2.71 was used. M- sand, which is locally available, conforming to Zone II as per IS 383 [14] with a specific gravity of 2.62 was used for this study. Silica fume is utilized in small amounts compared to other pozzolanic materials is obtained from locally available Astra chemicals.

### Cement

In this project, Zuari Cement is being used throughout the project 53 grade Ordinary Portland Cement is used. The cement confirms to IS 12269:1987. Ordinary Portland Cement (OPC 53) grade was chosen to get the maximum strength advantage out of cement.

### Silica Fumes

silica fume is utilized to create the pozzolanic effect in concrete. It is 150 times smaller than a cement particle and has a diameter of about 0.15mm. Silica fume is a next generation construction material. It reacts promptly with calcium hydroxide, which is delivered during cement hydration.

### Fine Aggregate

Natural sand that was retained on a 75-micron size after passing through a 4.75 mm IS sieve is the typical fine aggregate used (0.075mm) Fine aggregate is referred to as IS Sieve. Natural river sand is typically used as fine aggregate. In this project, common river sand that conforms to zone II is used.

### Fly Ash

Fly ash is a pozzolanic material, which means that when it comes into contact with water, it reacts to make cement. Fly ash creates a substance that resembles Portland cement when combined with lime and water. In this project, fly ash of class F is utilized.

### Basalt Fiber

Basalt fibre has no adverse effects on human health and hasn't caused any negative interactions with water or the atmosphere. It has a great fire, is inexpensive, and is more readily available than any other material, which significantly lowers the cost of basalt fibre. It is entirely synthetic. Basalt fibre ranges in thickness from 6 to 13 microns. Since basalt fibre substitutes asbestos in all uses, fewer health issues will arise.

### Metakaolin

Metakaolin, a pozzolanic material produced from chosen kaolin following refining and calcinations under particular circumstances, is a dehydroxylated version of the clay mineral kaolinite. It is a very effective pozzolana that, through a pozzolanic reaction, quickly produces calcium silicate hydrates and calcium alumina silicate hydrates from the excess

**Table 1** Chemical characteristics of materials

Materials	Fly Ash	Metakaolin	Basalt Fiber
Chemical Composition in %			
SiO <sub>2</sub>	56.80	51.2	60.51
Al <sub>2</sub> O <sub>3</sub>	23.40	40.18	9.02
CaO	5.40	2.0	5.62
Fe <sub>2</sub> O <sub>3</sub>	5.20	1.23	9.1
MgO	0.91	0.12	2.41
SO <sub>2</sub>	0.10	0.00	0.00
Na <sub>2</sub> O	-	0.00	2.74
K <sub>2</sub> O	-	0.53	1.61
LOI	1.10	0.00	0.00

**Table 2** Mix designation

Mix Designation	Binder Composition in %				
	Course And fine Aggregate	Fly ash	Silica fumes	MK	Basalt fiber
CC	100	5	5	0	0
B 1	100	5	5	5	0.5
B 2	100	5	5	10	0.5
B 3	100	5	5	5	1
B4	100	5	5	10	1



**Figure 1** Casting of specimen



calcium hydroxide left over after OPC hydration. A useful additive for cement and/or concrete applications is metakaolin. Metakaolin often replaces 8–20% of the weight of opc.

#### Superplasticizer

Superplasticizer effectively makes concrete easier to work with while reducing water use. Significant improvements in overall quality are achieved by significantly reducing the water requirement in a concrete mix to increase durability by decreasing concrete permeability while expanding sand of the highest quality.

#### Water

Water used for mixing and curing must be pure and free of impurities such salts, acids, and oils.

### Concrete Mix Design

The objective of proportioning concrete is to arrive mix ratio at the most economical and practical combinations in different ingredients to produce concrete that will satisfy the performance requirements under specified conditions of use. This chapter describes the mix design for M60 grade concrete using IS 10262: 2019.

#### Specimen Details

The variables taken for the preparation of high strength concrete. Cement is partially replaced by metakaolin by 0 to 15%, silica fumes of 5%, fly ash 15% and addition of basalt fiber of varying proportion is been added. Super plasticizing admixture based on selected based brown solution- sulfonated naphthalene polymers that immediately disperses in water. A detail of mix designation is given in **Table 2**. The ratio of water and superplasticizer is 0.3 and 0.8 is used. The properties of total of four concrete mixes have been studied and compared with conventional concrete.

#### Sample Preparation for Physical Testing

To prepare specimens dry materials such as fly ash, silica fumes, basalt fiber, metakaolin, coarse aggregates and fine aggregates, taken after weighing, were dry mixed for about 3 minutes. Later, the solution of superplasticizer of 0.8 ratio and water cement ratio 0.4 is added. The samples were then cast in to the moulds. The mould size used are  $100 \times 100 \times 100$  mm,  $100 \times 200$  mm and  $100 \times 100 \times 500$  mm. The mixed concrete is placed in three layers. The cubes, cylinders and beams were demoulded after 24 h. The necessary number of samples for each combination have been prepared, and the average of the three samples was used to determine the findings. The casting of samples is shown in **Figure 1**.

Slump test is used to determine the workability of fresh concrete. The apparatus used for doing slump test is slump cone and tamping rod. The slump value is found as 120 mm.

#### Compressive Strength

Compressive strength for cubes is conducted for determining the strength properties. The compression test was carried out on cubes according to IS:516-2004 [16]. The test set up and progress of testing is shown in **Figure 1**. For each combination of mix and tested. The average of the three values for a mix proportion is noted. proportions, triplicate samples were prepared. The samples were tested at 7 days, 14 days, 28 days at ambient curing. The test set up and tested samples are shown in **Figure 2**.

Maximum load causing failure was noted. The investigation is done for the four different mixes, and it has been compared.

#### Split Tensile Strength

Split tensile test was carried on the cylindrical specimens which was prepared. They are tested at 7 days, 14 days and 28 days according to IS 5816-1987 [17]. The test set up and progress of testing split tensile is shown in **Figure 3**.

#### Flexural test

Flexural tests were carried on the prism specimens which was prepared. They are tested on 7 days, 14 days, and 28 days. **Figure 4** Test setup of Split Tensile Strength Test according to IS 5816-987 [17]. The test set up and progress of testing flexural test is shown in **Figure 4**.

#### Ultra Sonic Pulse Velocity Test

An electro-acoustical transducer kept in touch with one surface of the concrete member being tested generates an



**Figure 2** Testing setup of compressive test



**Figure 3** Test set up of split tensile test



**Figure 4** Test setup of flexural strength test

ultrasonic pulse of 50 to 54 kHz, and an identical transducer in contact with the surface at the other end measures the transit time, T. The pulse velocity ( $V = L/T$ ) is determined using the path length L (i.e., the distance between the two probes) and time of travel T. The density and elastic characteristics of the material being examined influence the ultrasonic pulse velocity. When using aggregate with a 20 mm size, the path length will have very little of an impact as long as it is greater than 100mm. The shape of the specimen will not affect pulse velocity as long as its smallest lateral dimension does not fall below the wavelength of the pulse vibrations. The pulse velocity may be slightly yet significantly influenced by the moisture content of the concrete. In general, the velocity rises as the moisture content rises, with the effect being more pronounced for lower-quality concrete. Here CC1&CC2 denotes conventional concrete and B1, B2 denotes basalt incorporated RC beam.

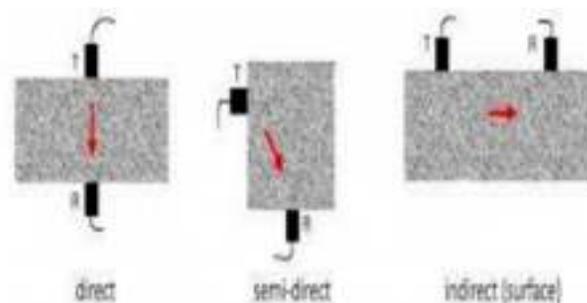
#### Flexural Test on RC Beam

The test above demonstrates the 15% metakaolin and 1% basalt fiber to fly ash and silica fumes gives the optimum value specimen good at flexural strength. Hence, the RC beam is also tested to have better clarity and behaviour of concrete. Where 15% of Metakaolin and 1% basalt fiber replaced beams (B1 & B2) are compared with the controlled beams CC1 and CC2 in order to know the major differences and behavior changes. The static load is used to test different beam specimen types. Whereas the test takes into account deflection, crack development, the number of cracks, their spacing, and their width. The beam specifications were 1200 mm × 100 mm × 150 mm, four points bending test, two numbers of a controlled specimen with 100% cement and two numbers of 10% of Metakaolin and 1% basalt fibre, 12 mm diameter rebar of Fe 415 for longitudinal reinforcement and 8 mm diameter rebar of Fe 415 grade, and curing period was 28 days at normal temperature 30-40°C, respectively. The concrete grade was M60.

**Figure 6** displays the 4 point load test configuration for the RC beam specimen. It is necessary to compare mixes of ordinary concrete with basalt fibre and metakaolin concrete. The following test will be performed on four specimens of cast beams with dimensions of 1200 mm × 150 mm × 100 mm.

**Table 3** Concrete based on ultrasonic pulse velocity test

Pulse Velocity Concrete Quality	
>4.0 km/s	Very good to excellent
3.5 km/s – 4.0 km/s	Good to very good, slight porosity may exist
3.0 km/s – 3.5 km/s	Satisfactory but loss of integrity is suspected
<3.0 km/s	Poor and loss of integrity



**Figure 5** Methods of ultrasonic pulse velocity test

**Table 4** Specimen details for 7 days curing period

Sample No.	Load (KN)	Compressive strength (MPa)	Average Compressive strength (MPa)
CC	420	42.0	44.53
	454	45.4	
	462	46.2	
B1	412	41.2	41.6
	420	42.0	
	418	41.8	
B2	390	39	39.1
	398	39.8	
	387	38.7	
B3	412	41.2	41.8
	424	42.4	
	418	41.8	
B4	391	39.1	38.3
	378	37.8	
	381	38.1	



**Figure 6** Test setup of flexural strength test of RC beam

**Mix Proportions**

Set 1 = 0% replacement in cement.

Set 2 = Addition of basalt fiber 1% and 10% metakaolin replacement in cement.

**RESULTS AND DISCUSSION**

**Compressive Strength**

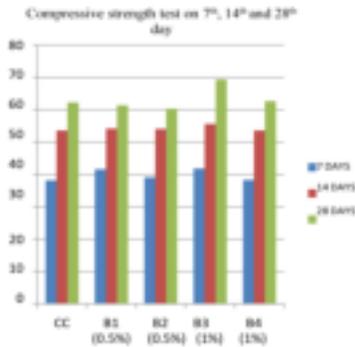
The graphs below display the results of the compressive strength test for various ambient curing time periods. All of the blends' compressive strength grew over time. With the addition of fly ash and silica fumes (B3), the strength of basalt

**Table 5** Specimen details for 14 days curing period

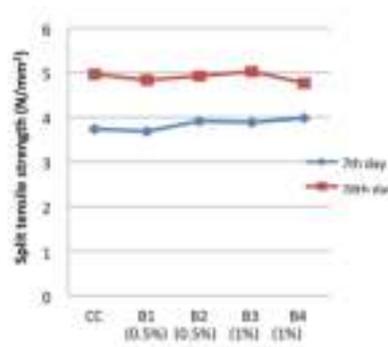
Sample No.	Load (KN)	Compressive strength (MPa)	Average Compressive strength (MPa)
CC	526	52.6	53.36
	516	51.6	
	535	53.5	
B1	550	55.0	54.2
	532	53.2	
	544	54.4	
B2	573	52.3	54.06
	549	54.9	
	550	55.0	
B3	573	57.3	55.6
	553	55.3	
	540	54.0	
B4	536	53.6	53.6
	531	53.1	
	550	54.3	

**Table 6** Specimen details for 28 days curing period

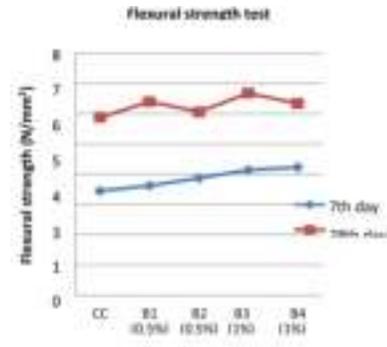
Sample No.	Load (KN)	Compressive strength (MPa)	Average Compressive strength (MPa)
CC	633	63.3	62.26
	621	62.1	
	614	61.4	
B1	611	61.1	62.4
	622	62.2	
	609	60.9	
B2	623	62.3	61.4
	613	61.5	
	632	63.2	
B3	633	63.3	69.3
	642	64.2	
	655	65.5	
B4	646	64.6	62.6
	636	63.6	
	628	62.8	



**Graph 1** Compressive strength test values



**Graph 2** Split tensile strength



**Graph 3** Flexural strength test

**Table 7** Split tensile test values

Sample No	Avg. Split Tensile Strength in (MPa) 7 <sup>th</sup> day	Avg. Split-Tensile Strength in (MPa) 28 <sup>th</sup> day
CC	3.73	4.96
B1	3.63	4.83
B2	3.91	4.92
B3	3.88	5.02
B4	3.98	4.76

**Table 8** Flexural strength test result

Sample No	Average Modulus of rupture (MPa) 7 <sup>th</sup> day	Average Modulus of rupture (MPa) 28 <sup>th</sup> day
CC	3.45	5.88
B1	3.62	6.4
B2	3.87	6.06
B3	4.14	6.68
B4	4.23	6.34

fiber with metakaolin concrete demonstrates a greater compressive strength of 69.3 MPa at 28 days.

### Split Tensile Strength

A method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. **Graph 2** shows the split tensile strength test results for different duration periods in ambient curing (7 and 28 days). The tensile strength varies from 3.8MPa from 7 days to 5.02 MPa at 28 days for 15% partial replacement of metakaolin and 1% basalt fiber (B3). The rate of increase of strength for all the mixes showed a similar trend of increase. The tensile strength of conventional concrete shows a similar strength of B4 at 28 days. This indicates that the behavior of mix concrete is almost like the conventional concrete.

### Flexural Strength

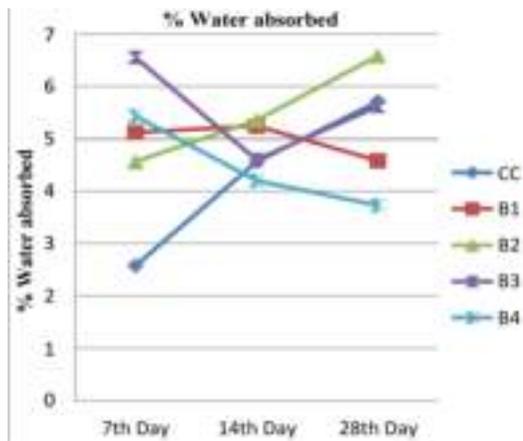
**Graph 3** shows the flexural strength of different mix proportions at various durations (7 and 28 days). The flexural strength varies from 3.45 MPa from 7 days to 6.34 MPa at 28 days for the partial replacement of 15% metakaolin with 1% basalt fiber to fly ash and silica fumes-based mix concrete showed the better results when compared to conventional concrete. The strength shows a similar trend of increase for all the mixes. The flexural strength value of the conventional concrete show's strength of 5.88 MPa at 28 days.

### Water Absorption

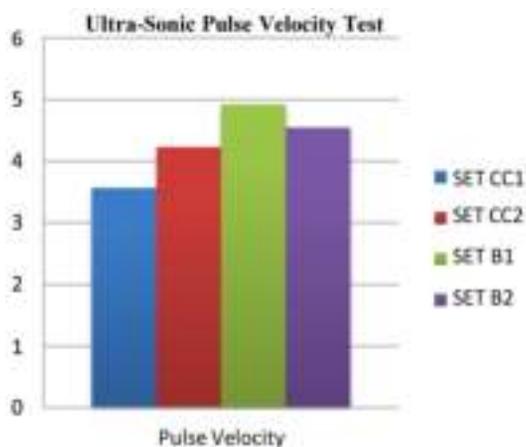
The results of percentage water content submerged in cubes for the water absorption test done on concrete cubes at 28 days for M60 grade concrete control mix concrete and concrete with replacement with Basalt fiber and metakaolin in several proportions.

### Ultrasonic Pulse Velocity Test

The Ultrasonic pulse velocity test results of RC Beam specimen submerged in the water test done on concrete RC beam



Graph 4 Water absorption



Graph 5 Ultrasonic pulse velocity test result

Table 9 Water absorption test results at 7, 14 and 28 days

Concrete mixes	24 Hours saturation Weight (W1) in kg	Oven dry Weight (W2) in kg	Water absorption %
<b>7<sup>th</sup> DAY RESULT</b>			
CC1	2.60	2.51	3.58
B1	2.46	2.34	5.12
B2	2.52	2.41	4.56
B3	2.44	2.29	6.55
B4	2.52	2.39	5.43
<b>14<sup>th</sup> DAY RESULT</b>			
C2	2.63	2.52	4.36
B1	2.41	2.29	5.24
B2	2.36	2.24	5.35
B3	2.50	2.39	4.60
B4	2.48	2.38	4.20
<b>28<sup>th</sup> DAY RESULT</b>			
C3	2.59	2.45	5.71
B1	2.51	2.40	4.58
B2	2.49	2.33	6.86
B3	2.44	2.31	5.62
B4	2.50	2.41	3.73

Table 10 Ultra-sonic pulse velocity values

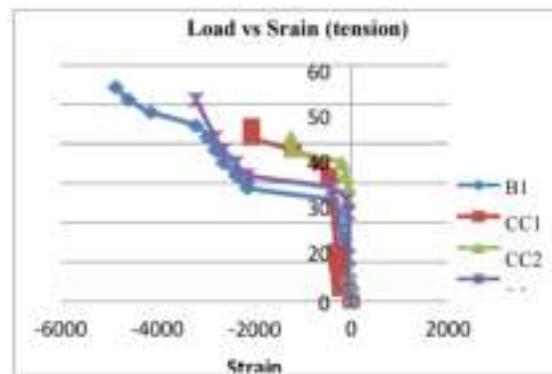
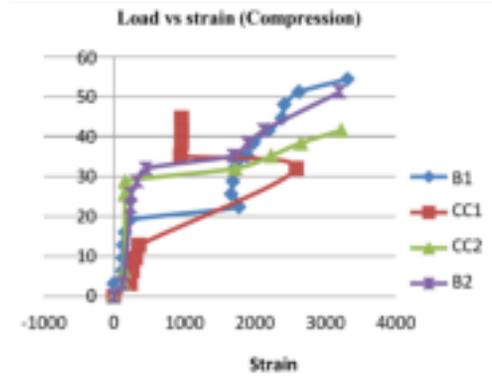
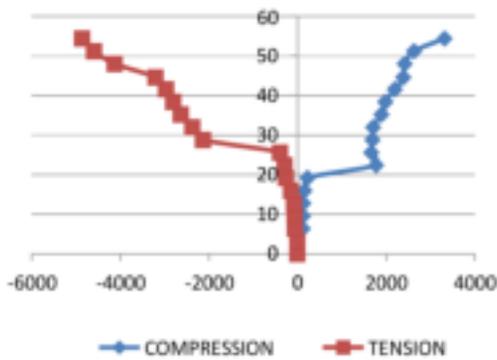
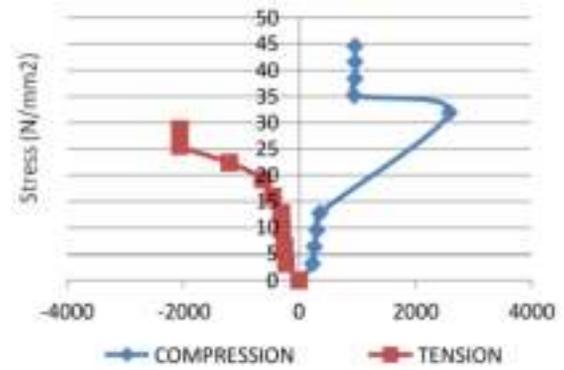
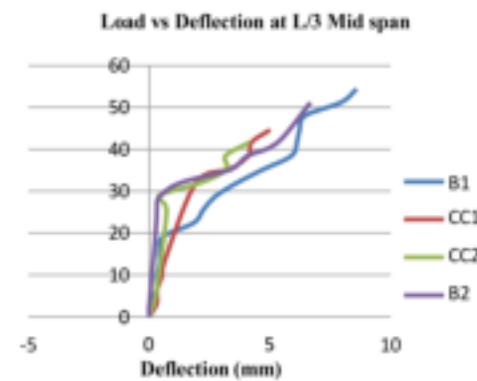
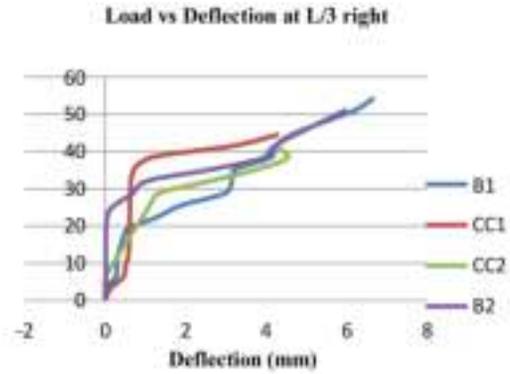
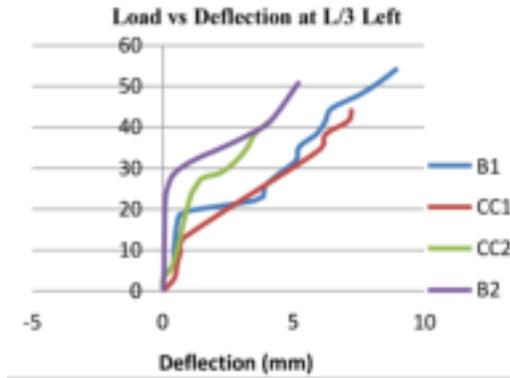
Pulse Velocity Values	SETCC1	SETCC2	SET B1	SET B2
	3.56	4.22	4.92	4.54

at 28 days for M60 grade concrete control mix concrete and concrete with replacement with Basalt fiber (1%) and metakaolin (15%) in proportions. Here CC1&CC2 denotes conventional concrete and B1, B2 donates basalt incorporated RC beam.

#### Flexural Test on RC Beam

The beam specimen is tested by the static load. Where, deflection, crack propagation, the number of cracks, crack spacing, and crack width are considered under the test. The concrete grade was M60 and the beam specifications such as dimension, type of flexural test, specimen, reinforcement and curing period are 1200 mm × 100 mm × 150 mm, four points bending test, two numbers of a controlled specimen with 100% cement and two numbers of 15% of Metakaolin and 1% basalt fiber, 12 mm diameter rebar of Fe 415 for longitudinal reinforcement and 8 mm diameter rebar of Fe 415 grade and curing period was 28 days at normal temperature 30–40°C respectively. A static load test was performed to validate the ultimate 200 strength and the flexural response of the beam. The load was applied in an ever-increasing manner until it gets failed. **Figures 4.6-4.8** show the graph of concrete mixtures showing the load deflection curve of various mixes with control beam and static load for various mixes. **Figures 4.9-4.10** show stress strain behavior of (CC1) and (B1) basalt fiber incorporated RC beam which had showed better results.

From **Figures 4.6-4.8**, describes that B1 with 15% metakaolin and 1% basalt fiber sustains higher load compared to control beam CC1 and CC2 were here crack is attain at early stage. The basalt fiber defects at 54.4 kN and 51.2 kN whereas control beam at 44.6 kN and 41.6 kN.





## CONCLUSION

From the experimental investigation the following conclusions can be arrived.

- ⊙ Slump cone test, compaction factor was measured on all the mixtures. The workability properties are decreased by the addition of fiber whereas it has increased with the addition of metakaolin when compared with control concrete.
- ⊙ The compressive strength of design mix Concrete shows good results when compared to Conventional Concrete at 28 days at ambient curing. The partial Replacement of 15% metakaolin and 1% basalt fiber to Fly ash and silica fumes gives the optimum value.
- ⊙ There is an improvement in strength for the partial replacement levels of metakaolin and basalt fiber to replacement of cement.
- ⊙ The Split Tensile Strength of design mix Concrete shows similar results when compared to Conventional Concrete at 28 days.
- ⊙ The behaviour of Flexural Strength design mix Concrete is similar to Conventional Concrete from the observation of its test results.
- ⊙ From above figure it describe that the 15% metakaolin and 1% basalt fiber sustains higher load than that of control beam whereas basalt fiber reinforced concrete beam carry higher load than that of control concrete.
- ⊙ Basalt mix good stress strain behaviour than that of mixes. More the stiffer lesser than deformation.
- ⊙ The strength of the Basalt fiber increases with the age Concrete.

## ACKNOWLEDGEMENT

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## REFERENCES

1. H Abdul Razak and H S Wong, Strength Estimation Model for High-strength Concrete Incorporating Metakaolin and Silica Fume, *Cement and Concrete Research*, 35(4), 2005, 688.
2. Anil Kumar Nanda, Prem Pal Bansal and Maneek Kumar, Effect of Nano Silica and Silica Fumes on Durability Properties of HSC. *International Journal of Civil Engineering and Technology (IJCIET)*, 9(2), 2018, 115.
3. S Arivalagan. Study on the Compressive and Split Tensile Strength Properties of Basalt Fibre Concrete Members, *Global Journal of Researches in Engineering Civil and Structural Engineering*, 12(4), 2012, pp 23-27.
4. B M Sunil, Manjunatha L S and Subhash C Yaragal, Durability Studies on Concrete with Partial Replacement of Cement and Fine Aggregates by Fly Ash and Tailing Material, *Advances in Concrete Construction*, 5(6), 2017, pp 671-683.
5. E Badogiannis, G Kakali and S Tsivilis, Metakaolin as Supplementary Cementitious Material, *Journal of Thermal Analysis and Calorimetry*, 81(2), 2005, 457.
7. S Barbhuiya, P Chow and S Memon, Microstructure, Hydration and Nano Mechanical Properties Of Concrete Containing Metakaolin. *Construction and Building Materials*, 95, 2015, 696.
8. Bhaskara Teja Chavali and Perla Karunakar, Effect of Varying Quantities of MK and FA on Strength Characteristics of Concrete, *International Journal for Technological Research in Engineering*, 4(2), 2005, 282-288[8].
9. Q Bi and H Wang, Bond Strength of BFRP Bars to Basalt Fiber Reinforced High-Strength Concrete, *Advances in FRP Composites in Civil Engineering*, 576, 2011.
10. K Srinivasu, M L N Krishna Sai and Venkata Sairam Kumar N, A Review on Use of MK in Cement Mortar and Concrete. *International Journal of Innovative Research in Science Engineering and Technology*, 3(7), 2007[10].



# Erection and Commissioning of Emergency Restoration System for Restoration of Power during Disaster Management

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**Abstract:** Emergency restoration system-ERS towers are Modular, reusable transmission tower systems are so versatile that they can be used in line crew of national grid, utility companies and associated with others power transmission and distribution companies for various applications such as: Restoring power following a disaster (flood, hurricane, war, etc), Conducting scheduled maintenance work on existing towers without major interruptions, temporary line extensions in a fast & efficient way (no civil engineering work required), Temporarily linking villages or remote locations (mining sites) to the main grid. Generally, when electrical transmission is interrupted because one or several transmission towers are damaged, there is a high economical cost for the Transmission and utility companies. Adiradh Energy offers Lindsey make ERS towers four models 1070-ERS Series, 800-ERS Series, 600H-ERS Series, 600L-ERS Series for in India.

**Keywords:**

## INTRODUCTION

This Paper contains some suggestions and recommended practices that should be followed when using the Lindsey Modular Emergency Restoration Structures. In order to maximize the potential benefit that can be derived from using these structures in an emergency situation, it is essential that sufficient planning and training be accomplished prior to the occurrence of an emergency.

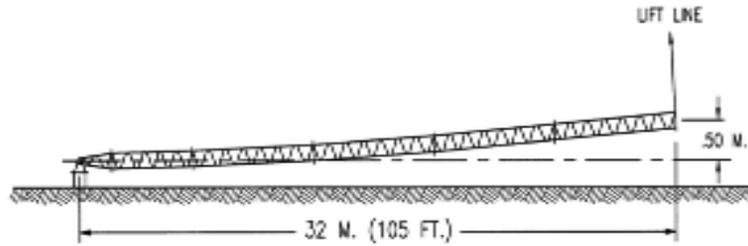
As with any other piece of equipment or tool, all normal safety precautions should be followed when working on or around these structures. Care should be taken to insure that the structures are not handled or used in a manner which may cause damage. This manual provides some general guidelines which, if followed, should insure satisfactory use of the Lindsey Emergency Restoration Structures.

Any and all national, state, local or company safety requirements should be observed at all times.

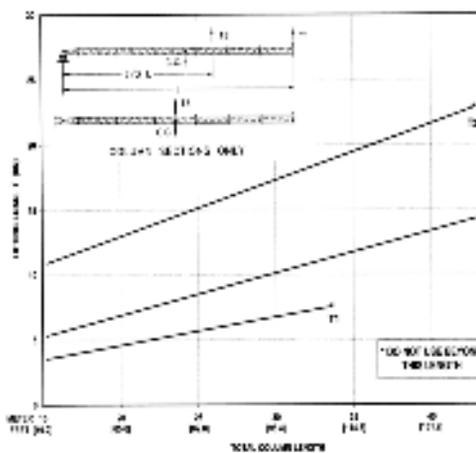
## GENERAL INSTRUCTIONS FOR ERECTION OF THE STRUCTURE

There are a variety of erection techniques that can be used on the ERS structures. Each particular utility develops their own specific techniques depending on the type of equipment which they have available, the type of terrain that they must work in and the type of structure that they will be erecting. Keeping this in mind, only the most commonly used techniques are described. As the user gains more experience with the structures, other techniques and methods can be tried as long as the basic rules explained below are maintained.

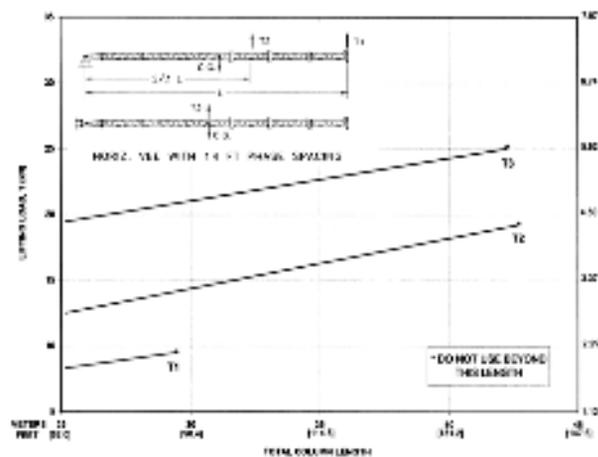
A common method of erecting the structures is tilting up the structure with a crane or helicopter. If the structure has been assembled with the foundation in its proper location with the structure horizontal, the structure can be picked at or near the top (usually with a helicopter) and tilted into place pivoting at the gimbal. It is important to note that the ERS structure is fabricated from aluminum and is very flexible compared to steel. When picking the top end of a 105 ft (32 m) column, with the base fixed to the ground, the top end will deflect or raise approximately 20 inches or 500 mm before the gimbal begins to rotate (**Figure 3.6-1**). If the 105 ft column is made up of 21 ft sections, and the maximum bending moment is calculated, 27% of the bending capacity of the structure is utilized when tilting up as described above. The lifting loads for various structures can be obtained from the ERS computer programs by opening the pull down menu "Towers" and opening "Erection". For a quick conservative reference use **Figures 3.6-2** and **3.6-3** to determine the maximum lifting load "T1" and the maximum column length that can be lifted. **Figure 3.6-2** assumes an ERS column is made up of only 14 ft sections, with eight guy plates at the top, and a reasonable amount of guy wire attached to the structure. **Figure 3.6-3**



**Figure 3.6-1** When lifting the end of a long column, the top of the column will move several inches before the gimbal begins to rotate due to the flexibility of the column. In the case of a 105 ft or 32 m column, the top will rise 20 inches or 500 mm before the gimbal begins to rotate.



**Figure 3.6-2**



**Figure 3.6-3**

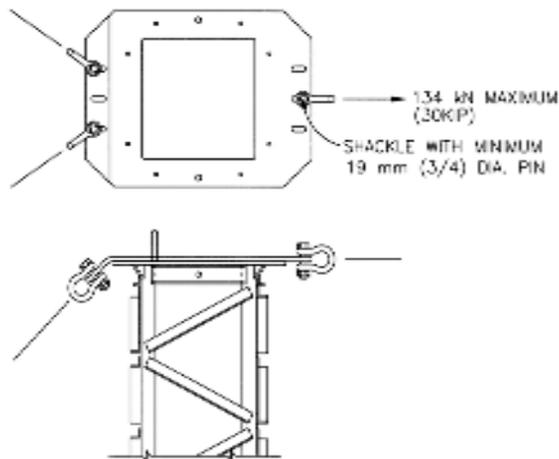
assumes an ERS column made up of only 14 ft sections, with eight guy plates and three box sections at the top, and a reasonable amount of guy wire attached to the structure. When lifting with a helicopter, tests have indicated that the lifting load “T1” will increase by approximately 10% due to helicopter downwash on the structure.

To minimize the bending moment on a tall simple column when tilting it up with a helicopter or crane, the column should be picked up approximately one third of the distance from the top (“T2” in **Figures 3.6-2** and **3.6-3**). Columns with box sections, or other top-heavy loads, should be picked up closer to the top. Special caution should be taken when erecting tall columns over 120 ft or 36 m.

If the foundation is not set in position when erection begins, the best method of transporting and setting an assembled column is to choke the structure slightly above the center of gravity (“T3” in **Figures 3.6-2** and **3.6-3**). The structure can then be picked straight up, thus minimizing the movement of the crane boom, and set on the ground below the pickpoint.

Since it is very difficult to plumb the column with a crane or helicopter, it is advisable to use the crane or helicopter to get the structure close to plumb and then use chain hoists on the guys to bring the structure into plumb. Past experience has shown that some form of positive hold on the guys is essential. Chain hoists and grips attached to the guys should be used when adjusting the position of the tower. Block and tackle should not be used. If a block and tackle without a positive stop is used and the column gets too far out of plumb, the force of the tower’s movement may be too great for the block and tackle and the column could fall.

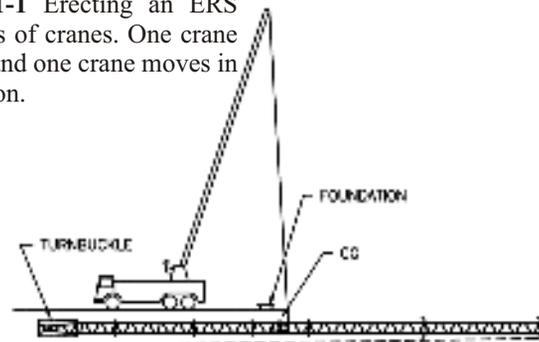
The allowable bending moment on a column is 140,000 foot-pounds or 190,000 Newtonmeters. This bending moment should not be exceeded during construction. **Figures 3.6-2** and **3.6-3** should give maximum lifting loads and maximum column lengths. If a particular application is outside of these parameters, the actual bending moments can be calculated by using the Lindsey ERS computer programs.



**Figure 3.6-5** The ultimate load on any one of the six attachment points of a guy plate is 30,000 lbs or 134 kN. A shackle with a minimum 3/4 inch or 19 mm diameter bolt should be used to attach to the guy plate.



**Figure 3.6.1-1** Erecting an ERS with two sets of cranes. One crane lifts the top and one crane moves in the Foundation.



**Figure 3.6.1-2**

As a general rule, when erecting a tall column, over 100 feet or 30 meters, and any column that will be subjected to high winds, the column should have intermediate guying. This intermediate guying will reduce the bending of the column due to wind loads, and dramatically increase the loading capacity of the structure. The ERS computer programs will provide the information for when an intermediate guy is necessary, and for locating the intermediate guys. The intermediate guys can be attached on a guy plate installed between sections for this purpose. There are also four holes on the end flange of each section, one on each side, which can be used for attaching intermediate guys after the ERS structure is installed. These same four holes can and should be used as attachment points for construction guys when using the section method of Gin Pole erection. It is important to keep the column straight when adding intermediate guying. Do not over tension the intermediate guy so that a bend is introduced into the column (**Figure 3.6-4**). The ERS computer programs allow for adding this “Additional Eccentricity (e3)” into the analysis (section 2.2.1.3).

Except under unusual circumstances, it is important to guy all structures at the same height as the load. Do not connect the load to the structure at one height and guy the structure at the section below or above, as this will create bending loads on the structure that may limit its capacity. To analyze this type of situation see Section 2.5. This rule is also true for the box section, back guy the box section to minimize shear on the box section.

The guy plates on the ERS have 6 points where guys or loads can be attached. Each of these six attachment points can hold an ultimate load of 30,000 pounds or 134 kN. It is important to insure that the maximum design load on any one of these points is below this limit (**Figure 3.6-5**). In cases where the maximum load may be above this limit, multiple guys should be attached to more than one attachment point. It is critical that the guy attachments have a large degree of flexibility and not be rigid connections. If a guy is attached without this degree of articulation, wedging or bending of the attachment hardware may occur, and the attachment may fail. For this reason, it is recommended that an anchor shackle with bolt nut and cotter pin (i.e. Lindsey Part No. 3262BNC), and a steel wire rope thimble (i.e. Lindsey Part No. 7950) be used with a preformed guy wire grip at the guy plate.

It is important when tensioning the top guys as well as the intermediate guys, that they not be over tensioned. In most cases, a pretension of about 500-1000 pounds or 2-4 kN, or simply taking the slack out of the line, is sufficient. In some instances, such as a tension or dead-end or angle tower, the pretension should only be enough to keep the column straight under normal conductor loading conditions. After the conductor is clipped in, it may be necessary to adjust the guy wire tensions to insure a straight column (**Figure 3.6-4**).

### ERECTION PROCEDURES USING A “BOOM-TRUCK” OR LIGHT DUTY CRANE

There are several techniques that can be used to erect an ERS structure with a crane. The choice of technique depends on



**Figure 3.6.1-4 (A)** The ERS Column is picked slightly above the center of gravity. The ERS Column is raised directly over the foundation



**Figure 3.6.1-4 (B)** The ERS Column and Gimbal is walked in toward the Foundation.



**Figure 3.6.1-4 (C)** Once the ERS Column is over the Foundation the Tie Rods on the Gimbal are released so that the bottom portion of the Gimbal can rotate. The ERS Column is lowered and the bottom flange of the Gimbal is bolted to the Foundation.

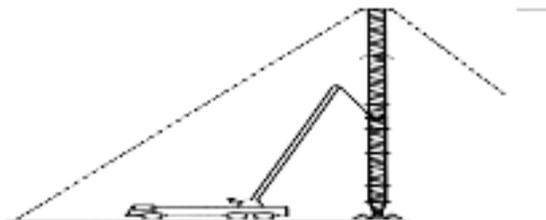
the type and capacity of the crane available. One technique has already been partially discussed in section 3.6. With a large crane, the entire column can be bolted together horizontally on the ground. The entire structure including foundation can be moved to the proper location, if needed, and the crane used to raise the top of the column to the near plumb position until the structure can be secured and plumed using chain hoists and grips attached to the guys. This method requires the crane to lift the end of the column while the boom is extended at least one half the height of the ERS column away from the crane's foundation, this necessitates a large crane. It also requires a skilled crane operator to raise a load and swing the crane boom as the end of the ERS column raises.

With two cranes, ERS structures have been erected where one larger crane remains almost stationary lifting the top end of the ERS structure (which was assembled and positioned near the final location of the foundation). At the same time, a smaller mobile crane lifts the bottom end of the ERS structure (including foundation plate) and moves the foundation to its final position. In this method the large crane never has to swing its boom (**Figure 3.6.1-1**).

However, for most applications where only a small crane or boom truck is available, or can get to the job site, the following technique is most useful. This technique can also be used with larger cranes.

The following steps are referred to in **Figures 3.6.1-2** through **3.6.1-6**.

1. Position the foundation in the desired location and stake into place.
2. Construct the column on the ground adjacent to the foundation. The center of the column should be located



**Figure 3.6.1-5** Attach the guys to their anchors and begin tensioning. Use the guywires, not the boom, to plumb the column. After the guys are installed the winch line can be slacked off.

approximately at the foundation. Leave the turnbuckles on the gimbal (but loosen the lock nuts).

3. Install pre-measured guys to the column, include temporary guys if required.
4. Locate the center of gravity (CG) by picking-up the column at various locations. Pick the column by choking all four main angles with a steel or nylon strap. Locate the straps one to two feet above the center of gravity, so that two linemen can lift the gimbal (**Figures 3.6.1-2 and 3.6.1-4**).
5. Begin raising the column using the winch line. The boom should only require minor adjustments in position. Have two crewmen walk the gimbal section toward the foundation..
6. Once the column is vertical, with the gimbal one foot off the ground, remove all four turnbuckles from the gimbal.
7. Position the column over the foundation and bolt the gimbal and foundation together. Maintain a minimal amount of tension on the winch line, enough to keep the column vertical without pulling the foundation upwards.
8. Attach the guys to their anchors and begin tensioning. Use the guy wires, not the boom, to plumb the column. After the guys are installed the winch line can be slacked off.
9. Have a crewman climb the column and release the sling from the column.

### **TILTING UP OR WHIPPING UP THE ERS COLUMN WITH A WINCH LINE**

Entire ERS columns have been erected using a winch line placed over the top of a standard gin pole (derrick) and attached to the top of the ERS column. Another method is to raise the top of the ERS column with a small boom and simply pull or “whip up” the column with a winch line. Still a third method is to use one already erected ERS column as a gin pole and tilt up another ERS column with the winch line.

When tilting up an ERS structure using a winch line and standard gin pole (derrick), another ERS structure, or when “whipping up” a column, the foundation will have a tendency to move horizontally in the direction of the pull, and to tip up during the initial stages of the lift. As more vertical weight of the column acts on the foundation the tipping will subside. This tendency should not pose any problems, although it is recommended that screw anchors be used to secure the foundation when using these erection techniques (**Figure 3.6.2-1**).

The ERS computer program shows the types of horizontal loads that are present when tilting up or “whipping up” a column. This type of analysis should be performed to determine the winch line load, uplift and horizontal load on the foundation as well as to insure that the capacity of the structure is not exceeded. In using the ERS computer programs for analyzing an ERS column being tilted up, set the dimension “B” in the program to the height of the gin pole or the winch line attachment point on an adjacent ERS structure.



**Figure 3.6.2-1** When whipping up a column, or erecting a column using a gin pole, the foundation will begin to tip, since the hinge point of the gimbal is above ground level. This tipping does not present a problem and the foundation will settle down after additional vertical column weight is on the structure. The ERS computer programs will calculate the horizontal and vertical loads on the foundation



**Figure 3.6.2-2**

The column being tilted up or “whipped up” should be guyed to each side to prevent the column from becoming unstable and rotating to one side. These two side guys should be attached to two separate anchors that line up with the foundation in a straight line on the ground perpendicular to the plane that the ERS column is being raised in. Since the ERS gimbal axis is approximately 2 feet off the ground, tension in these two side guys should be released as the column is raised to the vertical position, or additional slack should be left in the side guys.

Failure to leave sufficient slack in the side guys as the tower is raised can cause the side guys to over stressed and possibly break. The column should also be guyed on the side opposite from the winch line to prevent the column from tipping over if it is raised past vertical. See the sequence of pictures in **Figure 3.6.2-2**.

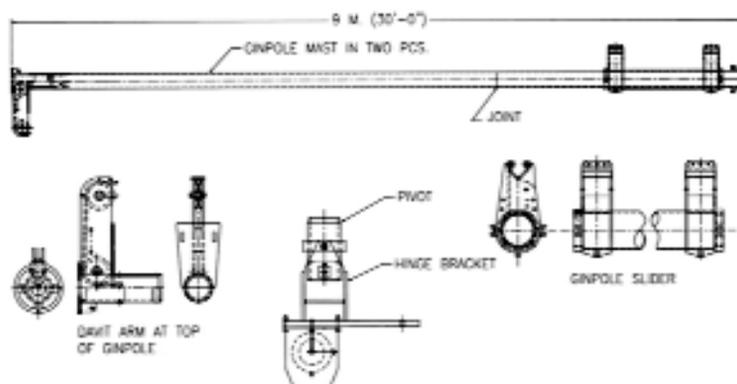
#### **ERECTION PROCEDURE USING A LINDSEY R-16289 SLIDING GIN POLE**

##### **A) Assembly of the Sliding Gin Pole**

1. Lay out the gin pole construction material on the temporary tower site as indicated in **Figure 3.6.3-1**.
  2. Assemble the gin pole and thread the ropes as indicated in **Figure 3.6.3-2**. Three ropes will have to be threaded to and through the gin pole. They are the main lifting rope, slider bracket lifting rope and the gin pole mast lifting rope. Use guy wire to thread the lift line through the center of the gin pole.
- Make sure the lifting line is between the keeper bolt and the pulley at the top end of the gin pole. The lifting rope **MUST** be attached before the gin pole is tilted up.
3. If the gin pole is not already assembled then assemble the gin as indicated in **Figures 3.6.3-1** and **3.6.3-3**.

##### **B) Erecting Gin Pole on Foundation**

1. Attach the tilt up bracket to the foundation using the two bolt holes on the corner of the foundation and gimbal joint connection (**Figure 3.6.3-4**).
  2. Attach four temporary stay ropes to the ring at the top of the gin pole mast (**Figures 3.6.3-5** and **3.6.3-6**).
1. Attach four ropes to the gin pole with shackles places in four holes at the top of the gin pole



**Figure 3.6.3-1**



Figure 3.6.3-3

2. Lay ropes out so that each one is located close to an anchor
3. Attach one snatch block to the top of the gin pole mast and one snatch block to the slider bracket.
4. Attach two snatch blocks to the tilt up bracket.
5. Layout a Tirfour grip used for hoisting the gin pole.
6. Attach the Tirfour grip to the top of the gin pole and to a temporary or permanent anchor (**Figure 3.6.3-7**).
7. Tilt up the gin pole..
8. Once the gin pole has been hoisted into place, tie off the gin pole using the four ropes, which were attached to the top of the gin pole and construction yoke plates at the permanent anchors..

**C) Lifting the First Column Section above Rigid Gimbal**

1. Position the first column section to be erected close the foundation.
2. Attach the lifting bracket and hoisting rope to the top of the column section.
3. Position one person at each of the anchors where the four ropes have been attached. These personnel are to remain at



Figure 3.6.3-4

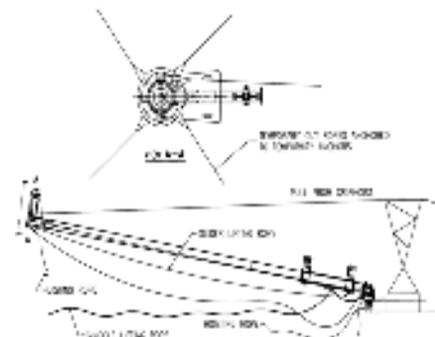


Figure 3.6.3-5



**Figure 3.6.3-6**



**Figure 3.6.3-7** Place box wrench in bolt holes on top of Gimbal Joint. This will keep the grip hoist cable from sliding on the Gimbal Joint during erection. Attach Grip Hoist to temporary anchor approximately 15 meters away from foundation on the opposite side from the gin pole.

**Figure 3.6.3-8** Tension grip hoist and pull gin pole in place. Note Position of davit arm. Always place vertical Note the Positioning Ropes, 4 Places used to keep gin pole centered when lifting

this location until the first column section is bolted onto the rigid gimbal.

4. Utilizing the hydraulic capstan (**Figure 3.6.3-9**), hoist the column section to the position above the gimbal joint. Two people should be located at the hydraulic capstan. One person should operate the capstan control foot pedal and pull the rope through the capstan. The other man should operate the HPU and then observe the lifting operation and give directions to the capstan operator.

5. Turn off hydraulic power unit (HPU). Slowly let the lifting rope slip back through the capstan, which will lower the column section onto the top of the rigid gimbal. The HPU should ALWAYS be turned off during this procedure in order to eliminate the noise of the motor. This will allow for better communication between the people on the tower and the people operating the capstan. This standard procedure is to be followed any time material is to be lowered with the capstan (**Figure 3.6.3-10**).

6. Keep tension on the lifting rope until the column section has been bolted into place and the four temporary stay wires have been secured and properly tensioned. Utilize the rope safety catch, which is located on the capstan assembly. This is an important safety procedure (**Figure 3.6.3-9**).

7. Attach four temporary Tirfour stay wires using the endless loop slings to attach the Tirfour cables to the top of the column section.

Attach the Tirfour to the construction yoke located on the anchor rod (**Figure 3.6.3-11**).

8. Remove the lifting bracket from the top of the column section and lower to ground.

Secure Column Section Using Four (4) Grip Hoists Attached to Slings at the Top of the Column The slings MUST GO around one or more of the 3" x 3" (76 mm x 76 mm) main vertical angles (see here).

DO NOT PUT THE SLINGS ONLY AROUND THE 2" x 2" (51 mm x 51 mm) DIAGONAL ALUMINUM ANGLES



1. Place capstan 20 to 25 meter from foundation inline with gin pole.
2. Align capstan and stake to ground.
3. Place HPU adjacent to capstan
4. Connect hydraulic hoses.
5. Start HPU, turn on pump
6. Operate capstan with foot pedal

Figure 3.6.3-9



Figure 3.6.3-10

#### D) Procedure for Moving Gin Pole to Second Lifting Location

1. Change the rope on the capstan to the one for lifting the slider bracket (Figure 3.6.3-12).
2. Raise the slider bracket (Figure 3.6.3-13).
3. Once the slider bracket is in position, turn the slider bracket 90 degrees until it faces the corner angle of the column section (Figure 3.6.3-14).
4. Clamp the slider bracket to the column section by closing the keeper clamps around the corner angle and tighten both keeper screws. These may need to be tightened up with a socket wrench.



Figure 3.6.3-11 Note the positioning ropes on the gin pole, four places used to keep gin pole centered when lifting.



Figure 3.6.3-12



**Figure 3.6.3-13**



**Figure 3.6.3-14** Turn the slider and close the swing clamps around the large angle.



**Figure 3.6.3-15** Hand tighten then tighten with wrench.



**Figure 3.6.3-16** Lift the Gin Pole Mast

DO NOT OVER TIGHTEN (**Figure 3.6.3-15**).

5. Remove the four temporary ropes that are attached to the ring on top of the gin pole mast.
6. Change the rope in the capstan to the one used for lifting the gin pole mast.
7. Lift the gin pole mast (**Figure 3.6.3-16**).
8. Once the mast has been raised to the top, place the two keeper bolts (or ERS Bolts) through the holes provided at the bottom of the gin pole and secure with nuts (hand tighten) (**Figure 3.6.3-17**).

**E) Procedure for Lifting Column Sections (Other than 1st Column Section)**

1. Change the rope in the capstan to the one used for lifting column sections (**Figure 3.6.3-18**).



**Figure 3.6.3-17** Once the mast has been raised to the top, place the two keeper bolts (or ERS Bolts) through the holes provided at the bottom of the gin pole and secure with nuts.



**Figure 3.6.3-18** Gin Pole Tilt Up Hinge



**Figure 3.6.3-19** Sequence of erecting a column section.



**Figure 3.6.3-20** The slings must go around one or more of the 3" x 3" (76 mm x 76mm) main vertical angles.



**Figure 3.6.3-21**

2. Attach the lifting bracket, hoisting rope and tag line to the top of the column section.
3. The column section should be located on the ground for lifting.
4. Raise the column section with the davit arm positioned 180 degrees away from the column section. This will keep the column section away from the ERS tower which will decrease the possibility of the column section being raised catching on the ERS tower.
5. Use the capstan to raise the column section to a position that is slightly higher than needed. Allow for the clearance of the alignment pins located on column section end plates.
6. To turn the davit arm 180 degrees place a spud wrench in one of the four holes provided on the gin pole mast at the bottom of the slider bracket and pull.
7. When the column section is directly over the tower slowly lower the column section by sliding the lifting rope back through the capstan (**Figure 3.6.3-19**).



8. The HPU should ALWAYS be turned off during this procedure in order to eliminate the noise of the motor. This will allow for better communication between the people on the tower and the people operating the capstan.

9. Once the second column is in place, attach four more temporary Tirtfour grip guy wires at the top of the column utilizing endless loop slings and construction yoke at the permanent anchor (**Figures 3.6.3-20 and 3.6.3-21**).

DO NOT PUT THE SLINGS ONLY AROUND THE 2" × 2" (51mm × 51mm) DIAGONAL ALUMINUM ANGLES.

#### REFERENCES

1. Dr R P Rokade, Senior Principal Scientist, CSIR-SERC, Chennai - An Indigenous Technology for Quick Restoration of Power.
2. Emergency Restoration System for Power Lines (ERS)-CSIR Structural Engineering Research Centre (CSIR-SERC), Chennai.

# Experimental Investigation of Geo Polymer Concrete in Different Mix Proportions by using Fly Ash and GGBS

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**Abstract:** Concrete is the world's most utilised construction material which required large quantities of Portland cement. The production of cement is a major source for the emission of green house gas such as CO<sub>2</sub> which leads to global warming. About 38.2 gigatonnes of CO<sub>2</sub> released by cement production between 1930-2013. Geopolymer concrete is a special concrete which doesn't require the Ordinary Portland Cement and also reduces the emission of CO<sub>2</sub>. The Geopolymer Concrete is made up of industrial by-products (which contains more Silica and Alumina) and activated with the help of Alkaline solution (combination of sodium hydroxide and sodium silicate). The high viscosity nature of Geopolymer Concrete had the ability to fail due to lack of compaction. In improvising the issue, Self Compacting Geopolymer Concrete (SCGC) has been introduced. The SCGC doesn't require any additional compaction it will flow and compacted by its own weight. For the present investigation following materials are selected. 1. GGBS as a binder. 2. 8 M NaOH, Na<sub>2</sub>SiO<sub>3</sub> is selected and alkaline to GGBS ratio is kept as 0.35. 3. Alkaline ratio (NaOH : Na<sub>2</sub>SiO<sub>3</sub>) varying from 1:1 to 1:3. 4. The steel fibre is selected in this investigation.

**Keywords:**

## INTRODUCTION

Geopolymer concrete can be seen as a more viable and sustainable solution to highly energy intensive conventional Portland cement concrete. The utilization of various industrial by-products such as fly ash, GGBS, rice husk ash, etc. as polymerized binder also alleviates their disposal problem as well. High early age compressive strength can be produced in geopolymer concrete. However, the major constraint of the use of GPC is the requirement for high-temperature curing. Extensive research is still required to obtain standard design mixtures of geopolymer concrete as well as to mitigate the need for high-temperature curing.

The reduction of pollution on the environment can be achieved by increasing the usage of industrial wastes instead of cement. The utilization of industrial waste in this segment could become an important way of reducing the construction cost and also one of the best methods for the safe disposal of industrial byproducts (Khan, et al. 2018). These comprise the use of supplementary cementitious materials such as silica fume, rice husk ash, metakaolin, fly ash and Ground Granulated Blast furnace Slag (GGBS) which is the choice for the binders as partial replacement of Portland cement. Extensive researches have been carried out, and it is found that geopolymer concrete is an appropriate alternative material which eliminates the use of OPC in concrete.

## GEOPOLYMER CONCRETE

Geopolymer was the name given by Daidovits in 1978 to materials which are characterized by chains or networks or inorganic molecules. Geopolymer cement concrete is made from utilization of waste materials such as fly ash and ground granulated blast furnace slag (GGBS). Fly ash is the waste product generated from thermal power plant and ground granulate blast furnace slag is generated as waste material in steel plant. Both fly ash and GGBS are processed by appropriate technology and used for concrete works in the form of geopolymer concrete. Geopolymer concrete is a type of concrete that is made by reacting aluminate and silicate bearing materials with a caustic activator, such as fly ash or slag from iron and metal production. It can be a suitable substitute for ordinary Portland cement (OPC).

It helps to reduce the stock of wastes and also reduces carbon emission by reducing Portland cement demand. The main constituent of geopolymers source of silicon and aluminium which are provided by thermally activated natural materials (e.g. kaolinite) or industrial byproducts (e.g. fly ash or slag) and an alkaline activating solution which polymerizes these materials into molecular chains and networks to create hardened binder. It is also called as alkali-activated cement or inorganic polymer cement.

The main constituent of geopolymers source of silicon and aluminium which are provided by thermally activated natural



Figure 1 Geopolymer concrete

materials (e.g. kaolinite) or industrial byproducts (e.g. fly ash or slag) and an alkaline activating solution which polymerizes these materials into molecular chains and networks to create hardened binder. It is also called as alkali-activated cement or inorganic polymer cement. It is a more environmentally friendly alternative to conventional Portland cement [1]. It relies on minimally processed natural materials or industrial byproducts to significantly reduce the carbon footprint of cement production, while also being highly resistant to many common concrete durability issues. Usage of cement from the recent years was increasing in a large scale due to the development of infrastructure. For the manufacturing of cement huge scale of natural resources are utilized due to this reason the natural resources were depleting. So, there is a necessity of identifying an alternative material in the place of cement as a binder in the concrete (Figure 1).

#### USES OF GEOPOLYMER CONCRETE

Geopolymer concrete is an innovative and eco-friendly construction material and an alternative to Portland cement concrete. Use of geopolymer reduces the demand of Portland cement which is responsible for high CO<sub>2</sub> emission. It is being used for railway sleepers, electric power poles, road pavements, cement mortar, Marine structures and Waste containments. The current trend of research is under way to develop geopolymer systems that create a low embodied energy, low carbon dioxide binder that has similar properties to Portland cement. Geo polymer cement concrete is produced with waste materials like fly ash and ground granulated blast furnace slag (GGBS). Fly ash is a debris in thermal power plant and ground granulated blast furnace slag is also a debris in steel plant. The fly ash and GGBS are refined and utilized in the geopolymer concrete in a specific methodology. This type of concrete helps in minimizing the stock of wastes. Utilization of geopolymer concrete brings economy in construction; reduce pollution and less harmful to the environment. So far in India, geopolymer concrete has been used in the Delhi Metro Project. Thus it can be considered that Geopolymer concrete, as a replacement for Portland cement has wide scope in India.

#### NEED OF GEOPOLYMER CONCRETE

Geopolymer concrete is economical, low energy consumption, thermally stable, easily workable, eco-friendly, cementless, and durable. GPC reduces carbon footprints by using industrial solid waste like slag, fly ash, and rice husk ash. To produce environmental friendly concrete, It is essential to replace the cement with some other binders which should not create any bad effect on environment. Geopolymer concrete is more resistant to corrosion and fire, has high compressive and tensile strengths, and it gains its full strength quickly (cures fully faster). It also shrinks less than standard concrete.

#### REVIEW OF LITERATURE

Abdul Aleem, et al (2012) studied the Optimum mix for the Geopolymer concrete and concluded that the Geopolymer concrete showed high performance with respect to workability and strength. The author found that high early strength was obtained in the Geopolymer concrete mix. There was increase in compressive strength with increase in percentage of fine and coarse aggregates up to the optimum level. The optimum mix of Fly Ash: Fine aggregate: Coarse aggregate was 1:1.5:3.3 with alkaline solution (NaOH and Na<sub>2</sub>SiO<sub>3</sub> combined together) to fly ash ratio of 0.35.

Abdullah, et al (2011) based on literature review on mechanism and chemical reaction of Fly Ash Geopolymer binder, they have observed that the exact geopolymerization mechanism is not well understood because the geopolymerization process involves a substantially fast chemical reaction and every material used in geopolymer has its own function and role to create a chemical reaction and mechanism.



Abhilash, et al (2016) have conducted an experimental study on the strength properties of Fly Ash (FA) and GGBS based Geopolymer Concrete. Fly ash and GGBS were used at different levels (FA 50% - GGBS 50%, FA 75% - GGBS 25% and FA 100% - GGBS 0%) using sodium silicate ( $\text{Na}_2\text{SiO}_3$ ) and sodium hydroxide (NaOH) solutions as alkaline activators. Specimens were cast and cured for different curing periods, namely, 7, 14, 28, 56 and 112 days at ambient room temperature to determine the mechanical properties of Geopolymer concrete. They have concluded that GGBS blended fly ash based GPC mixes attained enhanced mechanical properties at ambient room temperature curing without the need of heat curing. Using 100% fly ash decreases strength and the cost is also low compared to the 50% GGBS & 50% Fly ash.

Jeyasehar, et al (2013) developed fly ash based geopolymer precast concrete elements such as beams. In this research, in addition to the flexural study, the mechanical properties of geopolymer concrete composites such as compressive strength, tensile strength, and modulus of rupture were determined and compared with that of conventional OPC concrete. Totally five beams, each of size 125 mm  $\times$  250 mm  $\times$  3200 mm were cast and tested. One beam with conventional OPC concrete was taken as control specimen and the remaining four beams were geopolymer concrete beams prepared with varying ratios of alkaline solution to fly ash as 0.40, 0.45, 0.50 and 0.55. Sodium based activator solutions were used in this study to activate the fly ash. The experimental results of moment curvature and load-deflection performance were compared with the analytical solutions. The test results revealed that the strength of increased geopolymer concrete increased with increase in the ratio of activator solution to fly ash up to the ratio of 0.50. Among all GPC mixes, the geopolymer concrete with 8 molarity of NaOH exhibited higher strength.

Aravindan, et al (2015) This paper investigates about the long term strength and durability of alkali-activated and fly ash based Geopolymer concrete comparing with the conventional concrete of M40 grade. The alkali activators are prepared by combining sodium hydroxide and sodium silicate solution in the ratio of 2.5 and molarities are 12M and 16M by varying two different curing regimes namely dry curing and open air curing. Totally nine mixes were prepared with NaOH concentration of 12M and 16M and with two curing regimes namely open air curing and dry curing. Split tensile strength, flexural strength and durability tests namely rapid chloride permeability tests (RCPT) and sorptivity tests were conducted on 56 and 90 days. Compressive strength tests were carried out on 14, 28, 56 and 90 days. There is increase in strength characteristics with increase in concentration of sodium hydroxide solution and open air cured specimens gained more strength than dry cured specimens. However, the sorptivity and rapid chloride permeability test results were not found to perform well due to cracking of surface. When compared with conventional concrete results, the strength gained is more in AAS-FA based Geopolymer concrete. There was a large reduction in durability properties (both RCPT and sorptivity of AAS-fly ash based Geopolymer concrete) than nominal mix conventional concrete. Further research should be undertaken on durability properties.]

## EXPERIMENTAL INVESTIGATION

This chapter describes the properties of constituent materials, mix design for geopolymer concrete composites, preparation of test specimens, curing methods, and different testing methods carried out for the determination of compressive strength, split tensile strength, modulus of rupture, impact strength, and flexural behaviour of reinforced beams which was studied as part of this experimental work. The drying shrinkage is very low with regard to cement concrete. Thus, it becomes applicable for thick and greatly constrained concrete structural members. It contains low heat of hydration relating to cement concrete. According to ASTM 1202C, It has extreme compressive and tensile strengths. Specimens are tested after completion of curing and for 7 days, 14 days, 21 days and 28 days these are tested by Universal Testing Machine.

Thorough mixing of materials is essential for the production of uniform concrete. The mixing should be ensured that the mass becomes homogeneous, uniform in colour and consistency. The mould specimens were applied with oil in all inner surface of the mould and to be dumping the mixed fresh concrete in required steel mould. After 24 h demould the specimens without any damage. The test specimens are stored in a room temperature at 27°C for 24 h from the time of addition of water for dry ingredients. The specimen is removed from the mould and it is immersed in water for curing

## MATERIALS USE

- Fly Ash;
- GGBS;
- Manufactured sand (M.sand);
- Quarry Dust;
- 10 mm Coarse Aggregate;

- Alkaline activator - combination of sodium silicate solution and sodium hydroxide;
- Steel Fibres.

### Fly Ash

Fly ash is manufactured by the burning of coal in an electrostatic precipitator, a byproduct of industrial coal. One of the most important fields of application for fly ash is PCC pavement, where a large quantity of concrete is used and economy is an important factor in concrete pavement construction.

### Ground-Granulated Blast-Furnace Slag (GGBS)

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder.

### Manufactured Sand (M.sand)

Manufactured sand (M-Sand) is a substitute of river sand for concrete construction. Manufactured sand is produced from hard granite stone by crushing. The crushed sand is of cubical shape with rounded edges, washed and graded to as a construction material. The size of manufactured sand (M.sand) is less than 4.75 mm.

### Quarry Dust

Now-a-days the natural river sand has become scarce and very costly. Hence we are forced to think of alternative materials. The Quarry dust may be used in the place of river sand fully. The world wide consumption of fine aggregate in concrete production is very high, and several developing countries have encountered difficulties in meeting the supply of natural fine aggregate in order to satisfy the increasing needs of infrastructural development.

### 10 mm Coarse Aggregate

Coarse aggregates are any particles greater than 0.19 inch, but generally range between 3/8 and 1.5 inches in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the



Figure 2 Flyash



Figure 3 Ground-Granulated Blast-Furnace Slag (GGBS)



Figure 4 Manufactured sand (M.sand)



Figure 5 Manufactured sand (M.sand)



remainder.10 mm crushed river aggregate to concrete production specification. Blue grey to brown in colour this aggregate can meet many job application. A hard and durable rock, washed and screened, with consistent cubic particle shape.

### Steel Fiber

Use of crimped steel fibers of aspect ratio (a/d) 60 is used. Crimped stainless steel fibers are used. The use of fibers in concrete has the property to resistance against cracking and crack propagation. The fiber composite pronounced post cracking ductility which is unheard of in ordinary concrete. Low carbon cold drawn hooked end steel fibres having a modulus of elasticity of  $2 \times 10^5$  MPa, the density of  $7850 \text{ kg/m}^3$ , and yield strength of 650 MPa was purchased from Mumbai, India. The steel fibres are shown in **Figure 7**.

### Alkaline Activator

The main alkaline activator was the mixture of sodium silicate and sodium hydroxide, which was controlled by the silicate modulus and  $\text{Na}_2\text{O}$  content. Therefore, it is essential to investigate the effects of an optimum activator on the engineering properties of AAS pastes. To avoid effects of unknown contaminants in laboratory tap water, distilled water was used for preparing the activator solution. Activator solution was prepared at one day prior to its use in specimen casting.

Sodium Hydroxide: Sodium hydroxide (NaOH) with 97%-98% purity in pellet form was used to prepare the alkaline activator solution. It was purchased from M/s. Mercury Chemical Enterprises Company, Salem, India.

Sodium silicate: Sodium silicate in the form of the solution was used to prepare the alkaline activator solution. It was purchased from M/s. Mercury Chemical Enterprises Company, Salem, India. Its chemical composition was 14.7% of  $\text{Na}_2\text{O}$ , 55.9 of water and 29.4% of  $\text{SiO}_2$  by mass.

### Water

Distilled water was used to prepare the sodium hydroxide solution to attain the required molarity; an additional quantity of potable water was added to the mix to achieve the desired workability.



**Figure 6** Manufactured sand (M.sand)



**Figure 7** Steel fibres



**Figure 8** Alkaline Activator

### Mix Design

Concrete mixes are designed by selecting the proportions of the mix components that will develop the required strength, produce a workable consistency concrete that can be handled and placed easily, attain sufficient durability under exposure to in-service environmental conditions, and be economical. The mass of fly ash combined with alkaline liquid can be computed by knowing the density of concrete. The ratio of alkaline liquid to fly ash was taken as 0.4, and the mass of alkaline liquid and mass of fly ash were found out. Similarly, the ratio of sodium silicate solution to sodium hydroxide solution was kept as 2.5, and the mass of sodium hydroxide and sodium silicate solutions were determined.

### Preparation of Alkaline Liquids

Right now geo-polymer concrete is blends of fluctuating molarities of sodium hydroxide ( 8M, 10M). The sub-atomic load of sodium hydroxide is 40. To plan 8 M for example 8 molar sodium hydroxide arrangement, 320 g of sodium hydroxide drops are gauged and they can be broken up in refined water to shape 1 liter arrangement. For this, volumetric jar of 1 liter limit is taken, sodium hydroxide chips are added gradually to refined water to get ready 1 liter arrangement. The sodium silicate arrangement and the sodium hydroxide arrangement were combined in any event one day before use to set up the alkaline liquid with the steel fibers.

### Details of Mixing Proportions

This Chapter describes the experimental work. First, Mix design of geo-polymer concrete, manufacturing and curing of the test specimens are explained. This is then followed by description of types of specimens used, test parameters, and test procedures. The mix design has been done as per the Indian standard codes, IS: 10262-2009.

- ⊙ Mix 1 - Conventional concrete;
- ⊙ Mix 2 - GPC+ 8M in Alkaline solution;
- ⊙ Mix 3- GPC+ 10M in Alkaline solution;
- ⊙ Mix 4 -GPC+ 8M in Alkaline solution+ 0.5% Steel fiber;
- ⊙ Mix 5 -GPC+ 10M in Alkaline solution+ 0.5% Steel fiber;
- ⊙ Mix 6 -GPC+ 8M in Alkaline solution+ 1.0% Steel fiber;
- ⊙ Mix 7- GPC+ 10M in Alkaline solution+ 1.0% Steel fiber.

### Preparation of Geopolymer Concrete

The mix design in the case of geo-polymer concrete is based on conventional concrete with some modification. In the case of conventional concrete the material proportion can be found out for the required strength using the code, but in the case of geo-polymer concrete there is no design method or codal provisions.

### Mixing, Placing and Compacting

First, the quarry dust, coarse aggregate and fly ash are mixed in dry condition for 3-4 minutes and then the alkaline solution which is a combination of sodium hydroxide solution and sodium silicate solution with Steel fiber is added to the dry mix. The mixing is done about 6-8 minutes for proper bonding of all the materials. After the mixing, the cubes are casted with the seven mixes by giving proper compaction. The cubes are de molded after 1 day of casting and they are placed in the direct sun light for curing 3,7,14 and 28 days. The sodium silicate solution and the sodium hydroxide



Figure 3.8 Geopolymer concrete with steel fibre

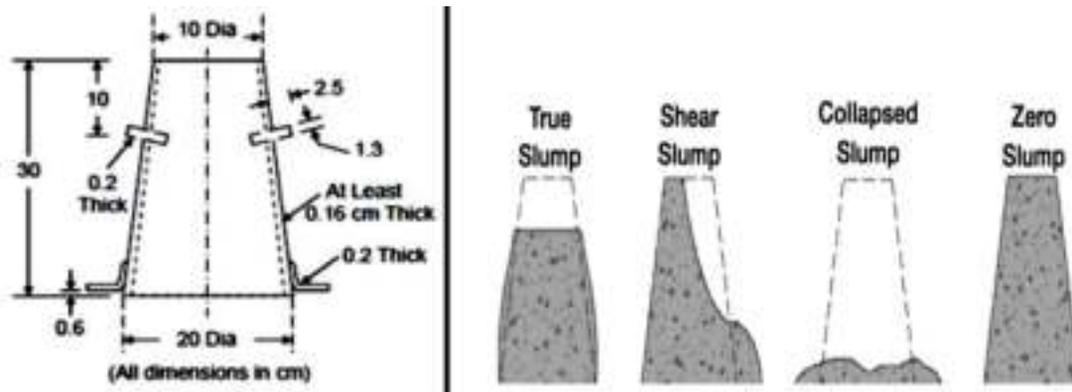


Figure 8 Slump test of geopolymer concrete

solution were mixed together at least one day prior to use the solution. Placement and finishing, although properly proportioned concrete mixes containing should benefit workability and finishing.

The concrete mix is placed in layers in standard steel moulds (cube, cylinder and beam) for casting the concrete specimens. The concrete placed was compacted using table vibrator. Before casting a thin coat of oil was applied on the interior faces of the mould to prevent damages to concrete on extraction. Normal procedure for screening, finishing, edging and jointing of conventional PCC are also applicable to Geopolymer concrete. The proper application of a curing compound should retain moisture in the concrete for sufficient period of time to permit strength development. After 24 hours of casting, the specimens are removed from the mould with great care. The surface of the specimens is cleaned gently to remove loose particles and is lowered in a curing tank containing clean fresh water.

#### EXPERIMENTAL PROGRAMME

Slump cone, compressive strength, split tensile strength, water absorption, water permeability, thermal shock, thermal resistance, and acid resistance were the tests conducted on fresh and hardened concrete for the mixes recorded above. Three specimens were casted for each test respectively for a mix. Geopolymer specimens were kept in open air in ambient room temperature (25–30°C). Cement concrete specimens were dipped in water for curing until the day of testing. The tests on fresh and hardened concrete were conducted as per Indian codal provisions.

#### WORKABILITY OF THE GEOPOLYMER CONCRETE

Slump cone was conducted to find the workability of concrete. Both the geopolymer and cement fresh concretes with various types of fine aggregates were allowed to conduct the slump cone test. The slump value of geopolymer concrete has been tested using a normal slump cone test as per IS 7320-1974. The dimensions of the slump cone are top diameter-10 cm, height-30 cm and bottom diameter-20 cm. The concrete has been placed into the cone in three layers and tamped properly to remove the air voids. The cone is then lifted vertically and the readings are noted using a steel scale.

In general, the viscosity of geopolymer concrete was high due to the presence of sodium silicate in the mix. One of the prime objectives of this research was to evaluate the workability of fresh geopolymer concrete. In this study, the workability of geopolymer concrete in the fresh stage was examined using a compaction factor apparatus.

The test was carried out for GPC mix and FRGPC mix. The ratio of partially compacted concrete and fully compacted concrete gives the compaction factor value. The test was carried out following the procedure prescribes in IS: 1199 – 1959 [33]. Figure 3.12 shows the compaction factor apparatus.

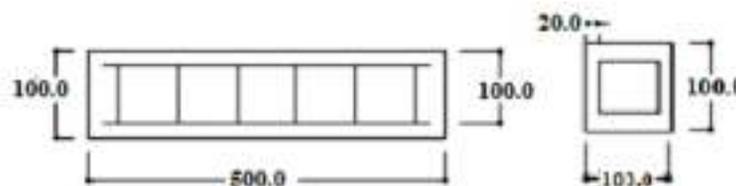


Figure 9 Cube compression test setup

### Compressive Strength

The cube specimens are taken of size 100 mm × 100 mm × 100 mm. The Geopolymer concrete specimens are tested for their compressive strength at the age of 3 days, 7 days, 14 days and 28 days. They are cured by direct sun-light and strengths are calculated for 3 days, 7 days, 14 days and 28 days. The result will show that the strength of Geopolymer concrete is increasing with the increase of the molarity of sodium hydroxide. The concrete cubes are tested for their compressive strength in the compression testing machine as per IS 516-1959 specifications.

### Splitting Tensile Strength

The splitting tensile strength of concrete cylinders (100 mm dia and 200 mm ht) are tested as per IS 5816-1970 specification. The rate of loading shall be applied without shock increased continuously at rate 1.2 N (mm<sup>2</sup>/min) to 2.4 N (mm<sup>2</sup>/min). The splitting tensile strength  $\tau$  of the specimen shall be calculated from the following formula.

$$\tau = 2P / \pi dL \text{ kg/cm}^2;$$

P = maximum load in kg applied to the specimen;

d = measured diameter in cm of the specimen;

L = measured length in cm of the specimen.

### Flexural Strength Test

Flexural strength is a measurement that indicates the resistance of a material to deformation when placed under load. The beam specimens were 100 × 100 × 500 mm in cross-section. Two-legged vertical stirrups of 8 mm diameter at a spacing of 100 mm centre to centre were provided as shear reinforcement. The clear cover of the beam was 20 mm. The geometry of the beam specimen is shown in **Figure** .



**Figure 10** Flexural strength test



**Figure 11** Impact test



**Figure 12** Water absorption

The test specimen was mounted in a universal testing machine of 1000 kN capacity. The load was applied on two points from centre of the beam towards the support. The flexural strength of the specimen shall be expressed as the modulus of rupture  $f_b$ .

The Flexural Strength or Modulus of Rupture ( $f_b$ ) is given by

$$f_b = Pl/bd^2 \text{ (when } a > 13.3 \text{ cm)}$$

$$f_b = 3Pa/bd^2 \text{ (when } a < 13.3 \text{ cm)}$$

where,  $a$  = the distance between the line of fracture and the nearest support, measured on the center line of the tensile side of the specimen (cm);  $b$  = width of specimen (cm);  $d$  = failure point depth (cm);  $l$  = supported length (cm);  $P$  = maximum load taken by the specimen (kg).

### **Impact Test**

The impact resistance of GPC was evaluated by conducting the repeated impact test of drop weight impact test as per the guidelines prescribed in ACI 549.2R-89 disc specimens of size 100 mm diameter and 65 mm height were cast for this study and test was carried out following the standards according to ACI 549.2R-89. The blows applied for causing the first crack and the blows applied for the ultimate failure of the specimen were counted and recorded. The ultimate failure was taken as a complete opening-up failure of the disc, and first crack strength and ultimate crack strength were calculated.

### **Water Absorption Studies on Geopolymer Concrete**

The durability of concrete has been evaluated in this study through parameters related to permeability. The absorption study was done to know the permeability characteristics of geopolymer concrete and was performed in accordance to ASTM C 642-82 at 7, 14 and 28 days. The specimens used for this test were  $100 \times 100 \times 100$  mm cubes with different concentration of NaOH ranging from 8M to 14M. Both specimens that are cured at room temperature and at  $60^\circ\text{C}$  are tested for water absorption criteria. The percentage absorption was calculated using the equation (4.5). The absorption values for all the specimens were compared with recommendations given by Concrete Society Board (CEB, 1989) and this comparison is presented in

$$\text{Absorption Percentage} = (W_2 - W_1) / W_1 \times 100$$

Where  $W_1$  = weight of specimen after complete drying at  $105^\circ\text{C}$  (kg);  $W_2$  = final weight of surface dry sample after immersion in water (kg).

## **EXPERIMENTAL RESULTS AND DISCUSSIONS**

### **Workability Test**

Concrete slump test or slump cone test is to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work. Concrete slump test is carried out from batch to batch to check the uniform quality of concrete during construction. The slump test is the most simple workability test for concrete, involves low cost and provides immediate results. Generally the water content is the main factor which affects

**Table 1** Workability test value for M40

Mix Id	Mix Designation	Slump (mm)	Compaction Factor
Mix 1	Conventional Concrete	120 mm	0.934
Mix 2	GPC+ 8M in Alkaline solution	90 mm	0.882
Mix 3	GPC+ 10M in Alkaline solution	85 mm	0.873
Mix 4	GPC+ 8M in Alkaline solution+ 0.5% Steel fiber	80 mm	0.851
Mix 5	GPC+ 10M in Alkaline solution+ 0.5% Steel fiber	88 mm	0.838
Mix 6	GPC+ 8M in Alkaline solution+ 1.0% Steel fiber	73 mm	0.827
Mix 7	GPC+ 10M in Alkaline solution+ 1.0% Steel fiber	70 mm	0.825

the workability otherwise called as slump of a concrete mix. The influence of addition of alkaline activator on the mixture of geopolymer concrete for slump was tested. The ratio of alkaline activator which resulted in best workable slump along with maximum compressive strength was identified as the best mix. The slump value slightly decreased with the increase in concentration of sodium hydroxide in the alkaline activator solution.

The compaction factor test determined the workability of geopolymer concrete with and without steel fibres presents the compaction factor values of GPC mix. The workability of GPC specimens varies from 0.81 to 0.90. The workability of 0.90 was obtained for 10% of GGBS with 90% of fly ash. The increase in GGBS content resulted in reduced workability. But there is only a slight decrease in workability and it may be due to the increase of GGBS content is mainly attributed to the angular shape of GGBS particles compared to the spherical shape of the fly ash and the accelerated reaction of the high calcium content in GGBS.

### Compressive Strength

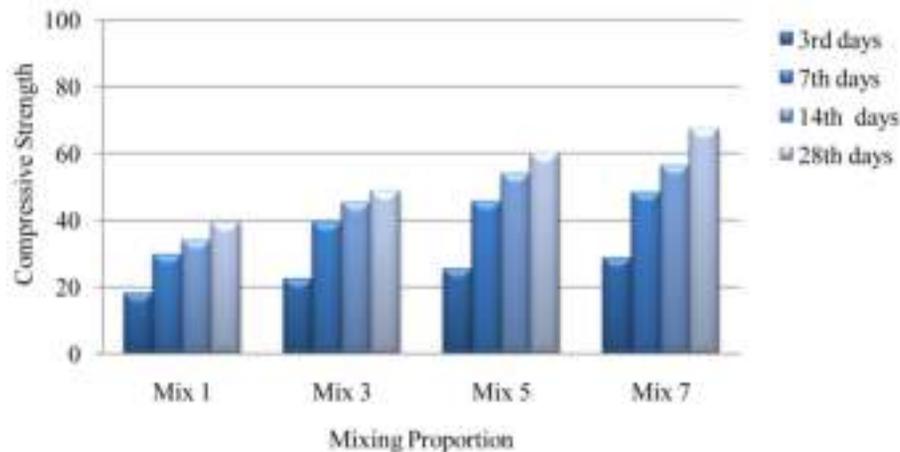
The compressive strength of conventional and simultaneously replacement for M40 and M60 grade concrete, is determined by testing 10 mm × 100 mm × 100 mm cubes for 3 days, 7 days, 14 days and 28 days strengths in compression testing machine. Cubes about a total number of 56 specimens from all 7 mix proportions are tested. All specimens are tested to obtain test strength from each variation. The specimens were tested on 1000 kN as per IS: 516-1983.

As the age of concrete increases from 7 days to 28 days, the compressive strength of concrete also gets increased. The compressive strength of concrete increased with the increase in the content of GGBS in the binder. Compared to GPC specimen, the compressive strength of other GPC specimens increased by 1.5 times to 4.5 times at the age of 28 days. From all the percentages of replacements for M40 grade concrete it can be observed that the maximum compressive strength is 67.54 N/mm<sup>2</sup> and lowest compressive strength is 39.33 N/mm<sup>2</sup>. In case of M60 grade concrete it can be observed that the maximum compressive strength is 58.77 N/mm<sup>2</sup> and lowest compressive strength is 83.54 N/mm<sup>2</sup>. The molarity increases the compressive strength also increases for different molarity. It was observed from the test results that the maximum compressive strength. The strength of geopolymer concrete was increased with increase in percentage of GGBS in a mix.

Comparison of the compressive strength are presented in the table 5.3 and 5.4. In the case of M40 the compressive strength was increased 42% at the age of 3 days and 28 days in Mix 7. Similarly, In the case of Mix1 the compressive strength at the age of 28 days was increased 58% with mix 7. In the case of M60 the compressive strength was increased

**Table 2** Compressive strength for the ratio of M40

Grade	Description	Compressive strength Mpa				Ratio M <sub>7d</sub> /M <sub>28d</sub>
		3 <sup>rd</sup> days	7 <sup>th</sup> days	14 <sup>th</sup> days	28 <sup>th</sup> days	
Mix 1	Conventional Concrete (M40)	18.16	29.65	34.11	39.33	
Mix 2	GPC+ 8M in Alkaline solution	20.67	38.56	42.34	46.34	1.18
Mix 3	GPC+ 10M in Alkaline solution	22.28	39.45	45.32	48.76	1.05
Mix 4	GPC+ 8M in Alkaline solution+ 0.5% SF	23.67	43.35	49.14	57.76	1.08
Mix 5	GPC+ 10M in Alkaline solution+ 0.5% SF	25.22	45.54	53.88	60.11	1.04
Mix 6	GPC+ 8M in Alkaline solution+ 1.0% SF	26.28	46.44	52.84	64.65	1.01
Mix 7	GPC+ 10M in Alkaline solution+ 1.0% SF	28.54	48.37	56.47	67.54	1.11



**Figure13** Comparison between the compressive strength for the ratio of M60

45% at the age at the 3 days and 28 days in Mix 7. Similarly, in the case of Mix 1, the compressive strength at the age of 28 days was increased 61% in Mix 7.

### Split Tensile Strength

The variation of split tensile strength measured at the end of 3,7,14 days and 28 days .The specimens were tested on 1000 kN as per IS 5816- 1999. The split tensile strength of conventional and simultaneous replacements for M40 and M60 grade concrete are determined by testing 200 mm × 100 mm cylinders for 3 days, 7 days, 14 days and 28 days strengths in compression testing machine. Cylinders about a total number of 56 specimens from 7 mix proportions are tested. All specimens are tested to obtain test strength from each variation. The test results are shown in **Table 5.5** and **Table 5.6**.

The Split tensile strength are presented in the **Table 5.3** . In the case of M40 the Split tensile strength was increased 1.2 times at the age of 14 days and 21 days in Mix 7. Similarly, In the case of Mix 1, Split tensile was increased 1.8 times at the age of 28 days n the Mix 7. In the case of M60 the split tensile strength was increased 1.2 times at the age of 21 days and 28 days in Mix 7. Similarly, In the case of Mix 2, the Split tensile at the age of 28 days was increased 1.3 times and Mix 5. The molarity of 10M can be adopted for Geopolymer concrete mixes using fly ash and sodium based alkaline solution. It is found to be similar to compressive strength of GPC.

The split tensile strength are presented in the **Table 5.4**. In the case of M60 the split tensile strength was increased 1.4 times at the age of 21 days and 28 days in Mix 7. Similarly, In the case of Mix 2, the split tensile at the age of 28 days was increased 1.8 times and Mix 5. In the case of M40 the split tensile strength was increased 1.1 times at the age of 14 days and 21 days in Mix 7. Similarly, in the case of Mix 1, split tensile was increased 2.0 times at the age of 28 days n the Mix 7.

### Flexural Strength Test

Flexural strength is a measurement that indicates the resistance of a material to deformation when placed under load. Beams about a total number of 56 specimens from 7 mix proportions are tested. All specimens are tested to obtain test

**Table 3** Split tensile strength for the ratio of M60

Grade	Description	Tensile Strength Mpa				Ratio $M_{mix}/M_{ref}$
		3 <sup>rd</sup> days	7 <sup>th</sup> days	14 <sup>th</sup> days	28 <sup>th</sup> days	
Mix 1	Conventional Concrete ( Mcc)	1.64	1.97	2.34	2.98	
Mix 2	GPC- 8M in Alkaline solution	2.24	2.53	2.94	3.31	1.11
Mix 3	GPC- 10M in Alkaline solution	2.54	2.89	3.22	3.33	1.01
Mix 4	GPC- 8M in Alkaline solution+ 0.5% SF	2.96	3.14	3.38	3.75	1.13
Mix 5	GPC- 10M in Alkaline solution+ 0.5% SF	3.11	3.27	3.64	3.94	1.05
Mix 6	GPC- 8M in Alkaline solution+ 1.0% SF	3.25	3.37	3.96	4.23	1.07
Mix 7	GPC- 10M in Alkaline solution+ 1.0%SF	3.32	3.87	4.12	4.93	1.17

**Table 4** Split tensile strength for the ratio of M60

Grade	Description	Tensile Strength Mpa				Ratio $M_{GPC}/M_{CC}$
		3 <sup>rd</sup> days	7 <sup>th</sup> days	14 <sup>th</sup> days	28 <sup>th</sup> days	
Mix 1	Conventional Concrete ( Mcc)	1.87	2.26	2.85	3.13	
Mix 2	GPC:1 8M in Alkaline solution	2.64	2.64	3.26	3.74	1.19
Mix 3	GPC:1 10M in Alkaline solution	2.81	2.95	3.42	3.96	1.06
Mix 4	GPC:1 8M in Alkaline solution + 0.5% SF	3.05	3.22	3.63	4.13	1.04
Mix 5	GPC:1 10M in Alkaline solution + 0.5% SF	3.28	3.65	3.97	4.35	1.05
Mix 6	GPC:1 8M in Alkaline solution + 1.0% SF	3.43	3.93	4.22	4.96	1.14
Mix 7	GPC:1 10M in Alkaline solution + 1.0% SF	3.87	4.38	4.87	5.12	1.03

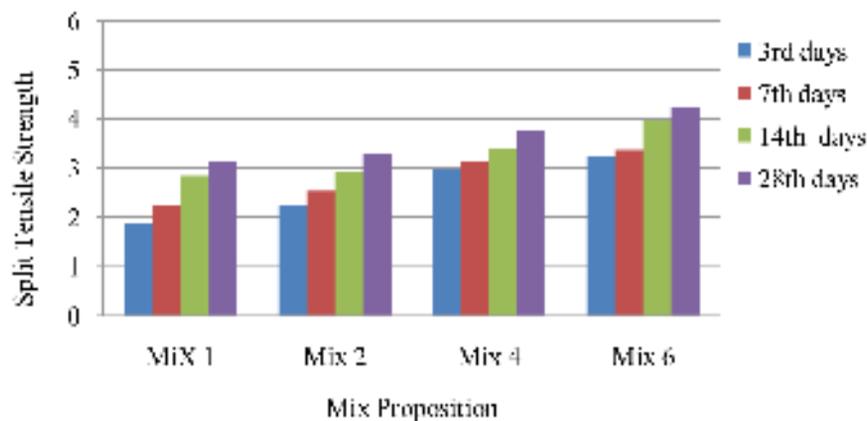
strength from each variation. The test results are shown in **Table 5.5** and **Table 5.6**. The beam specimens were 100 × 100 × 500 mm in cross-section. Two legged vertical stirrups of 8 mm diameter at a spacing of 100 mm centre to centre were provided as shear reinforcement. The clear cover of the beam was 20 mm.

Comparison of the flexural strength are presented in the **Table 5.6**. In the case of M40 the flexural strength was increased 32% at the age of 3 days and 28 days in Mix 7. Similarly, In the case of Mix1 the compressive strength at the age of 28 days was increased 43% with Mix 7. In the case of M60 the flexural strength was increased 37 % at the age at the 3 days and 28 days in Mix 7. Similarly, in the case of Mix1, the flexural strength at the age of 28 days was increased 46% in Mix 7. In terms of increase in the amount of GGBS, there is little improvement on the modulus of rupture regardless of the age of concrete. It makes the binder dense and improves the bonding effect between binders and aggregates.

Comparison of the Flexural strength are presented in the **Table 5.7**. In the case of M40 the flexural strength was increased 38% at the age of 3 days and 28 days in Mix 7. Similarly, In the case of Mix1 the compressive strength at the age of 28 days was increased 41% with mix 7. In the case of M60 the flexural strength was increased 39% at the age at the 3 days and 28 days in Mix 7. Similarly, In the case of Mix1, the Flexural strength at the age of 28 days was increased 44% in Mix 7. Test results showing the capability of the deformation of GPC specimens in the days ratio of M40 and M60 load appear in Table 4.11 and Figure 4.12. The modulus of rupture of GPC specimens ranges from 5.16 MPa to 8.96 MPa at the 28 days and 7.13 MPa to 10.11 MPa at 28 days. However, the modulus of rupture increases with increasing content of GGBS replacing fly ash. It makes the binder dense and improves the bonding effect between binders and aggregates. It can be seen that Geopolymer with 1.0% of steel fibres content has the highest modulus of rupture with respect to all aspect ratios.

### Impact Strength

The performance of Geopolymer specimens due to the addition of steel fibres in different aspect ratios and volume fractions has been studied. Totally 14 Disc specimens were used to find the impact strength. Seven mix proportion were

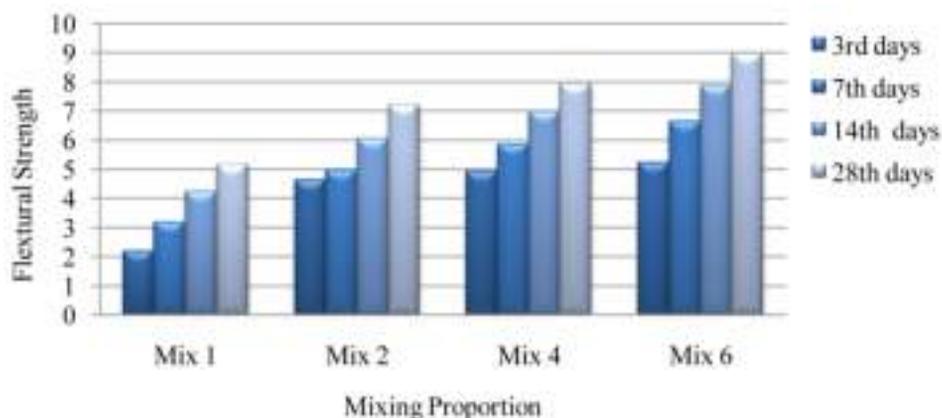


**Figure 14** Split tensile strength in the Molarity 8M for the ratio of M40



**Table 5** Flexural strength for the ratio of M60

Grade	Description	Flexural Strength Mpa				Ratio $\frac{M_{60c}}{M_{cc}}$
		3 <sup>rd</sup> days	7 <sup>th</sup> days	14 <sup>th</sup> days	28 <sup>th</sup> days	
Mix 1	Conventional Concrete	3.87	4.07	6.06	7.13	
Mix 2	GPC- 8M in Alkaline solution	4.27	5.16	7.14	8.14	1.14
Mix 3	GPC- 10M in Alkaline solution	4.98	6.14	7.95	8.76	1.08
Mix 4	GPC- 8M in Alkaline solution+ 0.5% SF	5.15	6.22	8.78	9.13	1.04
Mix 5	GPC- 10M in Alkaline solution+ 0.5% SF	5.89	6.84	9.11	9.64	1.06
Mix 6	GPC- 8M in Alkaline solution+ 1.0% SF	6.18	7.67	9.33	9.87	1.02
Mix 7	GPC- 10M in Alkaline solution+ 1.0% SF	6.98	8.17	9.84	10.11	1.02



**Figure 15** Comparison between the flexural strength 8 M or the ratio of M40

**Table 6** Water absorption for Geopolymer concrete for M40

	Weight of Concrete Before Specimen (kg)	Weight of Concrete Cubes After Acid Immersion) (Days) (kg)			Percentage of Water Absorption of Specimen After Immersion		
		7 <sup>th</sup> days	14 <sup>th</sup> days	28 <sup>th</sup> days	7 <sup>th</sup> days	14 <sup>th</sup> days	28 <sup>th</sup> days
Mix 1	2.84	2.9	2.93	2.96	2.11	3.17	4.23
Mix 2	2.92	3.0	3.03	3.05	2.74	3.77	4.45
Mix 3	2.94	3.03	3.07	3.08	3.06	4.42	4.76
Mix 4	3.11	3.177	3.19	3.25	2.15	2.57	4.50
Mix 5	3.14	3.23	3.25	3.29	2.87	3.50	4.78
Mix 6	3.2	3.28	3.3	3.32	2.50	3.12	3.75
Mix 7	3.22	3.31	3.32	3.37	2.80	3.11	4.66

used in the ratio of M40. The test results pertaining to first crack strength and failure strength of specimens are presented in **Table 5.8**. In the case of Mix 1 and Mix 7, failure strength were obtained 1.2 times of first crack strength. Using steel fibre in Geopolymer concrete were carry more strength than conventional concrete. It was observed that the Mix 2 specimen failed in a brittle manner and Mix 4 to Mix 7 specimen failed in a ductile manner. The test results reveal that the Mix 7 specimen has more crack resistance when compared to GPC specimens. The first crack strength of Mix 7 specimen is higher than that of the Mix 1 specimen.

The test results pertaining to first crack strength and failure strength of specimens are presented in **Table 5.9**. Seven mix proportion were used in the ratio of M60. In the case of Mix 1 and Mix 7, failure strength were obtained 1.4 times increased of first crack strength. Similarity of Mix 2 and Mix 4, failure strength were obtained 0.8 times increased of first crack strength. In the case of Mix 3 and Mix 5, failure strength were obtained 1.2 times increased of first crack strength. The test results reveal that the Mix 7 specimen has more crack resistance when compared to GPC specimens.

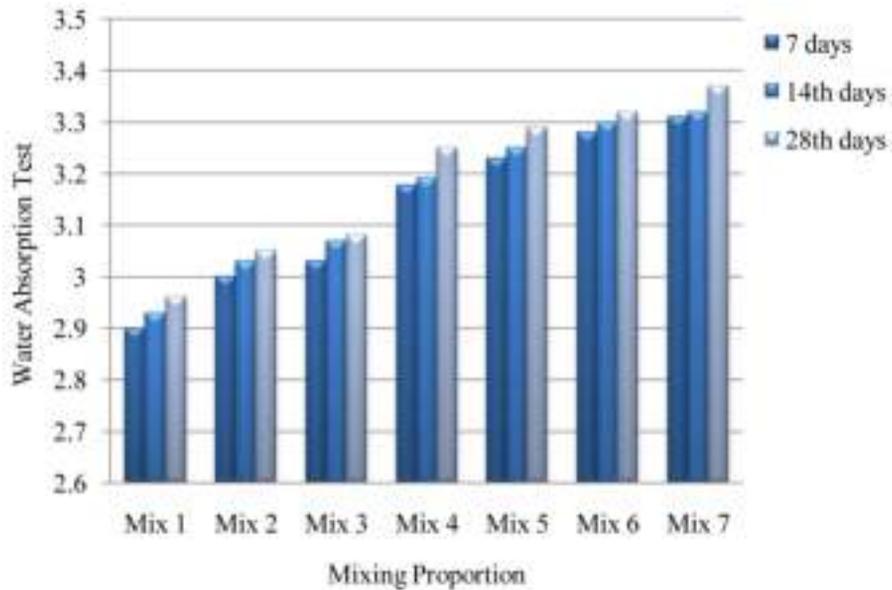


Figure 16 Comparison between the water absorption test for the ratio of M40

Table 7 Water absorption for Geopolymer concrete for M60

	Weight of Concrete Before Specimen (kg)	Weight of Concrete Cubes after Acid Immersion) (Days) (kg)			Percentage of Water Absorption of Specimen After Immersion		
		7 <sup>th</sup> days	14 <sup>th</sup> days	28 <sup>th</sup> days	7 <sup>th</sup> days	14 <sup>th</sup> days	28 <sup>th</sup> days
Mix 1	3.94	3.97	3.94	3.97	3.94	3.97	3.94
Mix 2	4.04	4.06	4.04	4.06	4.04	4.06	4.04
Mix 3	4.08	4.09	4.08	4.09	4.08	4.09	4.08
Mix 4	4.2	4.26	4.2	4.26	4.2	4.26	4.2
Mix 5	4.26	4.3	4.26	4.3	4.26	4.3	4.26
Mix 6	4.31	4.33	4.31	4.33	4.31	4.33	4.31
Mix 7	4.33	4.38	4.33	4.38	4.33	4.38	4.33

### Water Absorption

Water absorption characteristic of concrete plays an important role for the durability. The test was performed to evaluate the water absorption characteristics of geopolymer and control concrete. Test specimens for compressive strength and change in mass test were 100 × 100 × 100 mm cubes of control concrete and geopolymer concrete each. Table 5.11 and fig 5.12 presented in the ratio of M40, twenty one specimens for each test were prepared water absorption test and change in mass to take average result of the specimen.

The test was performed to evaluate the water absorption characteristics of geopolymer and control concrete. Test specimens for compressive strength and change in mass test were 100 × 100 × 100 mm cubes of control concrete and geopolymer concrete each. Table 5.12 and Figure 5.13 presented in the ratio of M60, twenty one specimens for each test were prepared water absorption test and change in mass to take average result of the specimen. Experimental results shown that the Weight of Concrete Cubes after acid immersion are increased 0.70 to 0.80 times than weight of Concrete before specimen at the ages of 28 days.

### SUMMARY AND CONCLUSION

In the current research, preliminary works were carried out to investigate the viability of utilizing Class F Fly ash collected from Mettur thermal power plant station to produce the Geopolymer Concrete (GPC). The development of GPC resolved the problems in the manufacturing of geopolymer concrete faced during primary works. The major problem that persisted in the preparation of geopolymer concrete was a delay in setting time, and the appropriate adding quantity of GGBS rectified it in it. The control volume fractions of fly ash and GGBS to attain the required strength were



determined from an adequate number of trials. The strength properties of the GPC were investigated. Based on the strength of GPC composite, the study was further extended to investigate the effect of steel fibres in different aspect ratios and volume fractions on the fresh property like workability and hardened properties such as density, compressive strength, split tensile strength, modulus of rupture, impact strength and water absorption test of geopolymer concrete (GPC) composites. Besides the determination of the said characteristics, the flexural behaviour of reinforced geopolymer concrete beams with and without steel fibres in different aspect ratios and volume fractions was also investigated. Based on the experimental investigation the following conclusions are listed below:

- The compressive strength is increased with the increase in the molarity of the sodium hydroxide;
- The split tensile strength has shown better performance compared to compressive strengths;
- The increase in compressive strength in comparison with control mix is nearly 15% in split tensile it was observed as 30%;
- When molarity of NaOH is changed from 8 Mole to 10 Mole, strength of the Geopolymer increased up-to 8%;
- Higher concentration (in terms of molarity) of sodium hydroxide solution results in higher compressive strength of fly ash and quarry dust based geo-polymer concrete;
- The mix GPC gives higher compressive strength, as it has high molarity of NaOH;
- Based on the experimental studies that were carried out on the conventional concrete slab and geopolymer concrete slab, it can be concluded that the strength characteristics of GPC is higher than the Normal RCC slab;
- The Geopolymer concrete slabs were used as the structural members due to its high strength and early strength gaining capacity;
- The developments of flexural cracks are relatively less in geopolymer RCC beams compared to conventional RCC beams;
- The failure occurred in the beams was in flexural mode and the cracks are generated from the tension zone to the compression zone;
- The compressive strength is greater than before due to decrease in porosity, as the fineness of fly ash is more in case of geopolymer concrete;
- The mix proportions, which are used to manufacture geopolymer and conventional concrete, are same;
- The limitations identified in the GPC are the delayed setting time and the requirement of curing to attain the required strength at early ages. The overall strength performance reflects through ductility, stiffness, energy absorption capacity and energy index was improved by the addition of steel fibres in different aspect ratios and volume fractions to GPC-1. These parameters are crucial in the design of earthquake resistant structures. In this context, it is desirable to add steel fibres in higher aspect ratios and volume fractions to enhance the impact resistance considerably. It is believed that steel fibre reinforced geopolymer concrete can be used in structures prone for impact loads.

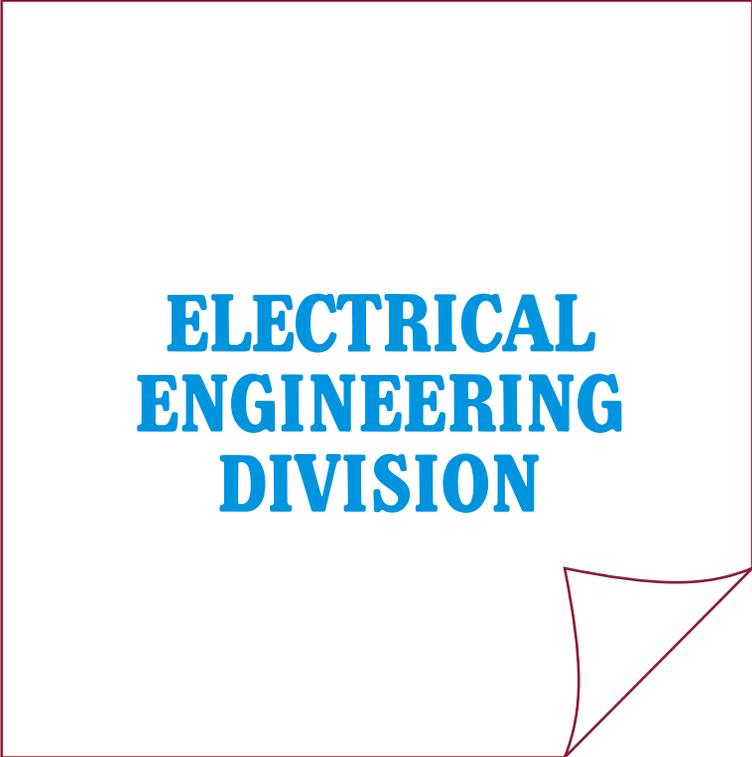
## REFERENCES

1. Aleem, M. I. Abdul and Arumairaj, P.D., Optimum mix for the Geopolymer concrete, Indian Journal of Science and Technology, ISSN: 0974- 6846, Vol. 5, No. 3, 2012.
2. Adam, A.A., Molyneaux, T.C.K. and Patnaikuni, I., Sorptivity and carbonation of geopolymer concrete Challenges, Opportunities and Solutions in Structural Engineering and Construction, London, ISBN 978-0-415-56809-8, 2010.
3. Abdullah, M. M. A., Hussin, K., Bnhussain, M., Ismail, K. N. and Ibrahim, W. M. W., Mechanism and Chemical Reaction of Fly Ash Geopolymer Cement- A Review, International Journal of Pure and Applied Sciences and Technology, ISSN 2229 – 6107, pp. 35-44, 2011
3. Abhilash, P., Sashidhar, C. and Reddy, I.V., Ramana, Strength properties of Fly ash and GGBS based Geo-polymer Concrete, International Journal of Chem Tech Research CODEN (USA), ISSN: 0974-4290, Vol.9, No.03, pp 350-356, 2016
4. Antony Jeyasehar, C, Saravanan, G, Salahuddin, M and Thirugnanasambandam, S 2013, Development Of Fly Ash Based Geopolymer Precast Concrete Elements, Asian Journal of Civil Engineering (BHRC), vol.14, no.4, pp.605-615.
5. Aravindan, S., Jagadish, N. and Guspher, A. Peter, Experimental investigation of alkali-activated slag and fly ash based geopolymer concrete, ARPN Journal of Engineering and Applied Sciences ISSN 1819-6608, Vol. 10, No. 10,



2015.

6. Behzad Nematollahi, Jay Sanjayan & Faiz Uddin Ahmed Shaikh 2014, Comparative deflection hardening behaviour of short fibre reinforced geopolymer composites, *Construction and Building Materials*, vol. 70, pp. 54-64.
7. Bhosale, M. A. and Shinde, N.N., Geopolymer Concrete by using Fly Ash in Construction, *IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE)*, ISSN : 2278-1684, Vol. 1, No. 3, pp 25-30, 2012.
8. Chetna, M. Vyas, Patel, I. N. and Bhatt, D. R., Durability properties of concrete with partial replacement of natural aggregates by recycled, *IJCSEIERD*, ISSN 2249-6866, Vol. 3, No. 2, 2013.
9. Chindaprasirt, P, Chareerat, T and Sirivivatnanon, V 2007, Workability and strength of coarse high calcium fly ash geopolymer, *Cement & Concrete Composites*, vol. 29, pp. 224-229.
10. Divya Rubina Chaudhary 2007, Mechanism of geopolymerization and factors influencing its development: a review, *Khale& Journal of Material Science*, vol. 42, pp. 729-746.
11. Djwantoro Hardjito, Steenie E. Wallah, Dody M.J. Sumajouw and Rangan BV 2004, Factors Influencing the Compressive Strength of Fly Ash-Based Geopolymer Concrete, *Civil Engineering Dimension*, vol.6, no. 2, pp.88-93.
12. Hardjito, D, Wallah, SE, Sumajouw, DMJ and Rangan, BV 2005, Fly Ash-Based Geopolymer Concrete, *Australian Journal of Structural Engineering*, vol. 6, pp.77-86.
13. Jayeshkumar, Pitroda and Umrigar F. S., Evaluation of Sorptivity and Water Absorption of Concrete with Partial Replacement of Cement by Thermal Industry Waste (Fly Ash), *International Journal of Engineering and Innovative Technology (IJEIT)*, Vol. 2, No. 7, 2013.
14. Jay G Sanjayan, Ali Nazari & Hesam Pouraliakbar 2015, FEA modelling of fracture toughness of steel fibre-reinforced geopolymer Composites, *Materials and design*, vol.76, pp. 215-222.



**ELECTRICAL  
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# Simulation on Interleaved Non-Isolated Quadratic High Gain DC-DC Converter by using Photovoltaic Partial Shading

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**Abstract:** A new high interleaved non-isolated high gain DC-DC Converter was proposed. The proposed topology DC-DC quadratic converter will provide high gain. The output of PV panel is low. We are integrating the PV panel into module to get the high voltage. Three modules of different irradiance are taken so that output of PV Panels is varying, by applying Maximum power point tracking the constant dc voltage can be obtained. We need DC-DC converter for step up the voltage. The boost converter is limited to gain of 6, more than that the efficiency will drastically fall. The evolution of High gain converter was introduced. Interleaved is multiphase operation of converter so that ripple will be lower. Interleaving of High gain converter nearly more than 20 times with high efficiency. The obtained dc voltage is fed to inverter with low pass filter so that the output voltage of inverter is nearly sinusoidal signal.

**Keywords:** PV Panel, High Gain DC-DC Converter, MPPT, Inverter

## INTRODUCTION

Now a days the non-renewable sources like Coal, diesel etc. They are exhausting in nature. The future of power generation is from renewable sources. The PV panel can be direct current or voltage source. Usually output of panel is 0.5 V so that we will be integrating many PV cells to obtain high voltage. The output voltage is dependent on the irradiance. MPPPT technique is applied to PV so that maximum power can be obtained. The obtained voltage is given to the High Gain DC-DC Converter. The High Gain converter usually they use coupled-inductor to get the high gain. The inductor will distort the input current waveform, to avoid this interleaving is employed so that input ripple current will be low. The quadratic converter will provide the less ripple current on input side, high voltage, and high efficiency. The output of quadratic converter is given to Multi Level inverter. The Multi-level inverter will provide better Total Harmonic Distortion than conventional single-phase inverter. MLI is connected to LC filter so that output voltage is close to sinusoidal. The limit of THD of output voltage is less than 5%. The obtained sinusoidal voltage is integrated to the AC grid. Most of the time Renewable energy sources are integrated to Micro Grid Applications.

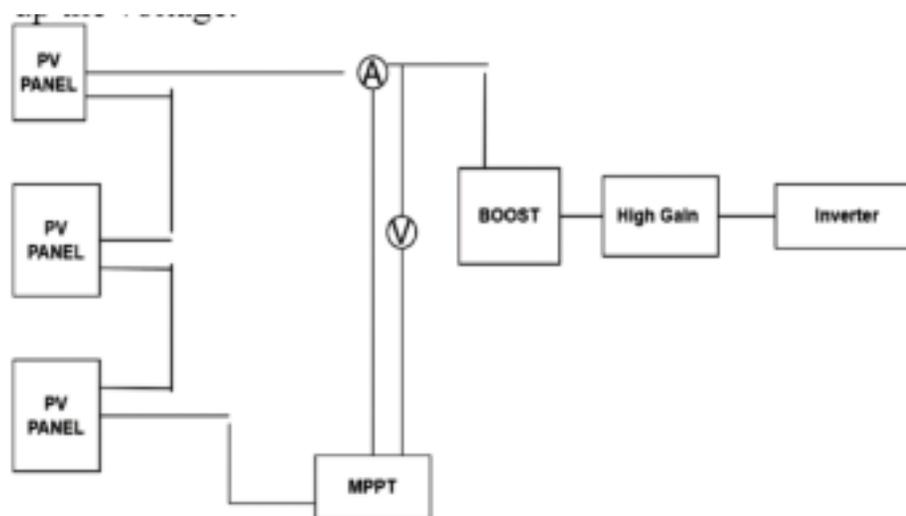


Figure 1 Overall control strategy of high gain DC-DC converter



## PARTIAL SHADING OF PV PANELS

The output of PV panel is dc voltage it is dependent on irradiance. The voltage varies accordingly to irradiance. Panels have two diodes named bypass and internal diode. The internal diode was connected so that stop the reverse flow of current. The bypass diode was used to the stop of reverse flow of voltage from one panel to another panel. This problem will occur due to mainly tree shading, atmospheric change etc. The panel voltage will be decrease then current will flow internally to avoid that bypass diodes are used. 3 Panels with different irradiation taken so that it will produce voltage. The regulation of voltage is mandatory. The MPPT is implemented on the Panels so that maximum power can be obtained. The voltage is obtained is low so that a boost converter was used to boost up the voltage.

## INTERLEAVED NON-ISOLATED QUADRATIC BOOST DC-DC CONVERTER

The boost converter has few disadvantages they have large input ripple current, gain is limited to 6 times after that the efficiency will drastically change, to overcome this high gain was implemented they are using coupled- inductor so that they have high gain and still have high ripple current on input side so that interleaved used. The interleaving will reduce the ripple current on input side. The quadratic converter also reduces the ripple current and removal of transformer. The gain of the converter is nearly 16-25 times of the input voltage. The output voltage will vary according to duty cycle. The interleaved quadratic converter consists of 2 switches, coupled inductor.

The upper switch S2 and lower switch S1 will operate at same duty cycle both turn on and turn off are same.

### Operation of Quadratic Converter

There are four modes of operation. 1) Upper and lower switch are on, again D4 on 2) Upper switch on and lower switch on, again D4 off 3) Both upper and lower switch are off, D2 and D3 on 4) Upper and lower switch off, D2 and D4 on 5) Upper and Lower switch off, only D4 on

#### Mode 1 Operation

The upper and lower switch are on. The current will flow L1 and L2 and switch. The current will be flowing inductor as inductor will not allow the sudden raise in current so that current will be in triangular shape. The inductor will charge in this time and diode is forward biased. Similar operation will happen in lower circuit. The D4 diode is on the current will flows from D4, L3, C3, C4, C5 to the load. The initial charged capacitor charge will supply to load

#### Mode 2 Operation

The upper switch is on and lower switch on. The current flow from L1, L2 to the S1 and S2. The output side D3 on with three output capacitors, (flow through D3, L3, C3, C4, C5) there will be continuously flow of current to the load.

#### Mode 3 Operation

The upper switch is off and lower switch also off. The current will flow from inductor L1 and diode of S1 in one path. In Another Path the current will flow from L2, C2, D2 and C1. The output voltage will support the load and capacitors will discharge at end of the interval

#### Mode 4 Operation

The upper switch is off and lower switch is off. The current will flow from L1 and S1, L2-D2-C1. Like the mode 3 operation. The D4 diode is on the output voltage side.

#### Mode 5 Operation

The S1 and S2 off. The current will flow from L1-C1-D5. The output voltage will flow from diode D4 and three capacitors. It has two modes 1) Continuous Current Mode 2) Discontinuous Current Mode. In DCM mode output side, the diode will reverse biased no flow of current to output side.

### Voltage Gain

The voltage across two capacitors C1, C2 are

$$V_{c1} = V/(1-D); V \text{ is Input Voltage and } D \text{ is Duty Ratio}$$

$$V_{c2} = (2-D) * V/(1-D)$$

$$V_{c3} = (2-D) * V/(1-D)$$



$$V_{c4} = D \cdot (2-D) \cdot V / (1-D)^2$$

$$V_{c5} = (3-3D + D^2) \cdot V / (1-D)^2$$

$$V_o/V_{in} = 5-4D + (D)^2 / (1-D)^2$$

The gain factor is mentioned above. Usually more than 50% duty ratio is operated. The converter will operate up to max 85% duty ratio. The gain will increase nearly from 10 to 40 times with increase in duty ratio. The voltage stress will be same as boost converter.

### MODIFIED CASCADED MLI

The obtained DC voltage is to be converted into AC supply so that we can integrate to the grid. The conventional single phase Voltage source inverter will offer 48% THD. It requires a very large filter to reduce the THD. Evolution of multi-level inverter occurred. The multi-level will produce n-level so that the voltage waveform will be near to sinusoidal waveform. The multi-level inverter is of three types, they are 1) Diode-Clamped MLI 2) Flying Capacitor MLI 3) Cascaded MLI. The Cascaded MLI is cascading of single phase VSI with independent DC sources. For 5 level the topology consists of 8 switches, we took a topology with 6 switches [1]. The modified cascaded MLI has better THD than the conventional. The cascaded MLI is implemented mostly on PV Panels or High Voltage DC voltage Transmission because for cascaded independent DC sources, whereas diode-clamped will have one DC source and good efficiency. The diode-clamped is widely employed in industrial applications. The capacitor MLI has switching redundancy due to it lacks when compared to diode-clamped. If many DC sources are available cascaded MLI is the best topology to employ.

### Operation of Modified Cascaded MLI

The output voltage will produce a voltage from 2V to -2V.

So that it will be 5 level. The V voltage will be obtained by S1, S4 switches on. The 2V Voltage will be obtained by S1, S4, S5 switches on. The -V Voltage will be obtained by S2, S3 switches on. The -2V Voltage will be obtained by S2, S3 and S6 switches on. The voltage sources are connected in the reverse polarity to generate 2V voltage. The diodes are connected in different directions for the flow of current.

### Design of Filter

The modified cascaded will produce a THD of 25% at 2kHz frequency. According to the power quality IEEE 512-1992 the THD should be less than 5%. The output voltage will consist of DC component + 3rd Harmonic + 5th Harmonic should be filtered. We should employ an LC filter; it will remove the unwanted component distortions in the waveforms. Design of inductor will be based on ripple current.

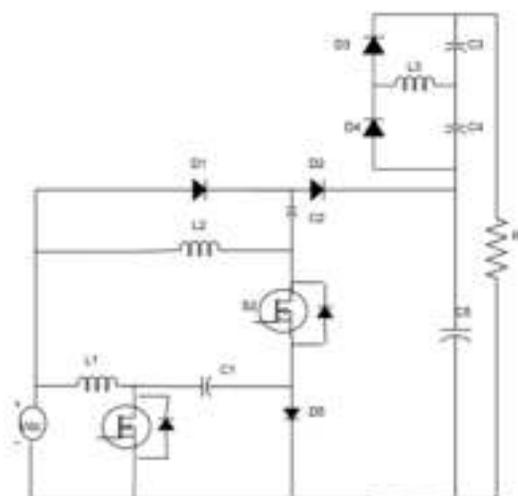


Figure 2 Interleaved non-isolated quadratic DC-DC converter[9]

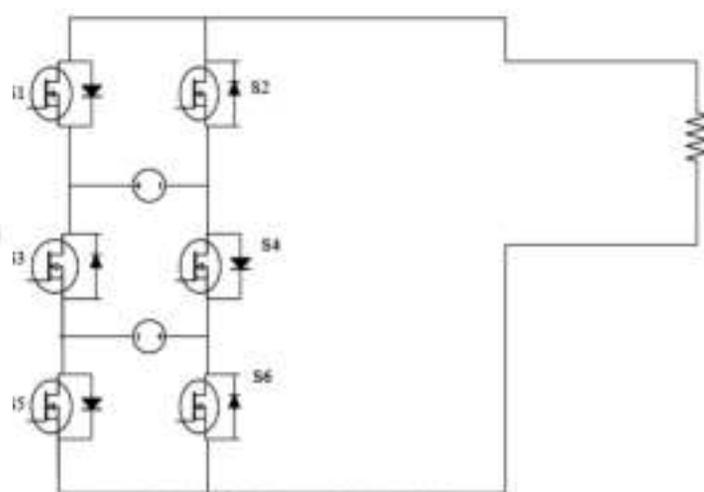


Figure 3 Modified Cascaded MLI[8]



$\partial I_{ind\_max} = 20-40\%$  of maximum current allowed;

$$\partial I_{ind\_max} = V_{dc} / (4 * L * F_{sw});$$

$$\text{Then } L = V_{dc} / (4 * \partial I_{ind\_max} * F_{sw});$$

Where  $V_{dc}$  = input voltage;  $F_{sw}$  = Maximum switching frequency

Design of the capacitor will depend on the reactive power

$$F_c = 1 / (2 * \pi * \sqrt{LC});$$

Where  $F_c \leq F_{sw} / 10$ ; C can be obtained from this formula.

After implementing LC Filter at the load side then output voltage will obtain nearly sinusoidal voltage waveform with THD less than 5%.

### MAXIMUM POWER POINT OF TRACKING

The PV panel will produce different voltage with variation of irradiance. The three PV panels at one instant it will produce a maximum power. The PV will have Open Circuit voltage and short circuit current. Usually, Panel can produce 0.5V, in that 0.1-0.35V panel will act as constant current source that will be short circuit current, 0.35V-0.5V the panel will act as Constant Voltage source. The intersection of open circuit voltage and short circuit current will obtain a maximum power. The technique used in this project is Incremental MPPT. It will track the voltage and current from total panels. The power curve will obtain from current and voltage multiplication. It will track the slope of the power curve. The duty ratio is constrained to 0.38-0.62 to obtain the maximum power. The duty ratio will depend on the slope of the power curve. When slope is zero the maximum power will obtain and slope increases the duty ratio also increase to compensate the power. Similarly, when slope decreases duty ratio decreases to compensate the power. The incremental in the power and voltage also tracked so that it can minimize the less error. If power error is positive and voltage error is also positive are greater than zero then duty ratio is incremented to 0.05 otherwise the duty ratio is decremented to 0.05. If power error is negative and voltage error is positive then duty ratio is decremented to 0.05 similarly, if voltage error is negative the duty ratio is incremented to 0.05. If The output of MPPT is pulses with different duty ratio. The pulses are compared to the triangular carrier. It will produce the pulses with constant duty ratio. The pulse is given to the boost converter. It will produce a constant output voltage with some transients. The boost converter is integrated to high gain DC-DC Converter.

### PARAMETERS FOR SIMULATION

The parameters for this simulation are shown in **Table 1**. These are the values and parameters for the simulation.

### SIMULATION RESULTS

The input voltage for the High Gain DC-DC Converter is 22V. The output voltage is 352V. The gain of DC-DC converter will be 17 at the duty ratio of 75%. The settling time is 0.1 sec. The frequency of DC-DC Converter was operated at 20Khz. The output dc voltage is given to input to modified cascaded MLI. The sinusoidal pulse width modulation is given to the modified cascaded Multi level inverter to have less THD %.

**Table 1** Parameters

Sl. No.	PARAMETERS Names	Values
1	Vdc Input for High Gain	22V
2	Output Resistance	25Ω
3	Output Voltage for Inverter	440V RMS
4	F <sub>sw</sub> for Inverter F <sub>sw</sub> for Converter	2khz 20Khz
5	Output Current	18A RMS
6	Output Power	8 KW
7	Inductance for filter	1.6mH

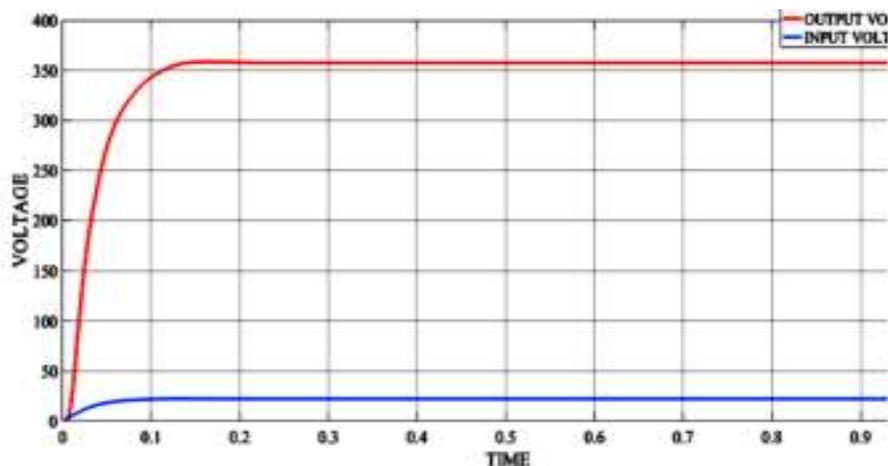


Figure 4 Input voltage vs output voltage for converter

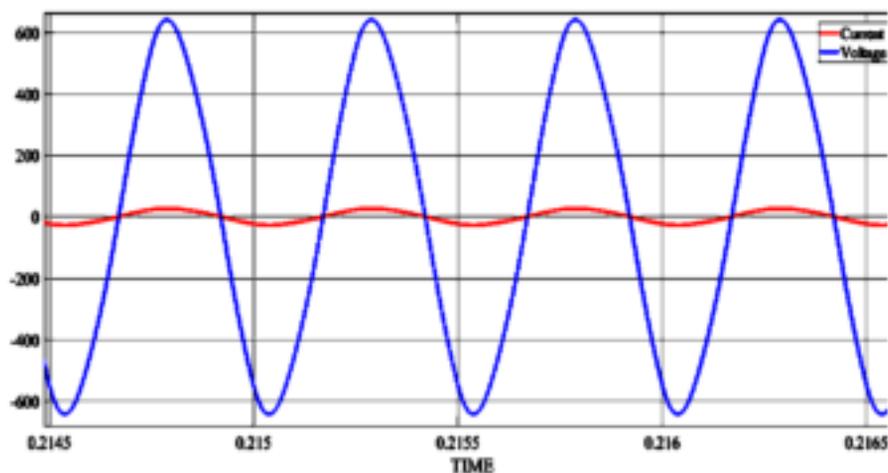


Figure 5 Output voltage and output current

The output voltage of inverter is 440V RMS with a peak voltage of 615V. The waveform of the output voltage is nearly sinusoidal with a THD of 3% after applying a filter. The waveform of the current also sinusoidal. The current and voltage waveform are in phase they are operating at unity power factor, as it is UPF we can integrate to AC Grid.

#### ACKNOWLEDGMENT

I took a Modified Cascaded MLI from [8] and High Gain DC-DC Converter from [9]. The Interleaved Non-Isolated High Gain DC-DC Converter and Simulation and result obtained was done by me. I solely responsible for this entire simulation of this project. I have simulated the project on my own.

#### CONCLUSION

In this paper, the partial shading of PV panels will produce the different voltage. So, by applying MPPT algorithm to entire panels regulation of voltage can be obtained. Interleaved non-isolated high Gain DC-DC Converter was proposed for renewable energy sources. The interleaved will reduce the input current ripple. It will produce high gain for step up the voltage. The operation of topology and was studied in this paper. The Modified cascaded MLI is modification of the conventional cascaded MLI. The switching sequences of modified cascaded MLI was studied. The obtained voltage waveform is pulsating so LC filter is kept at load end to filter out the harmonics. The sinusoidal voltage and current are obtained at the load side with unity power factor.



## REFERENCES

1. R. Rahimi, S. Habibi, M. Ferdowsi and P. Shamsi, An Interleaved Quadratic High Step-Up DC-DC Converter with Coupled Inductor, *IEEE Open Journal of Power Electronics*, vol. 2, pp. 647-658, 2021,
2. R. Morfin-Magaña, J. J. Rico-Melgoza, F. Ornelas-Tellez and F. Vasca, Complementarity Model of a Photovoltaic Power Electronic System With Model Predictive Control, *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 66, no. 11, pp. 4402-4414
3. M. Sinha, J. Poon, B. B. Johnson, M. Rodriguez and S. V. Dhople, Decentralized Interleaving of Parallel-connected Buck Converters, *IEEE Transactions on Power Electronics*, vol. 34, no. 5, pp. 4993-5006, May 2019
4. O. M. Hebala, A. A. Aboushady, K. H. Ahmed and I. Abdelsalam, Generic Closed-Loop Controller for Power Regulation in Dual Active Bridge DC-DC Converter with Current Stress Minimization, *IEEE Transactions on Industrial Electronics*, vol. 66, no. 6, pp. 4468-4478, June 2019
5. B. Bryant and M. K. Kazimierczuk, Modeling the closed-current loop of PWM boost DC-DC converters operating in CCM with peak current-mode control, *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 52, no. 11, pp. 2404-2412, Nov. 2005.
6. F. Wu, S. Fan and S. Luo, Small-Signal Modeling and Closed-Loop Control of Bidirectional Buck-Boost Current-Fed Isolated DC-DC Converter, *IEEE Transactions on Industrial Electronics*, vol. 68, no. 5, pp. 4036-4045, May 2021
7. H. Qin and J. W. Kimball, Closed-loop control of DC-DC dual active bridge converters driving single-phase inverters, 2012 IEEE Energy Conversion Congress and Exposition (ECCE), 2012, pp. 173-179.
8. K. Thakre, K. B. Mohanty, H. Ahmed and A. K. Nayak, Modified Cascaded Multilevel Inverter with Reduced Component Count, 2017 14th IEEE India Council International Conference (INDICON), 2017, pp. 1-5.
9. M. Rezaie and V. Abbasi, Ultrahigh Step-Up DC-DC Converter Composed of Two Stages Boost Converter, Coupled Inductor, and Multiplier Cell, *IEEE Transactions on Industrial Electronics*, vol. 69, no. 6, pp. 5867-5878, June 2022.

# System Engineering and Financial Modelling of Solar PV Projects through a Proprietary Web based Application

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**Abstract:** In this paper, a feasibility study has been done for a grid connected 250 kWp rooftop Solar PV project for a factory site in Ghaziabad (U.P.). Firstly, the system design of Solar PV project has been carried out to determine the technical parameters such as the no. of modules, no. of inverters, configuration of the modules in arrays per inverter, the electricity yield and performance ratio. Thereafter, the financial modelling of the project has been done to ascertain the financial indicators such as IRR, Payback period, Levelized cost of electricity etc.

The above analysis is carried out using proprietary web-based application. Python programming language, 'Python-Flask' and 'JavaScript-React' web frameworks have been used to develop it. The site-specific Solar irradiation and other meteorological data are taken from PVGIS.

The inputs such as data sheet parameters of the module and inverter, the expected losses, the capital cost, O&M cost, cost of funds, price of the electricity etc. are to be entered by the user. The complete input and output printed by the web application are delineated and discussed in the paper.

**Keywords:** Solar PV; System Engineering; Financial Modelling; Web Based Application

## INTRODUCTION

We design a 250 kWp rooftop Solar PV power project by a proprietary software application. This application is web based and can be accessed by anyone after registering on the platform.

The output of a Solar PV power plant is heavily dependent on meteorological conditions. Proper assessment of Solar irradiation, therefore, becomes very important. There are various commercial as well as free resources for this meteorological (Satellite) data such as NASA SSE, PVGIS etc. We have used PVGIS data which is a free-online resource for Solar irradiation and is maintained under the auspices of European Union.

We first briefly describe how a rooftop Solar PV plant works in section 2 of this paper. We carry out the detailed engineering of 250 kWp rooftop Solar PV plant, which is detailed in section 3.

We have referred the latest tariff schedule of UP power corporation ltd. (UPPCL) to get the applicable tariff for an industrial consumer having 250 kWp load. We carry out the financial feasibility analysis based on suitable assumptions and determine the Net Present Value (NPV), Internal Rate of Return (IRR) and Payback period of this Solar PV project. This analysis is detailed in section 4 of this paper.

The various references (online and offline) used to carry out the detailed analysis for this project are given in section 5.

The entire calculation and analysis described in these sections is done automatically in our web based application. The user has to just supply the desired inputs only. The output from the web-application is attached as “**Annexure B**”.

## HOW DOES A SOLAR PV POWER PLANT WORK?

The solar electricity is produced when the photons from the sun rays hit the solar PV panels as per the phenomenon of 'Photoelectric effect'. The solar panel generates DC current. Number of solar panels are connected in series and this arrangement is called as 'array' or 'string'. No. of arrays get connected to an inverter (depending upon inverter's parameters). The inverter converts the DC power into single phase/three phase AC power.

Output voltage of the inverter generally ranges from 230 V to 1500 V depending upon the manufacturer and the technology. Therefore, the ground mounted Solar PV plants of MW scale need to step up the voltage at the inverter output to be able to connect to the main transmission grid. Hence, a switchyard consisting of step-up transformer and protection equipment are also part of the ground mounted solar PV plant.



## SYSTEM DESIGN

The system design consists of the assessment and determination of the following aspects;

- a) Solar Resource Assessment
- b) Determination of No. of Modules and Inverter
- c) Loss Calculation
- d) Calculation of Electricity Yield (kWh)

Let us consider each of the above aspects one by one;

### a) Solar Resource Assessment

The latitude and longitude of the chosen site in Ghaziabad (U.P.) are;

Latitude - 28.6598322691466 degree

Longitude - 77.3378922182772 degree

The modules would be facing towards south direction to capture the maximum sun energy. The modules would be supported on the MMS (module mounting structure) with tilt angle of the module from the horizontal as 25 degrees.

### b) Determination of No. of Modules and Inverter

We first choose the rating of the individual module and inverter. The same have been chosen randomly for analysis purpose and this choice doesn't advocate for any brand or manufacturer.

#### i) No. of Modules

A poly-crystalline module with brand name 'Eldora 325-350 W' of manufacturer 'Vikram Solar' has been chosen. The datasheet of the module could be accessed at <https://www.vikramsolar.com/download-category/data-sheets/>

Capacity of individual module = 350 Wp

Therefore, no. of modules required =  $250 \times 1000 / 350 = 714$  modules

#### ii) No. of Inverters

Inverter of delta electronics of unit rating of 30 kVA has been chosen. The same can be accessed at <https://5.imimg.com/data5/WU/IX/GG/SELLER-107957931/delta-rpi-m30a-grid-tied-solar-inverter.PDF>

The min and max DC:AC ratio have been taken as 1.1 and 1.5, respectively.

Our web application outputs the no. of inverters = 7 with the corresponding DC:AC ratio = 1.19.

#### iii) No. of Strings (Arrays)

No. of modules are connected in series to form one string. Let's say that no. of modules in a string = m

Open circuit voltage of each module ( $V_{oc}$ ) = 46.7 V.

Maximum (Max.) operating voltage,  $V_{mpp}$  of each module = 39.7 V.

Max. operating current,  $I_{mpp}$  of each module = 8.83 A.

Maximum power point (MPP) voltage range of inverter = 520 V to 800 V.

Max. input voltage in Inverter = 1000 V.

Therefore,  $m \times 46.7 \leq 1000$  (1)

$m \times 39.7 \leq 800$  (2)

Max. input current in the inverter = 30 A per MPPT.

Let's say the no. of strings is 's' per MPPT. As the strings are connected parallelly to the inverter, so they should satisfy the following equation,

$s \times 8.83 \leq 30$  (3)



We solve the above equations and determine the no. of strings and no. of modules per string as delineated below:

No. of Inverters	No. of Strings per Inverter	No. of Modules per String	Total No. of Modules
7	6	17	$=7 \times 6 \times 17 = 714$

### c) Loss Calculation

All the DC power generated by the Solar PV modules doesn't get converted to AC power. There are certain losses in the system which are described as follows:

Type of Loss	Loss Description	Loss Value Adopted
Soiling	Losses due to soiling (dust and bird droppings) depend on the rainfall, and cleaning frequency. This would be lower for modules at a high tilt angle due to cleaning effect of rainwater	3% (Ref: - <a href="https://www.waaree.com/blog/soiling-losses-introduction-and-effects">https://www.waaree.com/blog/soiling-losses-introduction-and-effects</a> )
Shading	Shading losses occur due to obstructions on the far horizon, mutual shading between rows of modules and near shading due to trees, buildings etc.	0% (Assuming no obstructions around)
Incident angle	The incidence angle loss accounts for radiation reflected from the front glass when the light striking it is not perpendicular	1.48% (As per the formula in SANDIA report SAND2015-8803)
Module temperature	The efficiency of a PV module reduces for temperature rise above STC of 25°C	Calculated average loss is 6.27%/year
Module quality	This loss arises due to divergences in module characteristics from the specifications	0%
Module mismatch	These losses arise because the modules in a string don't present the same current/voltage profiles	0.50%
Degradation	As per the warranty provided in the module data-sheet	2.5% in the 1st year and 0.67%/year thereafter
Inverter performance	Inverter's efficiency varies with load.	1.5% (as per the inverter datasheet)
DC cable losses	I <sup>2</sup> R losses are usually <3% provided cable sizing is done properly	1.5%

### d) Calculation of Electricity Yield (kWh)

To calculate the energy yield (kWh), we need to find out the sun energy incident on the modules and then deduct various losses from it. To get sun energy incident on the tilted modules at the given coordinates, we find out the value of G<sub>Inc</sub> (kWh/m<sup>2</sup>) from the PVGIS resource. G<sub>Inc</sub> is the Solar irradiance on a tilted surface. PVGIS is an online free solar PV data resource of European Commission ( [https://re.jrc.ec.europa.eu/pvg\\_tools/en/](https://re.jrc.ec.europa.eu/pvg_tools/en/) ). For our project, the chosen tilt angle,  $\beta = 25$  deg.

G<sub>Inc</sub> is the Solar irradiation on the tilted surface for the given latitude and longitude. The month-wise value of G<sub>Inc</sub> is given in **Annexure B** under 'Yield Calculation Results and Performance Ratio Calculation'.

We get yearly G<sub>Inc</sub> = 2123.37 kWh/m<sup>2</sup>.

Area of single module = 1986 mm × 991 mm.

Total area of 714 modules,  $A = 714 \times 1.986 \times 0.991 = 1405.24 \text{ m}^2$

Let's denote the loss due to various factors are  $L_1, L_2, L_3, \dots, L_{n-1}$  and loss due to inverter performance be  $L_n$

Hence, DC energy yield from the Solar PV arrays to the inlet of the inverter =  $G_{Inc} \times A \times (1-L_1) \times (1-L_2) \times \dots \times (1-L_{n-1})$

Accordingly, the month-wise DC energy yield in MWh from the Solar PV arrays ( $E_{arr}$ ) in the 1st year is calculated and given in **Annexure B** under the heading 'Yield Calculation Results and Performance Ratio Calculation'.



Cumulative DC Energy yield at the inlet of the inverter in the 1st year = sum of DC yield of all the months in 1st year = 453.52 MWh

Cumulative AC energy yield in the 1st year = DC energy yield  $\times (1 - L_n)$ , where  $L_n$  is the loss due to inverter performance = 446.72 MWh

Yearly degradation is 0.67%, so energy yield in yr. 'N' =  $(1 - 0.67\%) \times$  yield in yr. '(N-1)'

Accordingly, the year-wise generation (kWh) is given in **Annexure B** under the heading "Year-wise Energy Generation Along with the Financial Data".

#### e) Single Line Diagram (SLD)

A simplified single line diagram of the above designed 250 kWp rooftop Solar PV plant is given as **Annexure A**.

### PROJECT'S FINANCIAL ANALYSIS

To analyze a project's feasibility, we find out if the benefits from the project would be more than the cost incurred in its installation and operations. Hence, we need to find out the revenues, operating profit, and cash flows from the project over its economic life of 25 years.

We consider time value of money and convert the future value of cash flows to its present value. We use discount factor for the same, which is expected rate of return from the project. Free cash flow here means the cash flow available after paying for all the operational costs.

The below sections describe the details of the project's financial modelling. Most of the values in this modelling have been considered as per CERC (Terms & Conditions for Tariff Determination from Renewable Energy Sources) 2020, referred as 'CERC RE Tariff Regulations, 2020 hereafter.

#### a) Discount Rate (WACC)

The discount rate is the rate of return that is expected by an investor for providing the capital. It is also called the weighted average cost of capital (WACC) or hurdle rate.

$$\text{Discount rate, } R = R_d \times (1 - T) \times W_d + R_e \times W_e$$

Where, T = Tax rate,  $R_d$  = Cost of debt,  $R_e$  = Cost of equity,

$W_d = D / (D + E)$ ,  $W_e = E / (D + E)$ , D = Amount of debt capital, E = Amount of equity capital

Accordingly, the discount rate is calculated as given in the table below:

D/E ratio = 70:30	2.33	Chosen as per Article 13(1), 'CERC RE Tariff Regulations, 2020'
Cost of equity	14.0%	Chosen as per Article 16(2), 'CERC RE Tariff Regulations, 2020
Cost of debt	9.95%	Chosen as per Article 14(2)(b), 'CERC RE Tariff Regulations, 2020
Tax rate (including surcharge)	27.50%	
Discount rate	9.25%	

#### b) Revenue

Post installation, the factory would meet substantial portion of its power consumption from the solar PV plant. This saving in electricity bill is the revenue of the factory from the Solar PV plant.

So, saving = energy yield (in kWh) from the Solar PV plant  $\times$  rate of electricity (Rs/kWh)

As per UPPCL's approved tariff for FY 2021-22, industrial consumers having load of 250 kW are categorized as HV-2(a)(1) with the following the charges:

Item	Unit	Value
Fixed charge	Rs/kVA/Month	300
Variable charge	Rs/kVA	7.10

Assuming a power factor of 0.9, this rate becomes  $7.1 / 0.9 =$  Rs 7.89/kWh. We, therefore, take Rs 7.5/kWh as conservative rate for useful power.

The year-wise revenue is accordingly calculated and given in **Annexure B** under the heading "Year-wise Energy



Generation Along with the Financial Data”.

### c) Operating Cost

Solar PV doesn't require any raw material unlike thermal power which requires coal/ natural gas. Hence, the operational cost of Solar PV is less and consists of labor cost and maintenance spares only.

We have considered O&M (operation and maintenance) cost of Rs 6 lakh/year and wage inflation of 5%. The cost of maintenance spares has been considered as 15% of O&M expense as per article 17 (c) of 'CERC RE Tariff Regulations, 2020.

The year-wise total O&M cost is thus calculated and listed in Annexure B under the heading “Year-wise Energy Generation Along with the Financial Data”.

### d) Depreciation and Interest

To calculate depreciation and interest cost, the following data has been considered:

Item	Value	Remarks
Rate of depreciation	4.67% till 15 years and then uniformly from 16th to 25th year	As per article 15(2), CERC RE Tariff Regulations, 2020
Salvage value of the plant	10%	As per article 15(1), CERC RE Tariff Regulations, 2020
Interest rate	9.95%	As per article 14(2)(b), CERC RE Tariff Regulations, 2020
Loan period	15 years	As per article 14(1), CERC RE Tariff Regulations, 2020

Accordingly, depreciation and interest cost have been calculated and listed in Annexure B under the heading “Year-wise Energy Generation Along with the Financial Data”.

### e) Free Cash Flow (FCFF), NPV, IRR & Payback Period

Any company has two class of owners – debt providers and equity holders. Free cash flow (FCFF) gives us the total cash available to both class of the owners.

$FCFF = \text{Profit after tax} + \text{Depreciation} + \text{Interest} \times (1 - T)$ , where T = tax rate

T = 27.5% here

$\text{Profit after tax} = \text{Revenue} - \text{Operating Cost} - \text{Depreciation} - \text{Interest} - \text{Tax}$

Accordingly, the FCFF has been calculated and listed in the output in **Annexure B** under the heading “Year-wise Energy Generation along with the Financial Data”.

If  $C_0$  is the initial capital investment (capex), then net present value (NPV) is given by;

$$NPV = (-)C_0 + TPV = (-)C_0 + C_1/(1+R) + C_2/(1+R)^2 + C_3/(1+R)^3 + C_4/(1+R)^4 + \quad (4)$$

Here, TPV = total present value of cash flows (for the entire life of the project), R is discount rate = 9.25% as calculated in section (a) above,

$C_1, C_2, \dots, C_n$  are free cash flows in year 1, 2, ...n and calculated in section (c) above, any project is worth investing only when its NPV is positive ( $\geq 0$ ).

IRR is that value of discount rate for which  $NPV = 0$ . If IRR is > than the cost of capital, then the NPV is > 0 and the project is economically feasible.

Accordingly, the NPV, IRR & payback period are calculated and summarized below:

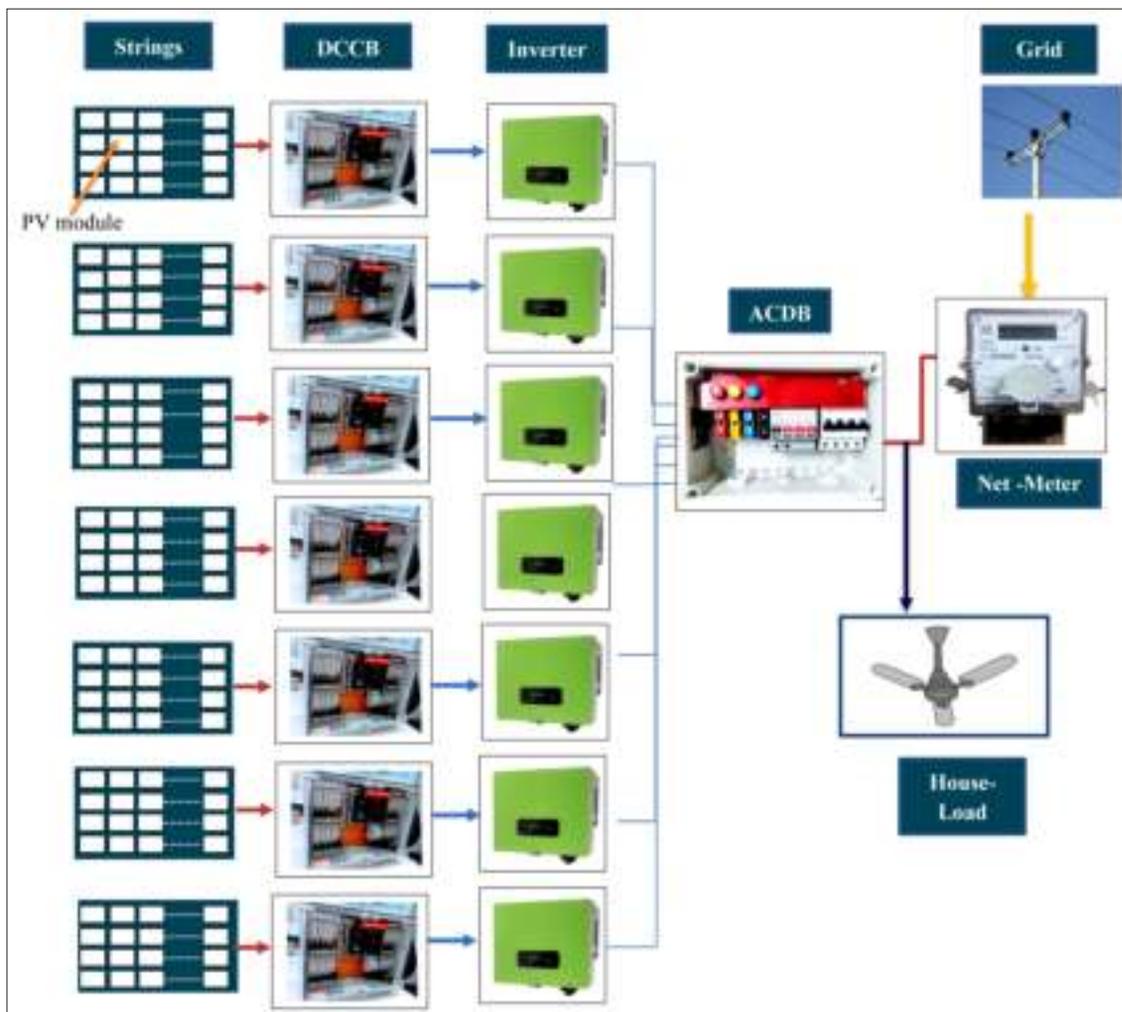
NPV (Rs Lakh)	46.68
Project IRR (%)	15.22%
Payback period (Years)	5.75

As the NPV is positive ( $>0$ ) and the project IRR (15.22%) is  $>$  discount rate (9.25%), this 250 kWp rooftop Solar PV project for the Ghaziabad factory is feasible and should be pursued.

#### REFERENCES

1. Prof Yogi Goswami, Principles of Solar Engineering, 3rd edition
2. Solar Irradiation Data from PVGIS - [https://re.jrc.ec.europa.eu/pvg\\_tools/en/tools.html#PVP](https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP)
3. Calculation of PV cell temperature, [https://www.homerenergy.com/products/pro/docs/latest/how\\_homer\\_calculates\\_the\\_pv\\_cell\\_temperature.html](https://www.homerenergy.com/products/pro/docs/latest/how_homer_calculates_the_pv_cell_temperature.html)
4. IFC (World Bank Group)'s 2015 document titled 'A project Developer's Guide to Utility Scale Solar PV Power Plants'
5. World Bank Report on Solar Resource Assessment in Nepal, March 2017
6. Central Electricity Regulatory Commission's tariff regulation titled 'Terms and Conditions for Tariff Determination from Renewable Energy Sources' Regulations 2020
7. UP Power Corporation's Tariff/Rate Schedule for FY 2021-22

#### Annexure A – Indicative Single Line Diagram (SLD) of 250 kWp Solar PV Plant





**Annexure B – Output of Web Application ‘SuEng-Tech’ (<https://www.sueng-tech.com>)**

**Financial Modelling of the Project**

**Financial Input Data entered by the customer**

Capex of the project in INR : 11250000	Selling price of electricity in INR/kWh : 7.5
Salvage value of the plant (in %) : 10	No. of years for application of WDV method of depreciation : 15
Rate of Depreciation (in %) : 4.57	Escalation of Labour Cost per Year (in %) : 5
Labour cost for the 1st year of operation in INR : 800000	Debt to Equity ratio (in decimal) : 2.35
Cost of Maintenance Spares as % of labour cost (in %) : 15	No. of years for repayment of Debt (in years) : 15
Rate of interest for Debt (in %) : 9.95	Risk free rate of interest (in %) : 7.5
Tax Rate (in %) : 27.3	Equity risk premium (in %) : 6.5
Enter company sensitivity value beta (default is 1) : 1	

**Yearwise Energy Generation along with Financial Data**

Year	AC Energy	O&M Cost	Depreciation	Interest Cost	Revenue	PAT	FCFF
Yr 1	446717.20	890000.00	525375.00	783226.35	3350379.00	980038.80	2073252.90
Yr 2	443724.19	724500.00	500830.99	759477.37	3327931.40	974482.73	2026218.81
Yr 3	440731.34	760725.00	477450.76	731295.86	3306634.32	968738.71	1976358.22
Yr 4	437738.21	798761.25	455153.81	701348.81	3283486.57	962982.91	1926593.15
Yr 5	434854.98	838698.31	433898.13	668455.81	3261487.21	957318.25	1875843.21
Yr 6	431951.37	88034.28	413635.06	632281.65	3239635.25	951886.07	1824025.35
Yr 7	429057.29	924985.99	394318.33	592913.67	3217925.69	947182.88	1771053.72
Yr 8	426162.61	970999.29	375903.66	548788.76	3196369.56	943063.93	1716826.45
Yr 9	423327.18	1019444.29	358348.96	500713.25	3174953.88	939624.38	1661290.44
Yr 10	420480.69	1070416.47	341614.00	447984.22	3153681.69	936802.78	1604311.19
Yr 11	417673.60	1123937.29	325660.69	389735.71	3132552.03	934583.30	1546802.37
Yr 12	414875.19	1180134.16	310452.33	325834.40	3111563.53	932978.70	1488860.97
Yr 13	412095.53	1239140.68	295994.21	255574.92	3090716.48	931533.68	1430779.71
Yr 14	409334.49	1301007.81	282133.16	178334.62	3070006.66	930248.41	1372046.90
Yr 15	406591.95	1366152.00	268857.55	93387.91	3049439.59	929024.46	1294346.24
Yr 16	403867.78	1434480.44	256130.43	0.00	3029008.38	927862.67	1276063.10
Yr 17	401161.87	1506183.47	243930.43	0.00	3008713.98	926760.07	1208380.50
Yr 18	398474.08	1581402.94	232230.43	0.00	2988555.61	925716.06	1140106.52
Yr 19	395804.30	1660587.27	221030.43	0.00	2968532.26	924730.07	1068320.58
Yr 20	393152.42	1743356.63	210330.43	0.00	2948643.12	923799.88	993705.29
Yr 21	390518.29	1830275.42	200130.43	0.00	2928887.21	922923.49	916176.92
Yr 22	387901.62	1921214.19	190430.43	0.00	2909263.66	922099.61	835584.24
Yr 23	385302.88	2016429.90	181230.43	0.00	2889771.60	921326.17	751788.80
Yr 24	382721.38	2116051.39	172530.43	0.00	2870410.13	920599.03	664913.45
Yr 25	380157.12	2220319.96	164330.43	0.00	2851178.38	919916.82	573793.95

**Abbreviations / Legends**

AC Energy : Annual AC Energy output from the Inverter kWh  
 O&M Cost : Annual Operation & Maintenance cost in INR  
 Depreciation : Annual depreciation value of the plant in INR  
 Interest Cost : Annual interest cost for the plant in INR  
 Revenue : Annual Revenue generation for the plant in INR  
 PAT : Profit after tax for the plant in INR  
 FCFF : Free Cash Flow to the Firm / Company for the plant in INR

**Predicted Financial Parameters of the Project**

Cost of Equity in % : 14.08  
 Cost of Capital in % : 9.25  
 Levelized Cost of Electricity, LCoE in INR/kWh : 5.25  
 Net Present Value of the Project, NPV in INR : 4667886.11  
 Payback Period for the Project in years : 5.75  
 Project IRR (Internal Rate of Return) in % : 15.22  
 Equity IRR (Internal Rate of Return) in % : 25.57

Thank you very much for using our Solar PV SaaS program. Hope it helped you. Please provide your feedback in the comment section.



GNI : Global Normal Irradiation in kWh / Sq.m  
 DNI : Direct Normal Irradiation in kWh / Sq.m  
 DHI : Diffuse Horizontal Irradiation in kWh / Sq.m  
 T\_Amb : Ambient Temperature Monthwise in degree cecigrade  
 G : Insolation or Irradiation in W / Sq.m  
 E\_Arr\_DC : Monthly DC Energy Produced by the Solar Module Arrays in MWh  
 PR : Monthly Performance Ratio in %

**Predicted Energy Output & Performance Ratio**

Yearly energy produced (DC energy) by Array of PV modules in MWh : 453.52

Yearly energy produced by the Inverters (AC energy) in MWh : 446.72

Performance Ratio of the PV Plant in % : 84.20





**Welcome to Sueng-Tech for modelling of a Solar PV based power project**  
Modelling Date : 11/ 6/2022 & Time : 10:25 : 9 PM

**Technical Input data entered by customer**

**General Plant Information**  
Name of the Plant or Project Name : Distributed Energy - Madhav Solar PV  
Desired DC rating of the Plant in MWp (kW DC) : 250  
Latitude in degrees N or S, negative value ( ) is for S : 20.95  
Longitude in degrees E or W, negative value ( ) is for W : 77.34  
Angle of tilt in degrees : 25.00  
Heat loss of the steel in years : 25  
Maximum DC/AC ratio selected : 1.50  
Minimum DC/AC ratio selected : 1.10

**Solar PV Module Input Information**  
Module name of the module : Vikram Solar Limited Polycrystalline Module  
Maximum power output at STC in watts : 330  
Open circuit voltage value in volts : 46.7  
Short circuit current in amps : 0.74  
MPP voltage value in volts : 36.7  
MPP current value in amps : 0.00  
Temperature coefficient for power output in % per degree centigrade : -0.38  
Module length in mm : 1986  
Module width in mm : 992  
1st year degradation of power output of module in % : 2.0  
Yearly degradation of power output of module, 2nd year onwards in % : 0.37  
Module efficiency in % : 17.76  
NOCT temperature of the PV module in degree centigrade : 44

**Solar Inverter Input Information**  
Inverter model name : Delta  
Inverter efficiency in % : 98.5  
Maximum MPP voltage in volts : 500  
Maximum DC input current in amps : 30  
AC rating in kW : 30  
Maximum dc input voltage value of the inverter in volts : 1000  
Minimum MPP voltage in volts : 500

**Solar PV Plant Loss Input Information**  
Shading loss in % : 0  
Module quality loss in % : 0  
Module energy mismatch loss in % : 0.5  
Soiling loss in % : 3  
LID (Light induced degradation) loss in % : 0  
HDC (high temp) loss in % : 1.5

**Technical System design output data calculated & predicted by the Modelling Platform**

**System Design Results**  
Total no. of modules in the PV plant are : 714  
Total no. of inverters in the PV plant are : 7  
7 no. of Inverters need total 6 arrays with each array having 117 modules in series  
Calculated DC / AC ratio will be : 1.10

**Yield Calculation Results & Performance Ratio Calculation**

Month	GHI	Ginc	DNI	DHI	G	T Amb	E an dc	PR
Jan	112.35	151.65	132.54	45.61	385.63	13.52	34.49	69.67
Feb	130.12	181.72	147.48	58.25	401.89	14.31	38.33	81.42
Mar	181.08	235.97	185.47	93.61	617.77	22.66	43.97	84.41
Apr	205.12	216.31	185.56	73.77	795.15	28.00	43.39	81.32
May	175.86	236.84	183.78	84.88	706.13	32.67	41.88	80.16
June	187.75	176.99	114.73	97.18	632.14	33.06	36.11	80.72
July	163.14	150.23	54.91	85.26	632.29	28.46	32.65	82.90
Aug	180.18	151.78	101.12	85.93	624.33	28.31	33.53	83.18
Sept.	161.52	174.41	129.68	93.62	695.63	27.86	36.83	83.16
Oct	161.08	190.79	172.12	69.64	659.17	26.54	41.73	84.00
Nov	125.45	181.24	161.12	58.83	485.41	20.40	37.05	83.51
Dec	111.28	156.93	142.66	42.75	398.83	16.36	33.43	80.16
<b>Annual</b>	<b>1815.38</b>	<b>2123.37</b>	<b>1718.62</b>	<b>809.70</b>			<b>463.62</b>	<b>84.20</b>

**Abbreviations / Legend:**  
GHI - Horizontal Global Irradiation in kWh / Sqm



# Challenges and Opportunities for Clean Energy Transition for Sustainable India

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**Abstract:** *The demand for electricity is rapidly growing, due to growing industrialization and domestic consumer requirements. The installation of renewable energy, primarily, the solar and wind is also rising rapidly, with the aim of reaching zero carbon emission and creating a clean environment. However, there are several challenges in dealing with large-scale variable renewable energy (VRE) and achieving goal. Again, establishing hybrid sources and linking them with the existing grid is to be addressed, with proper planning, and control schemes, to ensure reliability in the operation of the system. However, this integration hampers the reliable and stable operation of the grid by posing many operational and control challenges such as (i) Power system inertia and Grid stability and (ii) Variability and uncertainty of demand versus Power system flexibility. So, this paper highlights India's ambitious targets on decarbonization, greater demand for thermal plant flexibility in the coming years and major changes to the Indian power system both, on the power system's flexibility needs and flexibility resource deployment.*

**Keywords:** *Grid Stability; Power System Flexibility; Energy Storage; Renewable Energy; Power Plant Cycling*

## INTRODUCTION

The global warming is one indication of change in climatic, leading to extreme weather causing migration of varieties of animal population and birds. In India, the electrical installations were solely with thermal and hydro plants with a small percentage of atomic power units, till 1980. Then, gradually, wind energy electric conversion systems and solar photovoltaic units, with ratings in the order of 100 kW, came into operation, with increasing emphasis to achieving a pollution free atmosphere [1-2].

Currently, around 80% of global energy and 66% of electrical generation are supplied from fossil fuels; contributing approximately 60% of the greenhouse gas (GHG) emissions. So efforts are taken to reduce this pollution by almost half by 2030 and attain net-zero emission by 2050. So, obviously, countries should progressively bring down the dependence on fossil fuels and install alternative sources of energy that are clean, cost effective and sustainable. This planned advancement will also avoid deforestation and destruction of other living beings. Continued research in the establishment of renewable energy sources has substantially brought down their cost and ease of control of the various parameters involved in their operation such as load voltage, current and frequency, thus making renewables the most competitive sources of energy in several parts of India and the world [3]. A total of 152.90 GW of renewable energy capacity has been installed in the country as on 28 Feb. 22. As per the report of the Central Electricity Authority, India, the contribution by renewable energy sources would be around 40%, considering the total electrical power installation by the end of financial year 2029-30. There will be several challenges on the way in fulfilling this mission but it will also simultaneously promote many businesses venture leading to economic growth of our country.

## CLIMATE CHANGE AND SUSTAINABILITY

Sustainability in this context refers to the progress in meeting the increasing power requirement, making use of the naturally available resources without devastating the environment. United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs". Recently, the UN issued The Sustainable Development Goals as its main aim for the successful achievement of a better and more sustainable future. The 17 Goals include sustainable economic growth, no poverty, zero hunger, clean water and sanitation, affordable and clean energy, and responsible consumption and production, and it is hoped that they will be reached by 2030.

## CHALLENGES AND OPPORTUNITIES

India, attempting to enhance the availability of electrical power, has its own set of challenges and operational dynamics

in dealing with large-scale VRE. At present, coal fired power plants are the major sources and they will continue to go for some more years and they play a vital balancing role in integrating large-scale variable renewables.

In this scenario, the major aspects to be looked into in managing the high level of deploying VRE are (i) low inertia and grid stability and (ii) uncertainty and variability of demand—power system flexibility.

### LOW INERTIA AND GRID STABILITY

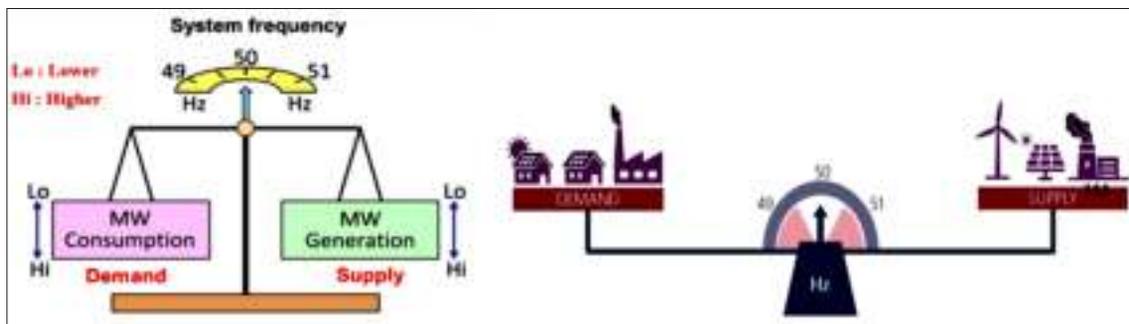
#### Inertia and its Role in Grid stability

Maintaining the Grid frequency is a measure of the stability of the grid, as it reflects the ability of a grid to balance the supply and demand as shown in **Figure 1**. Today's grid operating norms require strict tolerances on the grid frequency. The capability of a system to maintain nearly constant frequency under normal conditions and to recover from any imbalance conditions that may result in changes in frequency, is often referred to as frequency stability [4].

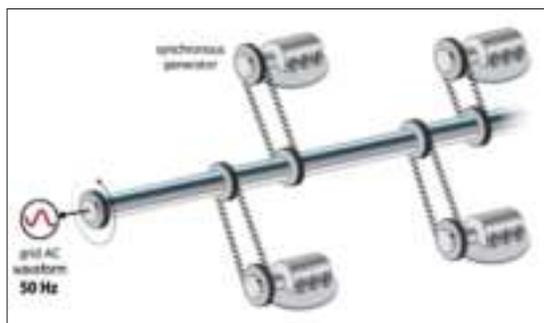
During normal grid operation, the supply of power from all the generators equals the demand for electricity, and the frequency remains constant. If there is a loss of a power output from any plant, the supply of power to the grid will drop almost instantaneously. However, the demand for electricity remaining the unaltered, the same amount of power will still be extracted from the system due to the inherent inertia of the system.

Stored energy is extracted from the inertia of the spinning generators and can temporarily make up for the loss of a small percentage of generation. In this way, in a large system consisting of hundreds of generators, running synchronously, in the event of a failure of few generators, inertia can resist a drop-in frequency and give the grid time to rebalance supply and demand [5]. **Figure 2** illustrates this conceptually — with all Synchronous Generators (SGs) connected via electromagnetic forces, represented by the chains [4]. These electromagnetic chains mean all the individual SG that are online, function together and contribute to grid inertia.

As per a recent study on power system inertia estimation in the all India grid by POSOCO, the Indian power system inertia shows a reducing trend, which can be mainly primarily attributed to increase in the addition of renewable energy sources in the system. It was also observed that in some cases, power system inertia is lower in peak hours, while it is



**Figure 1** Supply and demand balance in power grid



**Figure 2** The concept of synchronous generators working together in an electrical grid

higher in off-peak hours. This could be the result of a higher amount of solar PV generation during peak hours, as well as non-availability of agricultural loads [6].

It is important to note that the amount of inertia available from a generator is independent of power output and depends only on whether it is online (committed) and spinning at grid frequency. For example, a synchronous generator rated at 500 MW provides the same amount of inertia when it is generating 250 MW or the full capacity of 500 MW. As long as the generator is synchronized to the grid, the amount of inertia cannot be changed by any action taken by the generator operator [7]. Because of this built-in inertia of hydro, coal and natural gas plants, and practices like load shedding – which involves disconnecting a portion of the customer load – grid frequency typically stays within a safe range [8].

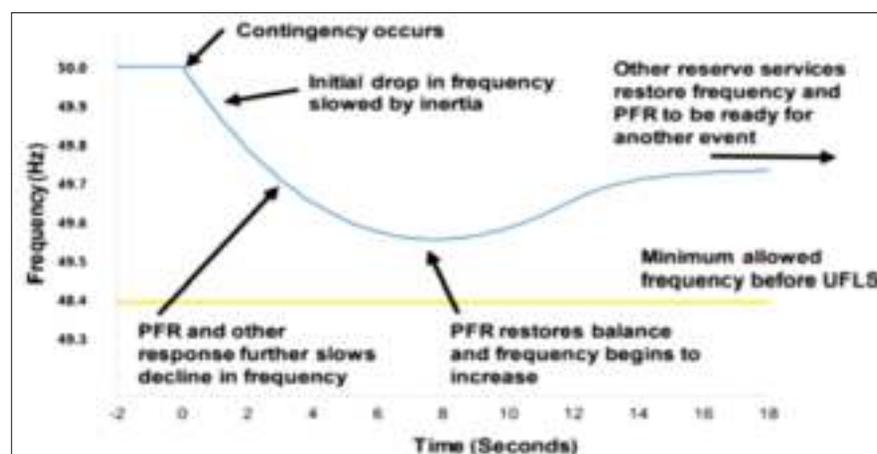
The level to which frequency falls prior to recovery depends upon its starting point as well as the system inertia. If system inertia is high, then frequency will fall slowly during a system casualty such as a generator tripping off line. If system inertia is low, then frequency will come down faster during this casualty. Although inertia is not frequency control per se, it does influence the time it takes for a given casualty to cause frequency to fall out of bounds, thus higher system inertia is beneficial than lower system inertia, since it will provide more time for governors to respond to the drop in frequency [9].

**Figure 3** shows the nearly constant frequency of a grid under normal operation (50 Hz), and then a large loss of generation (contingency event) occurring at  $t = 0$  seconds. To accommodate the imbalance between supply and demand due to the drop-in generation, the remaining online generators convert their rotational kinetic energy (inertia) into real power generation - referred to as inertial response, which gives time for the remaining online generators to detect changes in frequency and initiate primary frequency response (PFR). As generator output from PFR increases, the net imbalance reaches zero and frequency stops declining. Ideally, this sequence of events will prevent the frequency decline before it reaches the solid orange line, which is the point of under frequency load shedding (UFLS). PFR will then partially restore the frequency. In subsequent seconds and minutes, grid operators send signals to certain power plants to increase power to restore the frequency to 50 Hz and return the grid to normal operation. This action falls under the category of operating reserves.

### Inverter-Dominated Grids

VRE sources are connected to the grid through a power electronics circuits i.e., inverters which convert dc to ac and manages the flow of energy by controlling the semiconductor switching devices at a fast rate. In contrast to a synchronous generator, an inverter is strictly electronic and does not contain any mechanical components or rotating masses [9]. As more VRE added into power systems - the grid will have more inverter-based generators and much more distributed than the present pattern of power system, which is dominated by central-station consisting of conventional synchronous generators. This fundamental difference leads to further challenges in system operation.

As more of these inverter-based renewables are added to the mix and more traditional generators are switched off, the level of inertia available to grid operators decreases and so suitable steps are to be taken to ensure the stability of the grid during emergency situations. The increasing penetration of nonsynchronous sources could bring forth large power



**Figure 3** A successful recovery from a contingency event



swings in the system, with frequency deviations, and the rate of change of frequency (RoCoF, the time derivative of the frequency) has also become larger than before. The RoCoF is mainly determined by the magnitude of the power imbalance and the system inertia. These tendencies together have a negative effect on the stability of supply, even in large, interconnected power systems.

### Possible Solutions

Several technical solutions exist and they are at different stages of development. While some are already deployed in field operations, others are at the R&D stage and will need to be tested in real-life settings.

#### Specific Converters

Converters that provide frequency response or synthetic/virtual inertia, that allow RE generation to adjust very rapidly to a deviation in the frequency signal, example, by temporarily increasing power output, thereby helping to re-establish system frequency. This has already been implemented in Ireland and Quebec. Such situations are also being investigated in Australia and are being studied at the R&D project level in India.

#### Synchronous Condensers

A proven technology, historically used to maintain voltage in specific areas. The deployment of synchronous condensers, which are synchronous motors that draw energy from the grid to maintain a spinning mass and provide power to the grid in the same manner as a synchronous generator. The motors provide inertia and short-circuit power and they rotate freely, without producing electrical power. Synchronous condensers could be deployed by retrofitting generators from retiring plants or by equipping renewably fuelled synchronous generators with clutches that would enable them to act as synchronous condensers when not generating [5]. This method has been used in France, and more recently, in Denmark and South Australia and have proven effective at ensuring system stability. This solution has been proven in specific situations — a generalized rollout in the context of large scale system strength is yet to be evaluated.

#### Grid-forming Inverter (GFI) controls

Most inverter controllers today are grid-following and built on the assumption that system voltage and frequency are regulated by inertial sources. Such control approaches cannot guarantee system stability in low-inertia setting and are unlikely to sustain an inverter-dominated infrastructure [10]. This limitation has motivated a detailed investigation into grid-forming control methods for power electronic inverters, which provide functionalities that are traditionally provided by synchronous machinery. These inverters follow a control approach with the capability to control the terminal voltage directly and to form the grid voltage purely by inverters under consideration of necessary reserve and storage capacity. Such inverters can provide an inherent inertia to the system and have been successfully tested in the laboratory and on microgrids, but not yet at the scale of larger power systems. When grid-forming technology is combined with advanced automation and controls, it leads to the possibility of virtual synchronous machines. They can be used when large grids need to operate with various renewables. Full-scale experiments are planned in Europe in the coming years to validate this concept.

## POWER SYSTEM FLEXIBILITY

### Variability and Uncertainty of Demand

All power systems have some inherent level of flexibility — designed to balance supply and demand at all times. Variability and uncertainty are not new to power systems because loads change over time and sometimes in unpredictable ways also, and conventional resources fail. Conventional generations are the major source of power system flexibility. According to the International Energy Agency, the flexibility of a power system refers to "the extent to loads change over time and in sometimes unpredictable ways, and conventional resources fail unexpectedly [11]. Traditionally, power systems did not have any VRE — therefore designed to deal with non-VRE related variability and uncertainty. Main source of variability in conventional power systems is electricity demand, including both intra-day and seasonal variability. Main source of uncertainty is the loss of one or more of the largest in feeds (i. e., generators or transmission lines).

Increasing share of VRE in the mix - introduces additional levels of variability and uncertainty into the so-called net load [12]. As shown in **Figure 4**, the net load requirement dips when there is plenty of solar power available during the morning. In the evening, the net load requirement rises rapidly as solar generation dips. This curve indicates the ramping up requirements of power supply to serve the peak demand. This requires conventional generators to respond at a faster rate than traditional requirements to compensate for the loss of power output from solar generation. Hence, coal based



power plants, originally designed to be base loaded, increasingly need to be operated on a load following or cyclic basis. They need to cycle on and off and ramp up and down to part load more frequently, more rapidly and more cost-effectively. Most existing coal-fired power plants were designed for sustained operation at full load to maximize efficiency, reliability and revenues. Depending on plant type and design, these plants can adjust output within a fixed range in response to plant or market conditions. The need for flexibility is shifting their mission profile in three ways:

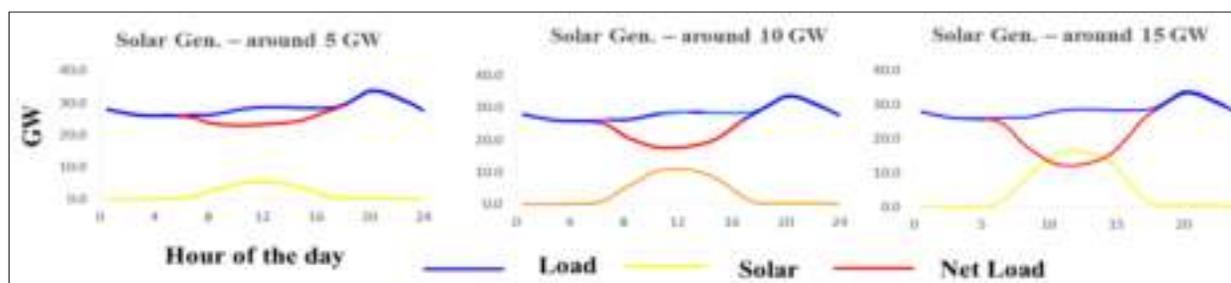
- 1) more frequent shutdowns when market or grid conditions warrant.
  - 2) more aggressive ramp rates (rate of output change) and
  - 3) lower desired minimum sustainable load, which provides a wider operating range and hence, enhanced usefulness.
- Figure 5** illustrates the dimensions of flexible power plant operation [13].

Increasingly, coal-fired power plants are being asked to make the transition to one or more of these duty cycles:

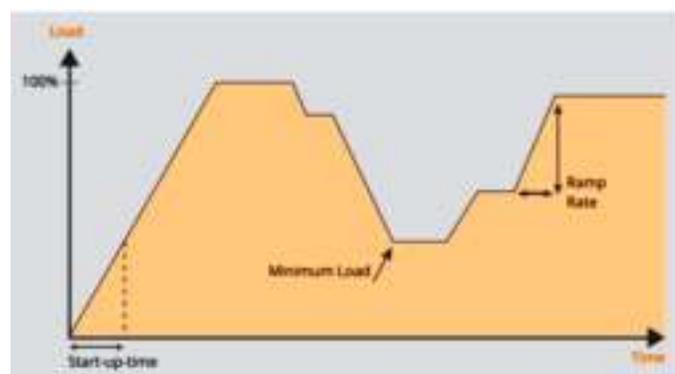
- Two-shifting in which the plant is started up and shut down once a day.
- Double two-shifting in which the plant is started up and shut down twice a day.
- Load-following in which the plant operates for more than 48 hours at a time, but varies output as demand changes.
- On-load cycling in which, for example, the plant operates at base load during the day and then ramps down to minimum stable generation overnight.

The above operating modes lead to fatigue and creep on components, which may result in higher capital and operational costs, increased forced outage rates and reduced lifetime. Cycling and ramping results in degraded performance and higher emissions (viz. CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>) over time.

With an increasing penetration of VRE, these challenges are only expected to increase in the future. Plants not designed for these operating modes can lead to more component failures, unplanned outages, increased heat rate, decreased revenue, and staff scheduling and training challenges [14]. At the same time, constraints on cycling operation can be imposed by new or upgraded emission control systems such as selective catalytic reduction [SCR] and flue gas desulfurization [FGD]. Compounding these challenges, many existing flexible coal-fired power plants are being taken



**Figure 4** Change in net load due to different levels of VRE (solar) deployment



**Figure 5** Dimensions of flexible power plant operation



out of service as a result of their age or difficulty in meeting new emissions requirements. These include small drum units with high design margins and fewer emission controls, which allow flexibility.

### Solutions

Various alternatives to address the challenges have been explored. These include Scheduling, energy storage and Coordinated generation.

#### Scheduling

Coal-based plants take a considerable amount of time to start up. Daily start/stop operation of the entire fleet is not feasible, technically as well as financially. The entire days scheduling of a coal-based unit needs to be done based on the forecasted value of the maximum evening load on the unit during the day. The units that are scheduled to operate on a given day would be expected to run at low loads when high solar power is available and ramp up gradually when solar generation reduces while the overall power demand increases.

#### Energy Storage Systems

Energy storage is not new. Batteries have been used since the early 1800s, and pumped-storage hydropower has been operating for many years. But the demand for a more dynamic and cleaner grid has led to a significant increase in the construction of new energy storage projects, and to the development of new or better energy storage solutions. Energy storage plays an important role in balancing grid supply and demand when integrated with renewable energy. Deployment of energy storage technologies also enables renewable energy time-shift and renewables capacity firming. The effectiveness of an energy storage facility is determined by how quickly it can react to changes in demand, the rate of energy lost in the storage process, its overall energy storage capacity, and how quickly it can be recharged. Flexible power from pumped and battery storage systems should be used along with two-shift operations of old and small coal-fired plants.

#### Coordinated Generation

Curtailement relates to a phenomenon where the power-grid operator issues an instruction to limit the power output of specific generators. Curtailement aims at lessening the stress on the grid at a given moment of the day. Most commonly, curtailement is associated with the reduction of in feed from renewable energy sources [15]. Curtailement of RE generation is permitted to maintain grid stability and system safety, as per the Indian Electricity Code instead of reducing power generation from other sources. As per the report by Central Electricity Authority, Ministry of Power, GOI, it is estimated that a 0.96 % curtailement of RE on an annual basis can improve the minimum thermal load of coal-based capacity from 25.7 % to 45 % in a business-as-usual scenario, and up to 56.80 % if gas and hydropower plants participate in coordinated generation.

### CONCLUSION

Climate change mitigation policies require substantial increased levels of electricity produced from variable renewable sources. Ambitious targets on decarbonisation present the need for massive integration of VRE in power systems in India. Stability of the power grid is vital to guard against outages and grid inertia acts as a shock absorber keeping the grid stable. Flexibility is a prized quality of power systems with increasing levels of VRE generation. Flexibility reduces curtailement and lower curtailement means reduced system operating costs and lower CO<sub>2</sub> emissions. Until large scale energy storage systems evolve, India will have a greater demand for thermal plant flexibility in the coming years. Gigawatt-scale tenders for energy storage to support transmission networks and enable solar PV integration have been announced by GOI in Feb. 22. Increasing the share of electricity generation that comes from wind power and solar PV beyond 35% as expected from the year 2030 will require several major changes to the power system both, on the system's flexibility needs and flexibility in resource deployment. All these aspects illustrated in this paper with relevant Figures, will be useful for further research to be carried out, in arriving at stable operation of power systems of the future, built with large percentage of renewable sources, with the aim of attaining zero carbon emission.

### REFERENCES

1. Greenhouse Effect 101, Natural Resources Defense Council, July 16, 2019, <https://www.nrdc.org/stories/greenhouse-effect-101>.
2. Lata Tripathi, A K Mishra, Anil Kumar Dubey, C B Tripathi, Prashant Baredar, Renewable Energy: An Overview on its Contribution in Current Energy Scenario of India, Renewable and Sustainable Energy Reviews, 60, 2016, pp 226-233, ISSN 1364-0321..



3. R M Elavarasan et al, A Comprehensive Review on Renewable Energy Development, Challenges, and Policies of Leading Indian States with an International Perspective, IEEE Access, vol 8, pp 74432-74457, 2020, doi: 10.1109/ACCESS.2020.2988011.
4. Denholm, Paul, et al, Inertia and the Power Grid: A Guide Without the Spin, National Renewable Energy Laboratory. NREL/TP-6120-73856. <https://www.nrel.gov/docs/fy20osti/73856.pdf>.
5. Benjamin Kroposki, Integrating High Levels of Variable Renewable Energy in to Electric Power Systems, J. Mod. Power Syst. Clean Energy, Springer, 5(6), 2017, pp 831–837, <https://doi.org/10.1007/s40565-017-0339-3>.
6. Report on Assessment of Inertia in Indian Power System, POSOCO and Indian Institute of Technology Bombay, January 2022.
7. Denholm, Paul, Trieu Mai, Rick Wallace Kenyon, Ben Kroposki and Mark O’Malley, Inertia and the Power Grid: A Guide Without the Spin. Golden, CO: National Renewable Energy Laboratory, 2020, NREL/TP-6120-73856. <https://www.nrel.gov/docs/fy20osti/73856.pdf>.
8. A Balancing Act: Renewables and Reduced Grid Inertia, Utility Magazine, 9 March 2021, <https://utilitymagazine.com.au/a-balancing-act-renewables-and-reduced-grid-inertia/>
9. Report No. ORNL/TM-2003/4, Frequency Control Concerns In The North American Electric Power System, December 2002, <https://info.ornl.gov/sites/publications/Files/Pub57419.pdf>
10. By Benjamin Kroposki, et al, Achieving a 100% Renewable Grid, IEEE Power & Energy Magazine, March/April 2017
11. Grid-Forming Inverter Controls, National Renewable Energy Laboratory, USA, <https://www.nrel.gov/grid/grid-forming-inverter-controls.html>
12. Jaquelin Cochran, et al, Flexibility in 21st Century Power Systems, <https://www.nrel.gov/docs/fy14osti/61721.pdf>
13. Flexibility Toolbox – Measures for Flexible Operation of Coal-Fired Power Plants, Indo-German Energy Forum, April 2018
14. Herminé Nalbandian-Sugden, Operating Ratio and Cost of Coal Power Generation, IEA Clean Coal Centre, December 2016.
15. Addressing Renewable Energy Curtailment—A Composite Approach, Council on Energy, Environment and Water, New Delhi, June 2018.



# Modified SEPIC Converter Fed BLDC Motor for EV Applications

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**Abstract:** Brushless DC (BLDC) motors have been popular in recent years due to properties like higher efficiency, higher starting torque, reliability, low maintenance requirements, higher power density and compact construction compared to conventional motors due to use of permanent magnets. A Brushless DC motor is a synchronous motor powered by a DC supply, which instead of a mechanical commutator based on brushes has an electronically controlled commutation system. The primary disadvantage of BLDC motors when compared with conventional motors is commutation torque ripple. In this paper, focus is on improving performance and to minimize the torque ripples present in a BLDC motor. In the configuration discussed in this paper, a dc-dc Improved SEPIC converter is used to carry out a DC voltage control strategy. The improved SEPIC converter has many advantages over conventional SEPIC converters namely higher gain and lower voltage stress on switches. With the help of dc-dc converter the required voltage is obtained and the controllable output of converter is used as the input of the inverter.

**Keywords:** Brushless DC Motor; Improved SEPIC Converter; Commutation

## INTRODUCTION

Due to the use of permanent magnets, Brushless DC motors offer features like lower maintenance, faster response, higher efficiency, higher power density and compact construction when compared to conventional motors, which makes them suitable for a variety of applications. The extensive application of BLDC motor includes vehicle tracking, gyroscopes, aircraft on board instrumentation, valves, fuel monitoring systems, and electric actuators. Continuous advancements in power semiconductors, controllers, and BLDC motor production over the past years have made it possible to produce solutions which are cost-effective and reliable, for a variety of automotive applications also. But the BLDC motor has a major drawback which is ripples in torque during commutation. In BLDC motors, ripples in torque are a major origin of acoustic noise, speed fluctuation and vibrations.

This study focuses on improved performance and reducing the torque ripples during commutation of BLDC motor. In this configuration, an improved SEPIC converter is used to carry out a dc voltage control strategy. The improved SEPIC converter has many advantages over conventional SEPIC converters namely higher gain and lower voltage stress on switches. This converter is used to achieve required dc voltage, which is then used as input of inverter. MATLAB/Simulink is used to perform simulation for closed-loop control of the BLDC motor. The two control loops are speed and current, and both loops contain separate PI controllers. The switching signals for the converter switch are generated by comparing the output of the current PI controller with the triangle waveform. The commutation signals for three phases of the motor are generated based on three hall sensor values which detect the position of the permanent magnets. These commutation signals are fed to switches of the voltage source inverter.

## BLDC MOTOR DRIVE SYSTEM

The conventional dc motors require brushes and require maintenance on the other hand BLDC motors are controlled electronically using switches which makes them maintenance free. Brushless DC motors have trapezoidal back emf instead of sinusoidal in PMSM's. The control of BLDC can be both sensorless or sensed using hall sensors, and it is generally two-phase control (only two phases are active at a time). The control techniques used for BLDC motors are fairly simple to implement compared to PMSM motors.

Elimination of brushes entails the need for a circuit controller in charge of feeding the different phases depending on the axis position and that of a sensor system, usually three, to detect its position. These sensors are usually Hall sensors, sensitive to the magnetic field. They are placed in the stator winding and close to the rotor magnets. The existence of these elements presents some disadvantages, such as the lower reliability and the assembly complexity of the sensors and their wiring, which makes the motor more expensive to manufacture. In recent years sensorless detection systems have been developed for those applications where torque is not required at very low speed. These techniques are based on determining the rotor

position from the voltages induced in the motor windings. However, you want that in the starting phase there are no voltages generated by the movement, different start-up techniques are used depending on the application; all of them based on microcontrollers or in specific integrated circuits.

As the BLDC motor stator is powered by dc power, electronic commutation circuit along with PWM controller becomes mandatory in drive system. Electronic commutator is a six-switch commutation circuit which receives logic pulses generated using hall sensors. Based on the position of hall sensors, the stator windings are excited through inverter to create a rotating magnetic field such that rotor magnetic field follows stator magnetic field.

**Figure1** shows connection of three phase winding BLDC motor fed by a 3-phase voltage source inverter. The voltage equations in a BLDC motor are given by:

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + e_a \quad (1)$$

$$V_b = R_b i_b + L_b \frac{di_b}{dt} + e_b \quad (2)$$

$$V_c = R_c i_c + L_c \frac{di_c}{dt} + e_c \quad (3)$$

Where  $L_a = L_b = L_c$  are self-inductances,  $M$  is mutual inductance,  $R_a = R_b = R_c$  are phase resistances,  $e_x$  is the induced emf of the respective phase. The equation for electromagnetic torque is given by

$$T_c = \frac{e_a i_a - e_b i_b - e_c i_c}{\omega_m} \quad (4)$$

### IMPROVED SEPIC CONVERTER

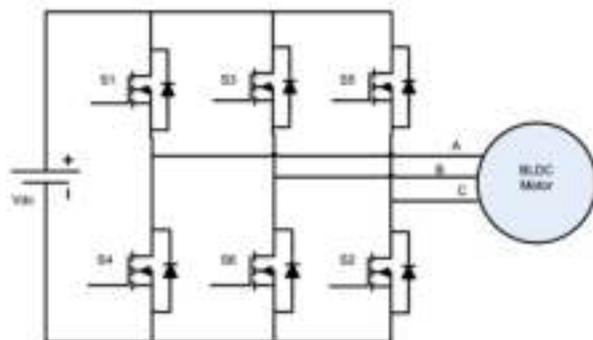
A conventional SEPIC converter is a dc-dc non-isolated converter which can produce stable dc output voltages higher, lower or equal to the input voltage. Conventional SEPIC converter works similar to a Buck-Boost converter with some additional advantages like continuous input current and output voltage polarity is non-inverted with respect to input voltage polarity. The output voltage is controlled by varying the duty cycle of pulse given to the controlling switch.

In this paper we will be using an Improved version of SEPIC converter, shown in **Figure 2**, which has some advantages over a conventional SEPIC converter like lower voltage stress on switches and can provide a higher voltage gain compared to conventional SEPIC. The pulse for the switches will be generated using Pulse-Width Modulation scheme.

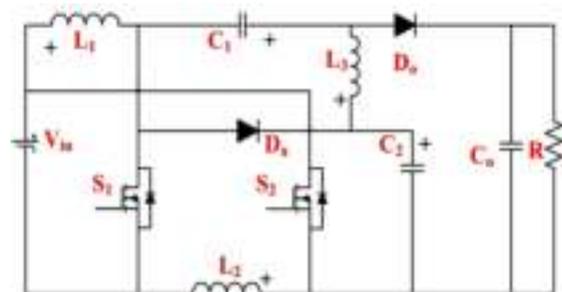
The Improved SEPIC converter consists of two switches  $S_1$  and  $S_2$ , two diodes  $D_o$  and  $D_a$ , three capacitors  $C_0$ ,  $C_1$  and  $C_2$  and three inductors  $L_1$ ,  $L_2$  and  $L_3$ . Both switches  $S_1$  and  $S_2$  are operated simultaneously by giving same firing pulses to both. The two modes of operation of the converter are: mode I - where both switches  $S_1$  and  $S_2$  are turned ON. So, both switches conduct and both diodes  $D_o$  and  $D_a$  do not conduct. And Mode II - where both switches  $S_1$  and  $S_2$  are turned Off, so both switches do not conduct and both diodes  $D_o$  and  $D_a$  conduct.

### IMPROVED SEPIC CONVERTER FED BLDC MOTOR DRIVE

A closed loop control configuration for brushless dc motor using dc-dc Improved SEPIC converter is proposed, which results in improved performance and reduction of torque ripple. The Improved SEPIC converter is used to carry out dc voltage control strategy. To reduce the ripples in torque, the current is controlled with an appropriate dc voltage. The block diagram of the system implemented is shown in below **Figure 3**.



**Figure1** BLDC motor drive



**Figure 2** Improved SEPIC converter

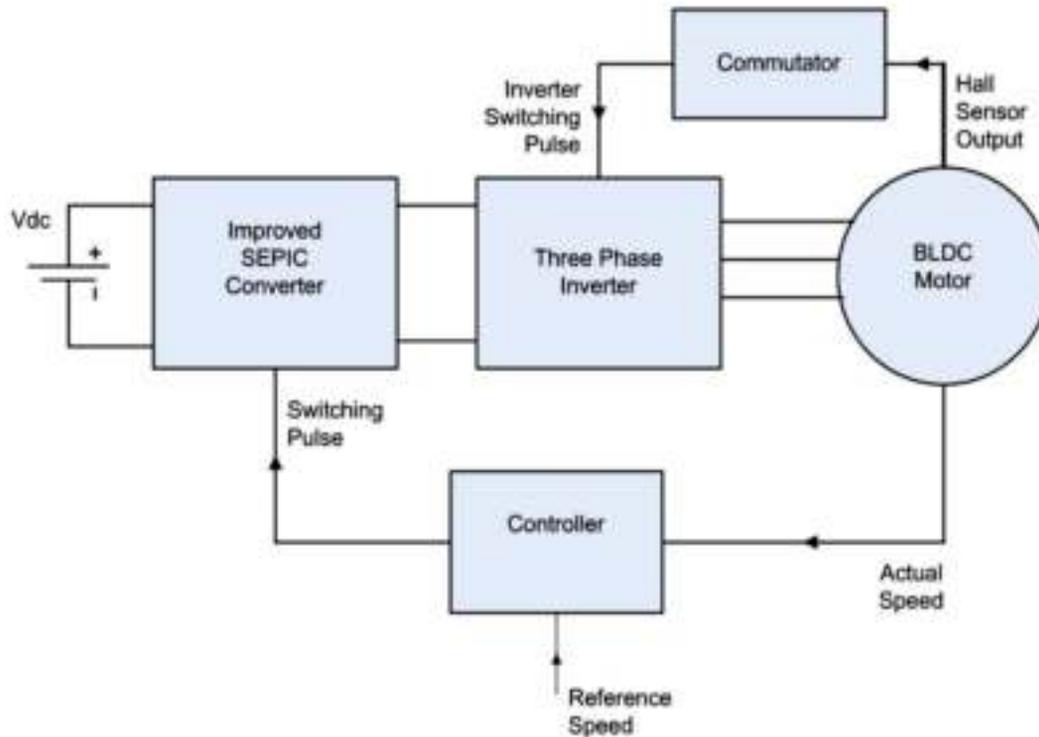


Figure 3 Block diagram of configuration

The block diagram of the proposed system consists mainly of a brushless dc motor, an Improved SEPIC converter, dc voltage source, commutator and a controller. DC input voltage is given as input to the improved SEPIC converter, whose controllable output is used as input of inverter module i.e., switching circuit.

The improved SEPIC converter is used to achieve the desired switching voltage. This helps in controlling the current and proportionally minimizing the torque ripple in the BLDC motor along with controlling the speed of motor. In this topology, the improved SEPIC converter uses two switches that performs the dc-to-dc conversion. Both the switches  $S_1$  and  $S_2$  are power MOSFETs. By operating the  $S_1$  and  $S_2$  switches properly, the energy stored in components, i.e.,  $L_1, L_2, L_3, C_0, C_1, C_2$  of the improved SEPIC converter can be adjusted to obtain the desired output. The hall sensors mounted on the stator of motor provides position feedback. They monitor the position of permanent magnets in rotor and output signals generated by them are used to drive commutation circuit. Based on these signals, the commutation circuit allows flow of current in the three phase windings of the stator in a controlled sequence such that the required speed and torque are produced by the motor. The efficiency of the configuration in improved response and reduction in torque ripple is analyzed by simulations.

#### SIMULATION OF BLDC MOTOR IN OPEN LOOP CONFIGURATION

A simulation model is developed to analyse the performance of brushless dc motor. First simulation model of BLDC motor is created in open loop configuration, so that we can compare it later on with the simulation of BLDC motor with improved SEPIC converter. MATLAB Simulink software is used to perform simulations. The BLDC motor parameters used for simulation are listed in **Table 1**.

**Figure 4** shows simulation results of BLDC motor with six-switch commutator using inverter. The firing pulses of switches for commutation are decoded using by commutation logic which take signals generated by from hall sensors as input. The signals generated by hall sensors gives us the information regarding position of the rotor permanent magnets and based on that information we can decide which phases should be conducting, and based on these switches are turned on and off so that the motor rotates. This commutation which happens due to switching at every 60 electrical degrees, is the primary cause of commutation torque ripple which can be seen in simulation waveforms.

**Table 1** BLDC motor parameters

Motor Parameter	Values
Rated Voltage	24 V
Rated Power	250 W
Phase Resistance	0.033 $\Omega$
Phase Inductance	0.3 mH
Pole Pairs	20
Rotor Inertia	0.000958 kg/m <sup>2</sup>
Rated Speed	1000 rpm
Rated Torque	1.7 Nm
Friction Coefficient	1.15e-3 N.m.s
Torque Constant	0.13 N.m/A

**Table 2** Improved SEPIC converter parameters

Converter Parameter	Value
Input Voltage	12 V
Output Voltage	24 V
Capacitor, C <sub>0</sub>	35 $\mu$ F
Capacitor, C <sub>1</sub>	69 $\mu$ F
Capacitor, C <sub>2</sub>	69 $\mu$ F
Inductor, L <sub>1</sub>	16 $\mu$ H
Inductor, L <sub>2</sub>	16 $\mu$ H
Inductor, L <sub>3</sub>	63 $\mu$ H

### SIMULATION OF BLDC MOTOR DRIVE FED BY IMPROVED SEPIC CONVERTER

**Table 2** shows the specifications and component values of the improved SEPIC converter used for simulation.

The simulation model of the dc-dc improved SEPIC converter fed BLDC motor drive in closed loop configuration is created corresponding to **Figure 3**. The BLDC drive is a two-stage controller consisting of two loops inner and outer, designed for the closed loop drive system. The commutation logic is similar to the open loop configuration, and same commutation logic is used to generate firing pulses for the switches. For the closed loop configuration, the reference speed is compared with actual speed to generate speed error. The speed error signal is fed to a PI controller which generates the reference voltage as output signal. Then the measured voltage at the output of improved SEPIC converter is compared with reference voltage to generate voltage error signal. This voltage error signal is again fed to a PI controller which generates duty cycle as its output. The Pulse Width Modulation (PWM) technique which takes duty cycle and carrier wave as input, is applied to generate firing pulses for the switches in improved SEPIC converter. In this topology, two feedback loops are there for speed and voltage control, so two PI controllers are designed to correct errors. The inner loop voltage control loop and outer loop is speed control loop. The simulation is performed at rated speed and different load conditions.

### SIMULATION WAVEFORMS

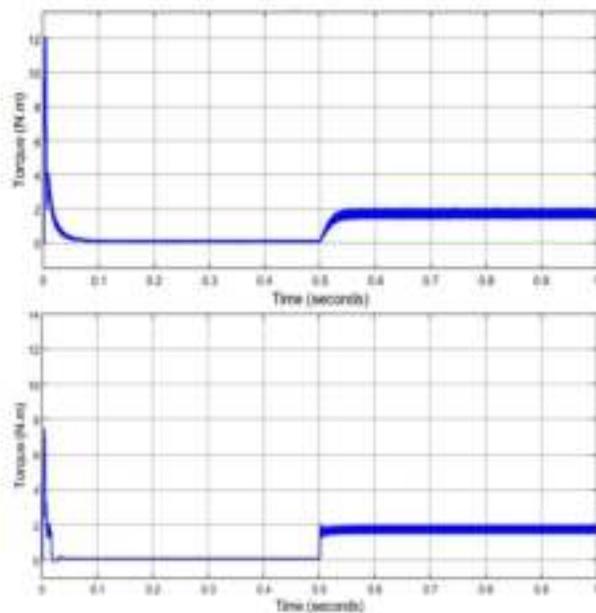
**Figure 4** shows simulation waveforms for speed and torque. Simulations was done for rated speed with no load and rated load conditions. The simulation is done for different reference speeds and load torque conditions. The simulations for both open loop configuration and closed loop configuration using improved SEPIC converter and their results are compared.

**Figure 4** shows torque waveforms for two configurations with reference torque set to no load initially and then full load. **Figure 5** shows speed waveforms for two configurations with reference speed set to rated speed, and load torque set to no load initially and then full load.

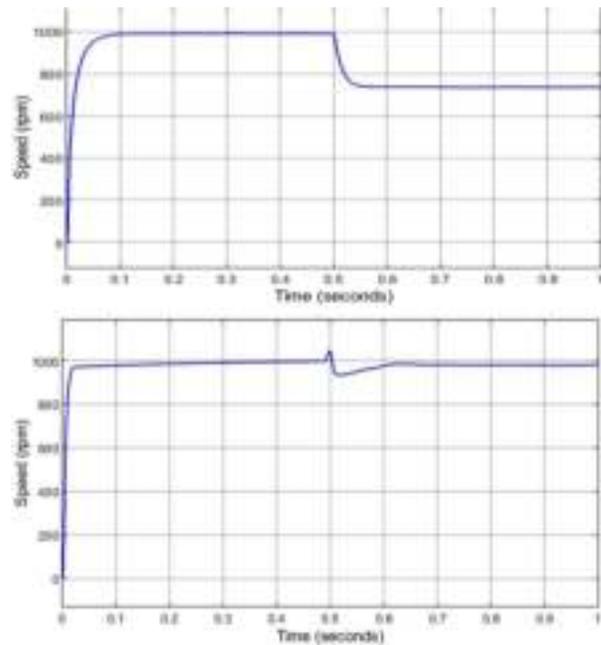
**Table 3** compares the transient and steady state speed response of motor and percentage ripples in torque under different speed and load torque conditions between the two cases where improved SEPIC converter is used closed loop and other is the open loop configuration. **Table 3** summarizes and concludes that the proposed strategy with improved SEPIC converter in closed loop configuration is effective in improving the transient and steady state response in speed and reduction of commutation torque ripples in BLDC motor.

**Table 3** Comparison of Simulation Results

Parameter	Speed Rise Time	Settling Time	Torque ripple	Speed at rated Torque
Open Loop	0.034	0.048	36%	780 rpm
Closed Loop	0.012	0.016	25%	980 rpm



**Figure 4** Torque waveform (a) open loop (upper) (b) closed loop with converter (lower)



**Figure 5** Speed waveform: (a) open loop (upper) (b) closed loop with converter (lower)

## CONCLUSION

In this paper, BLDC motor drive with closed loop configuration using dc-dc Improved SEPIC converter is discussed. The dc input voltage of the inverter used for commutation is controlled with the help of improved SEPIC controller. PI controllers are used for closed loop control to achieve desired voltage and speed. This configuration improves the speed response of motor and also reduces the ripples in torque which arise due to commutation in BLDC motor and the same has been verified using simulation.

## ACKNOWLEDGMENT

This work was supported by The Institution of Engineers, India under R & D Grant-in-Aid Scheme. [DR2022004].

## REFERENCES

1. S Ansari and JS Moghani, A Novel High Voltage Gain Noncoupled Inductor SEPIC Converter, IEEE Transactions on Industrial Electronics, 66(9), Sept. 2019, pp 7099-7108, doi: 10.1109/TIE.2018.2878127.
2. T Shi, Y Guo, P Song and C Xia, A New Approach of Minimizing Commutation Torque Ripple for Brushless DC Motor Based on DC-DC Converter, IEEE Transactions on Industrial Electronics, 57(10), Oct 2010, pp 3483-349, doi: 10.1109/TIE.2009.2038335
3. A. Sathyan, N Milivojevic, Y-J Lee, M Krishnamurthy and A Emadi, An FPGA-Based Novel Digital PWM Control Scheme for BLDC Motor Drives, IEEE Transactions on Industrial Electronics, 56(8), Aug. 2009, pp 3040-3049, doi: 10.1109/TIE.2009.2022067
4. Ki-Yong Nam, Woo-Taik Lee, Choon-Man Lee and Jung-Pyo Hong, Reducing Torque Ripple of Brushless DC Motor by Varying Input Voltage, IEEE Transactions on Magnetics, 42(4), April 2006, pp 1307-1310, doi: 10.1109/TMAG.2006.871937
5. Joong-Ho Song and Ick Choy, Commutation torque ripple reduction in brushless DC motor drives using a single DC current sensor, IEEE Transactions on Power Electronics, vol 19(2), March 2004, pp 312-319, doi: 10.1109/TPEL.2003.823177
6. Y. Liu, Z Q Zhu and D Howe, Commutation Torque Ripple Minimization in Direct Torque Controlled PM Brushless



- DC Drives, Conference Record of the 2006 IEEE Industry Applications Conference Forty-First IAS Annual Meeting, 2006, pp. 1642-1648, doi: 10.1109/IAS.2006.256756.
7. Gui-Jia Su and J W McKeever, Low Cost Sensorless Control of Brushless DC Motors with Improved Speed Range, APEC. Seventeenth Annual IEEE Applied Power Electronics Conference and Exposition (Cat. No.02CH37335), 2002, pp. 286-292 vol.1, doi: 10.1109/APEC.2002.989260.
  8. F Rodriguez and A Emadi, A Novel Digital Control Technique for Brushless DC Motor Drives, IEEE Transactions on Industrial Electronics, 54(5), October 2007, pp 2365-2373, doi: 10.1109/TIE.2007.900312.
  9. C Senthil Kumar, N Senthil Kumar and P Radhika, Torque Ripple Minimization in BLDC motor using SEPIC dc-dc Converter, Electrotechnical Inspection, ISSN 0033-2097, R.90 NR 9/2014
  10. R Carlson, M Lajoie-Mazenc and J C d S Fagundes, Analysis of Torque Ripple due to Phase Commutation in Brushless DC Machines, IEEE Transactions on Industry Applications, 28(3), pp 632-638, May-June 1992, doi: 10.1109/28.137450
  11. V Viswanathan and J Seenithangom, Commutation Torque Ripple Reduction in the BLDC Motor Using Modified SEPIC and Three-Level NPC Inverter, IEEE Transactions on Power Electronics, 33(1), Jan. 2018, pp. 535-546, doi: 10.1109/TPEL.2017.2671400.

# Smart Card based Electricity Payment and Energy Sharing System through IoT

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**Abstract:** Since the early 2000s, smart meters have been installed in numerous nations all over the world. The smart meter, a crucial component of the smart grid, is anticipated to benefit several stakeholders on the economic, social, and environmental levels. In this work, a single-phase energy meter with prepayment billing for household consumers is suggested. The system's ability to convert current conventional meters into smart prepaid meters with the connection of IoT and GSM is the key advantage. Utilizing GSM technology, units are purchased and then deducted based on electricity consumption. Through GSM technology, the consumer is informed of the whole bill amount and the due date. Normally a power outage will occur in a specific area for an extended period of time. It will have an impact on the youngsters and the elderly in the home. To mitigate this issue, decrease load sharing during power outages. This effort introduces a minimum amount of load per residence, such as one light and one fan during peak hours. IoT is used to remotely monitor energy use and turn on/off power supplies. Finally, the notable aspects of this study effort are the automatic restriction of electricity usage, the reduction of queues at the electricity billing counter, the disconnect of service if the bill is not paid, and the adoption of a completely new concept of "Prepaid Electricity Card".

**Keywords:** Smart Meter; IoT; RF ID; GSM Technology

## INTRODUCTION

TNEB now sends meter reader officers to their customers' homes on a monthly basis to read their energy meters. However, this method is no longer feasible due to the high cost. It is expensive since the number of consumers has expanded dramatically from year to year. As a result, the TNEB must dispatch more meter reader officers to residential areas to take energy meter readings. The issue is that the energy meter at the consumer's home may be unreachable. This could be due to a variety of causes, such as bad weather or a guard dog at the consumer's home, which prevents the officer from taking the meter reading. GSM-based Automatic Meter Reading (AMR) technology is already in use. This method, however, was exclusively employed for Large Power Consumers (LPC) [1]. A GSM module is fitted to each LPC's energy meter with this method. As a result, the meter reading is completed automatically without the need for a meter reader officer to visit the LPC site. This technique could not be applied to domestic consumers since the cost is prohibitively expensive given the enormous number of domestic users[2,3].

## PROPOSED SYSTEM

The study presented in this paper attempted to transform an existing energy meter into a smart energy meter capable of monitoring power use via an IoT-based power management system[3,4]. An IOT and GSM-based smart prepaid energy meter has been proposed to decrease the need for people in taking energy meter readings and bill payment. In this work, the appliances are turned on and off based on their power consumption.

To read the Domestic Energy Meter reading and wirelessly transmit it to a display unit using XBee technology. This technique enables the Electricity Department (TNEB) to read energy meters on a regular basis without requiring a meter reader officer to visit each consumer's home. This is accomplished through the employment of a microcontroller unit (PIC18F4550) that continuously monitors and records energy meter readings in its permanent (non-volatile) memory location. The energy meter reading will be displayed on a 16 × 2 LCD display before being communicated to the receiving-end PIC, and it will also be displayed on a 16 × 2 LCD at the receiving-end PIC.

## SMART METER

According to the International Energy Agency (IEA), the world generates more than 66% of its electricity from fossil fuels, with nuclear energy accounting for the remaining 8%. They are all non-renewable. As a result, there will come a moment when there will be no fossil fuels remaining and the globe would have to go dark. It's tough to fathom life before



electricity. There is a need for legal energy use. This will be impossible as long as current thievery continues. The Times of India reports in 2009-10, power theft cost India Rs 45K core. As a result, a successful power theft detecting module must be implemented. To contact with the authorities, a GSM module is needed. Normally, current theft is accomplished either direct line hooking or by bypassing the energy meter[7]. To detect this, we use the power line communication concept to continuously monitor the power delivered by the main transformer and compare this value to the power consumed by each consumer. If there is a difference between the readings, it indicates power theft, and the transformer will send an SMS to the authorities saying that current theft is taking place at that transformer. Also, if a customer consumes more electricity than the meter allows. The authorities will then receive an SMS confirming the current overload. A bill is a commercial document that specifies the units of power utilised. Normally, an officer would be dispatched to each property to collect the consumed units from the meter. This method is time-consuming, and he may not always be able to obtain access to the meter. With the use of an SMS, our project may send the customer's consumed units. The authorities would have to send an SMS to the main transformer requesting consumption units from each meter connected to it. The transformer would use power line communication to talk with each and every meter linked to it, and then send a message to the electricity department specifying the spent units of each user. In the event that any previous dues are not paid, the authorities might disconnect the current being delivered to the consumer by sending a single message. Control of all household gadgets is also feasible from afar by sending a single SMS. As a result, it is also a successful home automation system. We employed a PIC microcontroller, a GSM module, and a PLC module in the transformer part. A current sensor was also utilised to detect the power delivered by the transformer. To compute the consumed units, we used an Arduino controller, a few relays, a PLC module, and a rudimentary power meter in the consumer portion. We also employed a current sensor to detect the amount of power consumed by the user. It should be noted that only the PLC modem is used to communicate between the distribution transformer portion and the consumer section. At the distribution transformer section, there is a single GSM unit.

### **ZIGBEE COMMUNICATION**

Previously, projects used ZIG-BEE or established additional node sensors to evaluate data acquired by the sensor at the node to control the device. To use this Bluetooth, Wi-Fi, or zigbee, the transmitter had to be within a specific range, which was not always practicable. This operation will directly utilise the existing power line, making it substantially less expensive. Even if the controller and gadgets are positioned far apart, they can be operated effortlessly. Projects on current theft utilising power line communication are also present; they use PLC to communicate directly to the police. The downside of PLC is that it has a limited transmission range[9,10]. If the receiver is too far away from the sender, the signal from the current theft module will not be sent properly. This disadvantage is overcome by combining GSM with PLC, ensuring message delivery. Projects focusing on present theft have also proven to be expensive and difficult to implement. Furthermore, our project is inexpensive, cost-effective, and simple to deploy.

### **THEFT DETECTION**

Electrical power theft is the most widespread problem in our country. Our country has a large population, and electricity theft is becoming more common. Every year, a large number of home electricity thefts and industrial power thefts occur, resulting in a loss of distributed power to the supplier and, as a result, we face ongoing challenges such as power outages in urban and rural areas. This initiative helps to avoid challenges in meeting the country's electrical needs. Our proposed abstract is an electricity theft detection system that is utilised to automatically detect thefts done by the most unusual method of bypassing the transmission line with a piece of wire. A current sensor is utilised in this system to detect the entire amount of current consumed by the load. If the wire is tapped during transmission, the sensor will draw additional current, indicating that electricity theft has happened. The Arduino mega immediately accesses the theft information, and an SMS is sent to the cell phone through GSM technology.

This project's planned work focuses on the design and implementation of an electrical energy theft detection model. A significant portion of electricity revenue is wasted owing to power theft and poor management. The majority of these losses, however, are the result of electricity theft. The unauthorised use of electricity must be resolved electronically, with no human intervention. The goal of this work is to propose an implementation approach for detecting and managing electricity theft that allows violators to be discovered from a remote location. This design incorporates excellent solutions for electricity distribution system and home concerns such as power theft and transmission line fault. It employs embedded microprocessor technology and a wireless communication mechanism to detect energy theft and transmission line faults. Furthermore, gathering meter readings for billing processes from all consumers is a tough and time-consuming task that necessitates a large number of labours. The suggested approach employs a Global System for Mobile Communication (GSM)-based technology to automatically transmit the meter reading and detection alert to the authorised energy supplier via an alert message, therefore removing the numerous challenges associated with meter

reading and theft detection. We also monitor the power consumption of particular loads.

### SYSTEM ARCHITECTURE

The system primarily monitors and manages an electrical parameter such as voltage and current before calculating the power consumption. The primary purpose of this project is to create a freshly equipped, well-designed prototype for consumers to use in order to deliver secure power. The innovation of this system is controlling mechanism implementation. It delivers a notification to the user when a parameter exceeds its predefined values for controlling it. The method of managing electrical parameters that can be programmed using an ATMEGA256 controller and monitored from anywhere in the world through cell phone or PC.

The Trust Security Privacy (TSP) algorithm is used to provide greater confidentiality to the user. To offer a high level of security, the server assigns a user or authenticator id to consumers. As a result, users can only access their associated loads. Furthermore, the suggested system is user authentication, cost-effective, and simple to use. Because the system is adaptable and low-cost, we can save electricity outflow and so save consumers' electricity costs.

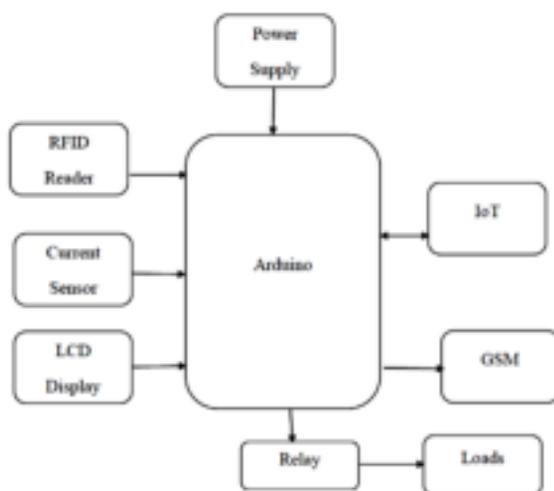


Figure 1 Block diagram of the proposed system



Figure 2 Hardware setup of the Proposed system



Figure 3 Power Consumption in the LCD Display



Figure 4 Demonstration of automatic cutoff of one load during power cut



## CONCLUSION

An Arduino and an IOT & GSM-based smart prepaid energy meter are proposed in this work. GSM technology is used to purchase units, which are then deducted based on electricity usage. This project proposes a single-phase energy meter with prepaid billing for household consumers. The primary advantage of this system is its ability to convert current conventional meters into smart prepaid meters via an Arduino and GSM connection (Prepaid Module). This eliminates the need to completely replace the energy meters. The most essential aspect of this task is the cost, which is extremely costly but will be reduced by three to four times after the project is completed. Currently, power supply businesses require labour for meter reading; however, after applying this, there will be no need for as many meter readers, resulting in significant savings. The concept of prepaying an electricity bill before to use is progressively gaining acceptance around the world, which is why the market for prepaid energy metering is expanding. Despite its numerous advantages, this project still need more safety checks and modifications, particularly the GSM module for the network coverage of the SIM that is being used, which must be robust in order for the GSM to function properly. A smart power management system based on IoT has been created. This system uses a wireless network to monitor and adjust the power consumption of home appliances automatically, manually, and remotely. The system is simple to develop, consumes little power, and is inexpensive and portable.

## ACKNOWLEDGMENT

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## REFERENCES

1. M Prathik, K Anitha and V Anitha, Energy Meter Surveillance Using IoT, IEEE International Conference on Power, Energy, Control and Transmission Systems (ICPECTS), 2018
2. Daminda Alahakoon, Xinghuo Yu, Smart Electricity Meter Data Intelligence for Future Energy Systems: A Survey, Volume, IEEE Transactions on Industrial Informatics, Volume: 12, Issue: 1, February 2016.
3. K L Zhou, S L Yang and Z Shao, Household monthly electricity consumption pattern mining: A fuzzy clustering based model and a case study, Journal of Cleaner Production, vol. 141, pp. 900-908, Jan 2017.
4. M A Rahman and G K Venayagamoorthy, A hybrid method for power system state estimation using Cellular Computational Network, Engineering Applications of Artificial Intelligence, vol. 64, pp. 140-151, Sep 2017.
5. Win Hlaing, Somchai Thepphaeng and Varunyou Nontaboot, Implementation of WiFi-based single phase smart meter for Internet of Things (IoT), International Electrical Engineering Congress (IEECON), 2017.
6. M A Rahman and G K Venayagamoorthy, A Hybrid Method for Power System State Estimation using Cellular Computational Network, Engineering Applications of Artificial Intelligence, vol. 64, pp. 140-151, Sep 2017.
7. Mohamed A and Abd El Ghany, Wireless IoT based Metering System for Energy Efficient Smart Cites, International Electrical Engineering Congress (iEECON), 2017.
8. Osmi Jaiswal, Dilip Chaubisa, Arduino Mega and IOT based Intelligent Energy Meter (IEM) to Increase Efficiency and Accuracy in Current Billing Methodology, International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS), 2017.
9. Bibek Kanti Barman, Shiv Nath Yadav, Shivam Kumar and Sadhan Gope, IOT Based Smart Energy Meter for Efficient Energy Utilization in Smart Grid, 2nd International Conference on Energy, Power and Environment: Towards Smart Technology (ICEPE), 2018.
10. Rishabh Jain , Sharvi Gupta , Chirag Mahajan and Ashish Chauhan, Research Paper on IOT based Smart Energy Meter Monitoring and Controlling System, International Journal Of Research In Electronics And Computer Engineering, 7(2), 2019.

# Collaborative Predictive Analytics Framework over AI-enabled IoT Device

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**Abstract:** Artificial intelligence (AI) enabled Internet of Things (IoT) devices, such as environment sensors reading for air pollution, are gaining popularity into industries and academia due to its feature to collect useful information after analysing huge gathered data. This information would be transferred as a small AI model to its master device as a data security and privacy. Further, the master device selects a few random models to build a powerful master AI (MAI) model. The selection of these IoT models among millions of received models that contribute to build a stronger MAI model is a challenging issue. To the best of our knowledge, there is no existing method to select the most effective random IoT models. We propose a novel collaborative predictive analytics framework based on deep neural networks (DNN) and gossip-based protocol to predict the best possible random IoTs to build an effective MAI model. Gossip-based protocol is used to label the qualified IoT devices whereas DDN computes the confidence of IoT models. Finally, a collaboration-based predictive system instructs the best possible IoT models to the master device. Theoretical analysis and experimental results show that the effectiveness of the proposed predictive MAI (P-MAI) model is outstanding with existing random selection mechanisms.

**Keywords:** AI; IoT; Deep Neural Networks; MAI Model

## INTRODUCTION

The aim of this paper is to analyze the natural component's variation, which are necessary in arrangement to establish the norm of the climate. In this errand, our paper open up an IOT-based Environmental Monitoring System created alongside the objective of wellbeing and security by means of the Internet exploiting the IOT structure. There is a troubled necessity for climatic natural checking technique that can Successfully give climatic ecological Monitored result to general designs like schools, Colleges , homes and business structures in the area where the National Ambient Air Monitoring Information System (NAMIS ) air natural estimation station isn't worked. This paper has been made as an Instance that screens various air ecological observation that remembers fine molecule and ozone for the climatic natural distinguishing gadget and move the information that incorporates the deliberate subtleties just as the position and working status of the checking gadget to the LTE organize and investigate them on the worker. On the report of the new examination, fine particles is for the most part brought about by burning of fuel, and it additionally causes different lung infections in the human body, photochemical response of NO<sub>2</sub> causes ozone and furthermore unpredictable natural mixtures (VOCs) delivered from vehicle fumes gas because of hard beams of daylight which causes respiratory framework illnesses. With the outcomes assembled from this framework, organization can make decision about how the environmental factors will impact the local area and what the local area is meaning for the environmental factors. Outside the organizations and other establishment, the detail is utilized by various individuals; in view of the climatic impact on a tremendous size of human's conduct, for example, agribusiness, transportation, etc.

Master AI Model is a thought and an example that post existent presence in the environmental factors of a variety of things that through wired and remote connection and individual tending to plans that can interface with one another and work together with various items to make new execution, Purpose and asset to arrive at want objectives. The model alludes to the quickly developing organization of connected items that can assemble and trade information utilizing embedded sensors. In these days finding extraordinary use in every single part assumes a primary part in the present natural checking framework. IoT crossing with distributed computing gives a novel way to deal with well organization of information getting from various sensors, assembled and transfered by least force, cheap microcontroller "Arduino UNO". An open source website page, Thingspeak is utilized to screen the components that are overhauled. IOT is a thought of giving a connected arrangement of anything, anybody, whenever, spot, administration, and organization. Little execution of IoT are brilliant Business, living, instruction, networks, Government, framework, utilities, versatility



and environment. The utilization of current advancements like Arduino, Raspberry Pi 3 and Adafruit IO can simplicity and supply considerably other purpose to IoT. It is compulsory to have the option to secure the versatile transmission network that provisions immense inclusion to screen the climatic ecological subtleties without limit on the space or position and to move it to the worker. The IoT supports to bring every one of the articles mutually and authorize us to collaborate with our own special items. The Data consequently gathered can be seen in a few contents. In this technique, the natural components can straightly be gotten to by the customer, accordingly dispose of the requirement for outsiders. Those the data is generated and stored in cloud environment with the support regular MAI model.

## LITERATURE SURVEY

To manage the ecological recognizing, critical accomplishment was affirmed in intense and diminished manner. The showing of climate distinguishing and the realities which are identified with WSN are coordinated by a ton of adventurer and have uncovered measurements information occasions. In 2008, Yang et al conferred, "An Environmental distinguishing System with joined Wired and Wireless Sensors" center a novel natural identifying framework with a direct on the broad technique planning for smooth co-activity of wired and remote sensors for long haul, inaccessible observing. A consolidated arrangement for sensor information gathering, reported, execution was additionally hand overed in this paper.

In 2009, Flammini et al announced, "Wired and remote sensor networks for mechanical applications" noticed a constant sensor networks for modern applications. Specific thought has been reward to the clarification of game plans and road for fruition and assessment was presented. This paper addresses the limits of wired organization and how it is overwhelmed by remote sensor organization.

Kaur et al , in 2014, described, "Examinations of wired and remote organizations: A survey", uncovered the likeness among wired and remote systems administration based on dissimilar equipment interest, ranges, adaptability, exactness and resources. Wired and Wireless organizations are more inconsequential in the private areas just as in the family applications. The wired organizations control a safeguarded and quick availability however the need of mobility, i.e., in any spot, whenever is influence the organization clients near remote innovation.

In 2015, a researcher called Amirah Mohamed Shahiri made a study to compare various approaches taken up in order to predict student performance so far. The approaches taken with their accuracies are Neural Networks, K-Nearest Neighbors, the Naïve Byes Classifier method, , Decision Trees and Support Vector Machine algorithm. He found the factors that are prominently influence and shape the efficiencies of each algorithm.

Gossip-based algorithms are a well-known and widely studied area of research. Grossi and his team made a study to explore knowledge-based approach to the problem of gossip in a multi-agentsystem, and they derived a theoretical basis for the reach of epistemic gossip protocols and that gossip algorithms are very robust in a probabilistic sense. Eugster and team summarize the known mathematical estimates of basic gossip spreading models. The team provides probability of an atomic infection, the proportion of the infected process, and an estimate of the infection latency.

## METHODOLOGY

The framework incorporates the fundamental units for detecting the flammable gases, CO<sub>2</sub>, CO, air quality and smoke. The sensors will accumulate the information from different ecological boundaries and give that information to Raspberry Pi 3 through Zigbee from the Arduino. The Raspberry Pi 3 will at that point transfer the prepared information on to the web . The framework is contained a few subsystems.

The motivation behind detecting unit is to distinguish every one of the boundaries utilizing an assortment of sensors that are picked cautiously to accomplish the best exhibition. In this work we are alluding the utilization of metal oxide semiconductor sensors on the grounds that the detecting materials utilized in these sensors furnish the sensors with a few benefits like minimal effort and high affectability.

- MQ7 gas sensor is profoundly touchy to Carbon Monoxide.
- MQ2 is essentially a universally useful gas sensor which can detect a wide scope of gases like LPG, Butane, Methane(CH<sub>4</sub>), smoke.
- MQ135 is an air quality or air contamination level estimating sensor gadget.
- The MG811 is profoundly touchy to CO<sub>2</sub>.
- MQ216 is appropriate for distinguishing of I-butane, propane, nitrous mixtures methane, liquor, benzene.

The Ground pin, DOUT pin, AOUT pin and VCC pin of the sensor are associated with the Ground pin, computerized pin,

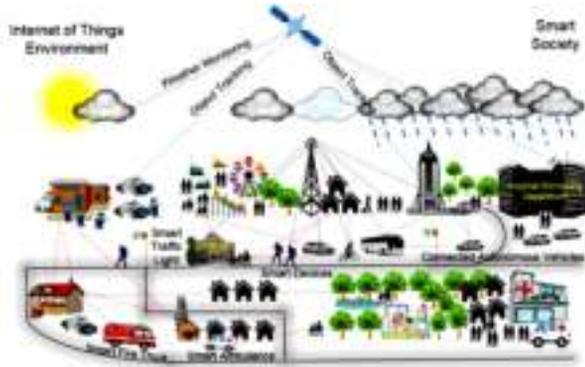


Figure 1 AI Enabled IoT Environment

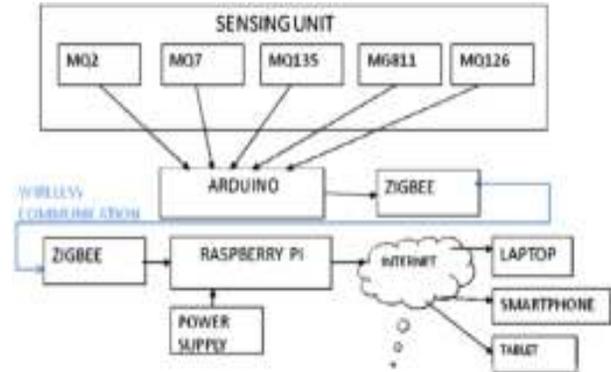


Figure 2 Model for Environment Monitoring

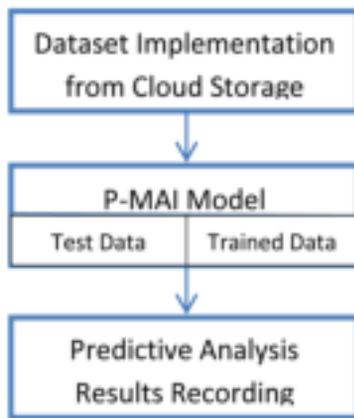


Figure 3 Model for proposed predictive analysis

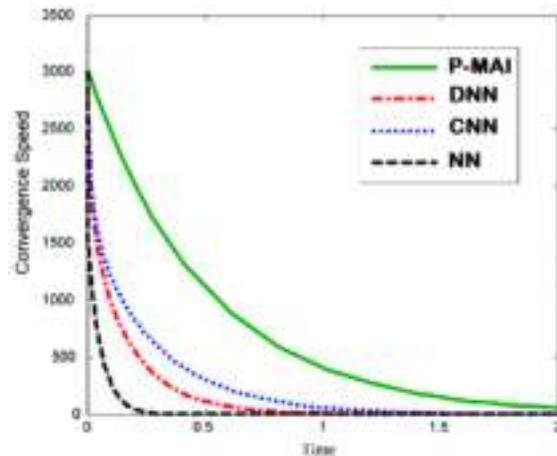


Figure 4 Comparison between proposed and existing models

simple pin and VCC pin of Arduino separately. The terminal AOUT gives a simple voltage yield in relation to the measure of gas the sensor distinguishes. The more gas it recognizes, the more prominent the simple voltage it will yield. On the off chance that if less gas it identifies, lesser the simple voltage it will yield. The recognized information from all sensors is shipped off the Arduino board. The Arduino IDE 1.5 adventures the help of chronic screen window to show the simple worth of the interfaced sensors . In the wake of transferring the program, in the event that there are no blunders, one can open the chronic screen window to peruse the program's yield esteems. This yield worth of Arduino addresses the aligned worth of toxins present in the climate. The XBee and XBee-PRO RF modules assumes a significant part in sending information from the Arduino board to the Raspberry Pi 3. The XBee is associated with the Arduino and XBee-PRO RF module is associated with Raspberry Pi 3 to communicate the information from Arduino to Raspberry Pi 3. Since we are utilizing the XBee and XBee-PRO RF modules a greatest distance of 100m can be kept up between the Arduino interfaced with sensors and the Raspberry Pi 3.

The Raspberry Pi 3 is the main unit and the center of the framework. It handles all the preparing and controlling required for the framework to work. It gets the detecting data from the Arduino through Xbee, measures it and produces the essential controls. Later transfer the information on the web utilizing Adafruit IO as IoT stage. Raspberry Pi 3 accompanies Wi-Fi, consequently no wired web associations are required. With the assistance of accessible Wi-Fi the Raspberry Pi 3 is associated with the Internet. The gathered information from the sensors has been put away in cloud worker and these information are sent as data to the page and afterward plot the sensor information as graphical insights , which can be available in the web from anyplace on the planet.



The architecture consists of pre-processing as the initial stage and then we need to convert the objects into categorical variables and have to assign a boolean value to those variables. Then we need to identify the test and train data from the selected dataset from the cloud. Later we need to encode the categorical variables.

The categorical variables places a crucial role in the model design as some of the features will have the string values which are needed to be converted to the accepted format by the modal. **Figure 4** explains the sample of output from proposed model for the prediction model with number of hidden layers with knowledge representation.

## CONCLUSION

This paper gives ecological observing framework that may offer a few likely advantages over the existing practices. The all out life-cycle cost of the framework is limited and could hypothetically run for quite a long time completely without the requirement for human mediation through the proposed model. Our effectively positioned framework can give effectively available environment information to the entire local area. Raising the familiarity with what society has meant for the area's natural strategies and has the information base to push for the change. Theoretical analysis and experimental results show that the effectiveness of the proposed predictive MAI (P-MAI) model is comparatively high with other existing mechanisms.

## REFERENCES

1. Ruchi Mittal, M.P.S Bhatia, Wireless Sensor Networks for Monitoring the Environmental Activities, IEEE, 2010, pp 1-5.
2. Shailendra Singh, Rajeev Jha, Priya Ranjan and Malay Ranjan Tripathy, Software aspects of WSN for monitoring in an Indian Greenhouse, International Conference on Computational Intelligence and Communication Networks (CICN), IEEE, 2015, pp 168-172.
3. Chen Xiaojun, Liu Xianpeng, Xu Peng, IOT- Based Air Pollution Monitoring and Forecasting System, International Conference on Computer and Computational Sciences (ICCCS), IEEE, 2015, pp 257-260.
4. Sean Dieter Tebje Kelly, Nagender Kumar Suryadevara et al., Towards the Implementation of IoT for Environmental Condition Monitoring in Homes”, IEEE Sensors Journal, Vol, 13, No. 10, October 2013.
5. Shifeng Fang, Li Da Xu et al., An Integrated System for Regional Environmental Monitoring and Management Based on Internet of Things, IEEE Transactions on Industrial Informatics, Vol. 10, No.2, May 2014
6. Apt, K, Grossi, D, Hoek, W, When Are Two Gossips the Same? Types of Communication in
7. Epistemic Gossip Protocols. 2018, <http://arxiv.org/abs/1807.05283>
8. Eugster, PT, Guerraoui, R, Kermarrec, A, Massoulie, L, Epidemic information dissemination
9. in distributed systems, in Computer, vol. 37, no. 5, pp. 60-67, May 2004, doi:10.1109/MC.2004.1297243.
10. Aazam, M.; Zeadally, S.; Harras, K.A. Fog computing architecture, evaluation, and future research directions. IEEE Commun. Mag. 2018, 56, 46–52.
11. Intel(R) Math Kernel Library for Deep Neural Networks (Intel(R) MKL-DNN). <https://intel.github.io/mkl-dnn/>
12. Berendea, N., Mercier, H., Onica, E., Riviere, E.: Fair and Efficient Gossip in Hyperledger Fabric, in 2020 IEEE 40th International Conference on Distributed Computing Systems (ICDCS), Singapore, Singapore, 2020 pp. 190-200. doi: 10.1109/ICDCS47774.2020.00027

# Energy Management System for Demand Regulation – Case Study

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**Abstract:** In the present scenario energy (power) demand has increased in compare to the last decade. Because nowadays energy management is a subject of great importance and priority on the management side. In the case of energy management some specific terms of system are playing a vital role to achieve the energy conservation goals. In this document, taken sample review paper combination to compare the techniques behind the energy conservation. Those techniques are Energy Management System (EMS), Conventional Grid (CG), Demand Response (DR), Energy Storage System (ESS), Electric Vehicle (EV) and Micro-Grid (MG). The goal of this paper is to present review on demand regulation with multiple energy conservation self-sustainable methodologies. To achieve the goal of demand reduction in future with the application of Smart Energy Management System (SEMS).

**Keywords:** Energy, Micro Grid, EMS, CG, Demand Response, Energy Management, Energy Storage System

## INTRODUCTION

A systematic method for continuously enhancing energy performance and maximizing energy savings is known as an energy management system (EnMS). The goal of an EnMS is to involve and motivate employees at all organizational levels to continuously control their consumption of energy. The use of Energy Management Systems has increased as a result of rising electrical demand and modern gadgets' emphasis on obtaining the most and least expensive energy feasible (EMS) is rising for utilities as well as end users. Utilities typically employ EMS capable of, for instance, lowering the costs of operations and maintenance tasks or even balancing the costs of fixed capacity for rising demand or the incorporation of renewable energy sources. However, end users want to be able to track real-time costs at their homes, small and medium-sized businesses, buildings, and facilities, as well as huge businesses. Different types of sources and loads are often dispersed throughout the main grid [1]. In order to prevent any power outages, it is also necessary to make predictions about how the system would respond as well as source selection in real-time.

Transmission losses are added by the stochastic character of loads, which can be somewhat predicted and which can be located quite far from the source location. The purpose of this paper is to present a system that can self-regulate a heterogeneous group of power sources and loads organized as a coherent group of entities, which is known as a microgrid, in order to optimize several criteria, such as cost and efficiency, without any interruption of the load supply, which is a necessary constraint [2,5]. In fact, if the amount of energy produced is insufficient to meet the energy needs of the loads, the system must make up the difference by using the more expensive energy that is available on the grid. Photovoltaic (PV), wind, fuel cell (FC), battery, or supercapacitor systems are some of sources for microgrids (SC). The final two elements may also be as a result of their ability to retain energy from given that they can supply energy to other elements or sources the loads as specified [2].

## Background

The energy management system has been designed using the Multi-Agent Systems (MAS from now on) paradigm. Each thing is modelled as an autonomous agent that may interact and has its own decision-making process. Each entity works with other agents to globally optimize the specified criteria while taking into consideration the features of the source type [6].

An agent is an autonomous and proactive system that evolves in an environment capable of interacting with other agents or with the environment in order to satisfy its objectives [2]. Multi-Agent Systems are used for a wide range of applications such as: complex systems modelling and simulation, open dynamic systems, optimisation, etc. Among the coordination techniques in the agency field the Contract Net protocol is one of the best-known [5].



## Observations

### End Users

The so-called smart grids will make up the EMS for end customers. These will be able to connect with smart homes and energy-efficient buildings gadgets that automatically balance use with power plant production and network capacity in order to reduce electricity expenditures. Distributed electrical-energy storage devices will also be used by future grids to manage peak demand periods while reducing the need for additional power plants.

Additionally, plug-in hybrid electric vehicles and large scale electric vehicle recharging are being accommodated by smart power networks. In order to integrate renewable energy sources (such solar-photovoltaic and wind energy), smart grid technologies are also required.

### System Observations

The main tasks of such a system are to monitor, control, and utilize power while also optimizing the flow. The production, transmission, and distribution systems of the power system network all have challenging applications for SEMS. Demand management and Real Time Pricing (RTP), two common Demand Side Management (DSM) strategies proposed by certain energy suppliers with energy management system functions, are significant applications. SEMS represents a considerable upgrade for commercial and residential customers. Demand response, demand side management, maximum shaving, and demand altering, which are used to address system operational issues, have the added benefit of easing the demand for more resilient and intelligent SEMS.

### Structure of EMS

An energy management system is a "computer system comprising a software platform providing basic support services and a set of applications providing the functionality needed for the effective operation of electrical generation and transmission facilities to assure adequate security of energy supply at minimum cost," according to the International Electro-Technical Commission (IEC) standard application programme about power systems (IEC-61,970) [6]. Data analytics, forecasting, optimization, human-machine interface (HMI), and network reconfiguration for real-time interface with the EMS are among the various EMS operations [4].

### Analysis

Case-1: The various energy management solutions for the microgrid, which include classical, heuristic, and intelligent algorithms, are reviewed in detail in this work. A brief introduction to the architecture of microgrids, various microgrid classifications, components of a microgrid, communication technologies used, standards available for implementation, and auxiliary services needed in the microgrid are also provided in this paper. It discusses important energy management applications, such as demand response, data handling, forecasting, and the control structure. This article also provides information on areas where research is still in its infancy and its potential to improve energy management [4].

Case-2: For the immediate prospect of implementing an energy management system, which is not through entity consumers, an overview and significant findings of several research studies are provided. However, there is a greater possibility due to the accumulation and assimilation of some consumers who are already present. Manufacturers of SEMS and utilities need to work together to assemble parts and provide specific levels of utility household contact. It is recommended to effectively incorporate top-down. The resources used change from centralised systems to power plants or grids to groups of buildings and finally to single buildings. SEMS is more than just information transfer and more than just an on/off switch technique. Goals for the completion of SEMS should typically be clearly specified and broken down for a variety of concentration groups, including researchers, government, manufacturers and consumers [3,6].

Case-3: EMS and SCADA existed before Smart Grids. SCADA systems have been giving utilities with data for a few information and command features to support and aid in grid management. Today's energy management and control systems offer a growing range of capabilities for the grid's dependable, secure, and effective operation. However, these systems require a growing amount and variety of information. In a setting of escalating demands and cyber dangers, they must interface a variety of systems and devices. More obligations are placed on the EMS as the grid grows smarter, which depends on the information provided and the capacity to actively manage the grid [2].

Case-4: An intelligent energy management system built on MAS is presented in this research. The system is made up of many energy sources, often known as energy producers. consumer loads are called. Each source or load is represented by an autonomous agent that can operate in accordance with its existing circumstances and predetermined objectives. A coordinated group of grid connected sources and loads is under the supervision of the MAS. The contract net protocol



serves as the foundation for agent interactions [1].

### OTHER RECOMMENDATIONS

This system offers a number of benefits. First, each source or load may have unique (and distinct) properties, restrictions, and decision-making processes. This makes modelling each entity simpler (source or load). Second, because each agent is autonomous, the system is open, allowing sources and loads to change during the course of the system's existence. Third, by using an interactions based management strategy, the system can self-organize to meet the objectives and limitations of each agent. An ideal state for the energy management problem is one that satisfies each agent's aims and restrictions.

### CONCLUSION

This paper presents a comparison of the four different methods of the Energy Management System (EMS) approaches, which classify in many terms like smart grid, micro grid, etc. The motive of this comparison is to compare the effective method for the future scope. By the comparison we can circle drawn or a particular method of Energy Management System and which can be further include to achieve a more energy efficient system

### ACKNOWLEDGMENT

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### REFERENCES

1. J Amaral, Cecilia Reis and R F Mesquita Brandao, Energy Management Systems, Conference: Power Engineering Conference (UPEC), 2013 48th International Universities.
2. M Cirrincione, M Cossentino, S Gaglio, V Hilaire, A Koukam, M Pucci, L Sabatucci, G Vitale, Intelligent Energy Management System” Industrial Informatics, 2009. INDIN 2009. 7th IEEE International Conference.
3. N Loganathan, P S Mayurappriyan, K Lakshmi, Smart Energy Management System: A Literature Review, MATEC Web of Conferences 225, 01016, 2018, UTP-UMP-VIT SES 2018, <https://doi.org/10.1051/mateconf/201822501016>
4. Battula, A R, Vuddanti, S, Salkuti, S R. Review of Energy Management System Approaches in Microgrids. Energies 2021, 14, 5459. <https://doi.org/10.3390/en14175459>.
5. G Dawei, J Zhenhua and L Qingchun. Energy Management Strategy based on Fuzzy Logic for a Fuel Cell Hybrid Bus. Journal of Power Sources, 1(185), 2008.
6. Javaid, N, Hafeez, G, Iqbal, S, Alrajeh, N, Alabed, M S, Guizani, M, Energy Efficient Integration of Renewable Energy Sources in the Smart Grid for Demand Side Management. IEEE Access 2018, 6, 77077–77096.
7. Cha, H-J, Won, D-J, Kim, S-H, Chung, I-Y, Han, B-M, Multi-Agent System-Based Microgrid Operation Strategy for Demand Response. Energies 2015, 8, 14272–14286.



# Online Rectification of Combined Isolating and Emergency Stop Valve of Turbine Generator to Continue Power Plant Operation

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**Abstract:** In Madras Atomic Power Station, twin units of 220 MWe capacity, steam produced in the boilers is routed to the turbine through Combined Isolating and Emergency Stop (CIES) valves. There are two CIES valves one at each side of the main steam header. Each valve is hydraulically operated through relay gear unit. Relay gear unit of each CIES valve consists of three components namely trip valve, pilot valve and power piston unit. Operation of trip valve will admit or drain the relay oil from the pilot valve assembly which will dictate the amount of oil supplied to the power piston unit assembly and thus decides the position of the valve. In an occasion, while one of the units power rise was underway after synchronization to the power grid, CIES valve (RHS) was getting tripped. As full power operation of unit could not be attained with only one CIES valve open, possible reasons for CIES valve getting closed were reviewed and noted that the relay oil from the trip valve unit assembly is passing which in turn was causing the CIES valve to close. This deficiency was attended online while unit was in operation through development and fabrication of gag to prevent the movement of the pilot valve plunger unit. On removal of trip piston assembly, step (impression) marks were seen on the mating parts of trip piston and cylinder which caused the relay oil to get drained. The same was machined without any face out, assembled and leak test done and found that the trip valve is holding the relay oil without any passing. The unit operation was continued and power was raised to the full power within a short time of ~8 Hours and the deficiency was attended online and the concern was resolved without taking shut down of the unit.

**Keywords:** CIES Valves; Trip Valve; Relay Oil; Gag

## INTRODUCTION

Madras Atomic Power Station (MAPS) comprises of twin units with maximum continuous rating of 235 MWe for each unit. Heat energy from the reactor is transferred by pressurized heavy water to light water in eight boilers (four in north bank and four in south bank). Steam having pressure of around 41 kg/cm<sup>2</sup> and maximum flow of 1330 T/hr is produced in the boiler and routed to the turbine through two main steam headers – one each from the north and south bank boilers via Combined Isolating and Emergency Stop (CIES) valves. These are the first main steam stop valves on steam admission lines to the HP turbine. These CIES valves are provided to quickly interrupt the steam flow to HP and LP turbines in case of a trip. Each of the two CIES valves is a single seated valve with steam passages of venturi type. CIES valve is operated through relay gear mounted below the valve assembly. Relay gear is hydraulically operated by relay oil. Relay oil is supplied by high pressure auxiliary oil pump (HPAOP – Discharge Pressure of 26 kg/cm<sup>2</sup>) while startup and by the main oil pump (MOP - Dis-charge Pressure of 20 kg/cm<sup>2</sup>) once the turbine is rolled and synchronized.

The relay gear consists of emergency trip valve (trip device), pilot valve and power piston cylinder all of which are linked mechanically by a lever (**Figure 1**). Relay gear is opened and held open by the relay oil pressure acting under the power piston against the spring in the power cylinder and the admission as well as the release of relay oil is controlled by pilot valve. When the relay oil released from the power cylinder by the pilot valve, the spring compression acting on the power piston closes the valve. Emergency trip device consists of a chamber fed with relay oil, spring loaded trip piston mounted on a screwed spindle. During normal operation, trip piston is pressed to its bottom position against the spring force by relay oil pressure and the CIES valve is opened or closed by the movement of screwed spindle. When the screwed spindle is moved downwards, the pilot valve gets a downward movement through the link which in turn opens the relay oil to the power cylinder and opens the CIES valve. An onload test valve is present for each CIES valve to cutoff the relay oil supply to the emergency trip valve while testing.

## DESCRIPTION OF THE PROBLEM

In an occasion, MAPS-2 was synchronized to the grid and power raise was in progress. It was observed that RHS CIES

valve is getting closed while LHS CIES valve is fully open. As full power cannot be reached with one CIES valve open and shutting down of the unit would result in power generation loss, the problem/deficiency need to be identified and rectified in a minimum possible time.

### CAUSE IDENTIFICATION

Possible reasons for CIES valve (RHS) getting closed was reviewed one by one to narrow down the exact cause of the problem (Table 1).

### ONLINE RECTIFICATION OF THE DEFICIENCY

Before attending the deficiency in the emergency trip valve while unit in operation (online) some of the difficulties involved were addressed (Table 2).

A gag was fabricated for arresting the movement of pilot valve plunger before removal of emergency trip valve assembly (Figure 3). After ensuring pilot valve plunger is intact, emergency trip valve was removed from the location for inspection.

While inspection lapping marks (step marks) were seen in the trip piston and spring carrier mating surfaces (Figure 4). Leak test was conducted by filling acetone (acetone being a low-density liquid when compared with the turbine oil). It was observed that when the screwed spindle was operated, acetone was getting drained as sealing was not proper due to lapping (step) impressions on both trip piston and spring carrier seating areas. Accordingly, both the mating parts were machined without any face out. Emergency trip valve was assembled back in the location and gag was carefully removed after connecting the pilot valve plunger to the trip valve. Oil pressure in the CIES (RHS) trip valve was checked and found 20 kg/cm<sup>2</sup>. Unit power was raised to full power within minimum possible time.

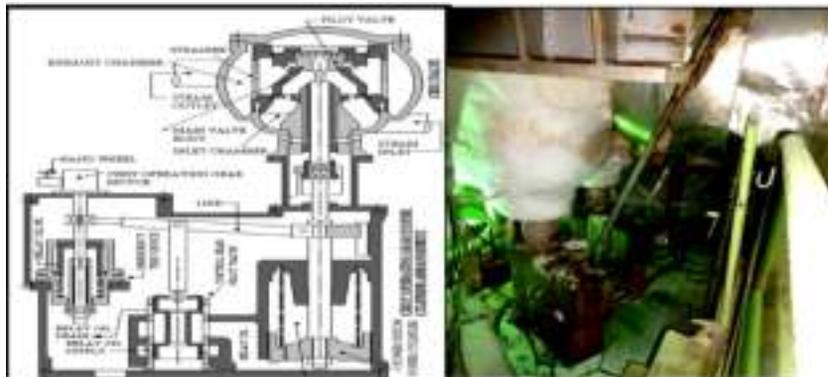


Figure 1: CIES valve and relay gear assembly (actual picture on right hand side)

Table 1 List of possible reasons for closing of CIES valve

S. No.	Possible Reasons for CIES Valve Getting closed	Remarks
1	Relay oil supply pressure from Main oil pump is low	Relay oil pump pressure at the pump discharge found to be around 20 kg/cm <sup>2</sup> . Hence ruled out.
2	Relay oil supply CV is not functioning properly	CV operation found normal in the field. Any abnormality in CV would have affected both the valves. Hence ruled out.
3	Orifice in the relay oil supply line or the supply line itself might have choked.	To rule out this option, relay oil supply to emergency trip device was cut off by gagging the onload test valve and pressure gauge (PG) was introduced in the relay oil supply line to emergency trip valve (Refer Figure 2). Sufficient pressure was observed in the PG. Hence ruled out.
4	Emergency trip valve inside the relay gear is passing	PG was installed in the pressure switch connection to the emergency trip valve chamber and found oil pressure in the order of 11.5 to 12 kg/cm <sup>2</sup> and the oil pressure drops to zero once the valve hand wheel is in full open position. This confirms that trip valve is passing.



**Figure 2** Gag for CIES valve (RHS) onload test valve

**Table 2** Difficulties addressed before performing the job

S. No.	Difficulties to be addressed	Action taken
1	Before removal of emergency trip valve assembly, movement of the pilot valve plunger should be restricted. (Downward movement of the pilot valve plunger will admit the relay oil to the power piston).	A gag was developed for arresting the downward movement of the pilot valve plunger
2	FME to be ensured throughout the job	Dummy cover installed to ensure FME (Refer Figure 3)
3	As unit s in operation, noise and working area temperature was higher.	Personal protective equipments as recommended in safety permit were used.



**Figure 3** Fabricated gag to arrest the movement of pilot valve plunger and FME dummy cover



**Figure 4** Lapping (step) marks observed on the mating surfaces of trip piston and spring holder

## CONCLUSION

1. Lapping (step) impressions observed in the mating surfaces of the trip piston and spring holder resulted in draining/passing of relay oil which caused the CIES valve (RHS) to close while unit was in operation and halted the power raise program.
2. Development of mechanical gag to arrest the pilot valve plunger movement before removal of emergency trip valve assembly ensured online rectification of the deficiency without shutting down the unit thus avoided the loss of power generation of the unit.

## ACKNOWLEDGMENT

Compliments to all the station personnel involved in the job for accepting the challenge to work online and their sincere effort to complete the job in minimum possible time.

## REFERENCES

1. BHEL Drawing for CIES Valve Operating Gear, BHEL drawing No. G2612757.

**ELECTRONICS  
&  
TELECOMMUNICATION  
ENGINEERING  
DIVISION**



# Introduction of an Automatic Chest Compression Device for Out-Hospital Cardiac Arrest (OHCA)

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**Abstract:** The proposed system will improve the accuracy and therefore the efficacy of the Cardio Pulmonary Resuscitation (CPR) given to person attacked with sudden Out-Hospital Cardiac Arrest (OHCA). It would analyze the cardiopulmonary response and apply immediate effective resuscitation without much injury. Presently available Mechanical chest compressors need the involvement of health care professionals and lot of other machineries too. But the proposed model is simple and does not require the much involvement of health care professionals. This can be operated in three different modes: Manual, Semi automatic and Automatic. For Semi automatic and automatic mode Wireless Sensors would be used to sense the status of Cardio Pulmonary functionality of the victim. Based on the different Signals obtained, actual nature of CPR shall be decided and applied accordingly. In Semi automatic mode the CPR will be controlled by health care professionals from a remote place like hospital or nursing home through Internet of Things (IoT) and in Automatic mode the same will be done through signal processing module embedded within the system.

**Keywords:** Out-of-hospital Cardiac Arrest (OHCA); Cardio Pulmonary Resuscitation (CPR); Chest Compression; Automated External Defibrillators (AED); Artificial Breathing; Return of Spontaneous Circulation (ROSC)

## INTRODUCTION

OHCA is a major public health concern accounting for a substantial number of deaths worldwide [1]. According to the American Red Cross, almost 80% of cardiac arrests occur at home and in association with family member. Probability of Surviving after sudden cardiac arrest primarily depends on the initial resuscitation and timely hospitalization. The survival rate of OHCA is 1 to 6% [2]. The initial resuscitation as given now is based on skill only and there are scopes to improve the survival rate. There are reasons for this low success rate like poor performance of manual chest compression and amount of hands off time during CPR. In India, alarming number of OHCA cases was recorded during post Covid period. Very recently, few lives were lost while the victims were either singing or dancing or playing or swimming. The common thing of all these cases is that Cardio Pulmonary Resuscitation (CPR) was not given. Even if the CPR were given, due to lack of skilled health care personals and/or unavailability of automated system. Even in some cases, severe injury occurred during CPR. The normal adult resting heart rate is between 60-100 beats per minute (bpm) but when stressed or exercising the same heart may rapidly increase to a rate of 140 bpm or more. The ability of heart to the change in rate is called chronotropism, the change in contractility is called inotropism and the change in conduction is called dromotropism. The inability to adjust with the raised demand of heart rate is another matter of concern[3]. India recorded a major hike in cardiac attack after the covid may be because of this summative or individual cause[4]. Doctors have also witnessed an increase in the prevalence of diabetes, hypertension, smoking, alcohol use and an unhealthy lifestyle in the last few years especially during pandemic situation.

## CARDIO PULMONARY RESUSCITATION

Cardio Pulmonary Resuscitation (CPR) is a lifesaving technique that is a combination of chest compressions and artificial ventilation (breathing) used to save a person's life when a person's heart stops beating or breathing ceases.

CPR should be given when a person stops breathing and their heart has stopped pumping blood. CPR continues oxygenated blood flowing to the brain and other vital organ of the body until the heart starts working normally.

As per the guideline of Medical council of India, presently manual CPR is applied with very low success rate. There are three parts of CPR in broader respect i.e. Chest Compression, artificial breathing and Automated External Defibrillators. One cycle of manual CPR consists of 30 compressions and 2 breaths. A good CPR needs 3 cycles in one minute. It is quite difficult to push the chest so hard and fast. In many cases the reliever gets exhausted.



## PROPOSED WORK

The proposed low cost model is highly applicable and would be a life saving asset at sports complex, gymnasium, auditorium, school and colleges, market place, etc.

- Signal  $e_1$  and  $e_2$  received from chest pad placed on chest 1 and 2, respectively and Signal  $e_3$  received from nostrils;
- If the heart beat is detected, the time interval between two successive peaks is calculated by Equation (1);
- Based on the heart rate and other sensors output the system will set the basic parameters;
- First the system will try to operate in automated mode unless forced to be operated manually;
- Then through specially designed app the control of the system will be handed over to the health care professionals.

Thus the proposed model is capable of delivering three different outputs two being mechanical support and one is electrical support. Sensors placed on the chest to receive the pulse bit and it is Heart Rate (HR) is calculated as

$$HR = \frac{1 \times 60}{\text{Time interval between two successive R}} \quad (1)$$

If HR is not obtained or found to be very prolonged, chest compression should be given immediately.

## MECHANICAL COMPRESSION

In this proposed model, CPR will be given with desired depth and rate through an automated mechanical device. Two different techniques have been attempted. The first one is a Cam and Follower attached with a DC motor has been used. Chest will be compressed through the up and down movement of the follower.

$$\text{Depth of Compression} = R - r \quad (2)$$

where,  $R$  is the largest radius of Cam and  $r$  is the smallest radius of Cam.

Depth of compression can be changed by changing the Cam either manually or automatically.

Let the desired rate of chest compression per minute be  $N$ . As in the proposed model dumbbell shape Cam has been used, there will be 2 compressions per  $360^\circ$  rotation of the Cam.

$$\text{Desired rpm} = \frac{N}{2} \quad (3)$$

The simulated model as designed through Simulink has been shown in the model in **Figure 2**.

The same compression can also be obtained using stepper motor. Only the driving pulse required to operate the motor is shown in the final model in **Figure 5**.

The general equation of a DC motor is

$$N = \frac{E_g 60A}{\phi Z P} \quad (4)$$

Where,  $P$  is Number of poles in the machine,  $\phi$  is Flux per pole in Weber,  $Z$  is Total number of armature conductors,  $N$  is Armature rotation in revolution per minute,  $A$  is number of parallel paths in the armature winding,  $E_g$  is induced EMF in any parallel path in the armature.

From (3)

$$\begin{aligned} \Rightarrow \frac{N}{2} &\propto \frac{E_g}{\phi} \text{ other parameters are internal and thus not considered} \\ \Rightarrow \frac{N}{2} &\propto \frac{V - I_a R_a}{\phi} \end{aligned} \quad (5)$$

Where,  $R_a$  is armature resistance,  $I_a$  is armature current and  $V$  is applied DC voltage.

Therefore, from (5) increase in series resistance attached with internal  $R_a$  will reduce the speed of the motor. This parameter can also be controlled from remote end through IOT.

## ARTIFICIAL BREATHING

After cardiac attack victim needs respiratory support in several cases. Several supporting tools and equipments are available in the market, some are manually operated and some are automatic. Manually operated machines are prone to



error and may cause fatality if used by unskilled persons. There the automation is required. But presently available automated respirators are costly and not suitable for out hospital use.

Air Compressor with Low Noise, oil free, low pressure, bacteria filtered is the prime requirement of a respirator. During acute respiratory failure, intubation and invasive mechanical ventilation may be life saving procedures [6]. In case both of chronic obstructive pulmonary disease (COPD) or acute respiratory distress syndrome (ARDS) artificial ventilation and weaning procedure is critically important. For victims when there are no advanced airways to apply CPR, the American Heart Association (AHA) recommends a pause after every 30 chest compressions to give 2 breaths (i.e., 30:2 strategies) [7].

In the proposed model there are two actuators which are responsible for inspiration and expiration phase [8]. These actuators are controlled by the central MCU. MCU generates the control signals in response to the sensors output and as per the program or as per the command received from the remote health unit.

The proposed model measures the parameters of lungs to form a model from the data received from a preset pressure and in the airway and the rate of lung inflation. Based on the respiratory resistance and compliance, the time constant of the lungs is determined [9].

The proposed model using a closed loop controller provides most of the required minute ventilation based on the patient's spontaneous breaths. The mandatory breaths may be large or frequent if the spontaneous breaths are smaller as compared to a preset value. Alternatively, if the patient's own respiratory efforts are larger enough the mandatory breaths may be diminished [10].

As the present article is primarily intended for OHCA, the flow generator ventilator is used here. The most common mode of mechanical ventilation also referred to as continuous mandatory or mechanical ventilation is the Assist Control (AC) mode. A key feature of AC mode is that the patient receives a supported breath with both patient-triggered (assisted) and time-triggered (controlled) breaths [11]. The function of the proposed model is to generate flow in line with the Assist Control mode.

#### **AUTOMATED EXTERNAL DEFIBRILLATORS**

In 40% of sudden out-of-hospital cardiac arrest (OHCA) cases the initially recorded heart rhythm is ventricular fibrillation (VF) [12]. One of the effective ways to treat VF is by applying a defibrillating electrical shock to the heart. Especially in an out-of-hospital setting, the shock needs to be delivered using an Automated External Defibrillator (AED). The first job in this regard is to detect the ECG signal and to decide if the victim is shockable or not.

Normal electrical and mechanical function of the heart may be restored by electrical anti-tachycardia pacing therapy and defibrillation in case of Ventricular-tachycardia (VT) and ventricular fibrillation (VF) [13]. On the other hand, non-shockable arrhythmia like asystole and bradycardia ( $HR < 60$ ) are not responsive to electric shock therapy. It is impossible to differentiate between these two types of arrhythmia by manual inspection of ECG segments within the short time duration before triggering the device for electrical therapy [14]. The decision is based on the following algorithm.

1. Average amplitude of the rhythm should be small.
2. Isoelectric baseline should not be large.
  - (a) For organized rhythm the HR should be greater than 150.
  - (b) For unorganized rhythm if wave rate is high then also the shock is applicable.

Accurate diagnosis of shockable condition is extremely desirable for the activation of AED. In AI based techniques Machine Learning algorithms are used to detect the shockable condition.

Normally these AEDs are used in critical care unit or by trained professionals in case of OHCA. The users must be trained and should be capable to decide when and how to use the AED.

Due to the lack of data, it could not be considered the deleterious effects of inappropriate AED use in collapsed patients with a shock able or non-shock able rhythm [15]. But based on the discrete hospital record it is considered that the availability of AEDs and the knowledge of their use are insufficient. Hence the proposed system with automation and/or involvement of health care professionals through IOT technology will be a real beneficiary for the society.

The proposed model can be used even by untrained and all activates are to be controlled through automatic or through

semi automatic mode. As soon as the AED pads are placed, it measures the person's heart rhythm and determines if a shock is needed or not. The model is programmed to give shock of desired intensity if shockable else starts CPR at the rate of 100 compressions per minute. Electrical activities of the heart are reassessed through the sensors and If the assessed data is suitable for Return of Spontaneous Circulation (ROSC), post CPR will be applied else the process will be repeated. Sensors output amplified to a detectable level of Micro Controller Unit (MCU) are received by the MCU. Now the MCU calculates the heart rate using the following algorithm.

- Detection of QRS Regions: The derivatives of the QRS region have higher amplitude as it consists of high frequency component of the order of 5-15 Hz.
- Detection of R Peaks: These are detected by relative magnitude comparison in each QRS regions.
- Processing of RR Intervals: First the average RR interval is calculated. Now, by comparing with the calculated average RR interval all the successive RR intervals are processed. There may be missed peaks or false detections. These error can farther be rectified as \_
- Elimination of Peak: If the RR interval between any two detected peaks is less than 70% of the average RR interval(a preset value) then the 2nd peak is eliminated.
- Search of New Peak: If the RR interval between any two detected peaks is more than 180% of the average interval then a new search has to be initiated after changing the threshold level [16].

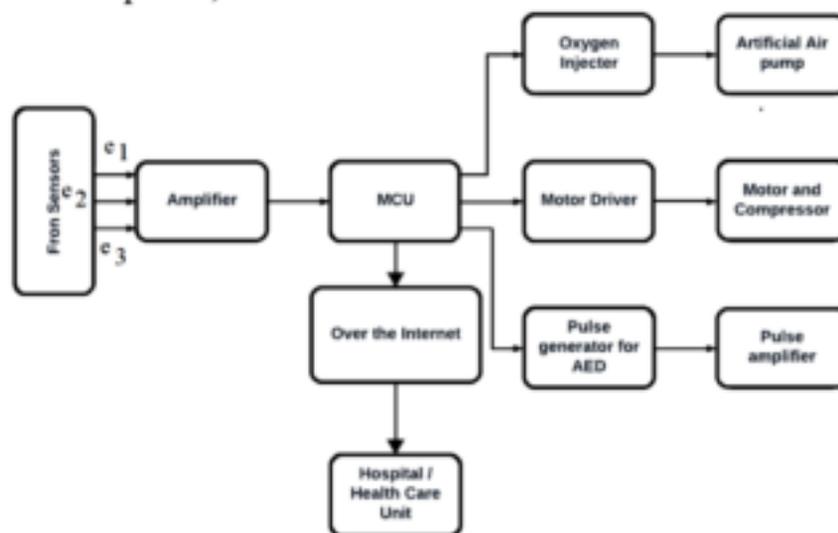
There may be two different cases i.e. the Heart Rate is either below 40 or above 100. Immediately after the cardiac arrest heart's electrical activity is disrupted. Either a dangerously fast heartbeat (ventricular tachycardia) or a fast and irregular heartbeat (Ventricular fibrillation) is the common symptom of the attack [15].

CPR after cardiac arrest can keep blood flowing to the heart and brain for a sometime. But defibrillation can restore the heart's rhythm. These treatments when applied alternately can improve the chances of survival.

## RESULT

For the operation of the artificial breathing unit the simulink has been used with the attached parameters as shown in the adjoining tables. The amplitude of the exponential graph generated with a fixed upper limit, is inversely proportional with the nostril pressure. The other parameters are either as per common standard or values set by health care professional from remote end.

The top graph in the **Figure 5(a)** indicates the artificial breathing and the bottom one represents the chest compression if operated through stepper motor. The operation with DC motor will be controlled by the graph in **Figure 5(b)**. Here it has been showed that the artificial breathing shall begin after the completion of chest compression (the bottom graph).For



**Figure 1** Block diagram of the proposed system

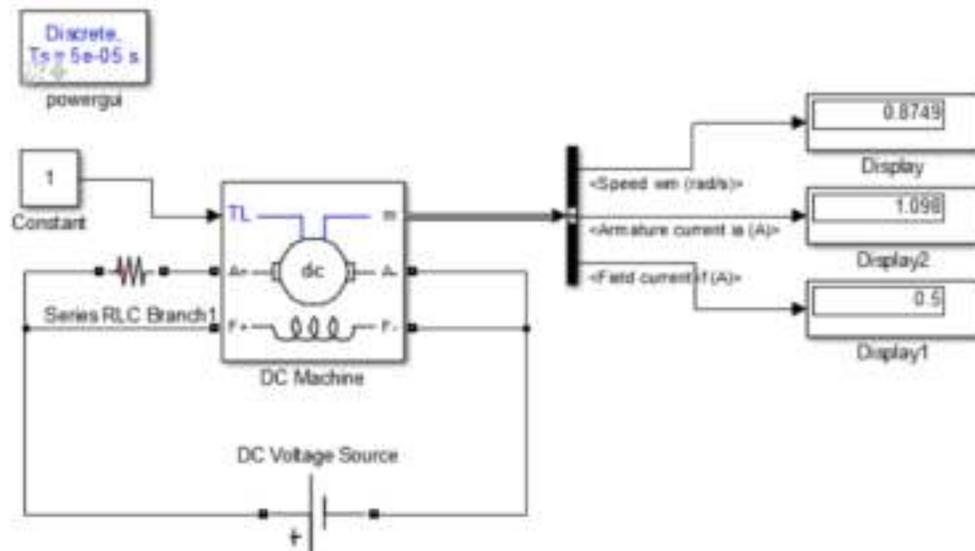


Figure 2 Mechanical compressor model through Simulink

Table 1 Motor parameters (External)

Sl. No	Parameters	Value
1	Torque Load (TL)	1
2	Series Resistance	108 Ω
3	DC Supply	120 V

Table 2 Motor parameters (Internal)[5]

Sl. No	Parameters	Value
1	Armature Resistance ( $R_a$ )	0.87 Ohm
2	Field Resistance ( $R_f$ )	550 Ohm

Table 3 Parameters of the Simulink Model

Sl. No.	Module	Parameters	Value
1	Step	Step time	1
2		Initial value	0
3		Final value	1
4		Sample time	5
5	Step 1	Step time	1
6		Initial value	0
7		Final value	1
8		Sample time	5
9	Pulse generator	Amplitude	1
10		Period	2
11	Pulse generator 1	Pulse width	33%
12		Amplitude	1
13	Pulse generator 1	Period	5
14		Pulse width	97%

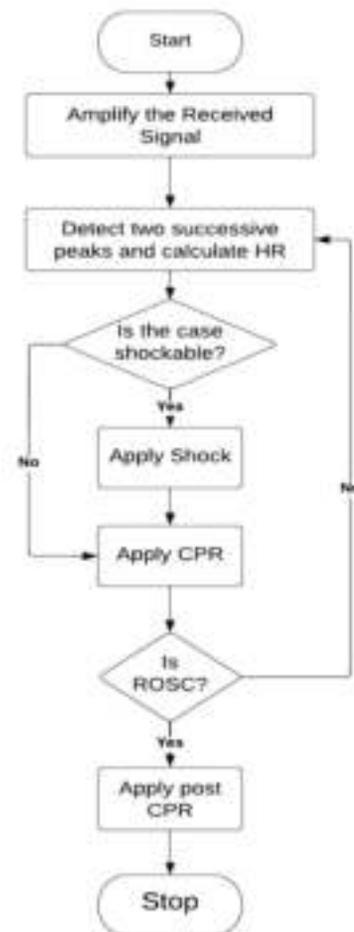


Figure 3 Flow chart of the proposed model

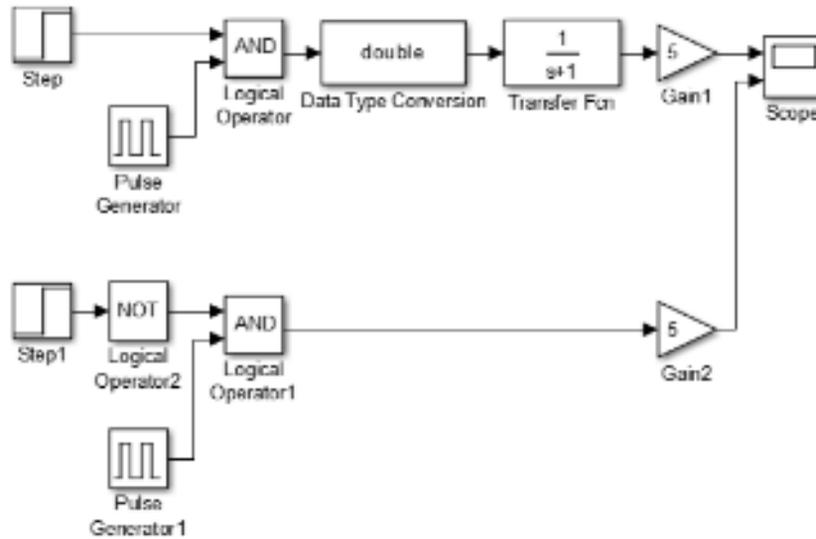


Figure 4 Timer design through Simulink

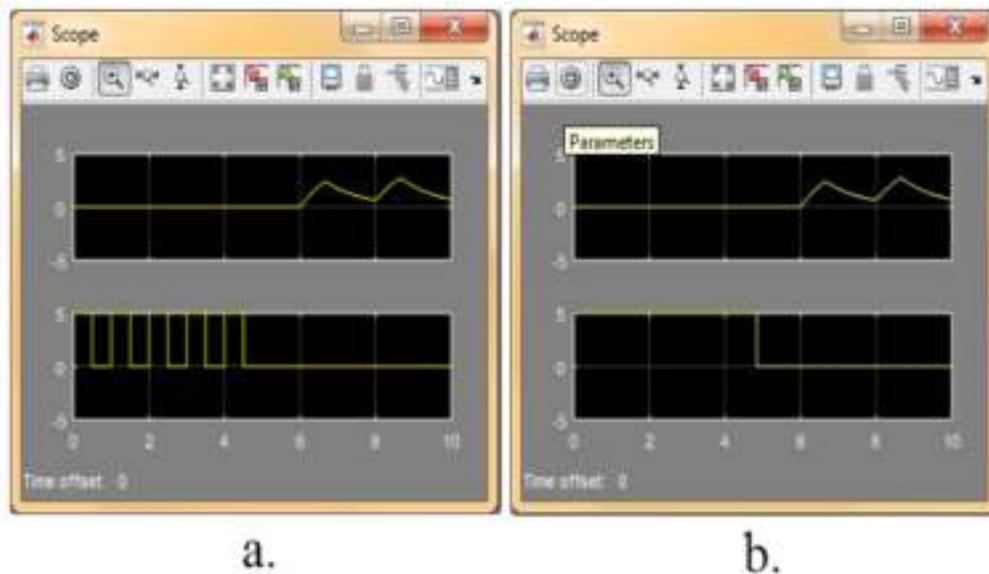


Figure 5 Simulink model output

the ease of representation only five compressions have been shown for stepper motor. For DC motor the speed is regulated from motor circuit only the duration for the compression period is set by the simulator in **Figure 4**.

The generated wave as in **Figure 5**, with the desired parameters based on the model generated for lungs. The mechanical compressor as shown in fig 1 is operated with some preset values which are also modified from the remote end otherwise in automated mode except the duration all values are preset.

### CONCLUSION

The objective of this model is to develop low cost, automated and efficient system for OHCA. The manual mode of the proposed model will assist the first aider to apply the CPR with necessary limit of safety and without physical exhaustion of the reliever. The system can be switched to automated mode immediately till it is connected to a doctor. In the automated mode the rate and depth of compression are preset values or decided by the MCU based on the sensors output. Finally, when connected through the internet with health care unit, the model would be very effective and solve the



problem of lack of skilled first aid provider. Therefore, the victim and or his kith and kin can never feel that they are away from health care unit. The victim can obtain first aid within first few minutes (golden minutes) after the attack.

## REFERENCES

1. Stuart Berger, MD; Survival From Out-of-Hospital Cardiac Arrest: Are We Beginning to See Progress?
2. Abella B.S., Sandbo N., Vassilatos P., Alvarado J.P., O'Hearn N., Wigder H.N., Hoffman P., Tynus K., Hoek T.L.V., Becker L.B. Chest compression rates during cardiopulmonary resuscitation are suboptimal: A prospective study during in-hospital cardiac arrest. *Circulation*. 2005;111:428–434.
3. Alwin Zweerink, Anne-Lotte C.J. van der Lingen, M. Louis Handoko, Albert C. van Rossum, Cornelis P. Allaart, Chronotropic Incompetence in Chronic Heart Failure.
4. Business Express report dated 26th Aug, 2022 on “Clear spike in heart attack cases after Covid-19 outbreak, say doctors”
5. Miklosevic, Kresimir ; Spoljaric, Zeljko & Jerkovic, Vedrana Department of Electromechanical Engineering, Faculty of Electrical Engineering, J. J. Strossmayer University of Osijek, Osijek, Croatia; Analysis of Electric DC Drive Using Matlab Simulink and SimPower Systems.
6. Moerer O. Weaning from mechanical ventilation: Which strategies are useful? *Anästhesiologie, Intensivmedizin, Notfallmedizin, Schmerztherapie*. 2013
7. Benton R. Hunter, MD, reviewing Schmicker RH et al. *Resuscitation* 2021, June 5; 30:2 Cardiopulmonary Resuscitation Might Outperform Continuous Compressions in Out-of-Hospital Cardiac Arrest
8. Marian Walter and Steffen Leonhardt Philips Chair for Medical Information Technology, Helmholtz Institute for Biomedical Engineering, RWTH Aachen University, Aachen, Germany; Control Applications in Artificial Ventilation.
9. Marcus Henrique Victor Júnior\*, Luiz Alberto Forgiarini Junior, Toru Miyagi Kinjo, Marcelo Britto Passos Amato, Takashi Yoneyama, Harki Tanaka 2015 Parameter estimation of an artificial respiratory system under mechanical ventilation following a noisy regime.
10. J D Young, M K Sykes, *Thorax* 1990;45:753-758; 1990; Artificial ventilation: history, equipment and techniques.
11. James M. Walter, MD, Thomas C. Corbridge, MD, and Benjamin D. Singer, MD; *Invasive Mechanical Ventilation*, *South Med J*. 2018 Dec; 111(12): 746–753.
12. Unai irusta zarandona, jesús maría ruiz ojeda; *New signal processing algorithms for automated external defibrillators*; 2010.
13. Fahimeh Nasimi , Mohammadreza Yazdchi; Published: February 25, 2022; LDIAED: A lightweight deep learning algorithm implementable on automated external defibrillators.
14. Sharma M1, Singh S2, Kumar A3, San Tan R4, Acharya UR5 18 Sep 2019, 115:103446, Automated detection of shockable and non-shockable arrhythmia using novel wavelet-based ECG features.
15. Patrycja Misztal Okońska<sup>1</sup>, Mariusz Goniewicz<sup>1</sup>, Magdalena Młynarska<sup>1</sup> , Wojciech Krawczyk<sup>1</sup> , Monika Butryn<sup>2</sup> ; Public awareness about the use of automatic external defibrillator (AED) in giving first aid.
16. Deboleena Sadhukhana, Madhuchhanda Mitra, Department of Applied Physics, University of Calcutta, 92, APC Road, Kolkata 700009, Calcutta, India; R-peak detection algorithm for ECG using double difference and RR interval processing.



# Performance Comparison of a SRM with Conventional PI, Fuzzy, ANN and CANN Controllers

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**Abstract:** This paper presents the idea of using the Switched Reluctance Motor (SRM) as an alternative to Ship Electric propulsion Systems. In order to show the advantage of the SRM, the speed control of a switched reluctance motor (SRM) is designed by various intelligent controllers. In this work, the performance of the switched reluctance motor is evaluated by subjecting the motor to five different criteria like speed settling time, maximum peak overshoot, rise time and peak time. Four different i.e. conventional PI controllers, fuzzy, Artificial Neural Network and Cascaded Artificial Neural Network are used for the controlled purpose of the switched reluctance motor and their performances are studied and compared. The work is completely done in MATLAB/SIMULINK environment. Results are discussed and tabulated based on the performance of the controllers. The simulation results show improved transient and steady state performance and robustness of the SRM based drive system with Cascaded Artificial Neural Network.

**Keywords:** Switched Reluctance Motor, PI Controller, Fuzzy Logic Controller, Artificial Neural Network, Cascaded ANN, Hysteresis Current Controller, Torque Ripple

## INTRODUCTION

All Electrified Ships is an innovative shipbuilding trend that allows the vessel capacity to be powered from the same source of electric power that operates the propeller, removing the need for a separate generation system for various propulsion and vessel loads [1]. Because worldwide rules addressing NO<sub>x</sub> and SO<sub>x</sub> emissions have become increasingly rigorous, shipbuilders have begun to incorporate power-driven propulsion by way of a method to increase fuel cost then minimize emissions. Fuel price fluctuations have also compelled the marine industry and the owner of the ships in general to familiarize and hybrid power propulsion systems as well as employ quite electrified [2].

Because all electric ship propulsion motors vary according to the category of ship and its function, various types of electric motors are employed in the ship propulsion systems. Commutated DC motors, doubly fed induction motor, synchronous motor, Commutator-less DC motor, induction motors, switched reluctance motors are the various motors used in ship for propulsion function. Out of which, some motors like induction machines, commutator motors of few megawatt and synchronous motor, are already in use for ship propulsion, while the rest have undergone experimental development. Other motor types have been suggested, such as synchronous reluctance motors, which will compete for usage in ship propulsion with traditional motors, notably permanent magnet synchronous motors, since various benefits of switching reluctance motors will be described later, and a suggestion to increase its performance will be presented [3,4]. However, benefits of employing a motor as a propeller differ on the ship's weight and the type of engine used. Electric propulsion interacts effectively with the ship's integrated system, is easy to change in terms of torque and speed, which produces less noise, is quick to fit and remove due to the need of an aligned shaft or gearbox and is ecologically friendly.

J. Hennen, J. Helge Brauer, and Rik W. De Donckers: Torque control and torque control, making machine analysis more difficult than in other typical machinery. [9] Torque-sharing features are recommended in this paper to achieve the SRM instantaneous torque and to reduce torque ripple during fixed or within-limits operation. To prepare for pulse width modulation using DITC, the idea to reduce ohmic losses was proposed. The key disadvantage in this study is that two phases SRM were swapped to extend any number of phases without requiring pre-calculated commutation current or couple control, with a rise in the benefit of time consumption.

Bearing less switching reluctance motor of the rotor has been proposed by Li Chen and Wilfried Hofmann without the

use of any mechanical support structure. The author's goal was to have a bearing less rotor magnetically hover in air without a mechanical support given by a single layer winding. [10] In this work, the number of windings was lowered from 8 to 6 to minimize the cost converter topologies. The speed limitation approach was proposed in conjunction with the driving philosophy. The main disadvantage is only fit for medium and low-speed applications. Field harmonics in stator and rotor, on the other hand, enhance the greater value of hysteresis and eddy current losses in these slots for high speed applications.

Garcia, C. Moron, E. Tremps, and J. A. Somolinos: This research presents the findings of the instantaneous torque control technique. The critical angle, or switching angle, of two adjacent phases has the same torque and current state or flow connection[11]. The enhanced current reference switching was then designed to reduce torque loss. The effect of the winding resistor on the supply voltage was not investigated in this paper.

Tzvi Natan Shaken: The main goal of this post is to keep everything running smoothly. This article torque ripple minimization may be used to optimize the current profile. A simple approach and the evolutionary algorithm are used to regulate the current waveform with a reasonably small number of optimization factors[12]. The new modified method was designed to reduce the maximum value of the current phase through inexpensive solution quality and a shorter time frame. The current expression of reference was chosen with only a few variables to establish the maximum STO range. It tests the universal SRM mathematical model's ability to represent the specified mathematical formula.

D. Lee, Z. Xu, and J. Ahn: The energy efficiency of SRMs is investigated in this research utilizing a zero-voltage switching mechanism. By lowering the flow connection peaks, null voltage loop switching can considerably increase SRM performance. The harmonic magnitudes are minimized by the magnetic flux densities within the SRM core.

## MODELING OF SRM AND ITS CONTROL

This section is clearly illustrating the mathematical modeling of the SRM drive, its characteristics and control drive.

### SRM Model

This section describes the mathematical formulae and corresponding electrical circuits for SRM electromagnetic torque and input power during dynamic and steady-state operations. **Figure 1** depicts the single phase circuit model for SRM. Mutual inductance is ignored.

The voltage in a phase is expressed by the sum of the voltage drop and flux linkage rate, which is as follows:

$$v = \frac{d\lambda(\theta, i)}{dt} + R_{ph} i \quad (1)$$

Where  $R_{ph}$  is the phase resistance,  $\lambda$  is the flux linkage and  $\lambda$  can be also defined in terms of phase current  $i$  and inductance  $L$  by:

$$\lambda = L(\theta, i) i \quad (2)$$

The SRM inductance  $L$  varies with phase current  $I$  and rotor position  $\theta$ . The voltage equation may be expressed as follows:

$$v = L(\theta, i) \frac{di}{dt} + R_{ph} i + e \quad (3)$$

Where  $e$  denotes the electromotive force, which is supplied by:

$$e = \frac{dL(\theta, i)}{d\theta} \omega_m i \quad (4)$$

Where  $\omega_m$  denotes the rotor speed. The instantaneous input power of the SRM is given by:

$$p = iv = L(\theta, i) \frac{di}{dt} i + R_{ph} i^2 + e i \quad (5)$$

The electromagnetic torque is given by:

$$T_e = \frac{1}{2} i^2 \frac{dL(\theta, i)}{d\theta} \quad (6)$$

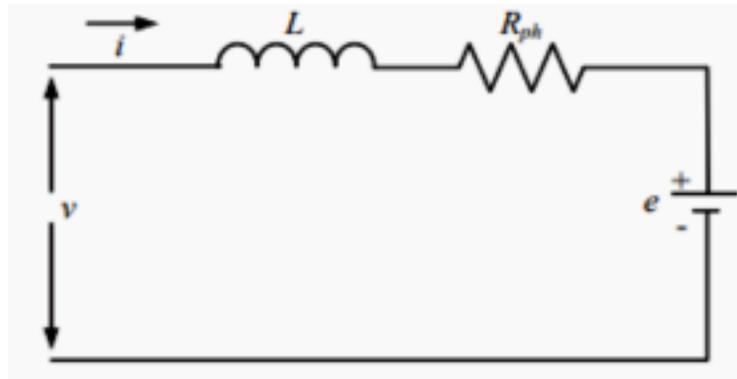


Figure 1 Single phase equivalent circuit of SRM [8]

The mathematical equations for the SRM demonstrate that the SRM is very nonlinear, and that the motor inductance varies with current and rotor position.

### CHARACTERISTICS OF SRM

The complex model is represented by the SRM distinctive curve. It links the magnetic coupling and phase current of the motor for various rotor positions. Figure 2 [13] depicts an actual 3-phase 2kW 6/4 SRM calibration curve. The alignment is complete when phase A is engaged by a DC current and the motor capacitance is at its maximum, which is at 90° (top blue curve). It is the point at which the stator coil A is positioned between two rotor teeth and the motor impedance is the lowest, which is  $360/4/2 = 45^\circ$  for the completely misaligned position (bottom yellow line). Variable reluctance machines have the ability to function as a motor or generator, depending on the operating region, which is one of their blank spot.

### SRM CONTROL

In Figure 3, the block diagram of the speed control of SRM is seen. The output of the speed controller is, the reference current,  $i^*$ . In this paper, the PI controller Fuzzy and ANN tuning is used as the speed controller. The system also consists of a hysteresis band controller which does current control, a converter and a trigger circuit which drives the switches in the converter into conduction or cut off. Speed control of SRM is done by hysteresis current controller and the block diagram is shown in Figure 3.

### PROPOSED SYSTEM

Figure 4 shows the overall block diagram of the proposed system. SRM is controlled with the by the driver circuit named

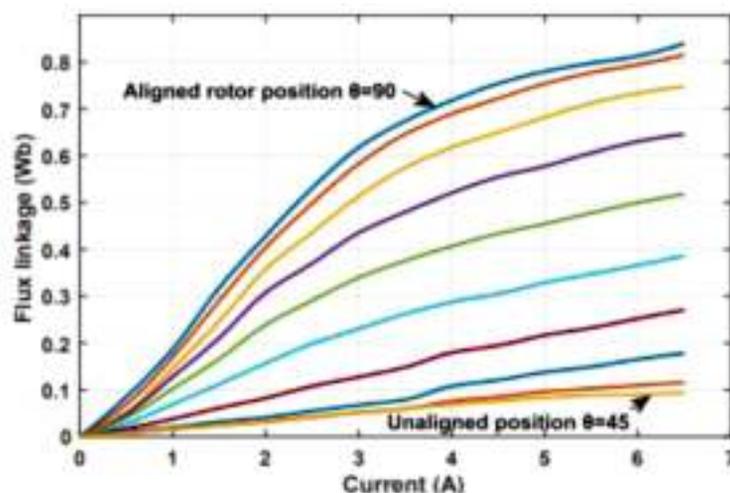


Figure 2 Characteristics of SRM [13]

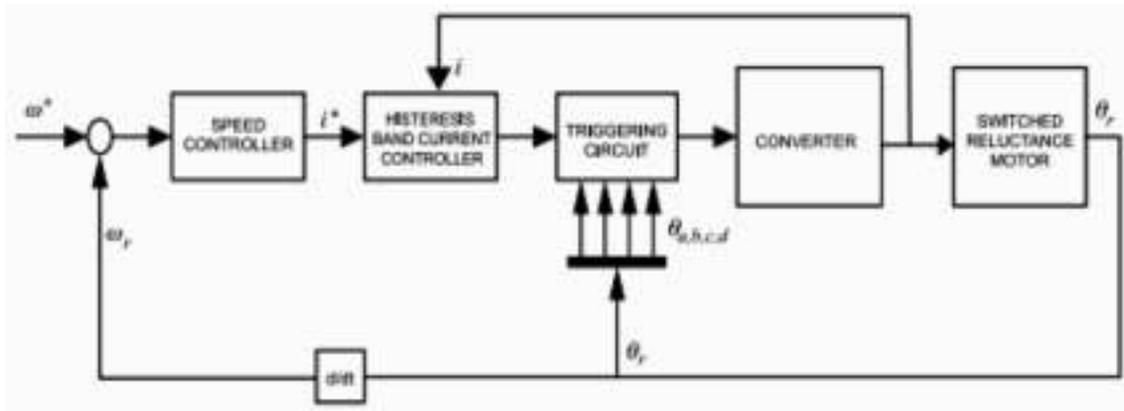


Figure 3 Speed control block diagram of SRM

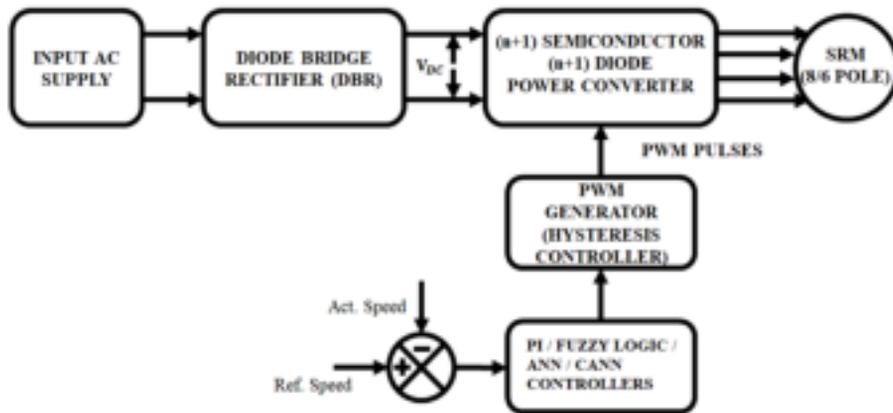


Figure 4 Block diagram of the Proposed Work

(n+1) semiconductor (n+1) diode power converter. Pulse is generated with the help of hysteresis current controller and PI tuning is possible by the various controllers like Fuzzy, ANN and cascaded ANN. Reference speed is set by 400 RPM and the actual speed is sensed by the position sensor.

## RESULTS AND DISCUSSION

### Design Target

Throughout this research, a three-phase 8/6 SRM is selected for use in electrical transportation applications. **Table 1** displays the motor's technical requirements.

This research uses simulation to demonstrate the viability of the suggested approach. The SRM performance is investigated and the PI-Fuzzy, PI-ANN and PI-CANN are applied using the Matlab/Simulink programme.

**Figure 5** depicts the simulation model for the speed control of SRM motor. According to the specifications, a different speed of 400 RPM is set. Through the return channel, the comparison receives the calculated speed. **Figure 6** illustrates how the PI controller processes the motor speed response for with and without step change. While observing the response, maximum peak is more and settling time is also more in PI controller.

**Figure 7** shows the flux, current and torque response of PI controller. Torque ripple is also high in the response. **Figure 8(a)** and **(b)** shows the membership function of fuzzy logic controller. Input and output function to the fuzzy controller

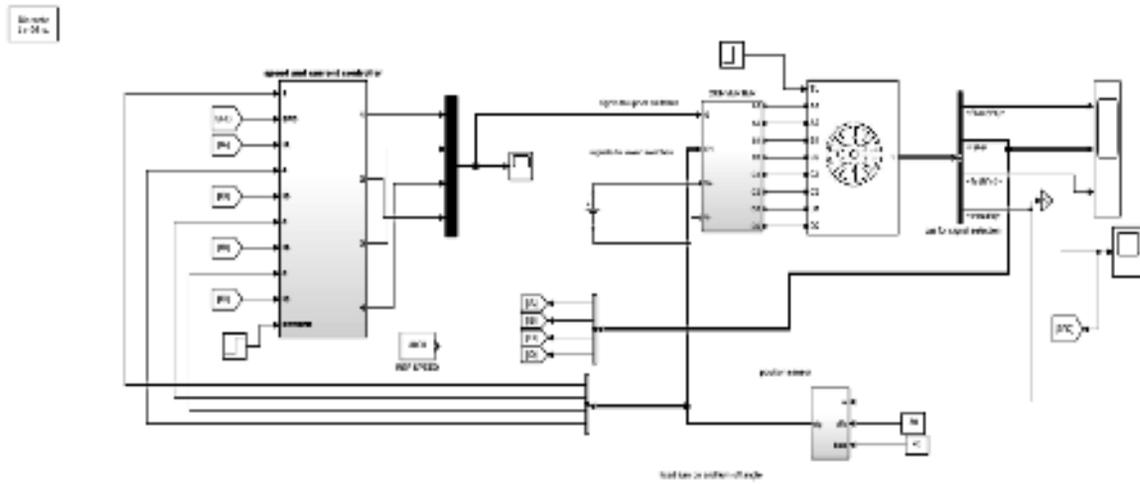


Figure 5 Simulink model of speed control of SRM

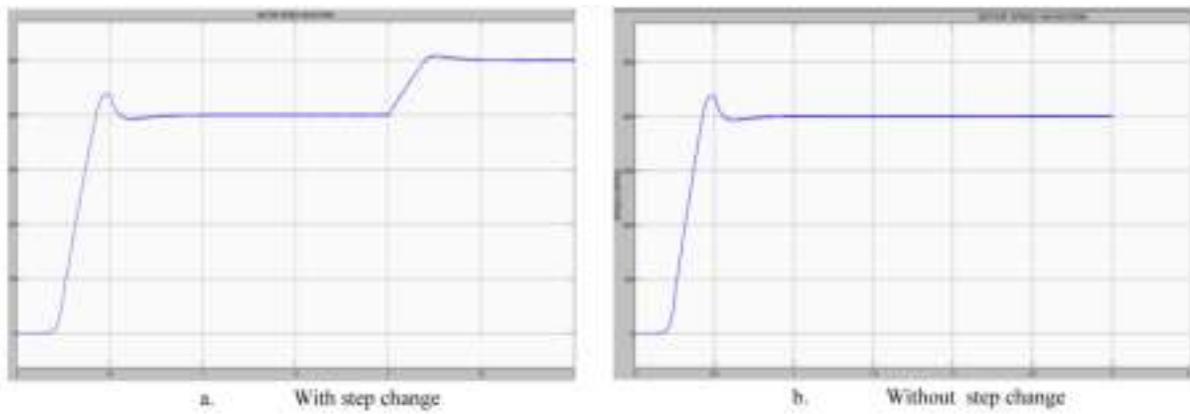


Figure 6 Motor speed waveform for conventional PI controller

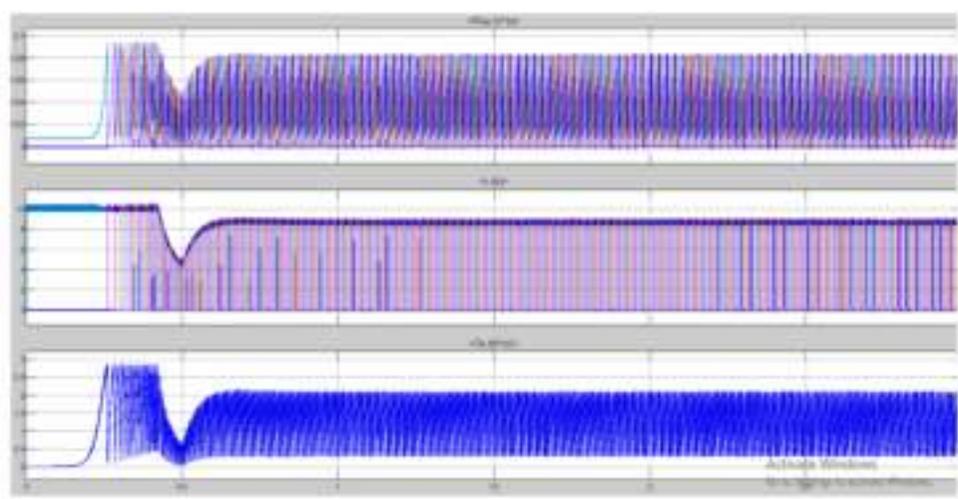
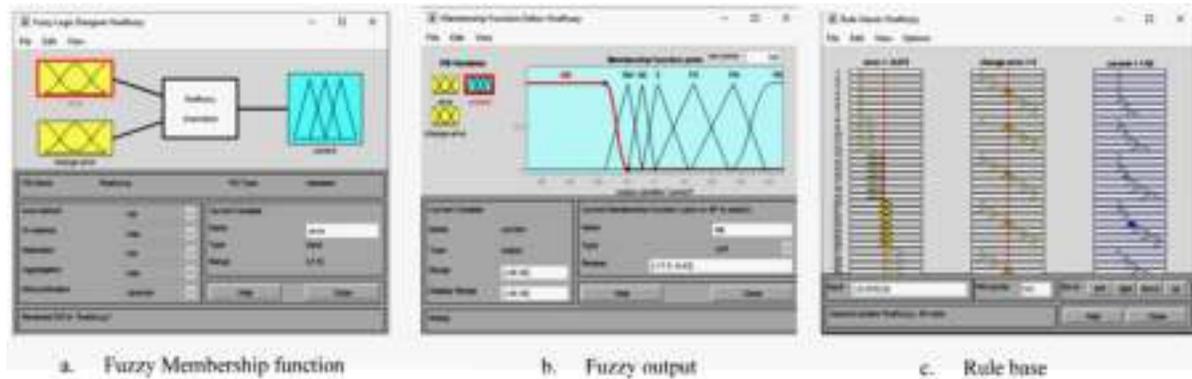
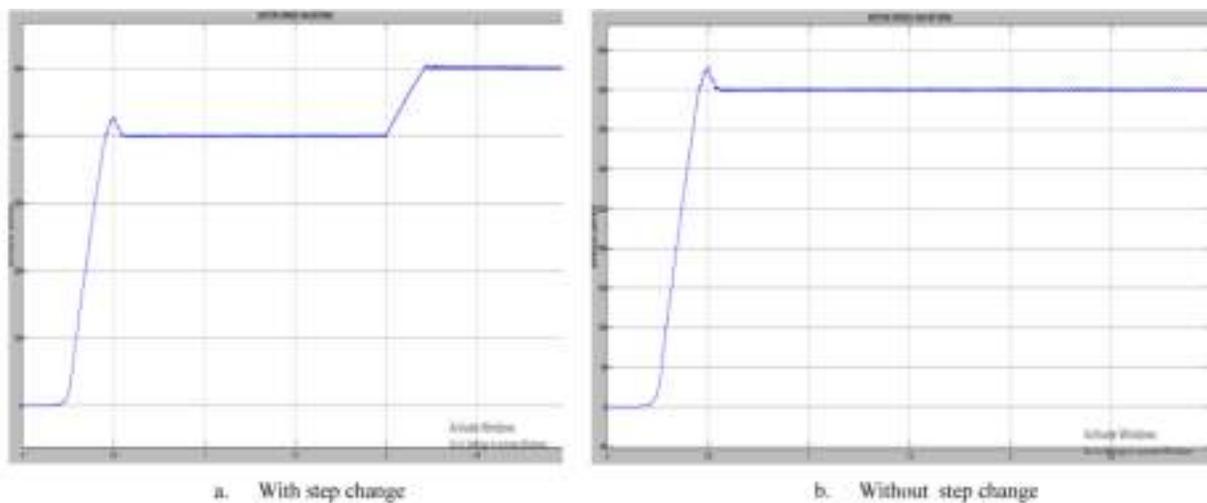


Figure 7 Flux, current and Torque waveform of conventional PI controller



**Figure 8** Fuzzy Logic controller\_ Membership function & Rule Base



**Figure 9** Motor Speed Waveform for conventional PI-Fuzzy Controller

and **Figure 8(c)** shows the rule base.

**Figure 9** illustrates how the PI-Fuzzy controller processes the motor speed response for with and without step change. While observing the response, maximum peak is little improved and settling time is also less when compare to conventional PI controller.

**Figure 10** shows the flux, current and torque response of PI- Fuzzy controller. Torque ripple is also high in the response.

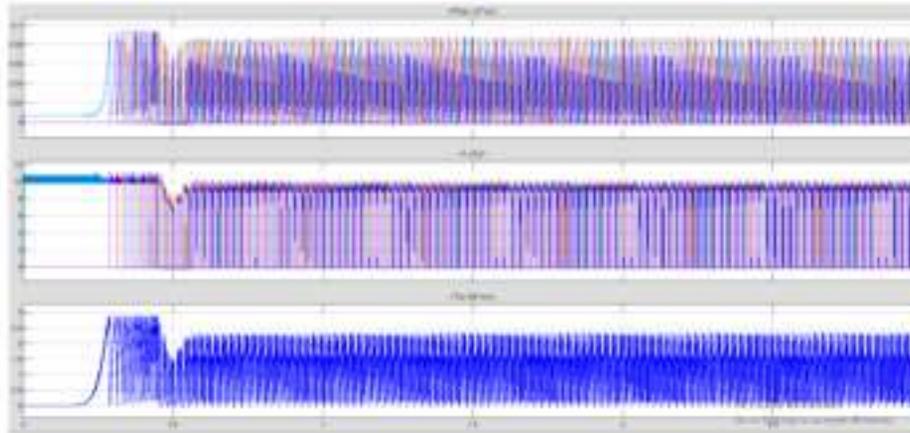
**Figure 11** illustrates how the PI-ANN controller processes the motor speed response for with and without step change. While observing the response, maximum peak is improved and settling time is also less when compare to conventional PI and PI- Fuzzy controller.

**Figure 12** shows the flux, current and torque response of PI- ANN controller. Torque ripple is also high in the response.

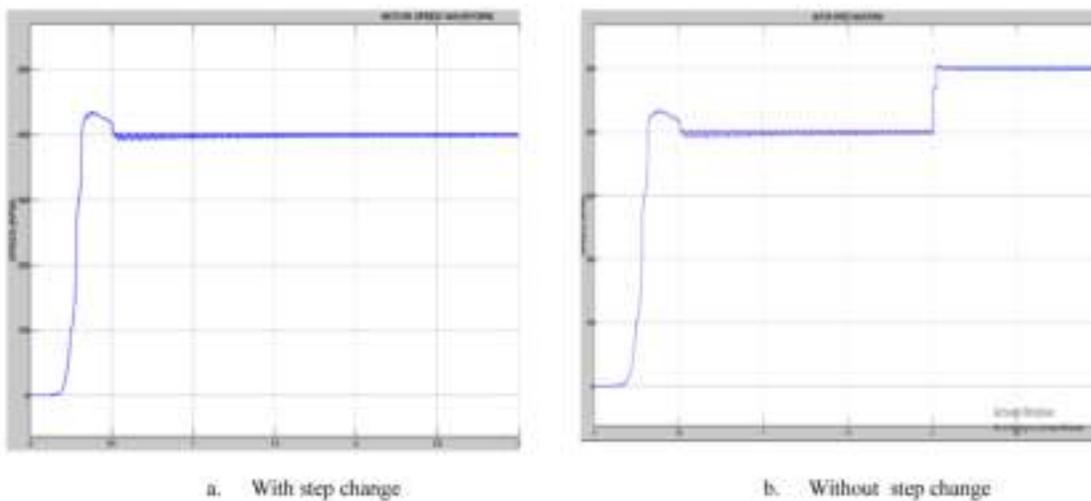
**Figure 13** illustrates how the PI-ANN controller processes the motor speed response for with and without step change. While observing the response, maximum peak is improved and settling time is also less when compare to conventional PI and PI- Fuzzy controller.

**Table 2** shows the comparative analysis of various controllers. From the table, it is clear that cascaded ANN shows best result when compared to other controllers. All the parameter of Cascaded ANN shows best when compare to other.

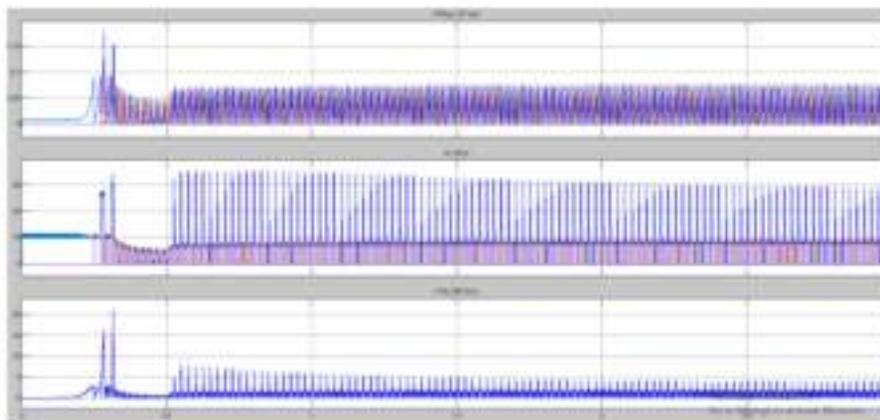
**Figure 14** shows the graphic representation of comparison of all the controllers.



**Figure 10** Flux, current and Torque waveform of PI-Fuzzy Controller



**Figure 11** Motor Speed Waveform for conventional PI Controller



**Figure 12** Flux, current and Torque waveform of conventional PI Controller

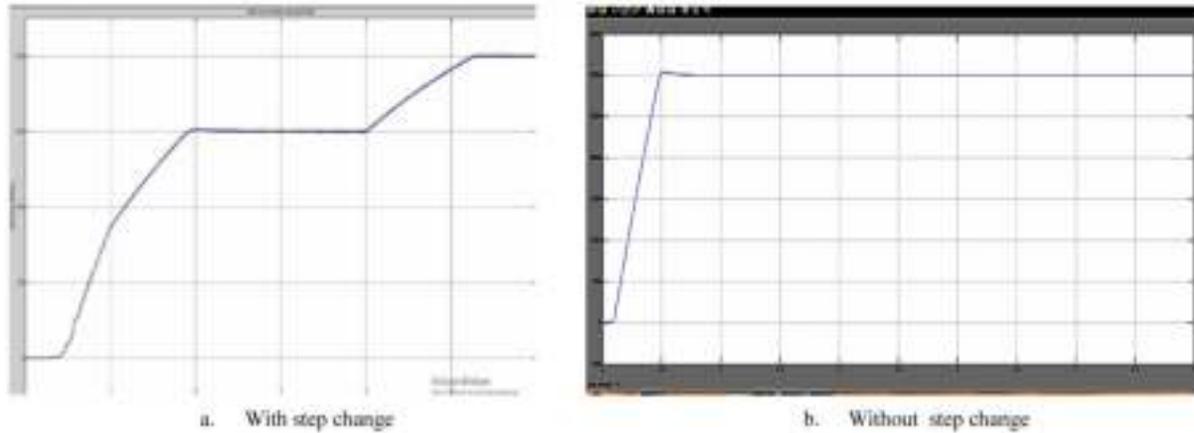


Figure 13 Motor Speed Waveform for conventional PI Controller

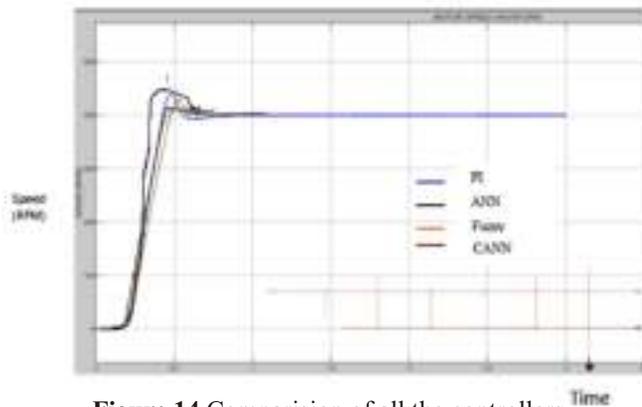


Figure 14 Comparison of all the controllers

Table 1 SRM parameters used in SIMULINK

Motor Parameters	Values
Rated power	5 HP
Number of phases	4
Number of stator poles	8
Number of rotor poles	6
Aligned phase inductance	23.6mH
Unaligned phase inductance	0.67 mH
Inertia	0.0082 kg-m <sup>2</sup>
Inertia friction coefficient	0.01 Nms
Stator resistance	0.01 Ω
DC supply voltage	400 V
Maximum current	450 A
Maximum flux linkage	0.486

Table 2 Comparison of different controllers controller

Algorithm	Rise time ( $t_{r1}$ )	% Overshoot	Settling Time ( $t_s$ )	Peak Time ( $t_p$ )
PI Controller	0.36	0.5	0.8	0.5
Fuzzy	0.25	0.48	0.62	0.48
ANN	0.21	0.40	0.5	0.47
Cascaded ANN	0.21	0.12	0.46	0.12

## CONCLUSION

A cost-effective option for an SRM motor drive is a PI controller. Numerous cutting-edge ways are developing to boost the PI controller's effectiveness. Some methods, such as PSO, have already demonstrated their efficacy in identifying the PI controller's parameters. In contrast to the traditional PI controller, a new efficient method called Fuzzy, ANN and Cascaded ANN are used in this article to monitor the speed of an SRM motor. Research shows that the device dies down quicker than the traditional PI-based approach. The recommended technique also has less dampening. Even though the prime times and extending are both zero, the time domain efficiency greatly supports the employment of the Cascaded ANN technique to alter the SRM motor's PI controller variables. The proposed method may bring a new viewpoint to the field of PI controllers for an SRM motor-driven system.



## REFERENCES

1. Suresh Kumar B, Varun Raj D, Venkateshwara Rao D (2020) Speed control of BLDC motor with PI controller and PWM technique for antenna's positioner.
2. Yedamale P (2003) Brushless DC (BLDC) Motor fundamentals. Microchip Technology Inc. 20:3-15
3. Bianchi N, Bolognani S, Jang JH, Sul SK (2006) Comparison of PM motor structures and sensor less control techniques for zero-speed rotor position detection. *Power Electron IEEE Trans* 22(6):2466-2475
4. Dutta P, Mahato SN (2014) Design of mathematical model and performance analysis of BLBLDC motor. *IEEE Int Conf Control Instrum Energy Commun India*. <https://doi.org/10.1109/CIEC.2014.6959130>
5. Fogel DB (2006) *Evolutionary Computation: Toward a New Philosophy of Machine Intelligence*. Press Series on Computational Intelligence IEEE, 3rd Edition: 128-138
6. Ziegler G, Nichols NB (1942) Optimum settings for automatic controllers. *Trans ASME* 64:759-768
7. Zhang L (2004) "Simplex method based optimal design of PID controller." *Inform Control* 33:376-379
8. Thomas Neenu, Poongodi Dr P (2009) Position control of DC motor using genetic algorithm based PID controller. *Proceedings of the World Congress on Engineering*.
9. Kim Dong Hwa, Jin Ill Park (2005) Intelligent PID controller tuning of AVR system using GA and PSO. Springer-Verlag Berlin Heidelberg: ICIC, Part II, LNCS 3645: 366-375. <https://doi.org/10.1007/1153835638>
10. Rubaii A, Kotaru R (2000) Online identification and control of a DC motor using learning adaptation of neural networks. *Ind Appl IEEE Trans* 36(3):935-942
11. Shyam A, Daya FJL (2013) A comparative study on the speed response of BLDC motor using conventional PI controller, antiwindup PI controller and fuzzy controller, *International Conference on Control Communication and Computing (ICCC)*: <https://doi.org/10.1109/ICCC.2013.6731626>
12. K Ang, G Chong, Y Li (2005) PID control system analysis, design, and technology. *Control System Technology IEEE Transaction on*, 13(4): 559-576
13. Kennedy J, Eberhart RC (1995) Particle swarm optimization. *Proc. IEEE International Conference on Neural Networks, Perth, Australia, IEEE Service Center, Piscataway, NJ: 1942- 1948*. <https://doi.org/10.1109/ICNN.1995.488968>
14. Shi Y, Eberhart RC (1998) A modified particle swarm optimizer. *IEEE International Conference on Evolutionary Computation, Anchorage, Alaska*. <https://doi.org/10.1109/ICEC.1998.699146>
15. Shi, Y, Eberhart RC (1999) "Empirical Study of Particle Swarm Optimization." *Proceedings IEEE: 1945 -1950*. <https://doi.org/10.1109/CEC.1999.785511>
16. Kennedy J. (2006). *Swarm Intelligence*. In: Zomaya A.Y. (eds) *Handbook of Nature-Inspired and Innovative Computing*. Springer, Boston, MA. [https://doi.org/10.1007/0-387-27705-6\\_6](https://doi.org/10.1007/0-387-27705-6_6)
17. Eberhart R, Shi Y, Kennedy J (2001) *Swarm intelligence*. Elsevier. <https://doi.org/10.1016/B978-1-55860-595-4.X5000-1>
18. Gaing ZL (2004) A particle swarm optimization approach for optimum design of PID controller in AVR system. *Energy Convers IEEE Trans* 19(2):384-391
19. Panda S, Padhy N (2008) Comparison of particle swarm optimization and genetic algorithm for FACTS-based controller design. *Int J Appl Soft Comput* 8(4):1418-1427
20. Zarringhalami M, Hakimi S, Javadi M (2010) Optimal regulation of STATCOM controllers and PSS parameters using hybrid particle swarm optimization, *IEEE conference*. <https://doi.org/10.1109/ICHQP.2010.5625436>



21. Mirjalili Seyedali, Mirjalili Seyed Mohammad, Lewis Andrew (2014) Grey wolf optimizer. *Adv Eng Softw.* <https://doi.org/10.1016/j.advengsoft.2013.12.007>
22. Potnuru D, Tummala ASLV (2019) Grey wolf optimization-based improved closed-loop speed control for a BLDC motor drive. In: Satapathy S, Bhateja V, Das S (eds) *Smart intelligent computing and applications smart innovation, systems and technologies.* Springer, Singapore
23. Muniraj M, Arulmozhiyal R, Kesavan D (2020) An improved self-tuning control mechanism for BLDC motor using grey wolf optimization algorithm. In: Bindhu V, Chen J, Tavares J (eds) *International conference on communication, computing and electronics systems lecture notes in electrical engineering.* Springer, Singapore
24. Zitzler Eckart, Simon Künzli (2004) *Indicator-based selection in multiobjective search parallel problem solving from nature-PPSN VIII.* Springer, Berlin Heidelberg
25. Shamseldin MA, EL-Samahy, AA (2014) Speed control of BLDC motor by using PID control and self-tuning fuzzy PID controller," 15th International workshop on research and education in mechatronics (REM), El Gouna pp. 1-9, <https://doi.org/10.1109/REM.2014.6920443>



# Entrepreneurship Development for Creating a Sustainable and Self-Reliant India

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**Abstract:** New technologies leading to innovations are transforming the world giving rise to various business investments and startups. With over 1.4 million schools, approximately 10500 engineering and related institutions, approximately 39000 colleges, India ensures that an estimated 150 million youth of India are entering the workforce over the next few years and can realize their true potential through access to a world-class innovation and entrepreneurial ecosystem, leveraging rapidly advancing, accessible, affordable technologies transforming the world we live in and enabling an incredible set of opportunities for innovation and new job creation. It is important that the opportunities to this young human resources are availed in maximum along with awareness about turning the ideas into innovations and transforming the same into business. Promoting Entrepreneurship and Startups will ensure long-deserved growth, prosperity and wellbeing that can serve the interests of the rest of the world as well as the spirit of New India. Creating a nation of not just job-seekers is important for sustainable growth. Even with thousands of challenges, opportunities for innovative entrepreneurial startups should be encouraged to succeed with possible global impact that will pave a significant road for creating a sustainable and self-reliant India.

**Keywords:** Innovation; Entrepreneurship; Self-reliant; Sustainable; Human Resource

## INTRODUCTION

Prime Minister Narendra Modi on the launch of 'Athma Nirbhar Bharat Abhiyan' (Self Reliant India Campaign) revealed the vision of self-reliant India and described that the 'magnificent building of Self-reliant India' will stand on five pillars like Economy, Infrastructure, System, Demography and Demand. To achieve this our objective should be to increase Skills, Productivity, Competitiveness and Technology leadership which bases with the Education system of our country. Back then most the Engineers stand behind the traditional engineering lens, to acquire knowledge and contribute to development by employing themselves with industries and firms.

Though that contributed to our Nation's development increasingly up to a scale, this is modern era and this time of our timeline provides enormous opportunities to improve our skills, build our network and expose ourselves to wider environment. In other hand, India as a whole being a fastest growing economy, we are in necessity to become self-reliant by producing within our country. This demands us to stand behind an entrepreneurial lens of innovating. As a whole, lessen our import and grow our export. In long term to contribute to the world the positive sustainability. With strong base knowledge, comes imagination leading to creativity and that being an innovation. The real growth that we can experience is indigenous developments and that requires more Indian entrepreneurs.

As per Global Entrepreneurship Monitor, India's entrepreneurial activity increased to 14.4% in 2021, up from 5.3% in 2020. But, United Nations quotes, only 47% of young entrepreneurs and start-ups were confident of sustaining beyond six months, while 25% did not see themselves lasting beyond 6 months. This is because of the issues in access to finance, insecurity in sustainability, disruption in supply chains and perceptions towards business recovery after the pandemic. Here comes the role of our government to aid the entrepreneurial sector in the form of adequate capital support, easing of regulations and compliances, schemes implementation and policymaking. Supportingly, our top schemes include ATAL Innovation Mission (AIM), Pradhan Mantri Mudra Yojana (PMMY) etc.,

As a whole, we will have to plan and deal with the technological aspects of placing ourselves as an innovation think tanks, and the ideas to increase the scale of entrepreneurial activities by young engineers. Also, in our Nations aspect to take up the steps in encouraging young entrepreneurs and need for emergence of innovations and awareness and knowledge to commercialize the ideas and products.

### TECHNOLOGICAL PROGRESS OVERVIEW

Recent developments in frontier technologies, including artificial intelligence, robotics and biotechnology, have shown tremendous potential for sustainable development. Robotics and Artificial intelligence are driving next-generation productivity and automation. 3D printers are making real-time conceptualization, design, prototyping and manufacturing. Internet of things are connecting sensor technologies to mobile and satellite Technologies in every Industry from enabling precision agriculture, healthcare, water cleansing and conservation, climate change controls, disaster prediction and management, driverless cars and space shuttles. Big Data and analytics and Artificial Intelligence are enabling complex decision-making through advanced easy to use tools. The market for these technologies is also set to expand rapidly, from \$32 billion in 2018 to \$499 billion in 2022, shows the market growth report. On the supply side, this growth is driven mainly by continued technical improvements and innovations. On the demand side, growth will come from the use of these technologies in large-scale manufacturing, packaging, and the automobile industry. Even some small and medium-scale enterprises adopt these technologies to best fit with the rapid growth of these aspects. **Figure 1** shows the country’s share in innovating and developing the frontier technologies.

Technological innovation creates new products variedly new opportunities for the industry growth in India. It will play a significant lead in economic growth as it creates business opportunities that can evenly compete in world market opening new arena of arising in global stand in business. It not is the future demand as a whole but be an indispensable change that is over to take place causing economic, social, monetary factors. Technology was and will be the key incentive to drive changes in our society and peoples growth along with the nations development.

### ENCOURAGING INNOVATIONS AND ENTREPRENEURSHIP IN INDIA

By providing social, economic, technological and political support to the ideas of the young mind of the country, it can be ensured that young students right after their graduation instead of becoming social liability for the government can prove to be an asset for the country.

India needs to create 1- 1.5 crore jobs per year for the next decade to provide gainful employment to its young population. Generally, being innovation driven entrepreneurship tends to resolve India’s manifold social problems like high-quality education, affordable health care, clean energy and waste management, and financial inclusion through technological innovations with engineering all aspects. India is the youngest startup nation in the world. Thus, this demographic dividend is expected to definitely boost the startup culture in the country. India is a home to almost 3100 startups establishing per year standing just behind the US, UK, and Israel according to the NASSCOM report of 2015. If the growth continues in the same pace then it is expected that Indian startups will generate a plenty of jobs in the next five years.

### INNOVATIONS IN MARKET

Adopting new technologies should increase productivity in every aspects, long term to achieve sustainability. At present, productivity is up to a level in the developed countries, but in relative terms, the most significant increase was in upper-

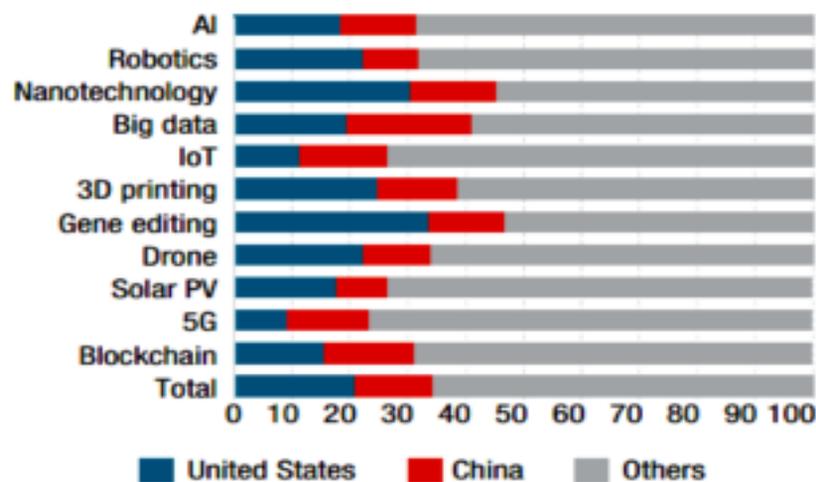


Figure 1 Source: UNCTAD



middle-income countries due to the market availability. There was also a substantial increase in lower-middle-income countries, but very little progress in low-income countries. This is partly because the poorest countries depend to a large extent on agriculture which offers less scope than manufacturing for technological innovations. In developing countries, there are large gaps in productivity between traditional and modern sectors. This is due to the scenarios created in the time of second world war. Long years back, India was a producer of various products, imported to numerous countries but with the invent of britishers turned into a market place. Now, India being a growing economy must basically provide the environment to turn these technological innovations to business fulfilling the demand in Indian market before it is supplied by other countries. The cutting edge technologies should be adopted and products should be innovated to improve basic infrastructure, while also investing in late-stage technologies to diversify into more complex products in traditional sectors where we can gain dynamic comparative advantage.

Also, awareness about inclusive and sustainable development of technologies to students should be done while mitigating the negative impacts of job displacement. A balancing act, involving innovation in both late-stage and modern technologies should be consistently promoted while diversifying their opportunities. **Figure 2** shows the factors to consider to readily use the technologies for business developments.

Initially it may be harder to upgrade because of changes in global production structures. The COVID-19 pandemic has created concerns and benefitted in diversifying the market scale and opened up wider pathway in setting up market for innovations. For example, the vaccines produced in India was been exported to various countries that were developed in so called global aspects. This shows us that the knowledge and ideas when used effectively can be a significant role in development of whole nation.

### CHALLENGES FACED BY STARTUPS IN INDIA

For starting a business, complex procedures and frameworks are the major obstacles in India. These complications tires the starter to get various clearances from different departments of the government.

Financing is the basic premise of all kinds of commercial undertakings. According to Economic Survey the position the accessibility of funds to business enterprise is not appreciable. The slowdown in time deposits, incomplete transmission of monetary policy, and unwillingness of banks to lend credit on account of rising non-performing assets are the some indicators of slow credit growth in the economy, highlighted by survey. Also, the funds allocated to research and development are not appropriate, the fact that from 2011 to 2012 only 0.88% of gross domestic product was granted for R&D exhibits the inadequateness of funds (NSTMIS, 2013).

Another main important challenge is due to the education system. The general education system still emphasises on grades and marks, career is not directed toward innovation, entrepreneurship and business. The issues of lack of infrastructure and good facilities in the educational institutions; delays in the funding system; and delays in the funds or other support reaching innovation projects further deteriorate the favorable environment of entrepreneurship. While industry does not approach to the educational institutions for their solution seeking, the institutions remain indulged in focusing on routine academic exercises producing manpower which is not suitable to innovative industries or entrepreneurship. When this is changed, the students are motivated to work and eventually get a mindset of starting a business with their knowledge acquired. Patent literacy is also very low, even among educated innovators, and there is a lack of expert help available, except in the medicine and pharmaceutical industry.

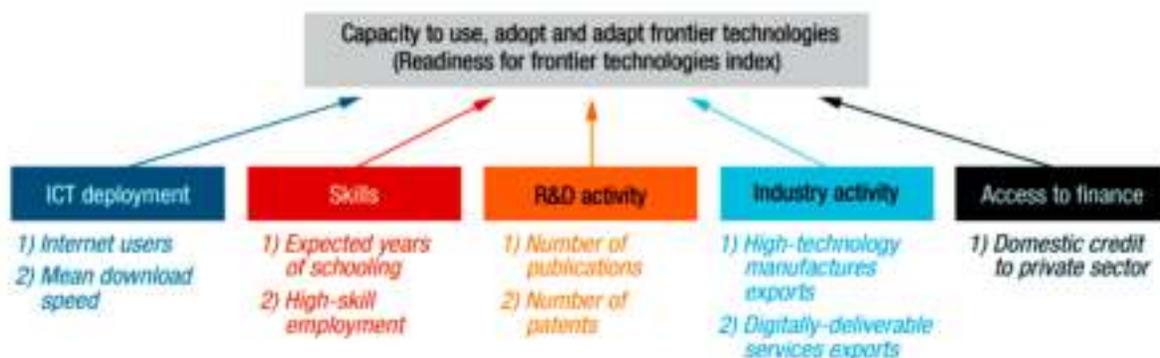


Figure 2 Source: UNCTAD



## GOVERNMENT INITIATIVES TO PROMOTE ENTREPRENEURSHIP

The Government of India since 2014, has been making efforts to attain its potential growth rate of above 9%. Since then, the Government of India has announced a number of measures that the focus on development-oriented policies to achieve higher rate of growth. The Prime launched a campaign of “Make in India”. After showing its intention of a robust industrial sector, the government announced initiatives like Skill India, Digital India, Start-up India, MUDRA Bank and infrastructural projects like Bharat Mala and Sagar Mala.

By providing tax concessions and facilitating ease of doing business the government wants to support start-ups and urges the young talent to choose entrepreneurship as their career. The Digital India initiative is a renewed push to address the delays plaguing the flagship programs and focus on universal broadband access and mobile connectivity. Further, Make in India Start-up India Digital India Skill India, Financial Support, Industry Academia Partnership Manufacturing Hub, The Union government’s Sagarmala project, aimed at promoting port-led development in India, could lead to annual logistics cost savings of Rs 35,000 crore and boost India’s merchandise exports to \$110 billion by 2025. Thus, through various programs, the government creates a conducive eco-system for entrepreneurship, faster the rate of economic growth and make the development more inclusive. Government should focus on each and every aspect of wholesome development right from school education, higher studied education framework and after process of academics and ease the idea of taking up business and inculcate in young generation that work seeking is not the only way after education, but promote innovations and marketing it.

## CONCLUSION

Entrepreneurship is all about the identification of an opportunity, formation of new concerns, and pursue with new association (Carton et al. 1998). Engineers can explore the environment, examine the alternatives, and capitalize them after proper analysis and entrepreneur it to provide numerous employments, innovation for nations development and a market seeker for the products developed. It is widely recognized that entrepreneurship is one of the basic tenets of development of a country. To become a global power and to effectively meet its social obligation such as poverty alleviation, enhancement in standard of living and employment generation sectors in India like manufacturing and technology to grow substantially. Indian young entrepreneurs’ contribution in making the future of millions, providing them employment in their enterprises is very significant to create a sustainable growth and make a self-reliant India in all aspects.

## REFERENCES

1. AatmaNirbhar Bharat Abhiyan, My Gov, <https://aatmanirbharbharat.mygov.in/> Accessed on 26 Nov 2022.
2. Arora, A., Gambardella, A. 2005. The globalization of the software industry: Perspectives and opportunities for developed and developing countries. *Innovation Policy*, 5: 1–32
3. Goswami, K., Mitchell, J. R., Bhagavatula, S. 2018. Accelerator expertise: Understanding the intermediary role of accelerators in the development of the Bangalore entrepreneurial ecosystem. *Strategic Entrepreneurship Journal*, 12(1): 117–150.
4. Scott, W. R. 2008. *Institutions and organizations: Ideas and interests*. Thousand Oaks, CA: Sage Publications.
5. Wright, M., Liu, X., Buck, T., Filatotchev, I. 2007. Returnee entrepreneurs, science park location choice and performance: An analysis of high-technology SMEs in China. *Entrepreneurship Theory and Practice*, 32(1): 131–155.
6. <https://news.un.org/>

# Design and Implementation of Intelligent Opening System of Doors and Windows on Detection of Carbon Monoxide Gas

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**Abstract:** In the present years there has been a warning over carbon monoxide risk from indoor heaters. Carbon monoxide is harmful when inhaled because it displaces oxygen in the blood and deprives the brain, heart and other vital organs that need oxygen. Exposure to moderate and high levels of CO over long periods of time has also been linked with increased risk of heart disease. Large amounts of CO can trounce anyone in minutes without warning that leads to lose consciousness and suffocate and finally to death. A recent tragedy in which eight tourists from Kerala due to suspected carbon monoxide poisoning from the gas heater kept inside their room highlights the need for precautions to be taken. Carbon monoxide poisoning can occur accidentally from a faulty ventilated home heating unit and air conditioner or by inhaling car exhaust. In general, carbon monoxide is produced due to incomplete combustion. CO is often called the "silent killer" because it is an odorless, tasteless, colorless toxic gas [1]. CO is made when any malfunctioning appliance that burns wood or fuel (oil, gas, propane, kerosene, coal) or poorly vented. Early symptoms of CO poisoning are often mistaken for those of the flu and include headache, nausea, sleepiness, dizziness, and confusion[2]. It is also produced when burning wood and by charcoal grills, propane grills, and many gasoline-operated instruments. In addition, carbon monoxide is also present in cigarette smoke. Because carbon monoxide is odorless, it cannot be detected, and sometimes victims are not even aware that they are being exposed to a lethal carbon monoxide environment. Carbon monoxide (CO) poisoning is a major threat to public health which needs to be addressed immediately. This could be carried out by developing an intelligent opening and closing system for windows and doors on detection of carbon monoxide gas, which would solve the problems such as the lack of intelligence of traditional windows and doors. The objective of the work is to design and implement automatic door and window intelligent hoist, data management system that automatically opens on detection of highly toxic carbon monoxide gas that is emitted accidentally from improperly combusted devices like room heaters, geysers and other household electronic equipments.

**Keywords:** Carbon Monoxide Gas Detection; Arduino; Intelligent Door; Intelligent Window

## INTRODUCTION

According to the internet of things smart windows will be a seamless integration of physical objects interfacing surrounding environment. More over IoT is a scenario to transfer data over a network without human intervention. Basically IoT is a combination of wireless technologies and internet. Based on IoT application can be used remotely to view the activity and get notification when motion is detected alarms will be obtained and the electromechanical system which is connected to the doors and windows would automatically open the doors and windows letting the carbon monoxide gas to exhaust through the openings. This reduces the suffocation inside the room and saves the life. The work also aims to design a highly secured multi-way windows automation system that allows the user to control all the electric and electronic devices from any smartphone. Presently automation techniques are implemented either using microcontroller or computer. Microcontroller cannot run multiple programs at a time. With the use of Microcontroller it is difficult to control both the appliances and surveillance at a time i.e., it is very complex to perform the multiple functions simultaneously. This is achieved with the computer, but using the computer is very expensive for this purpose and consumes more power. The arduino is a single board computer and it can be used to overcome these problems. Simply, the arduino system functions like a computer with small setup as shown in. It contains GPIO and USB ports [3,4]. Using these ports it is possible to control the appliances with the sensors as well as interface the camera for surveillance[5]. Arduino can be used for multiple purposes based on the requirement.

## METHODOLOGY DETAILING STEPWISE ACTIVITIES

The design and implementation of the intelligent opening and closing system of windows and doors is mainly composed

of three parts. Firstly the carbon monoxide gas detection sensor, intelligent opening and closing device of Windows and doors, and the mobile client[6]. The overall block diagram of the system is given in the following **Figure 1**. As soon as the carbon monoxide presence is sensed by sensor, it will control the door by sending the signal to motor driver. The motor driver will drive the motor and hence the door and windows[7]. The door and windows will be opened. An alarm system is also there. For the demonstration of the door and window a DC motor controlled system is used which controls the doors and windows.

The smart technology design with integration of smart sensors and embedded components to rapidly improve human lives which includes home automation, smart phones, smart healthcare, smart cars and so on.

### EXISTING METHODOLOGY

The gas detection system usually consists of a circuit having the following components: an MQ-6 sensor, GSM receiver and a microcontroller. The sensor sends the signal to the microcontroller and in the next step the microcontroller sends an active signal to other externally connected devices. An SMS alert is sent using the GSM module in case of a gas leakage.

### PROPOSED METHODOLOGY

Gas leakages cause detrimental impact to the lives of people and their future generations. In the present scenario, Carbon monoxide (CO) is the leading cause of poisoning deaths in many countries, including India. According to a descriptive study of fatal cases which were autopsied at the All India Institute of Medical Sciences (AIIMS), 80% of the cases were caused in winter months incidentally due to CO gas leakage from the room heater. CO leaks can be prevented by using a Carbon monoxide detection system. Existing detection methods are manual such as trying to identify for a hiss or a whistling noise for the source of the gas leak, Gas range test where the change in the colour of the flame indicates a gas leakage, soap water test in which the formation of bubbles will confirm the presence of a gas leak. Manual methods are unreliable and a proper, dependable system needs to be devised to prevent accidental mishaps. However, little work has been carried out to develop advanced systems to detect gas leakages and previous works have not comprehensively considered the possibility of the combination of the Internet of Things with the gas detection circuit. This paper suggests an effective method to detect CO gas using a gas leakage detection system using IOT and Arduino Uno with automatic door and window management system.

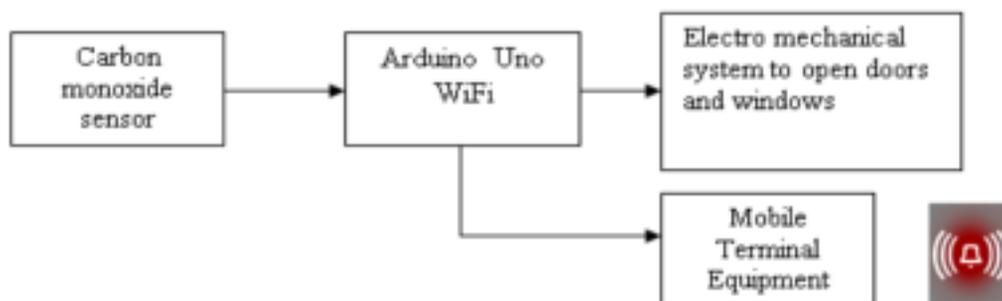
### IMPACT OF IOT

With the advancement in technology, SMS alerts have become rudimentary. And security has become a major concern in the present days. And to make things uncomplicated and automatic, a system has been devised to detect the problem and give a quick solution using the technology of IOT [8].

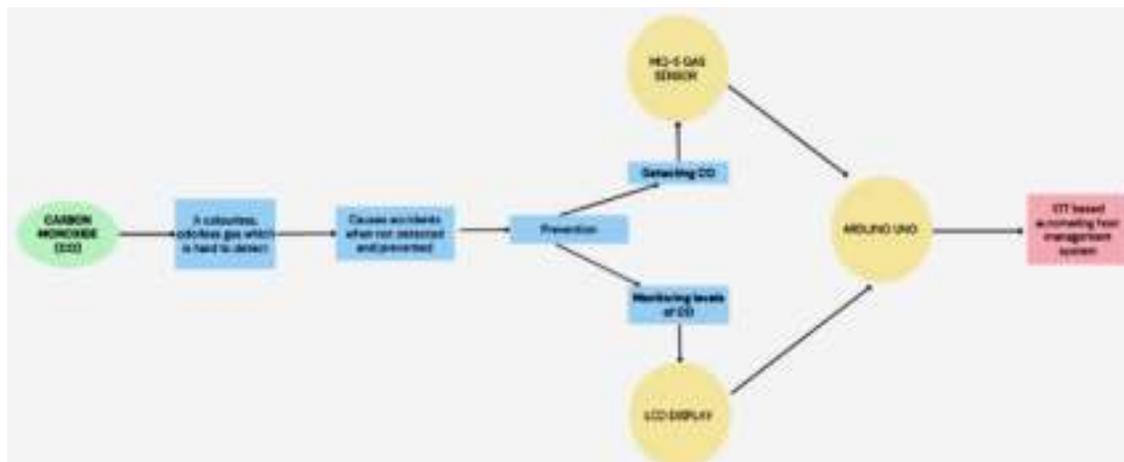
In the initial step the CO leakage is detected by the MQ-2 sensor and a signal is sent to the microcontroller with the help of Analog to Digital Converter (ADC). Once the microcontroller receives a signal sent by the gas sensor, it displays the CO levels on the LCD monitor and the IOT management system gets activated and the program to automatically open the doors and windows is executed. When the CO levels in the air are dropped and the normalcy is achieved the IOT management system runs the code that is responsible to close the windows and doors automatically. And the system is reset to reach the initial stage. The detailed block diagram of the proposed system is given in the following **Figure 2**.

### MQ-2 Gas Sensor

The MQ-2 Gas sensor has a detection sensor module which consists of four pins VCC, GND, Aout and Dout. It requires a



**Figure1** Block Diagram of intelligent door and window opening system



**Figure 2** Proposed algorithm

heating element in order to properly detect the CO gas. The sensor is manufactured with an anti-explosion network made of two layers of stainless steel mesh. This sensor is not only sensitive to CO but also to other hazardous, flammable gases like CO<sub>2</sub>, LPG, smoke etc. The concentration range of MQ-2 sensor is 200 to 10000 ppm.

### Arduino UNO

It is a microcontroller board based on a removable, dual-inline-package (DIP) ATmega328 AVR Microcontroller. It has 20 digital input/output pins. In the circuit we use a ESP8266 and connect it to the Arduino and to establish this connection, EP-01 adapter is used which has a built in 5V to 3.3 V regulator so that no resistors are required to be connected.

Then the ESP-01 adapter's VCC pin is connected to the 5V pin on the Arduino and the ESP-01 adapter's GND to GND on the Arduino. Next, the TX pin from the adapter is connected to the pin 2 on the Arduino and the RX pin from the adapter to the pin 3 on the Arduino. Then, the MQ-2 gas sensor is connected with the Arduino. The VCC and the GND pins on the gas sensor are connected to the 5V and GND pins on the Arduino. Then the A0 pin on the MQ-2 gas sensor is connected to the A0 on the Arduino.

On detection of CO leakage, the code constraints are satisfied and the program is run to activate the automatic closing and opening of doors and windows.

The effectiveness of the work has been analyzed by the following parameters. Firstly the distance of coverage and



**Figure 3** MQ-2 gas sensor



**Figure 4** Prototype of system developed



impact of carbon monoxide sensor is measured. Secondly the angle of inclination of door and window at the time of opening is calculated. Finally the time taken by the system to respond to the stimulus given on detection of CO gas.

## RESULT AND DISCUSSION

The design and implementation of the intelligent opening system of doors and windows is thoroughly explained.

The MQ 2 sensor plays to role of the CO detector and sends a signal to the Arduino microcontroller to activate the IOT program for Automatic Host Management System. In this system, a new approach for Carbon Monoxide leakage detection is proposed even at low concentration. The sensor sends signal to the externally connected devices. And the components each play their role to complete the working of the system.

## FUTURE SCOPE

The result of this work is the prototype of the Intelligent Opening System of Doors and Windows on Detection of Carbon Monoxide Gas. Electromechanical system is implemented on the door and window that controls the opening and closing of door and window. The prototype model also includes an alarm system. It has impact on home automation, smart phones and smart healthcare systems. The Intelligent Opening System of Doors and Windows on Detection of Carbon Monoxide Gas could be implemented in industries and homes which are equipped with air conditioners, geysers and other electronic gadgets. Carbon monoxide gas may be released due to improper combustion of electronic devices used in improperly used or malfunctioning equipments. According to the National Fire Protection Agency (NFPA), carbon monoxide detectors should be installed in a few different locations: Outside the doors of sleeping areas; on each floor of home; anywhere else required by local laws.

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## REFERENCES

1. Hiroshi Kinoshita, Hülya Türkan, Slavica Vucinic, Shahab Naqvi, Rafik Bedair, Ramin Rezaee, Aristides Tsatsakis, Carbon monoxide poisoning, *Toxicology Reports*, Vol. 7, pp. 169-173, 2020.
2. R.W. Byard, Carbon monoxide-the silent killer, *Forensic Sci. Med. Pathol.*, 15, pp. 1-2, 2019.
3. A. Sivanesh Kumar, D. Gobinath, P. Vijayakarhik, S. Dhanasekaran, N. Nithiyanandam, V. Jeyalakshmi, An Effective Gas and Oil Leakage Detection System over Industrial Environment using Internet of Things Assistance, 2022 3rd International Conference on Electronics and Sustainable Communication Systems (ICESC), pp.1735-1742, 2022.
4. S. Krithiga, A.R. Kalaiarasi, T. Deepa, S. Angalaeswari, D. Subbulekshmi, IOT Based Hazardous Gas Detection & Control, 2022 International Virtual Conference on Power Engineering Computing and Control: Developments in Electric Vehicles and Energy Sector for Sustainable Future (PECCON), pp.1-5, 2022.
5. V S D Rekha, Naga Sai Monika CH, Nikhitha Sri B, Sravya A, Condition Monitoring and Detection of Hazardous Gas Leakage using Smart Device, 2022 International Conference on Electronics and Renewable Systems (ICEARS), pp.396-400, 2022.
6. Gideon Buniel, Monalee Dela Cerna, i-Detect: An Internet of Things Voice-Activated Home Automation with Smoke and Fire Detection and Mitigation System, 2021 IEEE 13th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM), pp.1-6, 2021.
7. Mon Arjay F. Malbog, Honeylet D. Grimaldo, Luisito Lolong Lacatan, Rhowel M. Dellosa, Yolanda D. Austria, LPG Leakage and Flame Detection with SMS Notification and Alarm System: Rule-Based Method", 2020 11th IEEE Control and System Graduate Research Colloquium (ICSGRC), pp.323-327, 2020.
8. NagibMahfuz, Shawan Karmokar, Md. Ismail Hossain Rana, A Smart Approach of LPG Monitoring and Detection System Using IoT, 2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT), pp.1-4, 2020.

# Innovative Approach to Digital Engineering in Aerospace and Defense Industries

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**Abstract:** Digital Engineering (DE) brings innovation to the design and functioning of both products and systems, resulting in better business models and a boost in overall growth and productivity. However, now digital presents a new opportunity for A&D companies to embed it across their value streams, enabling them to design, build, and service products with greater speed, efficiency, and quality. A&D companies can use digital engineering to enhance their services. Digital Engineering helps in intelligent manufacturing, Industry 4.0, Artificial intelligence, machine learning, cloud computing, edge computing, big data, internet of things (IoT) as an application in digital engineering. As the world is entering digital era, the changes in the mindset and culture of the A&D industries are now at lower pace and but the same is rapidly gearing up for a big digital transformation. The paper brings out the position of digital engineering aspects in the industry, especially A&D sector.

**Keywords:** Digital Engineering; Digital Twin; Digital Transformation; Aerospace and Defense Industries

## INTRODUCTION

In the field of Aerospace and Defense (A&D) industries Digital Engineering is going to play a vital role in the coming years. A&D companies create some of technological marvels and have pioneered applications of digital and analytics technologies in many of their products. Digital Engineering is an umbrella term for the synergistic application of electronic and software technologies to facilitate the architecture, analysis, design, simulation, building, and testing of complex software-intensive systems-of-systems. Digital Engineering is the construction of digital (computer) models that represent every characteristics of a complex product or system that is to be developed. That process creates digital data and digital connectivity that can be leveraged to integrate that product's design, development, delivery, and full lifecycle support into a more agile, higher-performance product value stream than would be possible using a traditional Systems Engineering framework.

## DIGITAL ENGINEERING

Digital Engineering requires a culture committed to the use of those digital threads created in the model as the single "Source of Truth" that all stakeholders adhere to and depend on to keep all activities on track throughout development. It also requires a commitment to integrate into the process all the agencies like system engineering, planning, procurement & inventory, processing, quality assurance and inspection, packaging and supply to the end users. Digitally linking the entire chain of activities from the planner to the end user by means of digital thread is a part of DE. These stakeholders must work together fluidly in order to deliver on the accelerating demand for new complex products and capabilities, throughout the product's lifecycle. Digital Engineering's goal is to accelerate the development of complex products, systems, and sub-systems by overcoming the established engineering disciplines instead of Model-Based Systems Engineering (**Figure 1**). Digital Engineering honed, accelerated, and validates the realization process into a more fluid, consistent, workable approach than the conventional/traditional approach in varied developmental processes. Digital Engineering can be used anywhere product engineers want to make the product development process more agile and responsive to market demands rapidly.

Digital engineering (DE) describes a holistic approach to the design of a complex system: Design using models/data instead of documents, integration of data across models, and the culture change across project teams to realize significant risk reduction on construction cost and schedule. In the coming years, mega projects represent the sort of ambitious efforts that can change the world: better airplanes, integrated aerospace and defense systems, new nuclear reactor systems. The benefits of such projects are enormous, but the challenges can be daunting. DE is routinely used in aerospace, automotive and other industries to realize significant savings, quality and schedule improvements.



- Mortenson Construction, USA realized a 600-day schedule savings and 25% productivity increase using virtual design and construction (VDC) technologies on more than 400 projects;
- By building digital twins for assets, systems and processes, GE has avoided more than \$1.05 billion in customer, production and mechanical losses;
- Aerospace supplier grew its enterprise value by 2.5 times in four years.

### DIGITAL ENGINEERING STRATEGY

Digital Engineering Strategy (**Figure 2**) is a game-changer which led to greater efficiency and improved quality of all acquisition activities, making it easier than ever before to make informed decisions. Also the strategy creates a more uniform standard that allows those partner companies to optimize their own capabilities to fulfill on new products and systems with expertise, agility, and advanced resources. The ultimate goal of Digital Engineering is to produce Digital model, Digital shadow, Digital Twin: digital replicas of real and potential physical assets (i.e., “Physical Twins”) that include both inanimate and animate physical entities (e.g., hardware, software, “wet ware” [biological life]) for various purposes. One example of the application of digital engineering is the Digital twin Fig (3), which is a software simulation of the operation of a physical system both digital thread and digital engineering are an extension of product lifecycle management

A&D companies can use digital engineering to enhance their services by (a) assessing the performance and it’s upgrading, quick response to end users demand, adapting the design variation in the systems by modular approach and related inventory (b) automating pricing and service delivery (c) understanding the factors that correlate with greater customer lifetime value (d) streamlining customer support via automated tools to accelerate issue resolution and to create transparency. (e) Digital twin can also help to do various experiments without the fear of damaging the original airborne equipment’s that are costlier and avoids huge monetary losses.(f) Predictive maintenance can be achieved through huge volume of canned data that represents the real world scenarios, executed in the simulation Marginal variations may exist between Aerospace, Defense systems and other commercial applications and the same can be resolved.

### DIGITAL TWIN TECHNOLOGY

Digital Twin refers to the use of digital technology to describe and model a process or method consistent with the physical properties, behavior, and performance of a physical entity, also known as digital twinning technology. In 2015, General Electric Company .USA built a digital twin model of the Aero engine that was used to monitor the engine’s operating status, check engine performance in real time, and provide maintenance and maintenance recommendations based on its operating status. A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity. Digital twin systems transform business by accelerating holistic understanding, optimal decision-making, and effective action. Digital twins use real-time and historical data to represent the past and present and simulate predicted futures. Digital twins are motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge, and implemented in information technology/operational systems.

### METHOD FOR CONSTRUCTING DIGITAL TWIN MODEL—AEROSPACE & DEFENSE SYSTEMS

The construction of digital twinning model based on key features essentially embodies a modeling concept of demand-oriented digital twin model which is digitally integration of multiple models of sub systems and of multiple parts reflecting the state of the physical entities during entire manufacturing. The theoretical data expressed in the theoretical model must be organized according to the established key features. The geometric modeling of the theoretical model can be performed only for key features. For the digital twin model of machined parts, it needs to contain process information, machining information, inspection information, shape and material information, etc, and completely record the data.

An aircraft digital twin assembly workshop can collect various data of the aircraft assembly process in real time, realize the virtual simulation of the aircraft equipment process and control the assembly process of the aircraft according to the collected data. Many aircraft industries had applied the digital twin model for product configuration, production manufacturing IoT and data integration technology. In case of integration of large data in the manufacturing sector of multi source heterogeneous data digital twinning model is followed. At present, digital hygiene technology is mainly applied to processing equipment, production lines and workshops, and the research on digital twin model for process optimization.



Figure 1 Various digital engineering models



Figure 2 Digital Systems engineering strategy

**DIGITAL THREAD TECHNOLOGY**

A digital thread is an extensible, configurable, multi-directional integration of authoritative technical data, software, and information throughout a system’s life cycle, enabling the capture of decision making information and knowledge. The digital thread provides the framework for continuous feedback and incremental opportunities to build refine and verify in a Lean-Agile framework. The integration of manufacturing & production considerations with traditional Aerospace design matrices to support affordability based optimum design. These capabilities support A&D industries in their shift towards the design and realization of resilient systems which need to be manufacturable, readily deployable, easily modifiable and cost effective. Normally, aircraft and aerospace systems are complex in nature which typically includes airframe structure, engine, control surface, instrumentations, hydraulics and other systems. They have larger and precision parts and their operating environments are very hostile and extreme in terms of pressure, temperature and vibration. Aircraft generate a lot of data during its operation which makes it digitally manage the entire life cycle and possible to reduce the operating cost and improves the reliability. Dev\*Ops is a set of continuous practices that bridge the gap between development (Dev), operations (Ops), and all other organizations in between (\*) responsible for delivering the system. In addition to security (Sec), embedded systems demand a variety of features such as safety or air worthiness. Dev\*Ops achieves these goals by driving changes that deliver benefits such as faster time to delivery, improved quality and cost to the customer, and improved organizational efficiencies that increase productivity.

Digital Engineering helps in intelligent manufacturing, Industry 4.0 (Figure 4), artificial intelligence, machine learning, cloud computing, edge computing, big data, internet of things (IoT) as an application in digital engineering. Artificial

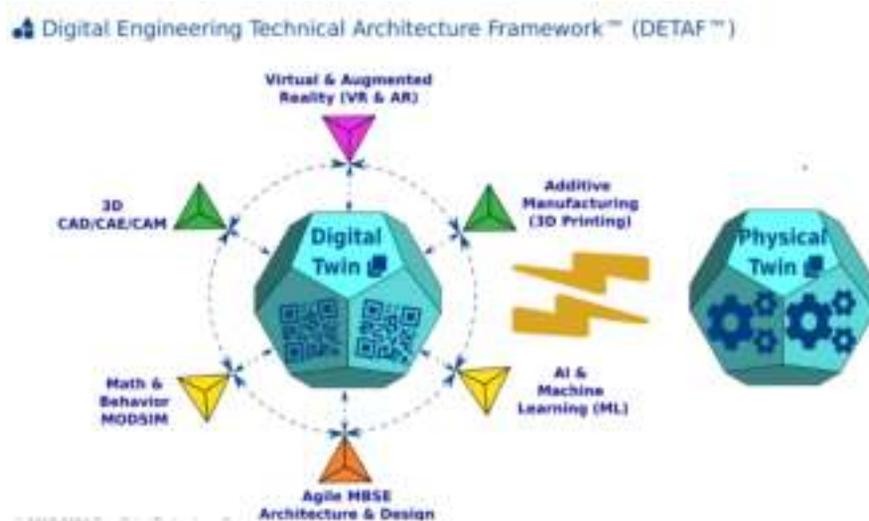


Figure 3 Concept of digital twin



**Figure 4** Digital Engineering – Industry 4.0

Intelligence enables to take a decision at the speed of the mission in complex and dynamic environments much faster rate. The result of using machine learning and artificial intelligence increases the reliability and performance with greater speed. AI&ML can process massive amounts of flight data, earth observation data, geo spatial data and deliver to the next level of demands.

Emerging technologies enhance project outcomes and produce innovative data and information. To keep up with such changes, some best practices to adopt are (a) Establishing Agile Development Practices: Competitiveness depends heavily on flexibility and agility (b) Ensuring Comprehension and Command of the already available technology(c) Implementing Modular Architecture.

## **TOSUMUP**

As a practice, digital engineering is still relatively new and unrecognized. As it flourishes, digital engineering approaches of A&D industries would increase efficiency, testing, safety, and the reuse of physical and digital products. Digital Engineering is getting a lot of impetus from both hi-tech and service-led verticals. Future eras of innovation will demand all processes, systems, and functionalities to be smarter, faster, and more interconnected to deal with all challenges. This implies a massive shift towards digital engineering principles & technologies. The companies adopt DE effectively will create a long-term competitive advantage. As the world is entering digital era, the changes in the mindset and culture of the industries are now at lower pace with inertia and expected to pick up. In the scenario of Indian A&D industries, many of them up skilled their knowledge and domain towards implementing DE. Sub system modular level digitizing is being followed by many firms which provide better performance, faster adaptability and cost effectiveness.

## **REFERENCES**

1. Reed Doucette, Sophie Hilaire, Varun Marya and Rob Wavra, Aerospace & Defense Practice Digital: The next horizon for global aerospace and defense, May 2021 McKinsey Co.
2. David Shepard and Julia Scherb, November 16, 2020, SEI Publications, What Is Digital Engineering and How Is It Related to DevSecOps?
3. Abhi Garg, July 18, 2022, Digital Tranformation, Understanding Digital Engineering: What it is, Implementation, Strategies, and Best Practices.
4. Engineering department of defense digital strategy, June 2018
5. Minglan Xiong, et al, Digital Twin application in aviation industry-a review., The International journal of advanced manufacturing technology, July 2022.
6. Aerospace Digital Transformation - Northrop Grumman- [www.NorthropGrumman.com](http://www.NorthropGrumman.com).



**ENVIRONMENTAL  
ENGINEERING  
DIVISION**





# Environmentally Benign Phyllosilicates for Converting Expired Medicines

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**Abstract:** To prevent the abuse of drugs and overdose related fatality, safe and secure disposal of the medicines that are expired becomes inevitable. It is evident that safe disposal of medicines always helps in preventing accidental ingestion by children, seniors, and pets. Pharmaceutical pollution in water bodies and supplies can be prevented by proper disposal leftover and expired pharmaceutical waste generated in our homes and healthcare system. This would also prevent risks of unintended exposures, drug diversion, and environmental pollution. In the present investigation, we propose an environmentally benign phyllosilicates that can adsorb the drug molecules and act as catalyst to convert them into useful products. By employing the naturally available catalyst the expired drugs and its pollution can be significantly reduced or eradicated in a cost-effective manner and add value from the waste via the value-added products and hence contribute to the circular economy, safety, and pollution control of the society.

**Keywords:** Medicinal Waste; Electrocatalyst, Bentonite Clay; Recycle, Value Added Products; Circular Economy

## INTRODUCTION

Increased population across the globe and health issues associated with stress, natural disasters and contagious disease breakthrough, increases the pharmaceutical demand continuously. Industrialization and urbanization had incessantly augmented the amount of pollutants in the ecosystem especially water bodies thereby making them unsuitable for drinking and other utility purposes. Due to the huge demand for pharmaceutical industries accumulation of unused or expired medicinal wastes, micro-plastics in the water bodies and ecosystem are happening at a disturbing rate. These wastes when it enters into the river ecosystem causes chronic risk to human beings, animals, and aquatic lives. The major problem in the contamination of water bodies with medicinal wastes include its anthropogenic activities via its ability to change the structure of the microbes and extinct several species of microorganisms. The higher concentration of the medicinal wastes (expired or unused) leads to myriad infections to animals and human beings. In order to avoid the adverse effects of these wastes on the human beings, animals, and aquatic creatures, various remediation methods had been investigated[1]. The present investigation focusses on naturally available phyllosilicates as electrocatalyst to break down the unused or expired medicines into useful products/chemicals that can be entered into the circular economy. This novel electrochemical process not only makes the medicine waste recycling cost effective but also a profitable process via generation of value-added products.

## MATERIALS AND METHODS

The unused or expired medicines were obtained from the pharmacies and used as such. The medicines used in the studies are aspirin, atorvastatin, clopidogrel, citicholine (Citimet). Medicines are not extracted and used as pharmaceutical formulations as such. Phyllosilicate such as Bentonite clay is procured from Cutch Oil and Allied Industries Pvt Ltd and used as such without any further purification. Deionised water is used for preparing solutions. Zahner Zennium E4 electrochemical workstation (Germany) is used to perform electrochemical degradation of the medicines. All the electrochemical experiments were performed using three electrode assembly with Bentonite coated stainless steel as working electrode, Ag/AgCl as reference electrode and Pt wire counter electrode. Electrolyte used being aqueous 1M MgCl<sub>2</sub> solution. Physiochemical characterization of bentonite clay, expired or unused medicines and the products obtained are performed. The porosity of the electrocatalyst bentonite clay is carried out via BET analysis. Coating of bentonite clay on stainless steel sheet is done by dip coating method. Bentonite clay is mixed with 1M MgCl<sub>2</sub> in deionised water and made as a slurry, stainless steel of 5×5 cm<sup>2</sup> is dip coated in the bentonite clay slurry and dried in an oven at 60°C for 3 h. The dried bentonite coated SS is used as working electrode.

## RESULTS AND DISCUSSION

The electrochemical degradation of unused and expired medicines such as aspirin, atorvastatin, clopidogrel and citicholine had been carried out. The physiochemical analysis of the electrocatalyst and the products obtained are performed extensively employing spectroscopic and chemical composition analysis techniques. The results on the experimental studies carried out and the products obtained are discussed elaborately in the following sections.

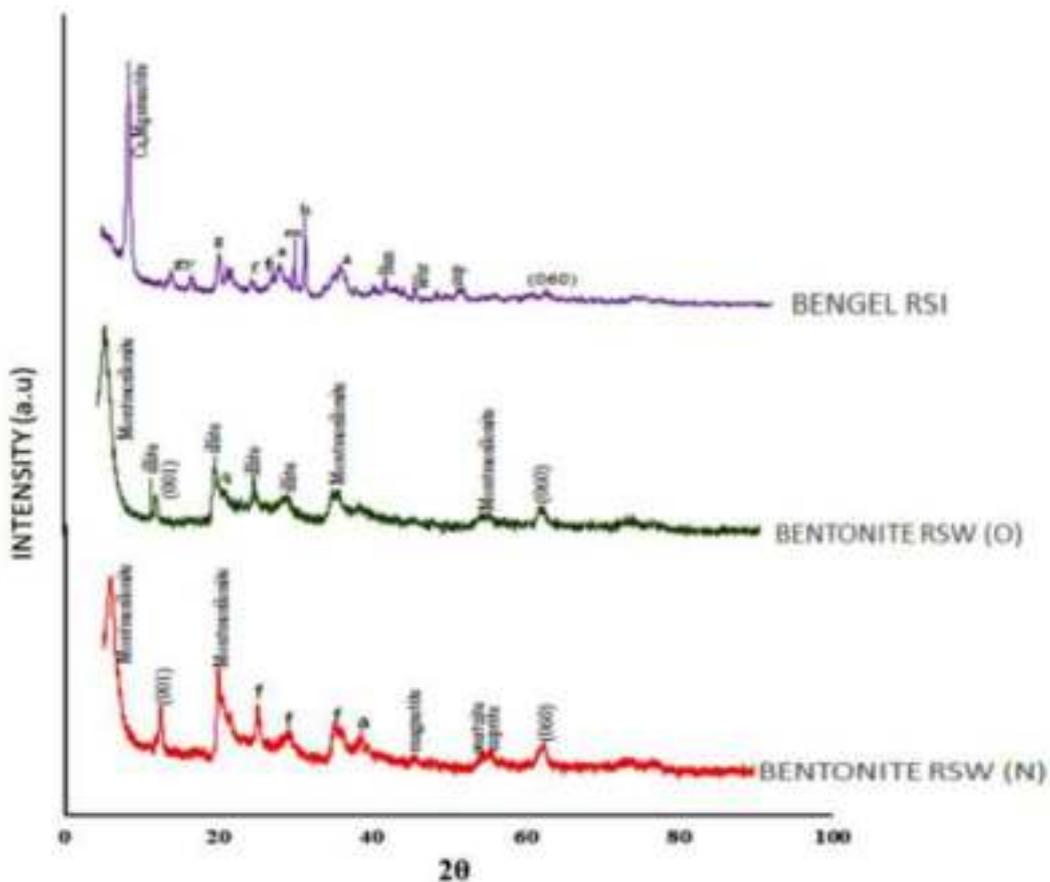
### Structural Analysis of Bentonite Clay

The X-ray Diffraction studies of three samples of bentonite clay had been done using Bruker powder XRD with  $K\alpha$ -Cu source and in the diffraction angle between 0 to 100°. The XRD patterns are provided in **Figure 1**.

From **Figure 1**, it is evident that the XRD patterns for all the samples agree satisfactorily with the literature[2]. Out of the three samples Bentonite RSW (O) and (N) are rich in Montmorillonite mineral and transformed into a sticky paste upon addition of aqueous solution of  $MgCl_2$ . Third sample Bengel RSI possess major composition as Ca, Mg Smectite (90%). This enables the bentonite clay BENGEL RSI as a better candidate for electrocatalysis of degradation of medicines in  $MgCl_2$  electrolyte due to easy  $Mg^{2+}$  incorporation and common ion effect between the electrocatalyst and the electrolyte under consideration.

### Structural Analysis of used or Expired Medicines

**Figure 2** demonstrates the XRD patterns of the medicines ECOSPRIN (tablet), CITIMET (capsule) and the biodegradable plastic encapsulation of the medicine capsule. The peaks agree well with the literature for aspirin, clopidogrel, atorvastatin, citicholine individually and in combined state in ECOSPRIN and CITIMET [3-6]. The medicine samples were crushed into powder to measure the XRD.



**Figure 1** XRD patterns of three samples of Bentonite clay procured from Cutuch Oil & Allied Industries (P) Ltd.

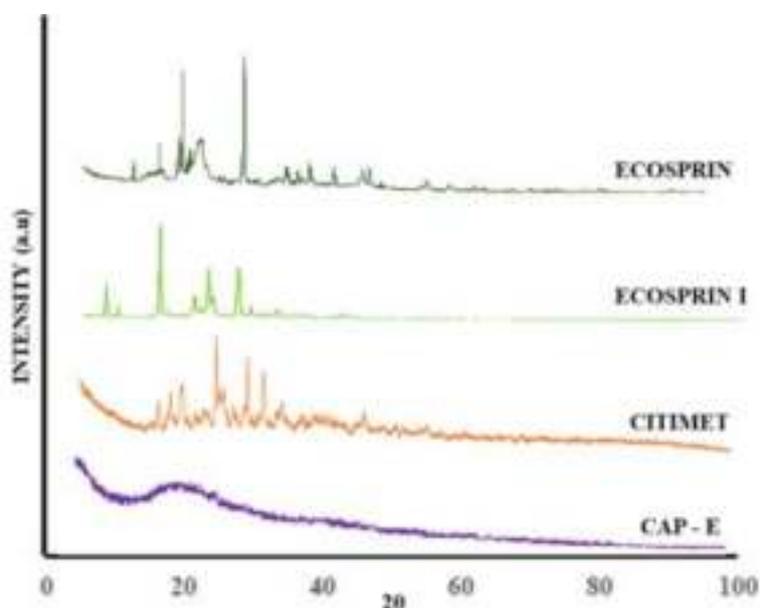


Figure 2 XRD patterns of pharmaceutical formulations of ECOSPIRIN and CITIMET

Table 1 XRD peaks identification for ECOSPIRIN

S. No	Ecospirin Peaks (2θ)	Remarks
1.	12.7764	Corresponds to 11.9 peak of Atorvastatin Corresponds to 12.28 peak of Clopidogrel
2.	16.6790	Corresponds to 15.59 peak of Aspirin
3.	19.7144	Corresponds to 18.13 peak of Aspirin
4.	19.8589	<b>Sharp and highly crystalline peaks</b> Corresponds to 19.1200 peak of Atorvastatin
5.	20.2058	Corresponds to 19.1200 peak of Atorvastatin
6.	21.3911	Corresponds to 20.6400 peak of Aspirin
7.	21.5356	Corresponds to 21.6900 peak of Clopidogrel
8.	23.2123	Corresponds to 21.6900 peak of Clopidogrel Corresponds to 22.6100 peak of Aspirin Corresponds to 23.0000 peak of Clopidogrel Corresponds to 23.2000 peak of Aspirin
9.	29.6300	Corresponds to (101) peak of TiO <sub>2</sub>
10.	36.1633	Corresponds to 36.07 peak of Aspirin
11.	37.8110	Corresponds to (004) peak of TiO <sub>2</sub>
12.	39.5155	Corresponds to (112) peak of TiO <sub>2</sub>
13.	43.3325	Corresponds to 43.51 peak of Aspirin
14.	48.5939	
15.	48.7673	Corresponds to (200) peak of TiO <sub>2</sub>

Tables 1 to 3 describes the identification of corresponding 2θ peaks for the above mentioned chemicals in the medicine.

#### Electrochemical Degradation of Medicines into Useful Products

Figure 3, cyclic voltammogram of ecospirin 75 (pharmaceutical composition), tagged to Bengal RSI on SS working electrode, Ag/AgCl reference electrode and Pt wire counter electrode, in 1M MgCl<sub>2</sub> electrolyte at different scan rates from 1 to 200 mVs<sup>-1</sup> in the potential window of -1.2 to 1.2 V. The pharmaceutical combination of Ecospirin 75 is a mixture of Aspirin 75 mg, Atorvastatin 10 mg and Clopidogrel with TiO<sub>2</sub> as pigment and orange dye.

The redox potential and current at 100 mVs<sup>-1</sup> (cf. Figure 3) agrees satisfactorily with the literature[7,8]. In the literature,

**Table 2** XRD peaks identification of CITIMET

S. No	Citimet Peaks (2θ)	Remarks
1.	16.3899	
2.	18.1244	Unidentified peaks, may be colorant
3.	19.8589	
4.	19.9167	
5.	21.8825	Corresponds to 20.5080, 21.3300, 22.2200, 22.3660 highly sharp crystalline peaks for Citicoline
6.	23.2990	
7.	24.8601	
8.	25.9297	Corresponds to 101 peaks of TiO <sub>2</sub>
9.	27.3173	
10.	29.2541	
11.	29.3698	Corresponds to 110 peaks of TiO <sub>2</sub>
12.	31.6246	
13.	34.5733	
14.	37.5509	Corresponds to 004 peak of TiO <sub>2</sub>
15.	46.5703	Corresponds to 200 peaks of TiO <sub>2</sub>
16.	55.9366	Corresponds to 211 peaks of TiO <sub>2</sub>

**Table 3** XRD peaks identification of the small tablet inside CITIMET capsule

S.No	Small Tablet Inside Citimet Peaks (2θ)	Remarks
1.	7.9487	Corresponds to 8.78 peak of Clopidogrel
2.	8.0932	
3.	9.7988	Corresponds to 9.62 peak of Clopidogrel
4.	15.8117	Corresponds to 15.59 peak of Aspirin
5.	15.8696	
6.	20.9574	Corresponds to 20.64 peak of Aspirin
7.	22.7208	Corresponds to 22.61 peak of Aspirin
8.	22.8943	Corresponds to 23.00 peak of Clopidogrel
9.	23.4725	Corresponds to 23.20 peak of Aspirin
		Corresponds to 23.26 peak of Clopidogrel
10.	27.1727	Corresponds to 27.08 peak of Clopidogrel
11.	28.9651	Corresponds to 110 peaks of TiO <sub>2</sub>
12.	32.9833	Corresponds to 32.73 peak of Clopidogrel

the oxidation potential of aspirin occurs at 0.7 V on edge plane pyrolytic graphite modified with graphene with respect to Ag/AgCl reference electrode. In the present investigation oxidation peak is observed at 0.65 V vs Ag/AgCl for bentonite electrocatalyzed ecospirin 75.

Two small humps were noticed at 0.8 and 1.05 V in the forward scan. The peak at 0.8 V could be due to oxidation of atorvastatin. The literature iterates that atorvastatin oxidizes on glassy carbon electrode at 1.004 V (vs Ag/AgCl) at 100 mV/s [9].

The oxidation peak observed at 1.05 V accounts for the clopidogrel base present in the pharmaceutical formulation. The observed oxidation potential of clopidogrel is identical to that of the literature value [9].

**Figure 4**, cyclic voltammogram of citimet (pharmaceutical composition), tagged to Bengel RSI on SS working electrode, Ag/AgCl reference electrode and Pt wire counter electrode, in 1M MgCl<sub>2</sub> electrolyte electrolyte at different scan rates from 1 to 200 mVs<sup>-1</sup> in the potential window of -1.2 to 1.2 V. The pharmaceutical combination of citimet is crystalline acetyl choline.

The redox potential and current at 100 mVs<sup>-1</sup> (cf. **Figure 4**) agrees satisfactorily with the literature (Ref. Sensors 2019, 19, 447). In the literature, the oxidation potential of citicholine occurs at 0.62 V on Ni-Al LDHs/CD modified Glassy Carbon Electrode (GCE) with respect to Ag/AgCl reference electrode in 1M KOH electrolyte. In the present investigation oxidation peak is observed at 0.43 V vs Ag/AgCl on BENGEL RSI coated SS working electrode with Citimet drop casted on the same.

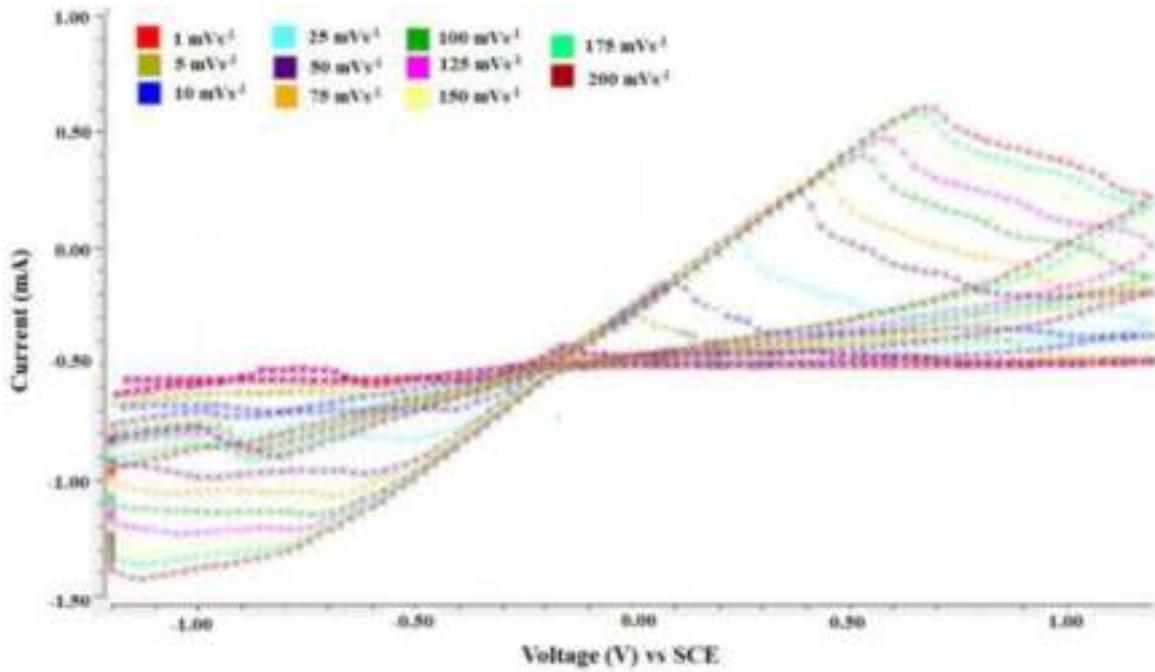


Figure 3 Cyclic Voltammogram of Ecospirin 75 (pharmaceutical composition)

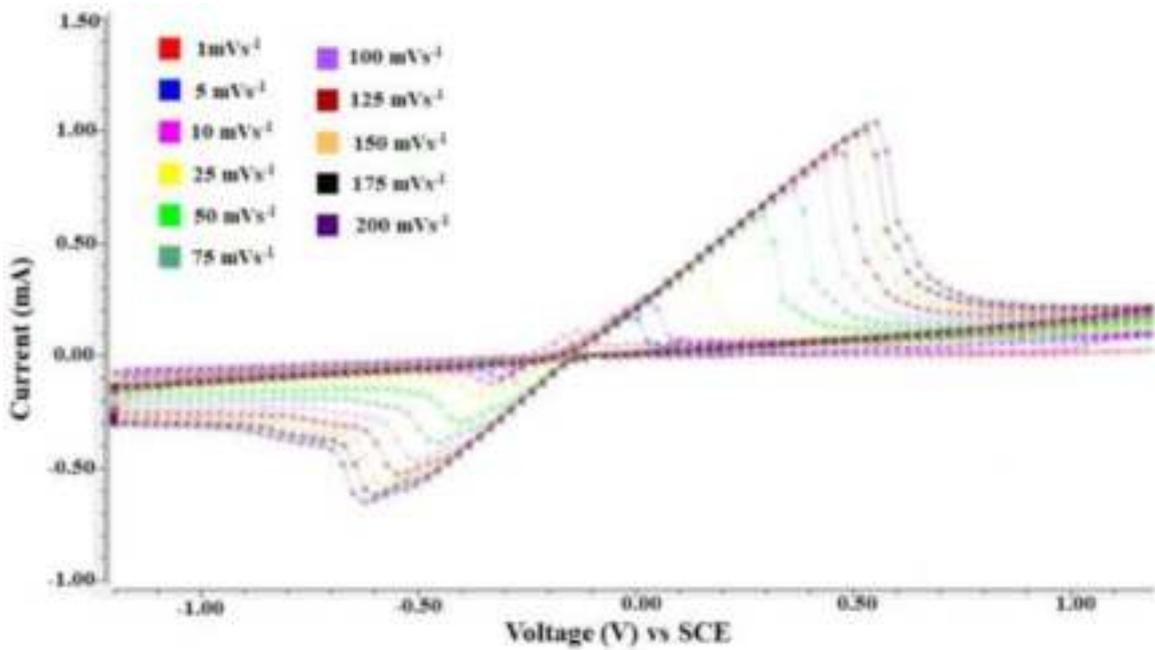


Figure 4 Cyclic Voltammogram of Citimet (pharmaceutical composition)

#### DEGRADATION MECHANISM AND PRODUCTS

The degradation mechanism deduced based on the electrochemical studies for the medicines under consideration are as follows (Figure 5).

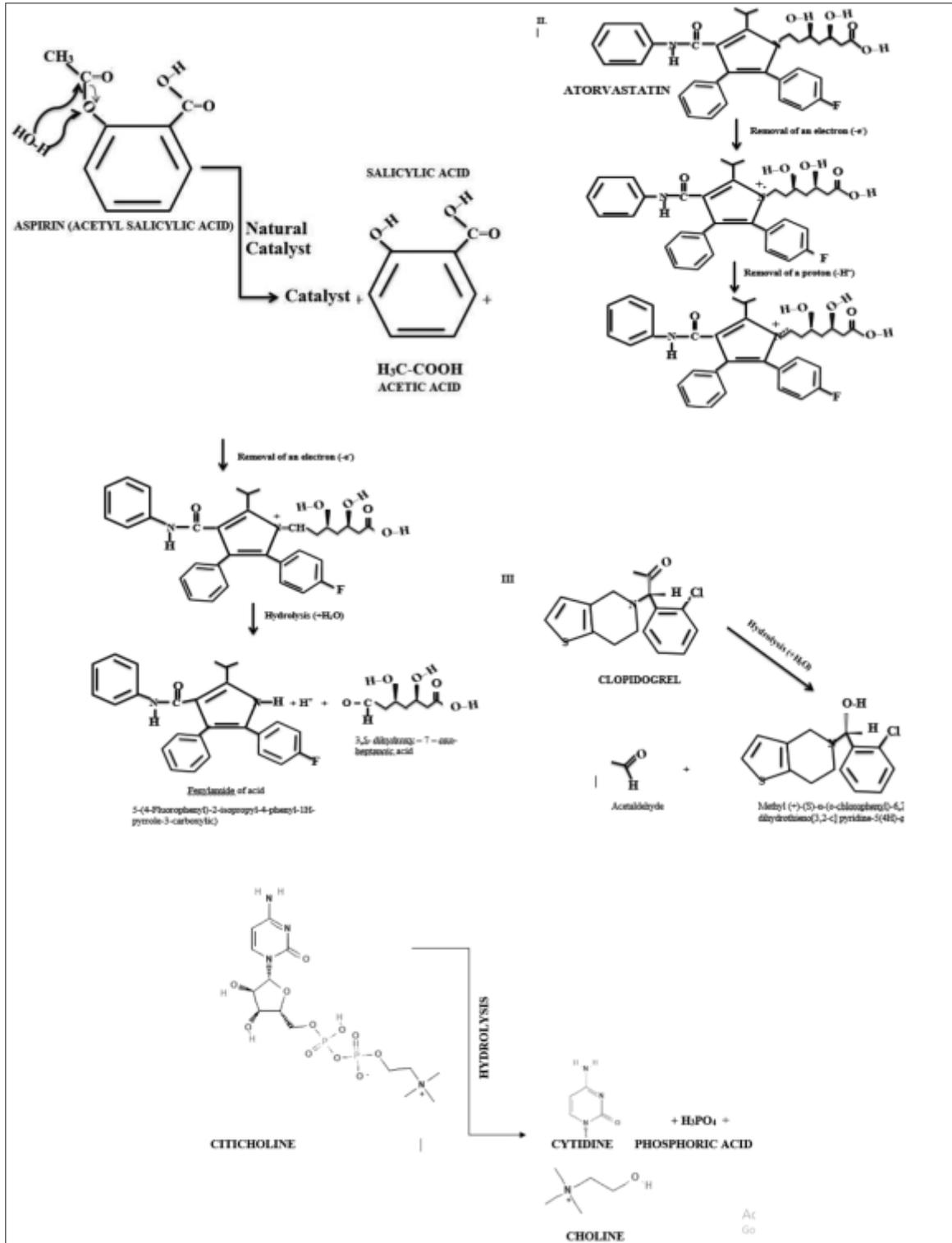


Figure 5



## PERSPECTIVES AND SUMMARY

From the above studies it is evident that the unused or expired medicines undergo regulated degradation in the presence of applied external electric field via cyclic voltammetric technique leading to the formation of value added products such as salicylic acid and acetic acid from aspirin, heptanoic acid and fentamide of acid from atorvastatin, acetaldehyde and substituted pyridine from clopidogrel, choline, cytidine and phosphoric acid from citicholine. The products obtained can be recirculated to the raw material industry for pharma formulation synthesis, automobile industry and other chemical industries. The products obtained upon proper purification will cater to the circular economy and supply chain of the raw material traders and suppliers.

## REFERENCES

1. Prateek Sharma, Lata Rani, Ajmer S Grewal and Arun Lal Srivastav, Chapter 2, Ecological Significance of River Ecosystems, 2022, pp 15-36.
2. S L Abdullahi and AA Audu, Chem Search Journal, 2017, pp 35 – 40.
3. C Muthuselvi, M Dhavachitra and S Pandiarajan, Journal of Chemical and Pharmaceutical Research, 2016, pp 804-814.
4. Asma B Pathan, Nita B Pawar and Ahad J Pathan, World Journal of Pharmaceutical Research, 2017, pp 586-597.
5. Ankush Choudhary, Avtar C Rana, Geeta Aggarwal, Virender Kumar and Foziyah Zakir, Acta Pharmaceutica Sinica B, 2012, pp 421-428.
6. Olivera R Klisurić, Srđan J Rakić, Miroslav J Cvetinov, Maja M Stojanović, Andrea R Nikolić, Suzana S Jovanović Santa, Ana R Marković, Ljiljana N Solomun, Journal of Research in Physics, 2013, pp 55-67.
7. Senee Kruanetr, Pat Pollard and Carlos Fernandez, Radhakrishna Prabhu, International Journal of Electrochemical Science, 2014, pp 5699-5711.
8. Samer Housheh1, Saleh Trefi, Mohammed Haroun and Mustafa Fawaz Chehna, Indian Journal of Pharmaceutical Science, 2016, pp 360 – 367.
9. Oana Gunache (Roşca), Alexandra Virginia Bounegru and Constantin Apetrei, Inventions, vol 6, 2021, pp 57-63.





# Contributions of Higher Education Institutions towards Realising SDGs through Various Government Schemes

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**Abstract:** The United Nations created 17 Sustainable Development Goals (SDG) in 2015 and aims to achieve them by 2030. All the 193 United Nations Member States agreed on these 17 goals to ensure well-being, economic prosperity, and environmental protection. As the fastest growing major economy of the world, today, India is uniquely placed to deliver on its promises to inclusive and sustainable development. Our nation has played a vital role externally, in modeling the SDGs to conform the balance among the three areas — economic, social and environmental. It has also launched many programs as internal initiatives to make progress towards these goals and provide a holistic and multidimensional view on development. Hence, interactions among the SDGs may cause diverging results. This paper aims to highlight the various initiatives implemented by the Indian government to contribute in realizing the SDGs with the contribution of our nation. The country has framed several forums to develop policies and formulate action plans to eliminate poverty, address climate change, promote gender equality, offer quality education, promote economic growth, build infrastructure etc., Many of the schemes launched by the government directly contribute to the development of SDGs and Higher Education Institutions are also invited to take part in such initiatives, thus involving the educational institutions in contributing to SDGs. Many Scholarship schemes like AICTE Pragati, Saksham, Swanath, etc., help the students pursue higher education without any financial constraints thus promoting the SDG-4 of Quality Education. The other novel competitions like AICTE Lilavati Awards, AICTE Clean and Smart Campus Award, Chhatra Vishwakarma Award, Smart India Hackathons, etc., kindle the minds of the teachers and students in striving towards SDGs in a number of ways. This paper provides an overview of various government schemes that can be adopted by Higher education institutions in contributing to SDGs.

**Keywords:** Sustainable Development Goals; Government Schemes; Quality Education; Higher Education Institutions; Scholarships and Awards

## INTRODUCTION

Sustainable development is progress that meets the needs of the present without compromising the ability of future generations to meet their own needs. The United Nations created 17 Sustainable Development Goals (SDG) in 2015 and aims to achieve them by 2030. All the 193 United Nations Member States agreed on these 17 goals to ensure well-being, economic prosperity, and environmental protection. As the fastest growing major economy of the world, today, India is uniquely placed to deliver on its promises to inclusive and sustainable development. Our nation has played a vital role externally, in modeling the SDGs to conform the balance among the three areas - economic, social and environmental. It has also launched many programs as internal initiatives to make progress towards these goals and provide a holistic and multidimensional view on development. The Indian Government has taken great initiatives in promoting SDGs through Higher Education Institutions (HEIs). It provides a number scholarship schemes to students pursuing higher education to encourage them to continue their studies. In addition, the Governments also conduct many flagship events and competitions to kindle the minds of students and staff towards sustainable development. In addition, the respective state governments also render their part to encourage students to pursue their higher education without any financial hurdles to attain sustainability in quality education for all. This paper is an attempt to highlight a few important government schemes which help the higher education institutions to contribute in realizing the UN SDGs.

## ROLE OF HIGHER EDUCATION INSTITUTIONS

It is key that education is critical to achieving sustainability (Leal Filho et al., 2018). The establishment of education for sustainability is geographically unequal, and more efforts are needed to reduce the differences around the world (Samuelsson and Park, 2017; Nagendra et al., 2018). Higher Education Institutions (HEIs) are significant performers in achieving the Sustainable Development Goals (SDGs) and the 2030 Agenda set by the United Nations General

Assembly in 2015. As representatives of knowledge, HEIs maintain a critical role in contributing to a socially fair, economically feasible, and environmentally safe world.

The HEI's can contribute to the achievement of the SDG's involves learning and teaching (SDSN, 2017). This method is aimed at equipping students with the necessary competencies required to address the multitude of sustainability challenges. Khalili et al., (2015), indicate that curriculum design is a necessary first step for the development of human capital, which is in turn necessary to create the basis through which sustainability challenges can be overcome.

The importance of research by HEI's aimed at generating knowledge, solutions and innovations related to sustainable development has been discussed in detail by Waas, Verbruggen and Wright (2010).

Research shows that education is fundamental to social change and hence the HEIs shall integrate SDGs in all the above areas such as curriculum, campus operation, innovation, idea incubation and creation of startups that can contribute to one or a combination of more goals under the SDGs.

### UN SDGS

The Sustainable Development Goals (SDGs), also known as the Global Goals, were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity. The 17 SDGs are integrated that action in one area will affect outcomes in others, and that development must balance social, economic and environmental sustainability (www.undp.org).

United Nations (UN) created the Sustainable Development Goals (SDGs), also known as the Worldwide Goals, in 2015 as a global appeal to action to eliminate poverty, protect the environment, and guarantee that everyone enjoys freedom and harmony by 2030 (de Villiers et al., 2021). The 17 SDGs are interwoven; they determine the impact of initiatives in one sphere and progress in social, economic, and environmental sustainability. These SDGs require everybody's creativity, understanding, technology, and financial resources in every environment. UNESCO aims to ensure that every child and citizen has access to a good education by fostering national connections and also cultural heritage and the equality of all civilizations (Addey, 2021). The Sustainable Development Goals (SDGs) are therefore an integral part of the country's extensive culture and heritage, and the goals largely represent India's aim towards development (Kakar et al., 2021; Manby, 2021) and also India had a major influence in formulating the goals for sustainable development.

Among the 17 SDGs, SDG 4 is the goal of pristine education (Ferguson et al., 2021). It endeavors to provide equal and unbiased education and create opportunities for continuous learning. This research focuses on promoting SDG 4 – Providing quality Education to all. It also brings forth the various schemes by the governments in contributing to SDG 4 directly and other SDGs indirectly.



Source: <https://sustainabledevelopment.un.org/sdgs>



## INITIATIVES BY THE GOVERNMENT IN REALIZING SDGS

India houses the one-sixth of all humanity and holds the key to the achievement of the 2030 Agenda. The post-independent India witnessed several key challenges in education and aptly the Indian governments have introduced new educational policies and as a part of its development agenda. They include 'Sarva Shiksha Abhiyan', 'Rashtriya Madhyamik Shiksha Abhiyan', 'Right to free & compulsory Education Act' etc. (Saini et al., 2021; Singh et al., 2021). These policies and schemes address the school education system. In a similar way, the higher education is popularized through a number of schemes presented below:

### Pragati Scholarship

AICTE is implementing the Pragati Scholarship Scheme to provide financial assistance for the girl students whose parental income is less than Rs.8 lakhs per annum, to achieve women empowerment in technical education. The selected girl students will receive scholarship of Rs.50,000/- per annum for every year of study — Diploma in Engineering & Technology — Maximum of 3 years for girl students admitted to the first year and a maximum of 2 years for girl students admitted to the second year through lateral entry. etc. ([www.aicte-india.org](http://www.aicte-india.org)).

### Saksham Scholarships

Saksham is a MHRD Scheme being implemented by AICTE, which aims at providing encouragement and support to specially-abled children to pursue technical education. This is an attempt to give every young student, who is otherwise specially-abled, the opportunity to study further and prepare for a successful future through technical education/knowledge. Specially-abled students, having disability of not less than 40%, are eligible. The family income from all sources should not be more than Rs. 8 lakh per annum during the current financial year. The scholarship amount would be of Rs.50,000/- per annum. ([www.aicte-india.org](http://www.aicte-india.org)).

### Swanath Scholarships

This Scheme is being implemented by AICTE to provide encouragement and support to orphans, wards of parents died due to Covid-19, wards of Armed Forces and Central Paramilitary Forces martyred in action (Shaheed) to pursue education. This is an attempt to give every such child, an opportunity to study further and prepare for a successful future through education in AICTE Approved institutions and courses. The candidate should be from any one of the following categories:

(i) Orphan

(ii) Either or both parents died due to Covid-19

(iii) Wards of Armed Forces and Central Paramilitary Forces martyred in action (Shaheed). The family income from all sources should not be more than Rs. 8 Lakh per annum during the financial year of the application. The candidate should be currently studying in the AICTE Approved institutions and courses at Degree/ Diploma level in regular mode. The scholarship amount would be of Rs.50,000/- per annum. ([www.aicte-india.org](http://www.aicte-india.org)).

### AICTE - Post Graduate (PG) Scholarship Scheme

In order to ensure development of technical education in India, the AICTE awards Post Graduate Scholarship of Rs. 12,400/- per month to full-time GATE/GPAT qualified students admitted to AICTE approved post graduate programs in AICTE approved Institutions/ University Departments as per AICTE approved intake. The Scholarship is tenable for 24 months or for the duration of the course. ([www.aicte-india.org](http://www.aicte-india.org)).

### AICTE Lilavati Award

This award intends to recognize efforts being made by AICTE approved institutions to treat women with 'equality and fairness' in all spheres of their lives. By means of this initiative, all the stakeholders (especially the girl students) in AICTE approved institutions get a unique opportunity to present a solution to the prevalent issues of gender discrimination, such as illiteracy, unemployment, economic and nutritional disparities, maternal mortality, human rights, etc., she/ he can showcase their efforts/ contributions. This award is being awarded under eight sub-themes such as Women and Adolescent Health, Self Defence, Environment, Sanitation & Hygiene, Literacy and Life Skills, Women Entrepreneurship, Legal Awareness, Technology for Women, Women Innovators (Rural/Urban). The award in the form of prize money will be given to the 24 winning teams(three under each sub-themes) as follows:

1. Winner: Rs. 1,00,000/-



2. First Runner-up: Rs. 75,000/-
3. Second Runner-up: Rs. 50,000/-

The AICTE Lilavati Award helps the Higher Education Institutions to strive towards the following SDGs with respect to the sub-themes.

- ⊙ Women and Adolescent Health – SDG 3, Good health and Wellbeing
- ⊙ Self Defence – SDG 16, Peace, Justice and Strong Institutions
- ⊙ Environment, Sanitation & Hygiene – SDG 6, Clean water and Sanitation
- ⊙ Literacy and Life Skills – SDG 4 - Quality Education, SDG 5 – Gender Equality, SDG 8 – Decent Work and Economic Growth
- ⊙ Women Entrepreneurship – SDG 8 – Decent Work and Economic Growth
- ⊙ Legal Awareness – SDG 16, Peace, Justice and Strong Institutions
- ⊙ Technology for Women – SDG 9- Industry, Innovation and Infrastructure
- ⊙ Women Innovators (Rural/Urban) - SDG 9- Industry, Innovation and Infrastructure

Thus, the AICTE Lilavati Award encourages and promotes HEIs to take up interventions in their areas of interest, thus contributing to the realization of many SDGs. ([www.aicte-india.org](http://www.aicte-india.org))

#### **AICTE Clean and Smart Campus Award**

The award aims to seek engagement with all stakeholders, primarily the student community to draw their attention towards immense scope and potential that the Technology offers for abstract objectives such as cleanliness, sustainability, environment etc. The rising use of technologies especially IOT, robotics, cloud and automation have immense potential to re-model a campus in to a smart campus. These smart campuses can minimally help in ‘forward delivery’ by optimizing the use of, inter alia energy and water consumption in the campus. Smart campuses would construct ‘Smart Citizens’ – those who are ‘future-ready’ for the Smart Cities and an even Smarter India. Clean and Smart Campus is also expected to facilitate dialogue and sharing of ideas amongst students, faculty and administrators towards the United Nations Sustainable Development Goals. ([www.aicte-india.org](http://www.aicte-india.org)).

#### **AICTE Chhathra Viswakarma Award**

The Vishwakarma Awards are inspired by the spirit of engineering and creation patronized by Lord Vishwakarma, the ruling deity of construction practices in India. The Awards are thus a means to provide a platform for our stake holders to look at the societal challenges, with an aim to provide an innovative and low cost solutions. These awards are an embodiment of encouraging truly successful efforts that have made a mark on the industry or the society in terms of delivering better outputs & processes and creating higher benchmarks. Hence the Awards are aimed for motivating young individuals, inspiring leaders and institutions/ organizations to raise their performance in their specific domains leading to significant contribution towards the growth and development of the nation as a whole. ([www.aicte-india.org](http://www.aicte-india.org)).

#### **Smart India Hackathon**

Smart India Hackathon is a nationwide initiative to provide students a platform to solve some of demanding problems we face in our daily lives, and thus inculcate a culture of product innovation and a mindset of problem solving. In SIH, the students would also have the opportunity to work on challenges faced within the private sector organisations and create world class solutions for some of the top companies in the world, thus helping the Private sector hire the best minds from across the nation. ([www.aicte-india.org](http://www.aicte-india.org)).

#### **Swayam Programme**

The program gets its name from Study Webs of Active – Learning for Young Aspiring Minds (Kumar & Mahendraprabu, 2021). Swayam is a programme initiated by Government of India and designed to achieve the three cardinal principles of Education Policy viz., access, equity and quality. The objective of this effort is to take the best teaching learning resources to all, including the most disadvantaged. Instructors from IITs, IIMs, and central universities will provide online training to residents of the nation as part of this initiative. All courses will be available for free study. If the learner desires an Authenticated Certificate, a modest cost will be charged. In the first phase, IIT Bombay, IIT Chennai, IIT Kanpur, IIT Guwahati, University of Delhi, Jawahar Lal Nehru University, IGNOU, IIM Bangalore, IIM Calcutta, and Banaras Hindu University will train students in engineering education, social science, power, governance, and science courses on their own and with the assistance of academic staff from international schools.



### Pradhan Mantri Kaushal Vikas Yojana

Pradhan Mantri Kaushal Vikas Yojana (PMKVY) is the flagship scheme of the Ministry of Skill Development & Entrepreneurship (MSDE) implemented by National Skill Development Corporation. The objective of this Skill Certification Scheme is to enable a large number of Indian youth to take up industry-relevant skill training that will help them in securing a better livelihood. This scheme helps the HEIs in realizing the SDG 8 – Decent work and Economic Growth. (<http://www.pmkvyofficial.org/>).

### CONCLUSION

The DG 4 – Quality Education, under the Sustainability development program is driven to provide quality education by removing the obstacles of poverty, funding, costly education, discrimination, and unavailability of resources. India is no longer behind in making the needful changes in its education system; and obviously HEIs too. All the HEIs must utilize the various government schemes for the benefit of the stakeholders. The HEIs can tap the funding available through scholarships to help the students from economically weaker sections to continue their studies without hindrances. Similarly, the students can be motivated to take part in a wide range of competitions to prove their mettle. Also, with the collective efforts of the HEIs and the government initiatives, it is sure that India will contribute to in contributing to the SDGs.

### REFERENCES

1. Leal Filho, W, Raath, S, Lazzarini, B, Vargas, V R, de Souza, L, Anholm, R, Quel-has, Q L G., Haddad, R, Klavins, M, Orlovic, V L, The Role of Transformation in Learning and Education For Sustainability. *J. Clean. Prod.* 199, 2018, pp286–295.
2. Samuelsson, I P, Park, E, How to Educate Children for Sustainable Learning and for a Sustainable World. *Int. J. Early Child. SDSN Australia/Pacific*, 49, 2017, pp 273–285
3. Getting Started with the SDGs in Universities. SDSN, 2017.
4. Khalili, N, Duecker, S, Ashton, W and Chavez, F, From Cleaner Production to Sustainable Development: The Role of Academia. *Journal of Cleaner Production*, 96, 2015, pp 30-43.
5. Waas, T, Verbruggen, A and Wright, T. University Research for Sustainable Development: Definition and Characteristics Explored. *Journal of Cleaner Production*, 18(7), 2010, pp 629-636.
6. <https://www.undp.org/sustainable-development-goals>
7. de Villiers, C, Kuruppu, S, and Dissanayake, D. A (new) Role for Business—Promoting the United Nations' Sustainable Development Goals through the Internet-of-things and Blockchain Technology, *Journal of Business Research*, 131, 2021, pp 598-609.
8. Addey, C, Passports to the Global South, UN flags, favorite experts: understanding the interplay between UNESCO and the OECD within the SDG4 context. *Globalization, Societies, and Education*, 2021, pp 1–12.
9. Ferguson, T, Roofoe, C, Cook, L D, Teachers' perspectives on sustainable development: the implications for education for sustainable development. *Environmental Education Research*, 2021, 1–17.
10. Saini, M, Singh, M, Kaur, M, Kaur, M, Analysing the tweets to examine the behavioural response of Indian citizens over the approval of national education policy 2020. *International Journal of Educational Development*, 82, 102356, 2021.
11. Singh, M, Adebayo, S O, Saini, M and Singh, J, Indian Government E-learning Initiatives in Response to COVID-19 Crisis: A Case Study on Online Learning in Indian Higher Education System. *Education and Information Technologies*, 2021, pp 1–39.
12. <https://swayam.gov.in/>
13. <https://www.aicte-india.org/schemes/students-development-schemes>
14. Kumar, K S, Mahendraprabu, M, Open educational practices of SWAYAM programme among research scholars. *Education and Information Technologies*, 2021, pp 1–25.
15. (<http://www.pmkvyofficial.org/>)





# Review Paper on Air Quality Monitoring System

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**Abstract:** Air pollution is stated as one of the most crucial problems for the mankind. The level of pollution is increasing gradually everyday. The major reasons of the increase in air pollution are factories, industries, urbanisation and increase in the number of vehicles. Harmful effects of decrease in the quality of air leads to mild allergic reactions of nose, eyes and throat and also to some serious and chronic diseases problems like heart diseases, bronchitis, asthma and pneumonia. According to a survey, around 30,000 premature death are caused due to air pollution worldwide.

This project proposes an air quality monitoring system. The system is to be developed using the Arduino uno microcontroller and MQ135 sensor. MQ135 sensor is used to detect most harmful gases that work as a deciding factor for Air Quality Index. It will trigger an alarm when the value of air quality goes down beyond a certain level. It is important to note that what differentiates this proposal from others is the implementation of periodic notification and the alert system when the value of air quality is below acceptable value. This project also aims to build a cost efficient air quality monitoring system with increased accuracy.

**Keywords:** Air Pollution; IOT; MQ135 Sensor; Arduino Uno

## INTRODUCTION

Any substance, whether chemical, physical, or biological, that modifies the atmospheric environment is referred to as an air pollution. Indoor or outdoor air pollution is a possibility. Household combustion appliances, automobiles, industrial operations, and forest fires are the main causes of air pollution. Maintaining clean air benefits everyone, and air pollution may be prevented. Lung cancer, heart disease, stroke, as well as acute and long-term respiratory conditions like asthma, can all be minimised by clean air. Since it can impact both human health and the ecosystem, poor air quality is a critical global issue.

The World Health Organisation (WHO) estimates that air pollution causes close to seven million deaths globally each year. Hence to track the effect of pollution on human life it is necessary to track the level of pollution in urban as well as rural areas.

The majority of the fine particles that contaminate our air are caused by human activity, such as burning fossil fuels to produce power, burning waste, burning transportation fuels, burning agricultural waste, which is a major source of methane and ammonia, and chemical emissions from factories. Most developing countries rely on wood and natural resources for the fulfilment of their household needs, such as cooking, heating and lighting. This extensive use of wood and coal leads to an increase in household pollution. The main mission of an air quality monitoring system is to record the concentration of pollutants in the air and provide the information to warn against any forthcoming danger. The implementation of air quality monitoring systems is a complex as well as costly task. This project mainly aims to build a cost efficient air quality monitoring system with increased accuracy.

A web server and the Internet are utilised to monitor the air quality using an IOT-based air pollution monitoring system. When the air quality drops below a specific point, an alert will sound. On the LCD, the device will display the air quality in PPM. The MQ135 sensor is used to monitor air quality since it can identify the majority of dangerous gases.

The MQ135 and MQ6 sensors are used by the system to monitor air quality since they can accurately measure and detect the majority of hazardous gases. Clean and fresh air is every living beings' basic requirement and air pollution is preventable. Breathing clean air can reduce the possibility of a disease from stroke, heart disease, lung cancer as well as chronic and acute respiratory diseases such as asthma. Reduction in the quality of air contaminates our environment and damages our health. Therefore poor air quality is a global challenge.

The pollution in the air may not be visible to us normally but it harms the lives of every human being. Even though we



cannot see it but the air we are breathing in right now is probably polluted. Every 9 out of 10 of us are breathing in the air that is damaging our health. Invisibly small particles penetrate through our nose and reach every cell of our body, hence affecting our organs, causing acute and chronic diseases, including asthma, strokes, heart attacks and dementia.

Therefore to compete with this kind of situation and save human lives it is necessary to monitor the quality of air we are breathing. This will help us to take right decisions at the right time towards the changes that we require to make in our daily lifestyle.

Our next generation, and all the future generations deserve to breathe in the air that is free from toxic pollution. 93% of children under the age of 15 are forced to breathe and grow up in an unhealthy environment. A large number of babies breathe polluted air right after the birth and in the critical period when the growth of an infant is being established. Air pollution has bad impacts on a child's physical health as well as mental health. In addition to harming brain development, these elements also have an impact on behavioural and mental health problems.

The national air quality monitoring network now only has a small area of coverage since the values that are obtained are just suggestive and there is a significant delay in reporting the data. This makes real-time activity impossible. The real-time data that the air quality monitoring system provides allows us to act quickly and appropriately for the benefit of human health.

## LITERATURE REVIEW

1. The following findings are extracted from the paper from reference no.1

A system for air pollution monitoring is proposed in this project. The Arduino microcontroller was used in the creation of the system. The real-time monitoring and analysis of air quality along with the logging of data to a remote server that receives updates through the internet are all features of the air pollution monitoring system. The measurement of air quality is done in Parts per Million (PPM), and Microsoft Excel was used to evaluate the results. The system's measurements of the air quality were precise. The outcome might be viewed on the display interface of the developed hardware and accessed over the cloud on any intelligent mobile device.

2. The following findings are extracted from the paper from reference no.2

This system's design makes use of a wireless sensor network, low-cost hardware, and software, as well as sensors, to successfully monitor the phenomenon of air pollution. An air pollution monitoring system is installed in a specific area where there are indications of acute air pollution in order to identify the gases that are present in the airborne mixture that may be harmful to human health and the health of other living things.

Remote air quality monitoring is possible thanks to the Wi-Fi module in the node MCU ESP8266. This makes it possible to check the air conditioning frequently.

3. The following findings are extracted from the paper from reference no.3

It is suggested that the air quality be improved by utilising a system to monitor the environment's air using an Arduino microcontroller and IOT technology. The use of IOT technology enhances the monitoring of many environmental parameters, including the air quality monitoring issue raised in this research. The Arduino microcontroller is the project's central component, and it controls the entire process. The MQ135 and MQ6 gas sensors are utilised in this project to detect several kinds of hazardous gases. The Wi-Fi module connects everything to the internet, and the LCD is utilised to display visual information.

## PROPOSED METHODOLOGY

A proposed methodology inspired from various existing air quality monitoring systems is explained in this section.

The proposed model is designed using Arduino uno, MQ135 and MQ6 sensors used for detecting the harmful gases present in the air and a buzzer that activates when the content of the gases goes down beyond the acceptable level. Following are required components for our Air Quality Monitoring System.

### Required Components

**Table 1** indicates the components required for creating a working prototype of the proposed model.

### Functioning Methodology

The complete method for the functioning of the system is explained below:

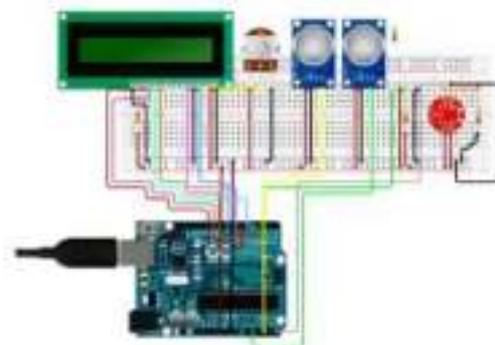
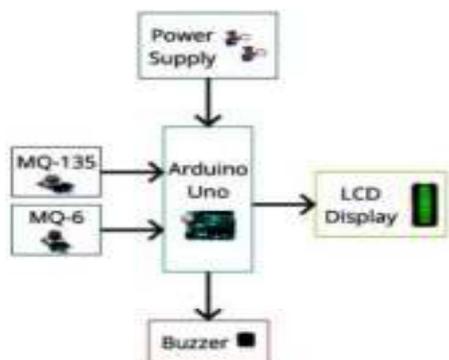
**Table 1**

S/N	Required Components	Quantity
1	Arduino Uno	1
2	MQ135	1
3	MQ6	1
4	ESP8266 Wi-fi module	1
5	16X2 LCD screen	1
6	Breadboard	1
7	Potentiometer (10K )	1
8	Resistors (1K ohm)	1
9	Resistor (220 ohm )	3
10	Buzzer Alarm	1
11	Connecting Wires	50

We'll connect the Arduino and ESP8266 first. If you power the ESP8266 with 5V from the Arduino, it won't function properly and might even be damaged because it needs 3.3V to function. The 3.3V pin on the Arduino must be wired up with VCC and CHPD (chip power-down). The ESP8266's RX pin, which runs at 3.3 volts, would not communicate with the Arduino when it was attached directly to it. As a result, we must build a voltage divider for it that will convert 5V to 3.3V. You can accomplish this by connecting three resistors in series, like we did in the circuit. RX pin of the ESP8266 should be connected to pin 10 of the Arduino, and TX pin should be connected to The Wi-Fi ESP8266 system enables internet accessor Wi-Fi access for your projects.. It is a reasonably inexpensive tool that gives your projects a lot of power. It is the most advanced gadget on the Internet of Things (IoT) platform and can interface with any microcontroller. Find out more about ESP8266 and Arduino integration here. The MQ135, MQ6 sensors and Arduino will then be connected. Connect the sensor's VCC and ground pins to the Arduino's 5V and ground, and the sensor's analogue pin to the A0 pin. A buzzer will be connected to the pin 8 of the Arduino, which will beep when the level of harmful gases goes down beyond threshold level.

At the end, we will connect LCD with the Arduino. The connections of the LCD are as follows

- Pin 1 (VEE) should be connected to ground.
- Pin 2 (VDD or VCC) should be connected to 5V.
- The 10K potentiometer's middle pin should be connected to pin 3 (V0), and the other two ends should be connected to the GND and VCC. The LCD's screen contrast is managed via a potentiometer. Other potentiometer values besides 10 K will also function.
- Connect the Arduino's pin 12 and pin 4 (RS).
- Connect Arduino's ground to pin 5 (Read/Write). We shall connect this pin to the ground since it is rarely utilised.
- Connect the Arduino's pin 11 to pin 6 (E). The control pins, RS and E, are utilised to transmit data and characters.



**Figure 1** Block diagram of air quality monitoring system    **Figure 2** Circuit diagram of air quality monitoring system



**Figure 3** Graphical data of AQI vs time



**Figure 4** AQI in year 2018

The following four pins are data pins which are used to communicate with the Arduino.

1. Connect pin 5 to pin 11 (D4) of Arduino.
2. Connect pin 4 to pin 12 (D5) of Arduino.
3. Connect pin 3 to pin 13 (D6) of Arduino.
4. Connect pin 2 to pin 14 (D7) of Arduino.

- Pin 15 must be connected to the VCC through the 220 ohm resistor. The brightness of the back light will be adjusted using the resistor. Greater values will considerably darken the back light.
- Connect pin 16 to the Ground.

#### STATISTICAL DATA

Below mentioned are some facts that showcases the adverse effect of poor air quality on our day to day lives-

- According to a study, air pollution causes 50,000 to 100,000 premature deaths annually in the United States alone. Known to cause respiratory and other illnesses, indoor and outdoor air pollution is a significant cause of morbidity and mortality.
- In India, the average exposure level is 83 micrograms per cubic meter, which is 16.6 times the WHO recommendations.
- 979,682 deaths in India were attributed to fine particle pollution in 2019, or 70 per 100,000 persons.
- Percent of deaths from each disease attributable to fine particle outdoor pollution in 2019-
  1. 21% Chronic disease(obstructive pulmonary)
  2. 17% Stroke
  3. 15% Tracheal, lung cancer, bronchus,
  4. 15% Heart disease(Ischemic)



5. 12% Diabetes (Type 2)
6. 13% Respiratory infections
7. 7% Neonatal disorders

Using the Air Quality Index, the daily air quality is recorded (AQI). It contains guidance on the quality and pollution levels of your air as well as any possible health risks. The AQI concentrates on every possible health effects that could happen hours or days after breathing in air pollutants. This dataset is fetched by kaggle.com.

## CONCLUSION

This project uses MQ135 and MQ6 Gas Sensors along with a Node MCU to measure the air quality in real-time. When the air quality falls below a specified threshold, Node MCU will send the data to the cloud platform and deliver the notification, alerting residents in that region. Here, the usage of these gas sensors allows for the detection of various toxic gases, while Arduino serves as the project's brain, directing every step of the way. The entire process is connected to the internet using a Wi-Fi module, and an LCD is used to provide visual output. It effectively promotes the concept of a healthy living while also supporting modern technology. People can use this system's features to use their mobile phones to track the amount of pollution.

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## REFERENCE

1. Kennedy Okokpujie, Etinosa Noma-Osaghae, Odusami Modupe, Samuel John and Oluga Oluwatosin, A Smart Air Pollution Monitoring System.
2. Meghana P Gowda, Harshitha G Y, Jyothi K N, Srushti, Padma R, Air Quality Monitoring System.
3. Harsh N Shah, Zishan Khan, Abbas Ali Merchant, Moin Moghal, Aamir Shaikh, Priti Rane, IOT Based Air Pollution Monitoring System.
4. Ramik Rawal, Air Quality Monitoring System .
5. Saravanan P., A Study on Air Pollution Monitoring System using Wireless Sensor Network Article, February 2018.
6. Kirti Goyal, Review of Air Quality Monitoring: Case Study of India Article, Indian Journal of Science and Technology, November 2016
7. Harsh N. Shah , Zishan Khan, Abbas Ali Merchant, Moin Moghal, Aamir Shaikh, Priti Rane, IOT Based Air Pollution Monitoring System, International Journal of Scientific & Engineering Research, Volume 9, Issue 2, February-2018
8. Review Paper on Air Pollution Monitoring system Snehal Sirsikar<sup>1</sup> , Priya Karemore<sup>2</sup> P.G Student, Department Of Computer Technology, Priyadarshini College of Engineering, Nagpur, India <sup>1</sup> Assistant Professor, Department Of Computer Technology, Priyadarshini College of Engineering, Nagpur, India <sup>2</sup>, International Journal of Advanced Research in Computer and Communication Engineering Vol. 4, Issue 1, January 2015



# Geospatial Solution for Water Management: Cost Benefit Analysis of MBBR based STP and GIS based RWH Scheme for Sustainable Development

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**Abstract:** The precious water sources are on verge of declining due to global warming, over exploitation, human interventions. Hence there arises an urgent requirement to conserve every drop of water as one of the Sustainable Development Goals set by United Nations (UN). As our responsibility towards achieving SDGs (Goal No.6) this study reveals the Challenges faced for selection of suitable treatment technology and design parameters of modern STP with Moving Bed Bio-film Reactor (MBBR) technology to treat sewage/waste water. Periodical evaluation of parameters viz physical, chemical, biological and multi criteria analysis such as economic, technical, environmental has been carried out regularly. Economic analysis reveals that this technology is very economical and effective considering life cycle cost, Outflows and many tangible and non tangible benefits, enhanced ground water potential, effective water conservation, improved public health, etc. The data thus generated is made available for geospatial analysis.

Rain water Harvesting potential of entire residential campus in Hyderabad was computed using open source GIS Software QGIS wherein the entire residential campus was digitally mapped and all the buildings and open areas were digitized. Roof top areas were computed from the vector layers and rainfall data was used to get the roof top RWH potential for the entire residential campus. Accordingly, Rainwater Harvesting scheme was framed and realized effectively by making use of contour data of the campus to recharge the bore wells in the campus. These studies can be helpful in achieving SDGs thereby making the campuses as zero waste disposal campuses.

**Keywords:** Wastewater; Rainwater Harvesting; Geospatial Analysis; QGIS; STP; MBBR; SDGs

## INTRODUCTION

The world is changing every moment with the manmade features being built around us so frequently. Over the last two decades rapid urbanization, change in life styles, steep increasing population, the management of wastewater in the country has emerged as a severe problem not only because of the environmental and aesthetic concerns but also because of the huge quantum of waste water generated on daily basis. According to the Central Pollution Control Board (CPCB) 72368 MLD Sewage water was Generated in India daily during the year 2021. Of the total waste water generated, approximately 31841 MLD (43.99%) was processed or treated [1]. This is quite concerning and adds to the responsibility of intellectuals working in this sector to seek a solution to resolve this serious issue of concern. By making use of 5R's (Refuse, Reduce, Reuse, Recycle and recover) principle [2], we have conducted periodical study on recycling of waste water confirming all relevant standards making it fit for gardening, toilet flushing, etc. and thus ensuring environmental sustainability in any campuses along with other goals to fulfill sustainable development goals

In this era of advancements and modernization, there arises a need of digitizing the utilities, updating existing as well as new such facilities being built. It becomes more critical and crucial for present and future analysis of the geographical data. Hence it becomes necessary to map such built in features around us as utilities along with their key features being captured in an organized way. The significant feature required for managing the information and retrieval of such information as per requirement needs an efficient mechanisms and software tools for easy updating and quick retrieval of geographical data. In today's era Geographic Information System has found its use in almost every field of Science and Technology for systematic way of organizing the data and retrieval of the same as required. Geospatial ecosystem is an integral part of India's vision to be a leading nation in sustainability.

Mapping of various utilities is an important task for any organization/campuses to manage them using geospatial database. Such mapped utilities in geospatial format can be used further for spatial study and analysis to understand its relationship with other assets or features, interpret the features, patterns, trends and subsequently visualize such mapped utilities to gain insights of the developments being taken place over a time period.



## LITERATURE REVIEW

MBBR is one of the modern technology used for treatment of waste water. Compared to other technologies available in market, MBBR is more beneficial in terms of its tangible and non tangible benefits. Operation and maintenance of existing conventional plants and sewage pumping stations are not satisfactory, as nearly 39% plants are not conforming to the general standards prescribed under the Environmental (Protection) Rules for discharge into streams as per the CPCB's survey report [3] Considering the urgency of preventing pollution of our water bodies and preserving our precious water resources, sewage treatment and reutilization of treated sewage is of utmost importance. Sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs. The 17 SDGs are integrated, they recognize that action in one area will affect outcomes in others and that development must balance social, economic and environmental sustainability. In this paper, the role of wastewater management in achieving the SDGs has been indicated. Wastewater treatment alone could assist us in achieving 11 out of 17 SDGs given by UN

## METHODOLOGY

In this project, Open Source QGIS Software package is used for realizing a Geo spatial solution for water management. Various vector layers are generated depicting the Buildings, Compound wall, GLR, Storm water drains, etc. of Pratyusha arcade residential campus at Hyderabad.

### Creation of CSV Files Containing Non Spatial Attributes

Non spatial attributes are tabulated in CSV files and are linked to Vector Layers (prepared earlier based on a common attribute (often primary and foreign keys). In QGIS, users can establish this kind of link by Join Tab under Properties of Vector Layers. We can load CSV files by using Add Layer.

In this project, standard attributes are defined for each layer and the data was tabulated against each attribute in MS Excel and stored as CSV files. These files were then linked with the attribute table of corresponding layer thereby creating a complete dataset for every vector layer. 'Buildings' vector layer was created with details like Name, Type, Area and Perimeter of Building. These fields were linked to the other parameters of building like Year of Construction, Number of Floors, Type of Construction, Fire Extinguishers etc., which were stored in CSV files.

## INFORMATION RETRIEVAL

One of the crucial feature of any GIS platform is its ability to interact with the available datasets and display the outputs meeting the specified criterions. To select features according to properties that we cannot see on the map we can write a query. The query selects feature that meet the specified condition using the values present in the feature attribute table and displays the features meeting the conditions. These are referred as Non Spatial Queries. Spatial queries are the ones which involves conditions related to the topological relationships.

### Spatial Query for Showing the Buildings in the Campus Having Roof Area more than 300 sq-m

A Polygon Vector Layer namely Buildings having all the details in the form of attribute table is created. Based on the geometry created in QGIS enables it to calculate its Area and Perimeter by default. Using the 'Select Feature with expression tool' a query is generated for displaying the displaying the buildings having Roof Area more than 300 sq-m. It can be seen from **Figure 2** that only those buildings are highlighted which are having Roof areas more than 300 sq-m. This certainly helps in assessing the rain water harvesting potential of each building in the campus.

### Non-Spatial Query for Showing the Borewells Which are Having its Yield more than 3000 LPH

A Point Vector Layer namely Borewell having the details related to its Name/ID/Number. etc in the form of attribute table is created. It can be seen from Fig.03, Bore wells locations are marked precisely in the Point Vector Layer with default attributes as Bore Well Name/ Number or ID. The other non spatial information like Size, Type, Year of Construction, Depth of Bore well, Average Yield of Bore well were collected and recorded in CSV Files. A common field to default attribute table and CSV File namely Borewell ID was kept and both were linked using the 'Join' tool in Layer Properties in QGIS.

This will enable us to integrate the data and perform queries on the combined data thus generated. Using the 'Select Feature with expression tool' a query is generated for displaying the most yielding bore well in the campus. This feature has also helped in planning the rain water harvesting zones adjacent to the most yielding bore wells which has turned helped in enhancing the yield of the Potential bore wells



Figure 1 Creation of vector layers



Figure 2 Spatial query for showing the buildings in the campus having its roof top area more than 300 sq-m

### Methodology of MBBR based STP

Figure 4 shows methodology chart and flow diagram which describe MBBR technology STP, Cost benefit Analysis and gives an overall picture of sustainability of the same. MBBR is an aerobic attached biological growth and sequential process of treatments majorly classified as Primary, Secondary and tertiary treatment confirming stipulated Physical, chemical and biological standards of CPCB/PCB.

### MOVING BED BIO-FILM REACTOR TECHNOLOGY

It is a biological wastewater treatment process that uses biofilm to remove waste from waste water. Microorganisms attached to media in the water consume unwanted waste, leaving water cleaner. This process saves space, easy to operate, having low-maintenance, can effectively resist shock loads and works efficiently.

### DESIGN AND CALCULATIONS OF STP

Input Data for Design: The study was conducted in an educational campus (Oakridge International School, Bachupally, Bowrampet, Hyderabad) where 100 KLD STP installed by M/s. Revolve Engineers Private Limited, Hyderabad and the total water consumption was estimated as 84 KLD. It was decided to explore suitable technology for treatment of 100 KLD (84 KLD +20% for future requirement) based on detailed survey duly evaluating all the available technologies like MBBR, MBR, SBR, FAB, SAFFT, FBBASP, e-STP, etc. and their performance, Life Cycle Cost [Table 5(a)] Sustainability, Operation and Maintenance and quality of treated water, etc. MBBR technology was found more suitable to meet the requirements and felt economical to reuse the recycled water for the purposes of toilet flushing, gardening/horticulture, recharging ground water, etc.

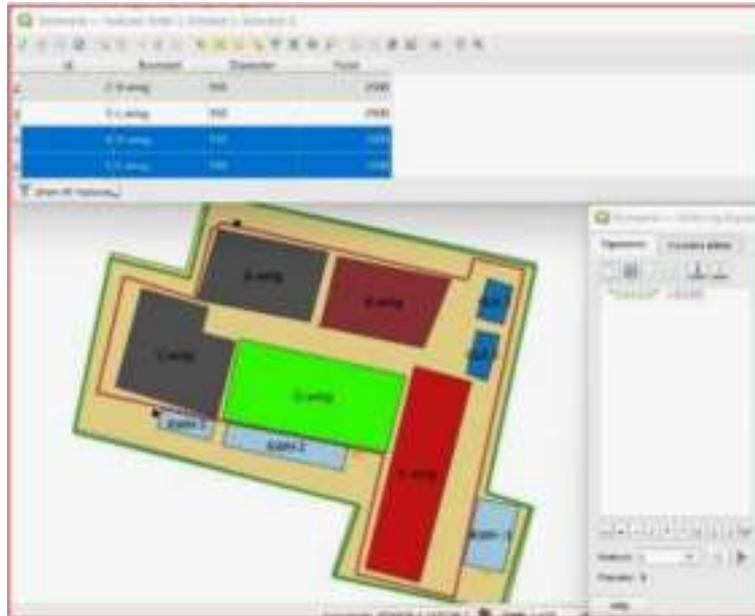
Benefits of Technology: MBBR is very compact (needs less foot print area/space) has Eco-Friendly Maintenance, Strong ability to withstand shock load, less operator intervention, easy to enhance the volume/capacity, Financial savings on discharge costs, exceptionally efficient, with a low Hydraulic Retention Time (HRT) of around three to four hours for biochemical oxygen demand and nitrogen removal.

### Design of MBBR based STP as Retro Fitting

The characteristic of inlet waste were considered for design flow: 100 kld, pH: 6.7-7.5, BOD: 250-300, COD: 500-600, O&G: < 50, MLSS: 2500, SVI: 100-150. All the components of STP were designed based on various design consideration and features and quality of raw and treated water, available foot print area, average flow rate (AFR), peak flow factor and retention time (RT) to meet the requirement for ensuring sustainable water management. Table 3 shows the summary of design calculation for all components of STP.

The data from GIS based utility mapping can be used to calculate the area, analysis of terrain for laying pipelines / sewer lines, chamber / drain location, site suitability analysis, short path analysis, Integration of sewage lines, monitoring / maintenance of in/out lines, etc.

Design Principle: A properly designed and engineered STP is a real challenge. It requires sound knowledge of the biology of the microorganisms, chemical and mechanical engineering principles and need an STP that achieves the desired outputs/results on a reliable and sustained basis, it should robust and trustworthy and lasts for at least 15-20 years



**Figure 3** Non-spatial query for showing the bore wells yielding more than 3000 LPH

without major repairs and shall have minimum life span of 30 years , Needs minimum amounts of money, energy and chemicals to accomplish the most wanted treated water quality ,easy to operate and maintain and enhance . The quality of water obtained from a well-designed, engineered and operated STP at very affordable treatment costs and confirming pH-6.7-7.5, BOD < 10 mg/L, Turbidity < 10 NTU<sub>2</sub>, E. Coli- Nil and other parameter as per standards. The incoming sewage must remain in the aeration tank long enough to let the bacteria complete the digestion process The bacterial population needs Oxygen to survive hence provide adequate Oxygen. Filter and to provide efficient system for disposal of excess sludge. Energy efficient fittings, motors/pumps/submersible pumps and solar based lighting were recommended to save electricity consumption

New STP was commissioned during 2016 in the institutional campus. Geospatial platform has been effectively used for effective monitoring, controlling, thereby enabling easy updating and quick retrieval of the accumulated data, addition/alteration, etc. and data is further used for Geospatial analysis and prioritizing the maintenance activities.

## RESULT AND DISCUSSIONS

After successful commissioning of STP, the output parameters in terms of quality, performance and sustainability, were evaluated periodically. The tangible and non tangible benefits of new STP were arrived based on performance evaluation and cost benefit analysis of STP. It is found that MBBR based STP have enormous benefits especially in terms social, environmental, economic and sustainable aspects. Periodical checking of the raw water and Treated water has been done through approved labs (Recognised by NABL, NABET-QCI, MoEF & CC) and all the parameters viz physical, chemical, biological parameters viz BOD, COD, O&G, pH, TSS, E-Coli, MLSS, etc. conform with IS/CPCB/PCB standards (**Table 2**). Noted that (through log book) few Indicators like pH, TDS, MLSS were checked at site on daily basis and final outcome of 4 to 5 kg sludge generated on alternate days from filter press is also used as compost.

### Cost Benefit Analysis

The STP with MBBR technology is operated efficiently and eco-friendly from the time of its inception. The Capital expenditure (CAPEX) and Operation and Maintenance (OPEX) is considered for this analysis. The cost benefit analysis was calculated by considering 12% interest on Capital expenditure/ Capital cost, Electricity charges, 24×7 basis Annual Operation & Maintenance cost including consumable, and considering standard factor like Capital recovery factor (CRF), Present discount factor (PDF) and Benefits from treated water and compost (Tangible), Net present value (NPV), Internal Rate of return (IRR) cash in/out flow are shows in **Table 4**.

The above economic analysis of wastewater management and treatment involves significant benefits. The potential

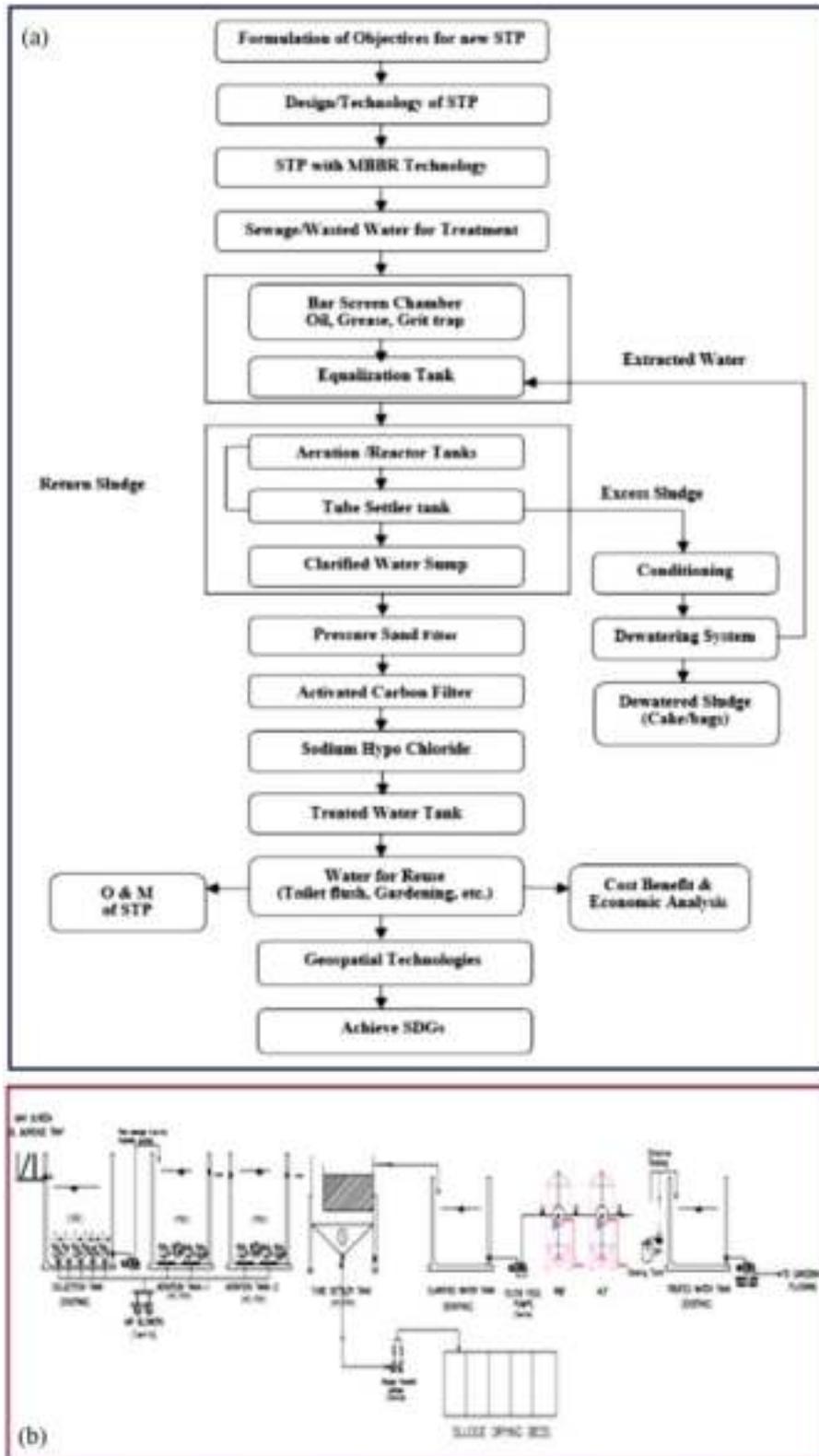


Figure 4 (a) Methodology chart and (b) flow diagram



**Figure 5** New 100 KLD STP with MBBR Technology

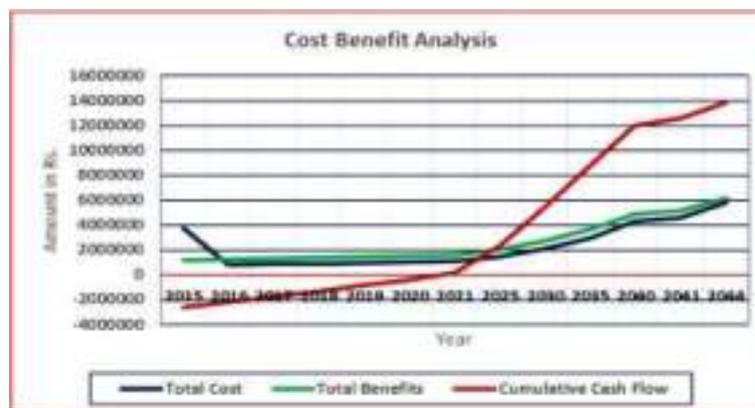
benefits of MBBR based STP and water management can be grouped into two general categories: Tangible (Money) benefits and non-tangible (Non monetary) benefits i.e. most of the environmental and health benefits explained above have significant value, but cannot be measured in monetary values as market prices are not available for this. Tangible benefits are easily identifiable and quantifiable, while environmental (non tangible) benefits are difficult to measure and there are no specific economic valuation methods. **Tables 5(b) & 5(c)** show tangible and non tangible benefits in detail which includes performance evaluation also.

New STP includes primary, secondary, tertiary treatments and all the machineries, pipelines, tanks, motors/pumps is consuming less foot print area i.e. around 47% less when compared with conventional STP.

It is being planned to implement/use technologies AI, ML, DL & IoT tools in the institutional campus for effective and better maintenance of water management systems/automation, installation of sensors at various places of plant to reduce expenditure and to ensure trouble free maintenance. Behavioral changes also play an important role for water sustainability. Training/seminar/conference/technical demo has been regularly conducted to create awareness and towards contribution of individual on SDGs.

**Exporting the Database generated using QGIS for Further Analysis** (Estimation of Roof Top Rain Water Harvesting Potential of a Campus)

The combined attributes (spatial and nonspatial) thus generated for all the buildings in the campus can be easily exported back to csv file and the resultant data is utilized further for doing roof top rain water harvesting potential of entire campus. Annual average rainfall data for the Hyderabad area is considered along with the Runoff Coefficients for CC Roof and Lawn areas to obtain the Rooftop RWH potential as follows.



**Figure 6** Cost benefit analysis of STP



Figure 7 Composition of utility Maps

**Composition of Utility Maps**

This is one of the unique feature of any GIS platform which enables us to develop any sort of Utility maps showing Campus boundary, utilities, facilities and infrastructure present in the campus as per the requirements for better analysis. Map composer module of QGIS helps us in importing all the Layers of QGIS canvas to Map composer. Each Layer is given a specific symbology for easy identification and categorization.

Table 1 RW potential

ROOF TOP RWH CAPACITY OF VARIOUS BUILDINGS						
Sl. No	Name	Area(m <sup>2</sup> )	Runoff Coefficient for CC Roof Top	Annual Avg Rainfall Hyderabad (mm)	Total Water Available from Roofs (Litres)	Total water available for RWH(Litres)
1	A Wing	385	0.7	821.7	224726	155
2	B Wing	381	0.7	821.7	221121	175
3	C Wing	387	0.7	821.7	220833	171
4	D Wing	411	0.7	821.7	234809	186
5	E Wing	351	0.7	821.7	208892	202
TOTAL WATER AVAILABLE FROM ROOF TOPS					1009381	691
Daily Per Capita Water Demand					555	Litres
Annual Per Capita Water Demand					20275	Litres
Roof top Water if harvested can suffice annual water requirements of					33	People

Table 2 Raw and treated water parameters of new STP

Description	pH @ 25.0°C		TSS @100-100°C		TDS @100°C		Calcium Cl <sub>2</sub>		Sulphate SO <sub>4</sub> <sup>2-</sup>		COD		BOD		Oil & Grease		
	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	Raw	Treated	
10/01/14	7.30-8.00		<200 Mg/L		<2100 Mg/L		<400 Mg/L		<1000 Mg/L		<200 Mg/L		<100 Mg/L		<10 Mg/L		
Raw Water	6.1-10.25	7.0-8.0	0-1000	0-100	0-1000	0-100	0-1000	0-100	0-1000	0-100	0-100	0-100	0-100	0-100	0-100	0-100	0-100
Year 2016	8.80	7.40	112	11	1019	910	215	210	128.29	102.40	20.2	44	160	14	3.39	0.0	
Year 2017	7.12	7.80	138	10	1019	1236	270	216	126.1	98.4	420	30	140	10	3	0.0	
Year 2018	7.24	7.26	132	10	1190	1009	300	215	126	76	490	32	156	6	2.65	0.0	
Year 2019	7.60	7.22	312	27	1150	1135	320	290	240	200	101	63	126	28	3	0.0	
Year 2020	5.90	7.26	219	16	1212	1113	336	340	301	380	100	50	101	24	3.05	0.0	
Year 2021	7.90	7.40	221	28	1016	1163	310	230	320	260	243	76	127	21	3.05	0.0	
Year 2022	7.1	7.51	78	10-0	913	807	201.47	180	144.93	111.3	102.48	40.32	46.80	7.20	7.44	0.0	

**Table 3** Summary of all Components of new MBBR based STP

Sl. No.	Description of Component	Purpose / Size / Volume / Capacity	Sl. No.	Description of Component	Purpose / Size / Volume / Capacity
	<b>Design Consideration:</b> Hydraulic Retention Time: MBBR Tank: 6-8 hr, Tube settling tank: 2-4 hr, Average retention time: MBBR Tank: 7.2 hr, Tube settling tank: 2-6 hr, Clarifier water tank: 2-3 hr, Sludge holding tank: 2-5 hr, STP System operation: 20 hr/day - BOD consider 200 - 250 mg/litres. Hence average flow rate is 4.16 cum/hr. for a treatment capacity of 100 KL per day		10	Activated Carbon Filter 	Activated carbon, also called activated charcoal, is a form of carbon processed to have small, low-volume pores that increase the surface area available for adsorption or chemical reactions. Capacity: 3.6M <sup>3</sup> /hr, Size: 900 mm x 1500 mm, Design pressure: 5 kg/cm <sup>2</sup> , Max Working pressure: 3 kg/cm <sup>2</sup> , Carbon Media: 250 kg, Filter Media: Activated Carbon
1	Bar screen Chamber (Coarse & Fine) 	A bar screen is a mechanical filter used to remove large objects, such as rags and plastics, from wastewater. Coarse Screen (more than 6 mm), Fine Screens (less than 6 mm) Chamber Size: 1000 x 600 x 900 mm	11	Dosing Pump 	Water chlorination is the process of adding chlorine (Cl <sub>2</sub> ) or hypochlorite to water. This method is used to kill certain bacteria and other microbes in waste water as chlorine is highly toxic. Capacity: 0-6 lph with manual adjustment, Dosing Tank Volume: 150 ltr.
2	Grit Chamber 	Oil and Grease or O&G Trap prevents the clogging of sewer by preventing the Oil, grease fats and solids from going through the sewer. Size: 2100 x 600 x 1750 mm	12	UV Treatment 	Ultraviolet germicidal irradiation (UVGI) is a disinfection method that uses short-wavelength ultraviolet (UV-C) light to kill or inactivate microorganisms by destroying nucleic acids and disrupting their DNA, leaving them unable to perform vital cellular functions.
3	Equalization Tank 	The equalization tank is the first collection tank. Its function is to act as a buffer tank and to collect raw sewage that comes at fluctuating rates, and pass it on to the rest of the STP components at a steady rate of flow. - 50 cum	13	Treated Water Tank	A minimum of 2 days' capacity shall be provided to store and use the treated water.
4	Aeration Tank - 1 (Reaction Tank) 	This is heart of the MBBR STP and bulk of the treatment is provided here, employing microbes/bacteria for the process to maintain a high population level of microbes and this mixture is called as MLSS (Mixed Liquor Suspended Solids). As per design required F/M is 0.10 to 0.12. -25 cum	14	Fiber Press 	A filter press is a tool used in separation processes, specifically in solid/liquid separation using the principle of pressure drive, provided by a slurry pump. The filter press is used in fixed-volume and batch operations, which means that the operation must be stopped to discharge the filter cake before the next batch can be started. No. of Chambers: 5/8, Cake holding capacity: 16.6 h
5	Aeration Tank - 2 - do - (Stabilization Tank)		15	AIR Blowers - 2 Nos (1W + 1S) 	Type: Twin lobe compressor consist of V-belt, Drive and driven pulleys Capacity: 125 cum/hr at 0.4 kg/sq.cm, Motor: 5 HP - 2 Nos (1W + 1S)
6	Tube Settler Tank 	The purpose of this tank is to allow settling of biomass solids in the Mixed Liquor coming out of the aeration tank 2, to the bottom of the settler. The clarifier tank is only a passive device and all the above actions occur due to gravity. The thick biomass is re circulated back to the aeration tank.	16	Pumps & Motors 	1) Raw Sewage Pumps - 2 Nos (1W + 1S) 2) Screw Pump - 2 Nos (1W + 1S) 3) Filter Feed Pumps - 2 Nos (1W + 1S) 4) Sludge Return Pumps - 2 Nos (1W + 1S) 5) Treated water Pumps - 2 Nos (1W + 1S)
7	Clarified Water Tank	Clear water storage tank to store water received from tube and feed to a Pressure sand filter, which is capable of removing finely divided colloidal particles -25 cum	17	Filter Media 	MBBR Media - 01 lot, Eff. Spec. Surface area: 400 m <sup>2</sup> /m <sup>3</sup> , Media: Height: 16 mm, Diameter: 22mm, No. of pieces-75000/m <sup>3</sup>
8	Sludge Holding Tank	This tank shall be mandatorily provided, to hold the excess sludge prior to dewatering. To store the excess sludge and for recirculation purpose - 20 cum	18	Diffusers & Media 	Coarse Bubble Diffusers -10 Nos. Design flow: 5-8 m <sup>3</sup> /hr, Flow range: 3m <sup>3</sup> /hr, Connection Type : 3/4" NPT Fine Bubble Diffusers - Design flow: 5-12 m <sup>3</sup> /hr, Flow range : 5-12 m <sup>3</sup> /hr, Inclined plates for tube settler tank + Modules for Tube Settler Tank
9	Pressure Sand Filter 	Sand filtration is frequently used and very robust method to remove suspended solids from water. Sand filter at a pressure of 3.5 kg/cm <sup>2</sup> to reduce the suspended solids present in the raw water. Design pressure: 5 kg/cm <sup>2</sup> , Max Working pressure: 3 kg/cm <sup>2</sup> , Sand Media: 600 kg Filter Media: Gravel sand pebbles of various sizes	19	Conducting Field tests: MLSS, Treated & Raw Water 	



**Table 4** NPV and cost benefit analysis of STP

Sr. No.	Year	Costs			Benefits			Net Cash Flow	Cumulative Cash Flow	Benefit Cost Ratio	Cost Benefit Ratio	
		Capital Cost	Maint. Cost	Power Cost	Total Cost	Basic Revenue	Compost					Total
1	2015	₹ 40,00,000	₹ 7,00,000	₹ 1,30,000	₹ 48,30,000	₹ 13,30,000	₹ 50,000	₹ 13,30,000	-₹ 35,00,000	-₹ 35,00,000	1.59	0.63
2	2016		₹ 7,50,000	₹ 1,30,000	₹ 9,06,000	₹ 13,78,000	₹ 53,000	₹ 14,31,000	₹ 5,25,000	-₹ 29,75,000	1.58	0.63
3	2017		₹ 8,10,000	₹ 1,30,000	₹ 9,66,000	₹ 14,60,000	₹ 56,100	₹ 15,16,000	₹ 5,50,000	-₹ 24,24,000	1.57	0.64
4	2018		₹ 8,81,798	₹ 1,30,000	₹ 10,31,798	₹ 15,48,321	₹ 59,511	₹ 16,07,832	₹ 5,76,074	-₹ 18,48,546	1.56	0.64
5	2019		₹ 9,57,347	₹ 1,30,000	₹ 11,07,347	₹ 16,41,320	₹ 63,124	₹ 17,04,444	₹ 6,03,092	-₹ 12,46,544	1.55	0.65
6	2020		₹ 10,28,324	₹ 1,34,300	₹ 11,83,029	₹ 17,39,693	₹ 66,911	₹ 18,06,604	₹ 6,21,375	-₹ 6,27,959	1.53	0.65
7	2021		₹ 11,14,811	₹ 1,59,338	₹ 12,69,949	₹ 18,44,878	₹ 70,926	₹ 19,15,804	₹ 6,45,055	₹ 2,086	1.51	0.66
10	2044		₹ 63,22,087	₹ 1,90,015	₹ 67,32,102	₹ 70,00,000	₹ 2,70,929	₹ 71,44,829	₹ 6,32,727	₹ 1,81,15,863	1.50	0.67
							188		18%			

**Table 5** LCC, Tangible and non tangible benefits of STP

(a) Life cycle analysis (LCC)	(b) Non tangible of benefits	(c) Tangible of benefits
<p>Life cycle analysis (LCC) has evolved as one of the tool for remaining the suitability of technology for use to treat the waste water which includes cost/land of plant, cost of Operation &amp; Maintenance, Electricity charges, etc.,</p> <p><math>LCC = \text{Total Annual Cost (TAC)} \times \text{Present Discount Factor (PDF)}</math>  <math>\text{Total Annual Cost (TAC)} = \text{Capital Recovery Factor (CRF)} \times \text{Initial Cost (IC)} + \text{Operation \&amp; Maintenance Cost (OMC)}</math>                      The economic life of STP and annual rate of interest have been considered as 30 years and 12% percent respectively</p> <p>Capital cost = 40 Lakhs, Average annual Operation &amp; Comp. Maintenance cost (Including, recurring, chemical, manpower, consumables &amp; electricity charges, Capital recovery factor (CRF) is considered 0.12414 as per Table No. 16.2.6 of Annuity tables [9], present discount factor considered 8.75. hence MBBR technology is most suitable and economic for waste water treatment and this technology can save space, Money, time and provide exceptionally effective water treatment capabilities and reliability to meet the decided standard</p>	<ul style="list-style-type: none"> <li>• Conservation of water which is precious natural resource thus to improve the ground water table efficiently</li> <li>• Increased the greenery area from 1 acre to 4.00 acre area and maintained neatly with the use of treated water and can be increased further</li> <li>• Waste water not discharged into public sewer/nallah</li> <li>• Environmental friendly as there is no foul smell and improved the aesthetic in the school campus.</li> <li>• Reduced the dependency on water from external sources thereby saving ground water and avoid excess exploitation of ground water</li> <li>• Environmental friendly as there is no foul smell and improved the aesthetic in the school campus.</li> <li>• Improve the ground water potential in the school premises by recharging water harvesting pits with use of excess recycled water.</li> <li>• Optimization of recycled water usage by providing drip &amp; sprinkler irrigation and installation of aerators in all taps</li> <li>• Development of green belt to absorb green gas emission since creating good environment and there is no air pollution</li> <li>• Environmental upgradation</li> </ul>	<ul style="list-style-type: none"> <li>• Reuse of treated water efficiently for gardening, Toilet flushing, road cleaning, cooling towers, etc. thus reducing the expenditure and we get monetary benefit (Ref. Table)</li> <li>• Considerable reduction in power consumption (Over conventional plant) compare with conventional old plant</li> <li>• Space (foot print area) saving due to MBBR based STP</li> <li>• Reasonable savings in O&amp;M cost compare with conventional old plant</li> <li>• Less capital cost since retrofitting and adoptions of efficient technology</li> </ul> <p>The performance of STP was evaluated for last Six years and found excellent</p>

**CONCLUSIONS AND FUTURE WORK**

GIS is one of the fast emerging fields being utilized in various civil engineering projects and is widely used for Utility Management applications. GIS is a continuously evolving technology and there are many tools which are directly relevant for management of natural resources, land and water management, vegetation, transport network, telecommunications, ground water etc.

In this project, Geospatial Database for Utility Management is created for a residential and institutional campuses viz the Geographic area, buildings, Rain water harvesting pits, GLR, Storm water drains etc. This database will act as an effective tool for Planning/ Design and also for varieties of Geospatial queries, analysis and decision making. These Utility maps are very helpful for proper Maintenance and effective monitoring of each and every facility and services.



Attribute Data corresponding to each vector layer allows us to manage, retrieve, and integrate the data available in different formats. GIS with its large storage and retrieval capacity is extremely useful for detailed studies regarding various parameters like Solar & Rain Water Potential. Various maps can be generated using Vector analysis module running simple and advanced queries. This GIS based Utility Management System will help all the Engineers and Users in crucial decision making process, prioritizing the maintenance activities and also effective monitoring and easy updating of various attributes of facilities in and around the campus.

This paper has indicated the role of Geospatial technology for effective monitoring and maintenance of STP (MBBR based 100 KLD STP, which is Eco-friendly and play a vital role in achieving SDGs) as well as for RWHS. The processing capability of Geospatial technology holds its potential at every stage viz from design, installation, commissioning till O&M. It also helps in effective network monitoring, controlling the quality and ultimately water management for achieving goals of Sustainable Development.

#### **REFERENCES**

1. CPCB, MoEF&CC Report on STP for the year 2021
2. S. Saravanan, Prashant P Angarakh, Waste to Energy Tech. for Sustainable MSW Management - IJTIMES, vol.4, Issue 6, June-2018
3. CPCB Survey Report 2021 on the Status of STP Installation in India
4. STP Guide, Karnataka PCB, 2011
5. GIS Development Website: [www.gisdevelopment.net](http://www.gisdevelopment.net)
6. ESRI Website : [www.esri.com](http://www.esri.com)
7. GIS Primer Website : [www.gisprimer.com](http://www.gisprimer.com)
8. Harpreet Kaur, Sanjay Sharma, A Comparative Study of Different STP Technologies, IRJET, vol. 9, 2022
9. Technical Hand book, CED, DOS/ISRO, 2006

# Wastewater Treatment and Reuse towards a Sustainable Environment

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**Abstract:** Water pollution primarily results from human activity and pollutants coming from agriculture and industry sectors. The increased human population has led to rapid increase of industrialization due to the demand of essential goods. Besides the production of useful products, industries also generate solid and liquid wastes, which cause various detrimental effects on environment and human health if it released without treatment. Mostly, the industrial wastewater can be reactive, toxic, ignitable and carcinogenic. Hence, proper treatment and management strategies have been applied for the wastewater treatment. Due to global water scarcity, the reuse of treated wastewater has become a necessity and it is widely recognized as a valuable water resource. For the treatment of textile industry effluent, activated carbon, adsorption, reverse osmosis, ultra filtrations are used. However, these techniques simply transfer the pollutants from one form to another medium causing secondary pollution and require further treatment of solid wastes and regeneration of the adsorbent, which will add more cost to the process, and are not able to remove recalcitrant contaminants present in the industry wastewater. As an alternative, advanced oxidation processes (AOPs) have been introduced as suitable techniques, are being included in industrial wastewater treatment techniques aiming to improve the biodegradability. Radiation, photolysis and photocatalysis, sonolysis, electrochemical oxidation technologies, Fenton-based reactions, and ozone-based processes are the AOP, which are used in the treatment of wastewater.

**Keywords:** Industrial Wastewater; Water Pollution; Reuse; AOP

## INTRODUCTION

During the past few decades Indian industries have registered a quantum jump, which has contributed to high economic growth but simultaneously it has also given rise to severe environmental pollution. The industrial discharge and anthropogenic activities release various kinds of hazardous materials into the environment, which contaminating the available water source (Ibrahim et al. 2021). The surface water is the main source to industries for waste disposal. It is found that almost all rivers are polluted in most of the stretches by some industry or the other. The quality and quantity of the wastewater generated from the industry is depends on the raw materials and chemical additives used for the process. Wastewater can be categorized into different types such as domestic wastewater, sewage wastewater, agricultural and industrial wastewater. Mostly, the industrial wastewater contains biodegradable (paper, leather, food, etc) and non-biodegradable (heavy metals, pesticides, plastic, textile, etc) compounds.

Development of feasible, robust, effective, cost-effective and environmentally friendly methods for treating the hazardous chemicals in the wastewater is necessary for reduce the accumulation of contaminants in the environment (Saravanan et al. 2022). In this context, the Advanced Oxidation Processes (AOPs) is considered as the promising approach for wastewater treatment. In general, AOPs are related to the formation of hydroperoxyl, reactive hydroxyl, sulphate radicals and superoxide, which are capable of partial or complete biodegradation of highly toxic pollutants in the industrial effluents (Pignatello et al. 2006; Perez-Gimeno et al. 2019; Priyadarshini et al. 2022). The most studied AOPs are Photochemical — based processes such as photofenton, heterogenous photocatalysis, UV/persulphate, UV/hydrogen peroxide, UV combined with ozone, catalytic ozonation, gamma radiation, hydrodynamic cavitation, plasma –assisted AOPs and combination of these methods (Priyadarshini et al. 2022). Various AOP techniques used in the decontamination of wastewater are depicted in **Figure 1**.

Photofenton is an efficient treatment technology used for the effective treatment of wastewater containing antibiotics and pesticides (Yi et al. 2022; Cokay and Eker 2022). Wang et al. (2022) compared the two treatment methods such as UV/peroxymonosulfate and UV/H<sub>2</sub>O<sub>2</sub> for the treatment of paper and pulp industry wastewater and revealed that UV/PMS process is efficient than UV/H<sub>2</sub>O<sub>2</sub>.



Figure 1 Various AOP methods in the wastewater treatment

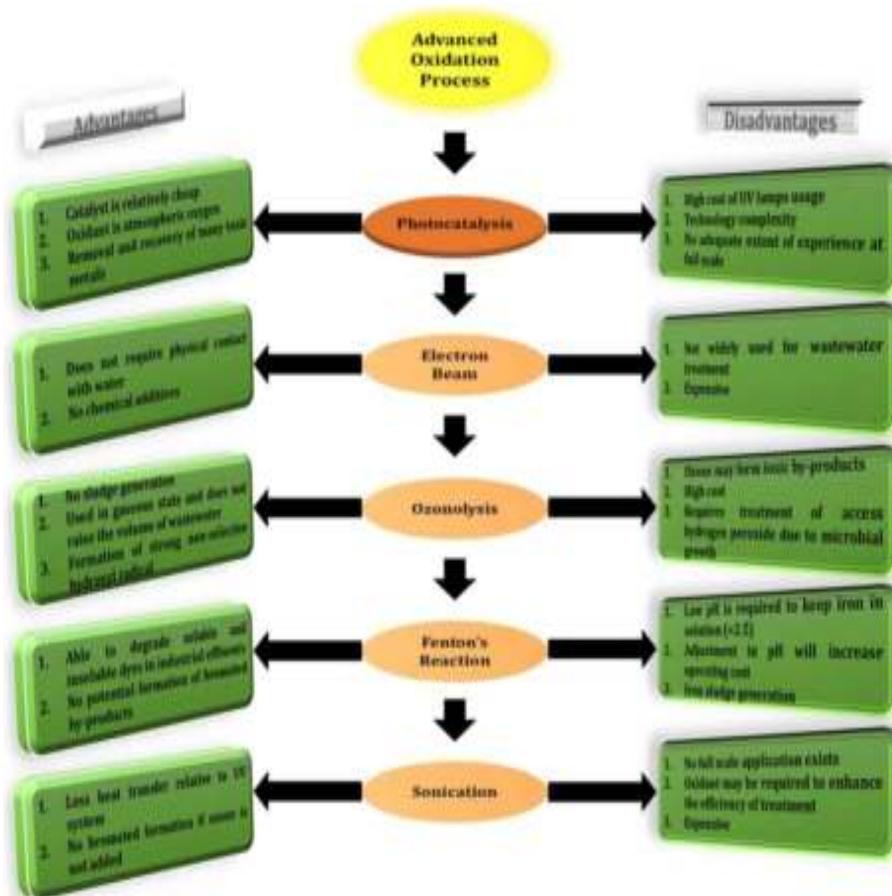


Figure 2 Merits and demerits of advanced oxidation process



### AOPs in Textile Wastewater Treatment

Textile manufacturing industry is the backbone of economics in many developing countries including India. It is one of the largest sectors globally and produces 60 billion kg of fabric annually. The wastewater load from the use of dyes is a key component of pollution and puts approximately 1 million people at risk. During the dyeing process, significant amount of water is required in each step, after the process more or less equal volume of the water released as effluent. The large volume of textile effluent and its diverse chemical composition leads to serious concerns to the environment as well as human health (Asghar et al. 2015). The Textile industry of India has the distinction of being the forerunner to the industrial development of India. It plays a significant role in the economy of the state and the export market of this industry is a source for earning foreign exchange. Textile dyeing industries consume huge quantity of water for its processing requirement like sizing, scouring, mercersing, bleaching, dyeing and printing and generate equally huge amount of wastewater with a variety of pollutants requiring attention as they affect the aquatic ecosystem by depleting the dissolved oxygen content resulting in anaerobic conditions, increasing alkalinity and toxic substances like sulphide and chromium color also often renders the water unfit for drinking and industrial purpose of the downstream users.

Coagulation, sedimentation, filtration and disinfection are the conventional methods mostly used in the wastewater treatment plants. Biological treatment process that removes dissolved organic matter from wastewater, where microorganisms use organic matter from sewage as their food supply. This process leads to decomposition or biodegradation of organic wastes. However, these techniques inefficient for the complete colour removal and need further process. AOPs are found to be an efficient treatment for the degradation of textile contaminants considered difficult to degraded by conventional methods (Sathya et al. 2019). Some literatures about the methods of AOPs and its efficiency on the textile wastewater treatment are furnished in **Table 1**.

**Table 1** Various AOPs in the treatment of textile pollutants

Advanced Oxidation Process	Pollutant	Degradation Efficiency (%)	References
Hydrodynamic Cavitation + Hydrogen Peroxide	Methylene Blue	83.7	Ji et al. 2022
Hydrodynamic Cavitation + Ozone	Methylene Blue	92.62	Ji et al. 2022
Spark plasma	Reactive Blue 19	80	Burlica et al. 2019
Adsorption and persulfate oxidation	Acid Yellow	88.4	Adar, 2020
UV-LED/persulfate	Direct Red 23	65	Rasoulifard et al. 2015
UV-LED/Photofenton	Antipyrine	93%	Davididou et al. 2017
UV-LED/Photofenton like process	Orange II	83.4	Ahmadi et al. 2017
UV-LED/Photofenton like process	Carmoisine	NA	Zhou et al. 2016
UV-LED/TiO <sub>2</sub> Photocatalysis	Malachite green dye	92% in 1 h 72% COD reduced	Jo et al. 2015
UV-LED/TiO <sub>2</sub> Photocatalysis	Brilliant blue	72.2	Jallouli et al. 2018
UV-LED/TiO <sub>2</sub> Photocatalysis	Ibuprofen	40	Zazouli et al. 2017



Basically, AOPs are the powerful technique to eliminate the contaminants in the wastewater with high reaction rate. However, it also has some disadvantages relatively high operating and maintenance cost. Some of the pros and cons of the AOPs are depicted in **Figure 2**.

## CONCLUSION

The highly polluting industries especially, textile industries discharge voluminous quantities of toxic effluents every day, which reduces the amount of pure fresh water for various uses. Advanced oxidation is one of the potential alternatives to decolorize and to reduce recalcitrant wastewater loads from textile dyeing and finishing effluents. Industries should be encouraged to re-use treated textile wastewater.

## REFERENCES

1. A O Ibrahim, K A Adegoke, R O Adegoke, Y A AbdulWahab, V B Oyelami, M O Adesina, Adsorptive removal of different pollutants using metal-organic framework adsorbents, *J. Mol. Liq.* 333 (2021), 115593.
2. Saravanan A, Deivayanai VC, Kumar PS, Rangasamy G, Hemavathy RV, Harshana T, Gayathri N, Alagumalai K. 2022. A detailed review on advanced oxidation process in treatment of wastewater: Mechanism, challenges and future outlook. *Chemosphere.* 308:136524. <http://doi:10.1016/j.chemosphere.2022.136524>.
3. Pignatello, J J, Oliveros, E, MacKay, A, Advanced oxidation processes for organic contaminant destruction based on the fenton reaction and related chemistry. *Crit. Rev. Environ. Sci. Technol.* 2006, 36.
4. Perez-Gimeno, A, Navarro-Pedreno, J, Almendro-Candel, M B, Gomez, I, Zorpas, A A, The use of wastes (organic and inorganic) in land restoration in relation to their characteristics and cost. *Waste Manag. Res. J.-Ternational Solid Wastes Public Clean. Assoc. ISWA 2019*, 37, 502–507.
5. Priyadarshini M, Das I, Ghangrekar MM, Blaney L, Advanced oxidation processes: Performance, advantages, and scale-up of emerging technologies. *J Environ Manage.* 2022 Aug 15;316:115295. doi: 10.1016/j.jenvman.2022.115295.
6. Yi H, Lai C, Huo X, Qin L, Fu Y, Liu S, Li L, Zhang M, Chen M, Zeng G. 2022. H<sub>2</sub>O<sub>2</sub>-free photo-Fenton system for antibiotics degradation in water via the synergism of oxygen-enriched graphitic carbon nitride polymer and nano manganese ferrite. *Environ. Sci. Nano*, 2022,9, 815-826.
7. Çokay, E, Eker, S. Pesticide Industry Wastewater Treatment with Photo-Fenton Process. *Environ. Sci. Proc.* 2022, 18, 15. <https://doi.org/10.3390/environsciproc2022018015>
8. Wang L, Fei Y, Gong C, Shan Y, Zhang Z, Zhang F, Cheng H. 2022. Comparative study of UV/H<sub>2</sub>O<sub>2</sub> and UV/PMS processes for treating pulp and paper wastewater. *Water Sci Technol* 86 (8): 2032–2044. doi: <https://doi.org/10.2166/wst.2022.326>
9. Ji H, Lan Y, Nie S, Qin T, Nie S, Zhou J. 2022. Synergistic effect of hydrodynamic cavitation characteristics of self-excited oscillation cavity for degradation of dye wastewater, *Journal of Cleaner Production*, 2022:135116. <https://doi.org/10.1016/j.jclepro.2022.135116>.
10. Asghar, A.; Raman, A.A.A.; Daud, W.M.A.W. Advanced oxidation processes for in-situ production of hydrogen peroxide/hydroxyl radical for textile wastewater treatment: A review. *J. Clean. Prod.* 2015, 87, 826–838.
11. R Burlica, I-D Dirlau and D Astanei. *Environ. Eng. Manag. J.*, 18, 2019, pp. 1799-1807, 10.30638/eemj.2019.17
12. Sathya U, Keerthi, M, Nithya, N, Balasubramanian. 2019. Evaluation of advanced oxidation processes (AOPs) integrated membrane bioreactor (MBR) for the real textile wastewater treatment, *Journal of Environmental Management*, 246: 768-775. <https://doi.org/10.1016/j.jenvman.2019.06.039>.
13. Adar, E. Removal of Acid Yellow 17 from Textile Wastewater by Adsorption and Heterogeneous Persulfate Oxidation. *Int. J. Environ. Sci. Technol.* 18, 2021, 483–498. <https://doi.org/10.1007/s13762-020-02986-5>
14. Jo, W K, Park, G T, and Tayade, R J., Synergetic effect of adsorption on degradation of malachite green dye under blue LED irradiation using spiral-shaped photocatalytic reactor. *Journal of Chemical Technology & Biotechnology*, 90(12), 2015, 2280-2289.
15. Zazouli, M A, Ghanbari, F, Yousefi, M and Madihi-Bidgoli, S Photocatalytic degradation of food dye by Fe<sub>3</sub>O<sub>4</sub>-TiO<sub>2</sub> nanoparticles in presence of peroxymonosulfate: The effect of UV sources. *Journal of environmental*



- chemical engineering, 5(3), 2459-2468.
16. Jallouli, N, Pastrana-Martínez, L M, Ribeiro, A R, Moreira, N F, Faria, J L, Hentati, O, Ksibi, M. Heterogeneous photocatalytic degradation of ibuprofen in ultrapure water, municipal and pharmaceutical industry wastewaters using a TiO<sub>2</sub>/UV-LED system. *Chemical Engineering Journal*, 334, 2018, 976-984.
  17. Rasoulifard, M H, Fazli, M, Eskandarian, M R. Performance of the light-emitting-diodes in a continuous photoreactor for degradation of Direct Red 23 using UV-LED/S<sub>2</sub>O<sub>2</sub><sup>-</sup> process. *Journal of Industrial and Engineering Chemistry*, 24, 2015, 121-126.
  18. Davididou, K, Montegudo, J M, Chatzisyneon, E, Durán, A, Expósito, A. J. Degradation and mineralization of antipyrine by UV-A LED photo-Fenton reaction intensified by ferrioxalate with addition of persulfate. *Separation and Purification Technology*, 172, 2017, 227-235.
  19. Zhou, G., Guo, J., Zhou, G., Wan, X., Shi H Photodegradation of Orange II using waste paper sludge-derived heterogeneous catalyst in the presence of oxalate under ultraviolet light emitting diode irradiation. *Journal of Environmental Sciences*, 47, 2016, 63-70.
  20. Ahmadi, M., Ghanbari, F., Alvarez, A., Silva Martinez, S. UV-LEDs assisted peroxymonosulfate/Fe<sub>2</sub><sup>+</sup> for oxidative removal of carmoisine: The effect of chloride ion. *Korean Journal of Chemical Engineering*, 34(8), 2017, 2154-2161.





# Recycled Aggregates : A Sustainable Solution of Construction Waste

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**Abstract:** Construction activities are going faster with the advanced lifestyle and modernization of cities, various advanced construction practices gaining popularity with development of society. As the duration of a structure crossed its service life there will not be any choice without destroying it. Construction of different structures need not be destroyed with the end of life but also because of current construction practices and to have better appearance of structures. Due to many advanced techniques of construction activities various waste generated every time, and this is termed as construction waste. Disposal of construction waste is very difficult in view of a pure environment, disposal of construction waste is a challenging task for all the people associated. Availability of natural construction materials is a big question as per demand of materials in current construction practices. Recycle aggregates can be a better option for fulfillment of construction demand.

**Keywords:** Construction Waste; Recycling; Service Life; Sustainability; Waste Management

## INTRODUCTION

Concrete is the single most widely used construction material in the the vicinity, far exceeding other materials as production of the concrete required much less energy and had a lower net atmospheric impact . Humans have been using concrete in their artistic architectural and structural works for decade. The globally concrete will require 8 to 12 billion tones of natural aggregates by the year 2010 (Keun-Hyeok et al., 2008). This huge demand of concrete seems to be increase at much faster rate in 2020 due to the modernization of cities, rehabilitation of old buildings, expansion of concrete pavements etc. Each construction material is manufactured from some combination of raw materials, and the basic ingredients of concrete are– sand and gravel (aggregate), a cement-like binder, and water out of these cement can be manufactured in industries but natural aggregates are usually obtained by mining cannot be manufactured in industries. As aggregates, raw material of concrete, are non-renewable and scarce therefore there is an urgent need to find the sustainable solution to get an alternative of natural aggregates. On the other hand due to renovations and refurbishments for reasons such as deterioration, alteration of needs, or change in fashion, many concrete structure and its components are changed and thus resulting in Construction & Demolished wastes. These processes sometimes occur frequently. It is estimated that 30-50% of overall construction waste results from renovation activities (Construction and Demolition Waste Practices and Their Economic Impact-Report, 1999). Sometimes waste are generated due to the structural problems of individual buildings like collapse of a building, due to earthquakes, illegal structuring, and urban transformation processes.

## EXPERIMENTAL INVESTIGATION

This experimental investigation test eight columns of dimension  $100 \times 100$  mm and height 500 mm, cast with M30 grade of conventionally vibrated concrete. The retrofitted specimens were also tested under monotonic concentric compression at uniform slow rate with stress-controlled universal testing machine to their ultimate load carrying capacity Three types of different mortar mixes were taken into investigation.

- (i) C1 & C2 - Controlled Specimen of M30 grade Concrete.
- (ii) R1 & R2 - Retrofitted Specimen of HPM mix 1:1.5.
- (iii) R3 & R4 - Retrofitted Specimen of HPM mix 1:2.
- (iv) R5 & R6 - Retrofitted Specimen of HPM mix 1:3.

## Cement

An Ordinary Portland Cement (OPC) 53 grade confirmed to IS: 8112-1989 reaffirmed 2005 were used in the

experimental investigation.

### Aggregates

Locally available river sand of specific gravity 2.60 and fineness modulus of 2.45 was used as fine aggregate. Confirmed to IS: 383 – specifications for fine and coarse aggregate.

### Admixer

Silica fume conforming to IS: 15388-2003 was used as a mineral powder as shown in **Figure 1**. Silica fume was used as a property enhancing material and Sulphanated naphthalene formaldehyde based super plasticizer was used in the present investigation.

### Steel Reinforcements

High yield strength deformed bars (HYSD) conformed to Indian Standards IS: 1786:2008 were used as reinforcing steel to construct the Control and Retrofitted series specimens. Welded Wire Mesh made from 1.16 mm diameter mild steel wires arranged in two orthogonal directions prefabricated in a square grid of size 50 mm were used as reinforcement in the jacket of retrofitted specimen.

### Mix Design for Control Specimen

M30 grade mix and high performance mortar mix which is used for preparing the specimens and strengthening the existing damaged column respectively.

### Reinforcements of Control and Retrofitted Specimens

All the column specimens were reinforced longitudinally with four bars each of 8 mm diameter. The transverse reinforcement consisted of six bars each of 6 mm diameter. The transverse reinforcement was provided in the form of

**Table 1** Physical properties of Cement

S.No	Properties	Results
1	Grade	OPC 53
2	Standard consistency	33%
3	Initial setting time	32 min
4	Final setting time	610 min
5	Specific gravity	3.16
6	Fineness	6.88

**Table 2** Physical properties of Fine and Coarse aggregates

S.No	Properties	Fine Aggregate	Coarse Aggregate
1	Specific gravity	2.6	2.84
2	Bulk density-Loose (kg/m <sup>3</sup> )	1491.7	1483.6
3	Bulk density Compacted (kg/m <sup>3</sup> )	1681.73	1587.25
4	Water absorption (%)	0.91	1.45
5	Fineness modulus	2.45	6.56

**Table 3** Physical and chemical properties of silica fume

S.No	Properties	Results	IS: 15388-2003
1	SiO <sub>2</sub> (% by mass)	94	>85
2	Specific gravity	1.96	Not specified



**Table 4** Mechanical properties of Reinforcing steel.

S.No	Diameter (mm)	Yield Stress (MPa)	Yield Strain
1	6	458	0.00245
2	8	455	0.0024

**Table 5** Mechanical properties of WWM

S.No	Diameter (mm)	Size of Square Grid (mm)	Yield Stress (MPa)
1	1.16	50	257

**Table 6** Mix design for M30 Grade concrete

Cement	Sand	C.A	W/C
1	1.5	2.6	0.45

**Table 7** Quantity of materials requires for the specimens

S.No	Materials	C1 & C2	R1&R2	R3 & R4	R5 & R6
1	Cement (kg)	5.2	4.2 + 4	4.2 + 3.3	4.2 + 2.5
2	Fine aggregate (kg)	7.8	6.2 + 6	6.2 + 6.67	6.2 + 7.5
3	Coarse aggregate (kg)	13.3	10.6	10.6	10.6
4	Water content (l)	2.4	1.9 + 1.8	1.9 +	1.9 + 1.125
5	Silica fume (kg)	-	0.4	1.5 0.33	0.25
6	Super plasticizer (l)	-	0.04	0.033	0.025

normal rectangular ties around the longitudinal bars. Both longitudinal as well as transverse reinforcement were of high yield strength deformed (HYSD) steel conforming to IS: 1786-2008. These dimensions of specimens were used to ensure short column behaviour as shown in **Figure 2**. Further the dimensions of column specimens were restricted to horizontal and vertical clearance of the testing machine. Clear concrete cover of 25 mm was provided for all the specimens and CFRP sheet is provided at both the end of specimens with the help of Epoxy resin.

## CASTING OF SPECIMEN AND TESTING OF SPECIMEN

### Casting of Specimen

The reinforcing cages for controlled and retrofitted specimen were cautiously placed concentrically inside the formwork using 25 mm cover block at the top and bottom ensuring 25 mm concrete cover consistently throughout the height and periphery of specimen[4]. CFRP sheet of 50 mm flat were placed at top and bottom around the specimen to prevent end failure during testing. The reinforcement detailed diagram for control and primary specimen as shown in **Figure 2**. The reinforcing cage for control and primary specimen as shown in **Figure 3** were cast. The specimens and cubes were then soaked in water for curing. All the specimens were white washed before testing so that cracks are easily seen using naked eyes.

### Testing of Specimen

Testing of all the controlled were done two days after white washing the cured specimen. Prior to testing, precautions were taken to prevent any accidental eccentricity loading in the axial load application by proper alignment of the test set-

### Average Yield Stress and Ultimate Load Carrying Capacity of Tested Specimens

Designation	Average Yield Load (kN)	Average Ultimate Load (kN)	Difference in the Yield Load (%)	Difference in the Ultimate Load (%)
C1 & C2	236	525	-	-
R1 & R2	292	571.5	23.7	8.85
R3 & R4	255.5	551.5	8.26	5.07
R5 & R6	241	531	2.11	1.15

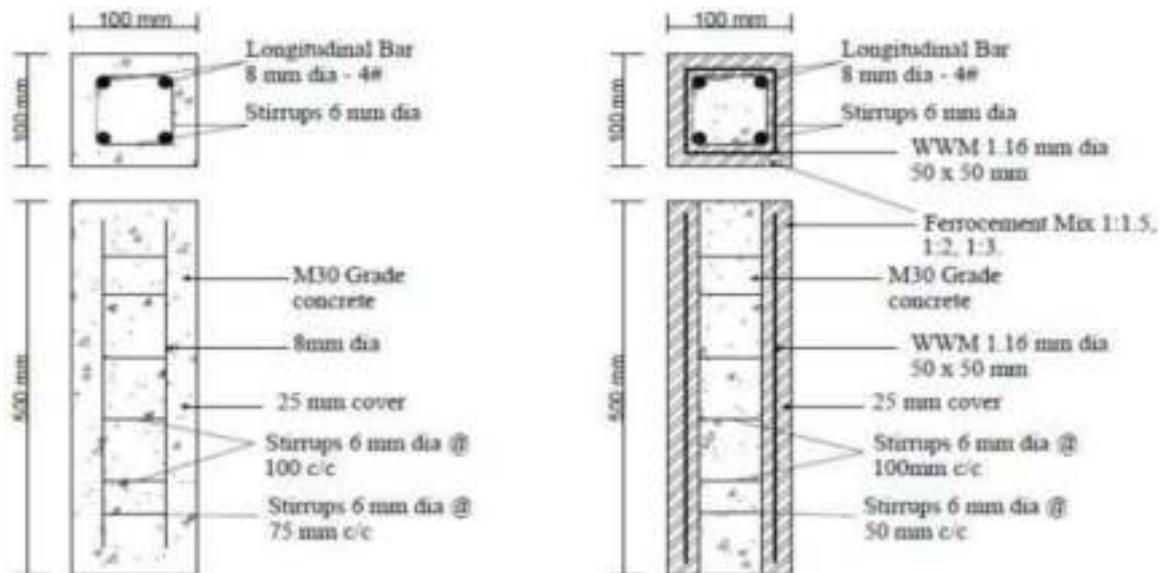
up in **Figure 5**. The position of the specimen was adjusted until its marked centre line matches the line of action of axial load. An initial load of 20% of the total ultimate load was applied. This preload also ensured the proper loading pattern without any non-uniformity in applying the load.

The damaged specimen named for retrofitted specimen is repaired and retrofitted using the Welded wire mesh of 1.16 mm diameter of 50 × 50 mm grid spacing and the high performance ferrocement mix of different proportions of 1:1.5, 1:2, and 1:3 are applied to the damaged specimen in the respective manner as named in Group 2, 3 and 4 respectively. After that, make it set for 24 h and then the retrofitted damaged column is kept for 7 days curing process and after that the specimens are taken out then dried. As same white wash is done on all the six specimens and now ready for the testing. As the same way testing done for the controlled one testing procedure is carried out for the retrofitted specimen and the testing is carried out till the ultimate load.

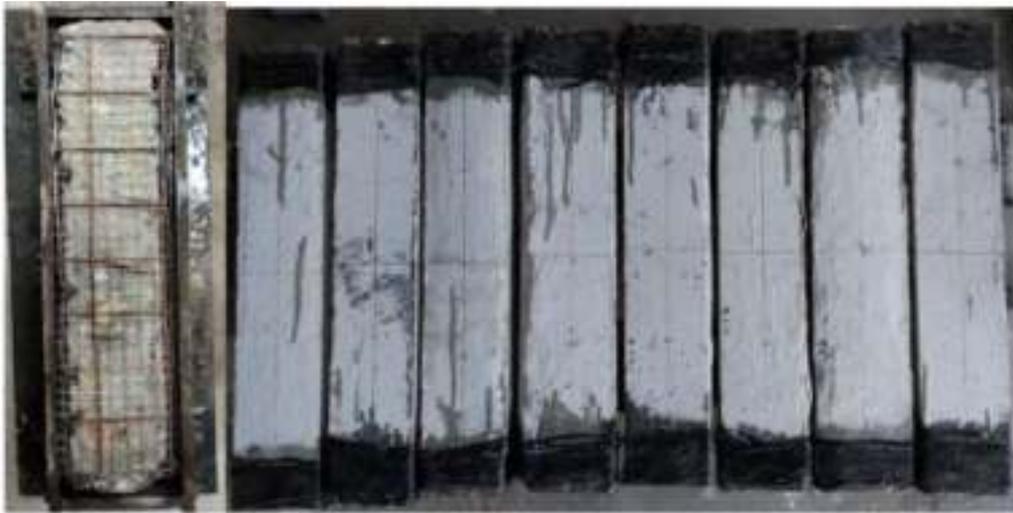
### TEST RESULTS AND DISCUSSION

Experimental results of axial loading test of both the controlled and Retrofitted specimens were discussed in the succeeding sections.

The experimentally obtained ultimate load carrying capacity for all the retrofitted column specimens are higher than controlled column specimens. The ultimate load carrying capacity is increased by 8.85%, 5.04% and 1.14%.[12] respectively than the average experimental values of control specimen. The deflection response of the controlled and retrofitted specimens are presented graphically in form of axial stress-axial strain and axial stress- lateral strain relationships in **Figure 9**. From the graphical representation shows group II specimen i.e high performance mortar mix with 1:1.5 proportions gives more effective than other mixes. So that from this investigation conclude that 1:1.5 – 1:2 -

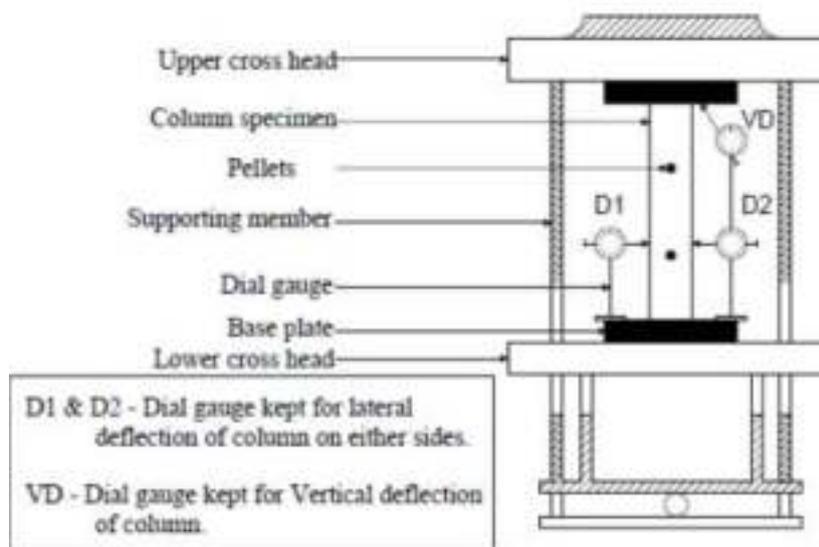


**Figure 2** Reinforcement Detail of Control and Retrofitted Specimen



**Figure 3** Reinforcing cage and wrapping of weld wire mesh

**Figure 4** Casted specimens



**Figure 5** Schematic diagram of test setup

1:3 mortar mix proportions is efficient series for ferrocement Jacketing Technique.

**Deflection Response**

Typical Load vs vertical Deflection curve for all tested specimens are shown in **Figure 7**. Load vs Lateral Deflection curve and also the stress – strain relationship also drawn for all the specimens[6]. From this graphical representation it is clear that all the jacketing retrofitted column are more ductile compare with controlled specimen.

**Failure Pattern**

Failure pattern of the tested specimen were shown in **Figure 6**. From this figure the author can conclude that non jacketed column starts to fail by crushing of concrete at the point of application of load. On the other hand, all jacketed columns start to fail from ferrocement jacket. Inretrofitted column Cracking and spalling of cover concrete from top to bottom occurred and Crushing occurs at bottom because of ferrocement reinforcement spalling not occurred.



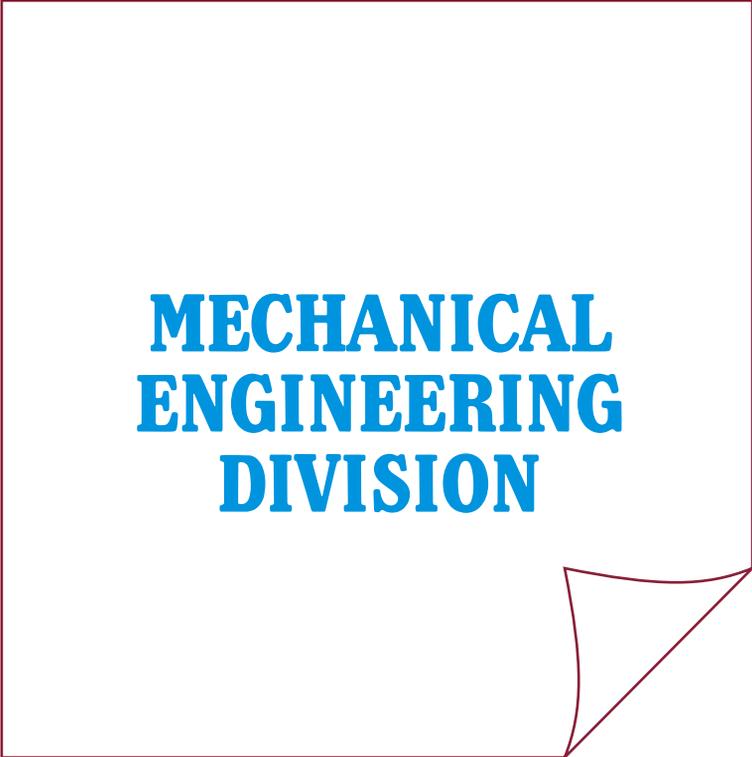
## CONCLUSION

From this experimental investigation of small scale ferrocement with High Performance Mortar jacketed RC column under concentric load, the following concluding remarks could be made:

- Ferro cement with High Performance Mortar using jacketing techniques improves the ultimate load carrying capacity and increases the ultimate axial deflection of RC column.
- Strengthening of Compression Member Ferro cement jacketing technique could be used effectively, if proper jacketing scheme is introduced.
- All the jacketing retrofitted column are more ductile compare with controlled specimen.
- This investigation conclude that 1:1.5 – 1:2 -1:3 mortar mix proportions is efficient series for fibrocement Jacketing Technique.

## REFERENCES

- M. Amala, M. Neelamegam. Experimental Study of Flexure and Impact on Ferrocement Slabs”, The International Organization of Scientific Research, 2015
- IS: 10262, Concrete mix proportioning-guidelines, Bureau of Indian Standards, 2009, New Delhi, India 12 IS: 269, 53 Grade Ordinary Portland cement: specifications, Bureau of Indian Standards 2015, New Delhi, India
- IS: 383, Specification for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standards, (2016), New Delhi, India.
- IS: 9103, Concrete admixtures-specifications. Bureau of Indian Standards, (1999), New Delhi, India 15 IS: 516 – 1959, Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, India.
- N. Divyah, R. Thenmozhi, M. Neelamegam, A comparative study on prediction models for strength properties of LWA concrete using artificial neural network, Journal of Construction, 19 (2020), 1, 103–111 doi:10.7764/RDLC.19.1.103-111
- S.LavanyaPrabha, J.K.Dattareya, M.Neelamegam, Stress strain behaviour of ultrahigh performance concrete under uniaxial compression”, International Journal of civil Engineering, , ISSN NO: 0976-6308(print) ISSN NO: 0976-6316(online), Volume 5 Issue No 3PP. 187-194, May 2014
- LavanyaPrabha S, Neelamegam M And Surendar M, Mechanical Properties of Micro-Steel Fibre Reinforced Copper Slag Resin Mortar,
- International journal of Earth science and Engineering, ISSN 0974-5904, Volume 10, No. 05 October 2017, P.P. 996-1001
- S.Christi, A.Arunraj, V.Venkatesan, R.Logaraja, Study on Behavior of Sustainable Ferrocement Overlay Beam using M-Sand, Journal of Green Engineering . Volume-10, Issue-1, January 2020.
- Mohan A, Saravana Karthika, Ajith J, Lenin dhal, “Investigation on Ultra-High Strength Slurry Infiltrated Multiscale Fibre Reinforced Concrete” Materials Today: Proceedings 22(2020) 904-911.
- V.Saravana Karthika, A.Mohan, R.Dinesh Kumar and Chippymol James, Sustainable Consideration by Characterization of Concrete through Partial Replacement of Fine Aggregate Using Granite Powder and Iron Powder, Journal of Green Engineering, Volume-9, Issue-4, December 2019, 514-525.
- K. Srividhya , A. Mohan , M. Tholkapiyan, A. Arunraj, Earth quake disaster mitigation (EQDM) through engineering design, Materials Today: Proceedings 22 (2020) 1074-1077



**MECHANICAL  
ENGINEERING  
DIVISION**



# Role of Engineers for Creating a Sustainable Surplus Indigenization and Manufacturing Hub for India Defence Forces

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**Abstract:** Substantial amount in defence budget is allocated for strengthening armed forces in terms of acquisition of equipment, strategic devices, missiles, instruments and support systems to conduct research & development (R & D) on emerging technologies to create a sustainable self reliant and surplus indigenization and manufacturing nation. This will facilitate import substitution, creation of MSMEs, employment generation, vendor developments and potential for exporting defence products, so that foreign currency reserve will be adequate. Self sustenance is a long awaited need for defence forces to cater for own needs and to become surplus hub in respect of defence production of global standards. India is dominated by import compulsions to meet own defence requirements to keep in pace with advancements in technology and innovative methods of warfare in terms of current laser based warfare, introduction of drone based attacks, physiological warfare, chemical and biological destructive methods amongst many others. The primary grey area is lack of indigenization program and potential to meet the time based need of armed forces to sustain and dominate in war fields. Also the establishment of such potentials will restrict the adversaries to negate the idea of advancement near to the international boarder, avoid create state funded terrorism to impact the social and economical harmony in the nation. Further indigenisation based products can not be conveniently assessed about the end applications and deliverables, so that the other countries can not predict the war tactics & capabilities. Obtaining field related problem statements and creation of scope for research gap filling are the immediate requirements to accelerate the indigenization to meet current and upcoming requirements. The complete objectives can be only fulfilled by trained and motivated engineers. A roadmap for above aspects are being taken care by both government agencies like DRDO, DPSUs, CSIR and also by private players like TATA, Reliance defence, L&T, Mahindra & Mahindra, Bharat Forge Ltd and many more.

**Keywords:** Affiliation, Interface, Skill, PPP, Data Analytics, Gap Identification

## INTRODUCTION

The India's military expenditure increased to Rs 4,78,196 crores in 2021, marking a 0.9% hike over the 2020 figure. The Defence Budget for the financial year 2022-23 is Rs 5,25,166 crores. The substantial amount is expended for procurement of equipments, missiles, optoelectronic, communication equipment and strategic devices. The recent steps taken by Indian defence agencies on "Make in India" and "Made in India" are two mile stones of indigenization and manufacturing sectors. The challenges encountered by defence forces and associated manufacturers for spares and equipment indigenization are unique in terms of technology infusion, war field requirements, matching performance with advance countries products, dedicated world class laboratories for R&D, tuned skilled manpower and the most important is capital expenditure requirements.

The aspects of vendor developments, acquisition of state of art plant and machineries including test and diagnostic equipments, Up skilling and Re skilling facilities and adopting international standards with industrial best practices are the other areas of concern.

The review by experts and visionaries revealed that in all aspects brought out above, the primary role of engineers for sustainable indigenization and manufacturing are justified for not only making the nation self reliant but also to make a leader in defence items export. The perfection and dedication of engineers in formulating operation planned schedule (OPS) for each activity, selection of suitable material with complete specifications, continuous improvement of technical skill, adoption of prescriptive maintenance through condition based maintenance (CBM) and shop floor involvement are the minimum expectations.

The corporatization of defence entities, optimum capacity utilisation and impact of modernization, labour productivity, R&D and technology assimilation, value addition to process and products, adopting concept of nomination to



competition, analysis of profit margin and accelerating reverse engineering program are the necessity for indigenisation and manufacturing hub.

### **DEFENCE INDIGENIZATION PROGRAM IN INDIA**

Keeping in view of diversified unique nature equipment used in depth and range by Armed Forces having most origin to advance nations and rapidity of modernization taking place in short span of time, the Atmanirbhar Bharat program is a critical time bound compulsion for Indian Subcontinent. The technical features required by Armed Forces during field trials and war situations demands customized specification changes and design modifications. Eventually these aspects calls for complete dependency on foreign manufacturers and involves higher expenditure and foreign currency drain. Therefore all out efforts are being made to carryout substantial indigenization on defence requirements. Both government and private entities are involved to accelerate the indigenization program under Atmanirbhar Bharat initiatives to meet the desired requirements and make the manufacturing facilities export ready by giving status of special economic zones (SEZs) and subsidies.

#### **The Network-centric Warfare Requirements**

generate a range of defense industry implications hence defining the current defence indigenisation programs. The industries are poised to take on new military transformation with science, technology and everyday innovations also catering for internal and external terrorism aspects. Also the full spectrum military operations which includes low intensity conflicts to major threat of wars redefines indigenisation program.

The reform measures taken so far include a hike in foreign direct investment (FDI) cap from the earlier 26 to 49% through the automatic route and articulation of a first ever defence exports strategy to strengthen the financial status of indigenisation sector. Self-sufficiency / reliance has been the primary reason for developing a vast defence industrial base (DIB), which now comprises defence laboratories and establishments under DRDO, defence public sector undertakings and ordnance factories and growing number of private entities.

The priority requirement of indigenization for Indian Armed forces are in the following identified domain:

- ❖ Armoured Technology and Autonomous Vehicles;
- ❖ Silent Watch Capability development for tanks using fuel cells without starting engine;
- ❖ Target Acquisition Systems (TAS);
- ❖ Integrated Tactical Power Management System (ITPMS);
- ❖ Secured Communication Devices;
- ❖ Radars , Interceptors and Surveillance systems;
- ❖ Guns and Ammunitions;
- ❖ Unmanned Arial Vehicles and Drones;
- ❖ Night Vision and Optical Devices;
- ❖ Solider comfort equipments;
- ❖ Rare Earth Material Applications;
- ❖ Non Conventional and Additive Manufacturing;
- ❖ Test and Diagnostic Equipment;
- ❖ AI & ML;
- ❖ Cloud Computing, Quantum computing and Data Analytics;
- ❖ Cyber Security for protection from cyber attacks;
- ❖ Nano Materials and Sensors with Telemetry;
- ❖ Laser Beam Technology as war head;
- ❖ Simulator developments for Augmented Reality and Virtual Reality;
- ❖ Identification of Foe and Friend in War field;
- ❖ Camouflaging and Image Analysis Technology ;
- ❖ R&D set up;
- ❖ Nuclear, Biological, Chemical and Radiation (NBCR) protection;
- ❖ Prescriptive Maintenance on IoT platform;



- ❖ Augmented Reality (AR) and Virtual Reality (VR) modules;
- ❖ Uninterrupted Navigation;
- ❖ Blockchain;
- ❖ Non Lethal Weapon (NLW);
- ❖ Multi Terrain Equipment (MTE);
- ❖ New and smart material development;
- ❖ Autonomous Vehicles;
- ❖ Alternative energy sources.

The role of engineers to develop following modalities in time bound manner will make India the hub of manufacturing fulfilling the above brought out facilities and will create an export potential nation as well:

- ❖ Effective and commercial viable PPP models;
- ❖ Organisation to be headed by domain experts;
- ❖ Autonomy of the organisations;
- ❖ Intensive Industry- Academia interface for mutual developments, Ideas and Innovations;
- ❖ Affiliate Marketing for global trading;
- ❖ Adaptability of niche technology;
- ❖ Artificial Intelligence and Machine Learning;
- ❖ Blockchain and Cloud Computing;
- ❖ Coding and Cyber Security;
- ❖ Telemetry and Data Analytics for real time assessments and decision making;
- ❖ Dedicated Funding Institutions;
- ❖ Prescriptive Maintenance;
- ❖ Participative Management in decision making;
- ❖ Professional Affiliations with R & D entities and standard institutions like BIS, BEE & PCRA;
- ❖ Continual Up skilling and Re skilling.

#### **CAPABILITY DEVELOPMENT FOR INDIGENISATION HUB & SUSTAINABLE GROWTH**

The slogan of “Make in India” and the reality of “Made in India” are the matter of intensive realization for actual need based implementation of potential indigenization deliverables and creation of related manufacturing hub for self sufficiency and export. The capability development on following areas requires immediate attention for the purpose:

- ❖ Capacity Requirement Planning (CRP);
- ❖ Need based Transfer of Technology (ToT);
- ❖ Memorandum of Understanding (MoU) with Original Equipment Manufacturers (OEMs);
- ❖ Adoption of Non Conventional (NC) machining;
- ❖ Adoption of Sensors, Transducers, Probes and IoTs ;
- ❖ Extensive uses of Prescriptive Maintenance along with Condition Based Maintenance (CBM);
- ❖ Uses of AI & ML;
- ❖ Application of Additive manufacturing, 3 D printing;
- ❖ Identification and use of alternative fuel source.

The key projects under make in India indigenisation scheme include setting up of defence corridors in Uttar Pradesh and Tamil Nadu, and testing of defence products like Akash Surface to Air Missile Systems, Dhanush Artillery Gun Systems, Medium Range Surface to Air Missiles, Agni-5, BrahMos, Pinaka Mk –I Rocket System and Pinaka Area Denial Munition Rocket Systems and Helicopter-Launched Anti Tank Guided Missile amongst others. The government had issued 568 Defence Industrial Licenses to 351 companies to work in customized manner. Currently 117 companies covering 170 licenses have started production commercially.

#### **ORGANISATIONS CONTRIBUTING TO DEFENCE INDIGENISATION PROGRAM**

Due to restrictions on commercial exploitation front for security reasons and stringent requirements on field trials, very



limited government and private entities are engaged in indigenisation support program in particular in product development and manufacturing. The rate of failure of prototypes are nearly 50% and time required to complete different rounds of pilot testing, user extensive validation and maintenance trials including multiple levels of quality assurance checks are unexpectedly high. The cost factor involved during these validation processes are much beyond anticipated project cost. Further by the time all set to roll on indigenized product, there is every possibilities of modifications required keeping in view of current situations and change of military leadership. Keeping in view of above attributes the following entities are engaged in dedicated indigenization support work for Defence sector:

- ❖ Institute of Defence Studies and Analysis;
- ❖ Centre for Joint Warfare Studies;
- ❖ Centre for Land Warfare Studies (CLAWS);
- ❖ Dedicated eight Army Base Workshops;
- ❖ Directorate of Indigenization under Army HQ;
- ❖ Ministry of Science and Technology, Govt of India through Council of Scientific and Industrial Research (CSIR);
- ❖ Defence PSUs like MIDHANI, BEL, GRSE, KSL, GSL, BDL, BEML, MDL, HAL;
- ❖ Defence Laboratories;
- ❖ Advanced Centre for Energetic Materials;
- ❖ Defence Metallurgical Research Laboratory;
- ❖ Defence Research and Development Laboratory;
- ❖ Research Centre Imarat;
- ❖ Naval Science & Technology Laboratory;
- ❖ Combat Vehicles Research & Development Establishment;
- ❖ Microwave Tube Research & Development Centre;
- ❖ Solid State Physics Laboratory;
- ❖ Restructured Ordnance Factories into seven DPSU clusters of specialization;
- ❖ Munition India Limited;
- ❖ Armoured Vehicle Nigam Limited;
- ❖ Advance Weapons and Equipment India Limited;
- ❖ Troops Comfort Limited;
- ❖ Yantra India Limited;
- ❖ India Optel Limited;
- ❖ Gliders India Limited;
- ❖ Other Prominent Institutions extending support;
- ❖ International Advanced Research Centre for Powder Metallurgy and New Materials;
- ❖ Raja Ramanna Centre for Advanced Technology;
- ❖ Indian Rare Earths Limited (India).

#### **PROGRESS MADE ON INDIGENISATION PROGRAM**

The deliverables of earlier mentioned organizations contributing to defence indigenization program are restricted due to several intrinsic factors of unique nature involved since war like equipments and associated components are under indigenization. Although the program is exhaustive and time consuming, following definite progress were achieved in recent time:

- ❖ Manufacturing of Special Maintenance Tools (SMTs) and Special Test Equipments (STEs) in respect of most of foreign origin equipment to carry out sustainable maintenance;
- ❖ Manufacturing of Spares (MoS) in respect of routine maintenance requirements of imported equipments;
- ❖ Establishing facilities for Metallurgical investigation as per international standards, product development using additive manufacturing and 3D printing and establishing reverse engineering facilities. Also creating facilities for non contact quality assurance systems and progressing product development on Rare Earth Elements, hybrid materials, smart and nano materials;



- ❖ Restructuring of 41 Ordnance Factories to seven specialized clusters with effect from 01 October 2021 as DPSUs having autonomy to carry out intensive indigenization activities.
- ❖ Mandating CSIR labs working in domain specialization like Institute of Minerals and Materials Technology (IMMT), Advanced Materials and Processes Research Institute (AMPRI) and Central Mechanical Engineering Research Institute (CMERI) to cater for defence indigenisation program.

#### **PRIORITIES OF DEFENCE INDIGENISATION**

The basic elements of indigenization under Atmanirbhar program in Defence sector are summarized below:

- ❖ Self Sufficiency in all fronts (Atma Nirbhar);
- ❖ Made in India Realization (MSMEs);
- ❖ Export Orientation (Up Skill, Re Skill);
- ❖ Import Substitution ( Alternatives);
- ❖ Infrastructure Development (R & D, Reverse Engg, Vendor Development);
- ❖ Special Economic Zones (SEZs);
- ❖ Dedicated Financial Institutions (EXIM, SIDBI, NABARD, ICICI, DIC, IDBI, IFC);
- ❖ Professional Affiliation with Standards bodies;
- ❖ Resource mobilization;
- ❖ Adoption of Green Technology;
- ❖ Identification of Alternative Fuels;
- ❖ Emphasis on Reuse, Re cycle and Reduce;
- ❖ Eco compatibility;
- ❖ Academia – Industry interface including PPP models.

#### **FEATURES OF DEFENCE INDIGENISATION**

- ❖ Continuous Evolution;
- ❖ Intermittent Evaluation;
- ❖ Mechanization & Automation;
- ❖ Security Classification;
- ❖ Unique Coding for Defence Applications;
- ❖ Capacity Requirement Planning (CRP);
- ❖ Coded Design Communication;
- ❖ Shop Floor Control (SFC);
- ❖ Material Requirement Planning (MRP);
- ❖ Computer Aided Process Planning (CAPP);
- ❖ Concurrent Engineering;
- ❖ IT Enabled Service (ITES);
- ❖ Discrete & Continuous Manufacturing;
- ❖ Simulation;
- ❖ Aesthetic Approach as per Defence Requirement;
- ❖ Reliability Assessment at Field level;
- ❖ Creative & Innovative Design;
- ❖ Brain Storming & Participative Management;
- ❖ Quality Cycles;
- ❖ Ergonomic Approach.

#### **INDIGENISATION CYCLE FOR DEFENCE FORCES**

As the indigenization activities is unique to Defence requirements, hence following customized cyclic steps are used in product development:



- ❖ Need Analysis of Product or Service;
- ❖ Formulation of Blue Print of Model or capturing all specifications called General Staff Requirements (GSR);
- ❖ Prototype or Pilot Sample development;
- ❖ Prototype Trial on Select Users in field formation and consequent modifications;
- ❖ Amendment to Design Parameters on the basis of user trial;
- ❖ SWOT Analysis on the basis of friendly foreign countries;
- ❖ Continuous Vendor Rating;
- ❖ Bulk or Mass Production;
- ❖ Warehousing and forwarding by dedicated and customized supply chain;
- ❖ Packaging & Preservation for extreme temperature and weather conditions at users end;
- ❖ Shipment and Customized Delivery in remote locations and diversified terrains;
- ❖ User Feedback after field use or exercises;
- ❖ Competitors SWOT Analysis;
- ❖ Need Analysis for Continual Improvements on user feedback;
- ❖ Design Modifications as per real time threat perceptions;
- ❖ Discard Policy for implementing new features on time bound manner and prevailing threats.

#### **CHALLENGES IN INDIGENISATION PROCESS**

As the indigenization process in India may upset many potential countries in terms of supplying defence items hence many challenges are created by those countries and few limitations are inherent in our system. Few extreme challenges encountered by various entities are mentioned below for immediate attention and follow up remedies:

- ❖ Cyber Security since indigenization programme is intensively IoT dependant;
- ❖ Defense Industrial Implications of Network-Centric Warfare is fast changing unpredictably;
- ❖ Data capturing, Telemetry and Data Analytics are techno intensive hence requires required infrastructure and experts for handling systems;
- ❖ Adequate dedicated funding in long term repayment basis;
- ❖ Uses of Predictive & Prescriptive Maintenance to keep functioning Plants, Machineries and Specialist Equipment meant for indigenization;
- ❖ Participative Management to share ideas & smooth functioning;
- ❖ Adequate professional affiliation with standards bodies, Academia & R & D institutions;
- ❖ Continuous Upgradation & Reskilling to match with competitors;
- ❖ Development of in lieu materials to reduce cost and making ease of functioning;
- ❖ Introduction of Alternative fuels and Non Conventional energy source during indigenization process to adhere green technology requirements and eco balance.

#### **CONCLUSIONS**

Keeping in view of military transformations and current hostile situations and strained relationships with neighbors, it is felt by higher leadership to go for indigenization program in war footing manner under Atmanirbhar Bharat Aviyan to develop technology, infrastructure, best practices, smart materials development, trained highly skilled manpower, working ambience and above all making government entities autonomous. However the under mentioned critical aspects are required to be in fore front always:

- ❖ Field users first;
- ❖ Continuous Requirement Assessment as per ground reality;
- ❖ Identification and up keeping of Skills for sustenance;
- ❖ On Job Training for Up Skilling and Re Skilling;
- ❖ Adoption of Just in Time (JIT) attitudes;
- ❖ Affiliation with Professional Institutions like BIS, CII, FICCI, CSIR, DRDO, BEE and others;
- ❖ Global Standards Adoption;



- ❖ Set Up SEZs to support indigenization and substantiate foreign currency reserve;
- ❖ Single Window Clearance for rapid materialization of projects;
- ❖ Establishing professional affiliation with national and international R & D institutions;
- ❖ Enhancing capital expenditure for indigenization and manufacturing capacity in terms of plants, machineries, test equipments, qualitative material supply chain are the other priorities.

#### REFERENCES

The author was extensively involved on manufacturing at Army Base Workshop for more than two and half decades and was involved in indigenisation, method engineering, process planning, formulation of operation planned schedule and trial evaluation of indigenized products of Defence equipments. The author was posted as Deputy Director , IHQ (Army), MoD New Delhi during 2015 to 2020 dealing with HR issues and skill development of civilian workforce engaged in indigenisation activities. Presently the author is posted in Military College of Electronics and Mechanical Engineering of Indian Army as an instructor where besides routine duties, working on modern manufacturing training facilities.



# Parametric Investigation of Integrated System for Power and Cooling Effect Generation

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**Abstract:** In the world, energy consumption is increasing day by day continuously because of the population growth, and industrial demand. World is also struggling with global warming effect. Due to inefficiency of the conventional energy conversion system, less portion of the fuel is converted into the power but the most of the energy lost in the environment and the systems are unable to meet the energy demand. The use of renewable energy sources looks prominent solution to overcome critical environmental issues like global warming etc. and, in addition, the increased efficiency of the energy used. Therefore, the present study performs a parametric investigation of the integrated system having solar energy as primary source of energy for running gas turbine and organic Rankine cycle along with Vapor Absorption refrigeration cycle for recovering the waste heat from exhaust gases coming out from the gas turbine. The investigation has been performed based on the first and second law of thermodynamics to understand the impact of the different important parameter like cycle pressure ratio, turbine inlet temperature etc. The results revealed that the integration of the organic Rankine cycle and Vapor Absorption refrigeration cycle improves the cycle performance in comparison of the gas turbine standalone performance.

**Keyword:** Energy; Exergy; ORC; Power; Cooling

## INTRODUCTION

The use of renewable energy is developing extremely quickly. According to researchers, practically all energy requirements must be met by renewable sources of energy, such as water, wind, and solar energy, to prevent the crisis due to unavailability of petroleum due to its excessive usage and time required to replenish the same future production of petroleum from fossil fuels. Researchers from all around the world have been focusing their attention on the solar energy in particular because it is a source of limitless energy[1]. Other different technologies for the clean energy production are fuel cell technologies but they depend upon fossil fuels to start[2-3], wind energy technologies depending upon continuous supply of wind[4], etc.

The researchers are trying to find out the best possible integrated system for the generation of power and cooling effect simultaneously. Chen, et al[5] presented a thermodynamic investigation of the solar powered gas turbine integrated system for the power and cooling effect generation based on the 1st and 2nd law of thermodynamics. This work offers a practical method for effectively combining solar and natural gas for electricity and cooling cogeneration. Wang, et al[6] performed a review of the solar powered power and cooling cogenerating technologies and presented the comparison in between the different solar utilization technologies and performed evaluation based on the 1st and 2nd law of thermodynamics along with the environmental analysis. Jani[7] presented simulation and modeling of the solar governed cycle for the cooling effect generation to survive in the hot as well as humid environment. Ghorbani, et al[8] investigated a power, cooling effect generation cycle and hydrogen production through the recovery of the waste heat of the combined energy arrangement. Liu[9] presented a review about the solar technologies and made a comparison about them. Ayoub, et al[10] presented a review article for the absorption cycle integrated system for the power and cooling effect. This study concluded that the systems that are directly developed from absorption chiller cycles like single- or double-effect cycles or sophisticated GAX cycles appear to be the most suitable combined absorption power and cooling systems for solar applications in buildings. Chowdhury, et al[11] presented a technical overview about the recent development in the solar governed power and cooling effect producing cycle in their manuscripts. Kumar and Singh[12] presented an investigation based on the first law of thermodynamics and performed economic analysis of the fuel cell integrated system which is capable of producing the power and cooling effect simultaneously. Temiz and Dincer[13] utilized integration of the renewable energy sources like wind energy and solar energy system to meet the energy and cooling effects demand in the remote locations. They have compared different energy system for meeting the energy demand the remote location. Ahmed, et al[14] presented a comprehensive review about integration of solar energy

harvesting and radiative cooling for getting the cooling and power cogeneration system. Chen, et al[15] investigated a combination of power, cooling and heating producing system based on the exergo-economic analysis to provide a cost effective system to utilize the renewable energy resource. Feng, et al[16] have performed an energetic and exergetic analysis of the combined power and cooling system along with an economic and multi optimization of the system. Nami, et al[17] presented a solar and biomass assisted combined arrangements to get the power and cooling effect simultaneously. Other researchers like Siddiqui and Dincer[18], Hou, et al[19] are also trying to find out best possible combined energy system to get the better system performance in the terms of efficiency and work output.

After performing literature survey, the authors found that the combined energy arrangements are the best option to improve the system performance. Therefore, the authors integrated solar assisted gas turbine cycle and VARS for cooling effect generation which is integrated for the utilizing the waste heat of the arrangement. And the authors performed a parametric investigation of the solar governed gas turbine combined arrangement based on the thermodynamic modeling. The impact of the pressure ratio and inlet temperature of the organic Rankine cycle has been investigated on the system performance.

### ARRANGEMENT DETAIL

The combined arrangement consists of the solar energy capture system, gas turbine, organic rankine cycle (ORC) for producing the energy as electricity, and vapor refrigeration system (VARS) to get the cooling effect. In the arrangement, first the air is compressed in the compressor then compressed air is sent through the heat exchanger having molten salt. This molten salt receives heat through the sun and transfers it into the compressed air to achieve the desire temperature at the inlet of the turbine. The exhaust gas of the turbine has some potential for the getting energy that can be produced through the system which operates at low grade energy. And this energy can be utilized for any purpose. Therefore, an ORC and VARS system is employed at the exit of the turbine for utilizing the low-grade heat of the waste coming out from the gas turbine. Splitter sends some portion of the waste heat into the ORC and VARS respectively. An ORC system is running with R1233zd€ organic fluid to get effective utilization of heat. The portion of the waste heat that goes into the

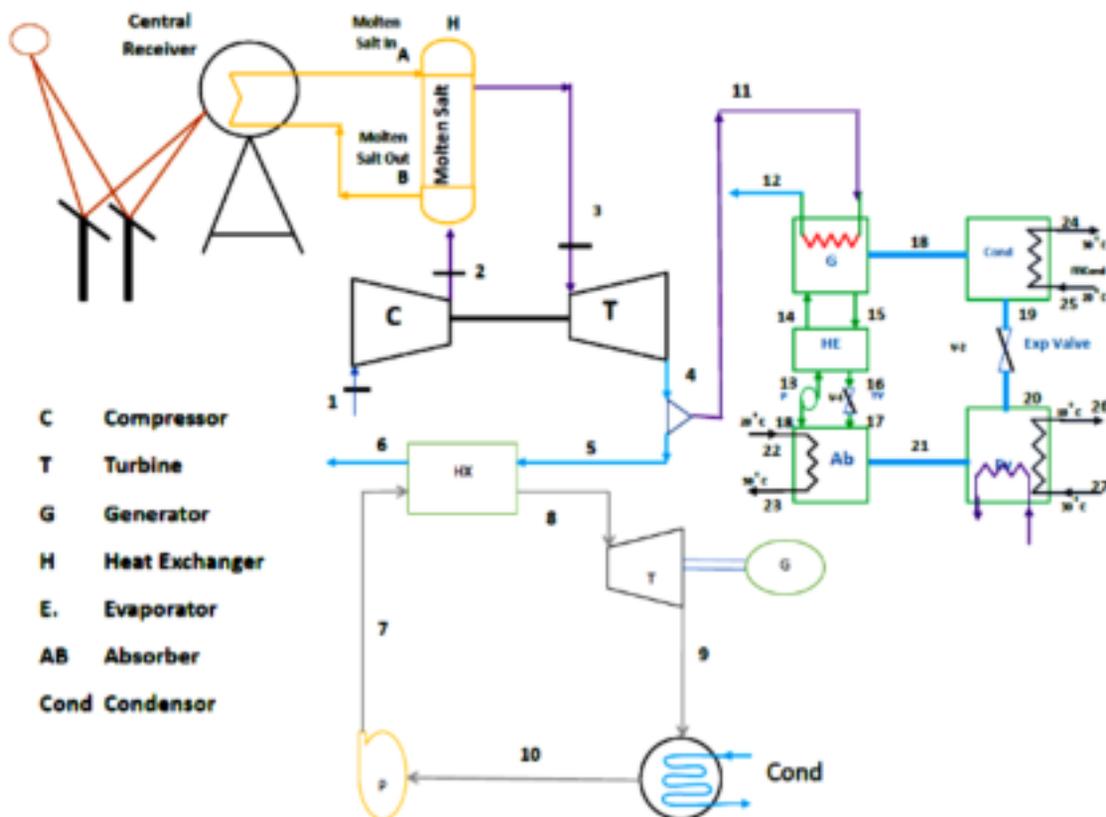


Figure 1 Schematic arrangement of the combined system



VARS is used for generating the cooling effect for the system. VARS is having ammonia as a refrigerant and water as absorber to get the high amount of refrigeration.

### THERMODYNAMIC MODELING OF THE ARRANGEMENT

In order to represent the coupled cycles under consideration thermodynamically, a few assumptions are made. They are given below as follows:

- I. There are steady state circumstances.
- II. Adiabatic pumps and turbines are used.
- III. The kinetic and potential energy hardly change at all.
- IV. Throttling is an adiabatic process.
- V. Losses in pressure are very small and ignored.

The molar forms of 21% oxygen and 79% nitrogen make up air. In the gas turbine cycle, it is a working fluid. Enthalpy change is expressed as

$$\text{Enthalpy change} = \int c_p dt$$

For the thermodynamic evaluation point of view, the calculation has been performed based on the first law of thermodynamics. Equations used in this evaluation process are similar to the presented in the Sachdeva and Singh [20].

Mass conservation applies in the system as:

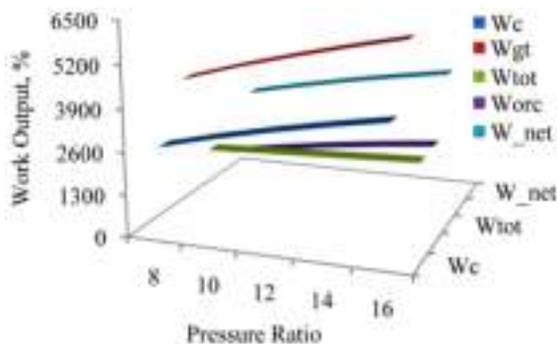
$$\sum m_i - \sum m_e = dm_{cv} / dt$$

### RESULT AND DISCUSSION

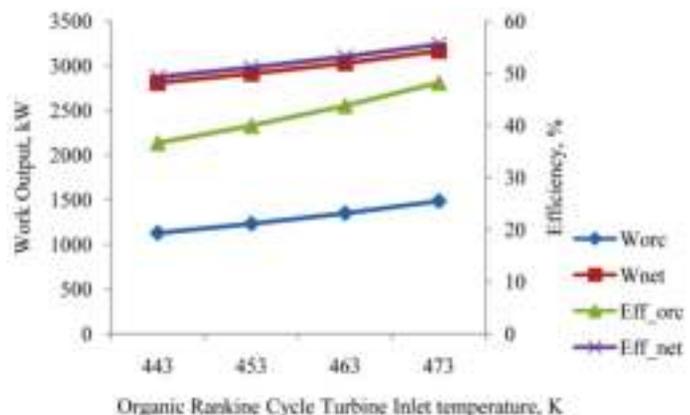
The results obtained through thermodynamic study of the solar powered combined arrangement to get the cooling and power simultaneously are shown in the graphs below along with their description.

**Figure 2** shows the work output generated and consumed in the energy system. The overall work output of the solar powered gas turbine increases from 1679 kW to 1971 kW at ambient temperature 300 K as the pressure ratio of the solar powered combined cycle rises from 8 to 16 bar. The work output of the combined cycle has also increased by 2013 following the integration of the Organic Rankine cycle in the Solar Assisted Gas Turbine cycle having pressure ratio of 6 and an input temperature of 463 K and it produces a 14.2 ton of refrigeration through the vapor absorption refrigeration system.

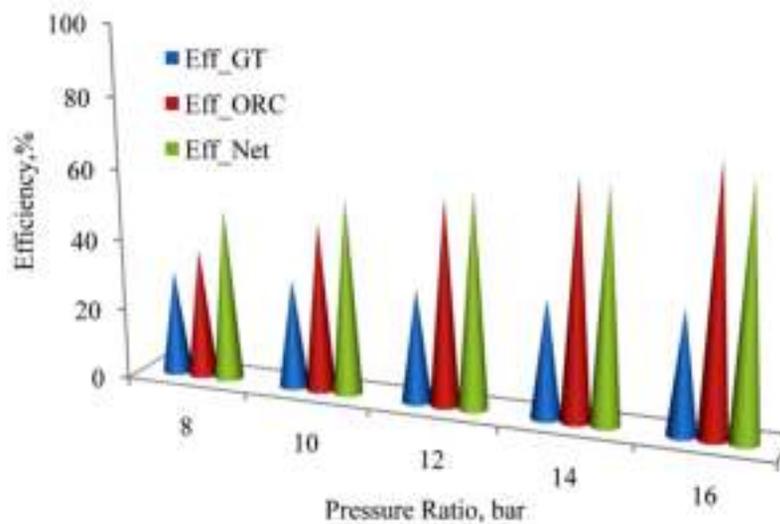
**Figure 3** represents the impact of the ORC turbine input temperature on the system and sub component performance. These performance parameters are efficiency and work output to see the impact of the variable. The output of the organic



**Figure 2** Pressure ratio vs work output



**Figure 3** Turbine inlet temperature of organic Rankine cycle vs work output vs efficiency



**Figure 4** Pressure ratio vs efficiency

Rankine cycle rises as the inlet temperature of organic Rankine cycle rises, which shows the great impact on the combined cycle's work output as well as the efficiency. The combined cycle's output rises from 2810 kW to 3166 kW as a result of the ORC's growth from 1129 kW to 1485 kW, at a pressure ratio of 6 bar for the organic Rankine cycle and 8 bar for the gas turbine cycle. As the inlet temperature of the ORC system raises from 443 K to 473 K then the performance of the combined arrangement increases.

**Figure 4** represents the impact of the pressure ratio on the efficiency of the sub component like ORC, gas turbine, and combined system to understand the share of percentage of efficiency involved in the combined system. The figure depicts that as pressure ratio increases from 8 to 16 like 8, 10, 12, 14, and 16 then efficiency of the sub system like gas turbine, ORC system, the overall system increases. This increment is cause of the improvement in the work output of the sub component of system like gas turbine output changes from 1680 kW to 1970 kW and work output of ORC changes from 1129 kW to 2013 kW. Therefore, the obtained efficiency of the gas turbine, ORC, and overall system are 34.5%, 73.9%, and 69.8% respectively for the input parameter of 6 bar pressure of the system, and 300 K ambient temperature along with the 463 K inlet temperature of the ORC turbine.

## CONCLUSION

The present study performs a parametric investigation of the combined solar driven arrangement for the power and cooling purpose. The conclusions made from the study are as follows:

- (i) The performance of the combined arrangement of solar powered gas turbine cycle with organic Rankine cycle and VARS is much better than the performance of the gas turbine standalone.
- (ii) Generated cooling effect through VARS may be utilized for any useful refrigeration purpose or to reduce the inlet air temperature of the compressor for improving the system performance.
- (iii) Rise of the cycle pressure ratio have a positive impact on the system performance parameters.

## REFERENCES

1. Khademi M, Ahmadi A, Dashti R, Shirmohammadi R. Thermoeconomic optimization of a solar-assisted supercritical CO<sub>2</sub> Brayton cycle, organic Rankine cycle and multi-effect distillation system. *Energy Reports*. 2022 Nov 1;8:13494-503.
2. Kumar P, Singh O. A review of solid oxide fuel cell based hybrid cycles. *International Journal of Energy Research*. 2022 Jun 10;46(7):8560-89.
3. Kumar P, Choudhary T, Ansari MZ. Thermodynamic assessment of a novel SOFC and intercooled GT integration



- with ORC: Energy and exergy analysis. *Thermal Science and Engineering Progress*. 2022 Sep 1;34:101411.
4. Jung C, Schindler D. On the influence of wind speed model resolution on the global technical wind energy potential. *Renewable and Sustainable Energy Reviews*. 2022 Mar 1;156:112001.
  5. Yi Chen, Dongjie Xu, Zheng Chen, Xiang Gao, Wei Han. Energetic and exergetic analysis of a solar-assisted combined power and cooling (SCPC) system with two different cooling temperature levels. *Energy Conversion and Management*. 15 February 2019;182: 497-507.
  6. Jiangjiang Wang, Zepeng Han, Zhimin Guan. Hybrid solar-assisted combined cooling, heating, and power systems: A review. *Renewable and Sustainable Energy Reviews*. November 2020; 133:110256.
  7. D.B.Jani. Simulation of solar-powered desiccant-assisted cooling in hot and humid climates. *Renewable Energy Systems-Modelling, Optimization and Control*. 2021, Pages 363-387.
  8. Bahram Ghorbani, Mehdi Mehrpooya, Milad Sadeghzadeh. Process development of a solar-assisted multi-production plant: Power, cooling, and hydrogen. *International Journal of Hydrogen Energy*. 6 November 2020; 45(55):30056-30079.
  9. Can Liu, Summary of gas turbine power generation technology based on solar power. *IOP Conf. Series: Earth and Environmental Science* 2019;300:042050.
  10. Ayou DS, Bruno JC, Saravanan R, Coronas A. An overview of combined absorption power and cooling cycles. *Renewable and Sustainable Energy Reviews*. 2013 May 1;21:728-48.
  11. Chowdhury MT, Mokheimer EM. Recent developments in solar and low-temperature heat sources assisted power and cooling systems: A design perspective. *Journal of Energy Resources Technology*. 2020 Apr 1;142(4):040801.
  12. Kumar P, Singh O. Thermo-economic analysis of SOFC-GT-VARS-ORC combined power and cooling system. *International Journal of Hydrogen Energy*. 2019 Oct 18;44(50):27575-86.
  13. Temiz M, Dincer I. Development and assessment of an onshore wind and concentrated solar based power, heat, cooling and hydrogen energy system for remote communities. *Journal of Cleaner Production*. 2022 Nov 10;374:134067.
  14. Ahmed S, Li Z, Javed MS, Ma T. A review on the integration of radiative cooling and solar energy harvesting. *Materials Today Energy*. 2021 Sep 1;21:100776.
  15. Chen Y, Xu J, Zhao D, Wang J, Lund PD. Exergo-economic assessment and sensitivity analysis of a solar-driven combined cooling, heating and power system with organic Rankine cycle and absorption heat pump. *Energy*. 2021 Sep 1;230:120717.
  16. Feng C, Yu Z, Liang W, Wang D. Energetic, exergetic and economic analysis and multi-objective optimization of two novel ammonia-water absorption combined power and cooling cycles driven by low-grade heat sources. *Energy Conversion and Management*. 2021 Nov 15;248:114781.
  17. Nami H, Anvari-Moghaddam A, Nemati A. Modeling and analysis of a solar boosted biomass-driven combined cooling, heating and power plant for domestic applications. *Sustainable Energy Technologies and Assessments*. 2021 Oct 1;47:101326.
  18. Siddiqui O, Dincer I. Design and assessment of a new solar-based biomass gasification system for hydrogen, cooling, power and fresh water production utilizing rice husk biomass. *Energy Conversion and Management*. 2021 May 15;236:114001.
  19. Hou H, Wu J, Ding Z, Yang B, Hu E. Performance analysis of a solar-assisted combined cooling, heating and power system with an improved operation strategy. *Energy*. 2021 Jul 15;227:120516.
  20. Sachdeva Jatin, Singh Onkar. "Comparative evaluation of solarized triple combined cycle for different ORC fluids". *Renewable Energy* 163:2021;1333-1342.



# Sustainable Development in Manufacturing of Lead Acid Battery

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**Abstract:** India Energy Storage Alliance (IESA), reports that the market for electric vehicles in India is expected to grow at a CAGR of 49% between 2021-30, with annual sales in the segment estimated to surpass 17 million units by 2030. This projected expansion is likely to be fuelled by a variety of factors including growing fuel prices, the entry of new competitors, advancements in EV technology, continuous support for subsidies from the central and state governments, as well as the planned implementation of emission standards. Due to the growing demand for e-rickshaws, Lead-Acid Batteries (LAB) continued to dominate the Indian EV ecosystem in 2021, accounting for 81% of the market. The objective is to study the Value Chain Analysis (VCA) of Lead Acid Battery Management Storage System for Sustainable Manufacturing of LAB in Chennai. The methodology adopted is collection of primary data on manufacturing by supporting activities like Infrastructure, Human Resource Management, Technology Development Procurement, and Primary Activities for production like inbound logistics, operations, outbound logistics, sales/marketing and service to get profit. The infrastructure need land, building of 1000 sqft area where 25% capital investment subsidy may be obtained from Government of Tamil Nadu under Capital Subsidy Scheme as announced in MSME Policy, 2021. HRM is requirement of 10 workers like 2 skilled, 3 semi-skilled, one each on helper, Manager, Accountant, Typist and Office Assistant where training on skill may be provided under Skill Development Training where Rs.2000 is refunded per employee for 6 months from Department of Industries and Commerce (DIC), Government of Tamil Nadu and Tamil Nadu Skill Development Corporation (TNSDC). Procurement of raw materials like lead from Pondicherry in turn from Australia and sulphuric acid from local market, technology development by using latest technology and marketing on primary activities like inbound logistics like raw materials (lead + sulphuric acid), operations using sophisticated machinery like furnace for lead plate manufacturing cost of Rs.1,30,000, die cost of Rs.60,000, cell grading machine cost of Rs.90,000, punching machine of Rs.40,000, intersect welding machine cost of Rs. 2 lakhs, heat sealing of Rs.2 lakhs, gas welding machine of Rs.20,000, 5 hp compressor of Rs.60,000, battery leakage test machine of Rs.80,000, charger of Rs.3,00,000 etc amounting to the project cost of Rs. 15 lakhs where 25% machinery subsidy may be obtained from DIC, outbound logistics cost of one LAB around Rs.2500 of 50 no's LAB per day for 25 days and 1250 nos per month, Marketing / sales of 1250 nos of LAB for hybrid two-wheeler vehicle (4 no's LAB \*12 v) and service station for LAB which exists in many places in Chennai. To conclude the Profit obtained on this VCA on manufacturing of LAB of 1250 no's is Rs. 8 lakhs per month. The total cost of conversion to hybrid two-wheeler is Rs.30,000 including controller, LAB, Hub motor etc. Government should give licence for use of hybrid vehicle where for every 100 km petrol engine may be used for 40 km and battery may be used for 60 km on the hybrid 100 cc two-wheeler.

**Keywords :** Sustainable Development; Manufacturing; Lead Acid Battery

## INTRODUCTION

India Energy Storage Alliance (IESA), reports that the market for electric vehicles in India is expected to grow at a CAGR of 49% between 2021-30, with annual sales in the segment estimated to surpass 17 million units by 2030. This projected expansion is likely to be fuelled by a variety of factors including growing fuel prices, the entry of new competitors, advancements in EV technology, continuous support for subsidies from the central and state governments, as well as the planned implementation of emission standards. Due to the growing demand for e-rickshaws, Lead-Acid Batteries (LAB) continued to dominate the Indian EV ecosystem in 2021, accounting for 81% of the market.

A cluster is a group of enterprises located within an identifiable and contiguous area (to a large extent) or a value chain that may go beyond a geographical area and producing same / similar products / complementary products/ services, which can be linked together by common physical infrastructure facilities. It must address their common challenges which is the core reason to take up the project under this scheme. The essential characteristics of enterprises in a cluster are (a) Similarity or complementarity in the methods of production, quality control and testing, energy consumption, pollution control, etc., (b) Similar level of technology and marketing strategies / practices, (c) Similar channels for communication among the members of the cluster, (d) Common market and skill needs and/ or (e) Common challenges

and opportunities that the cluster faces [1].

Ministry of MSME, GoI runs various schemes targeted at providing credit and financial assistances, skill development training, infrastructure development, marketing assistance, technological and quality upgradation [2]. One such Scheme offered by the Ministry to enhance the competitiveness of MSMEs is Micro and Small Enterprises Cluster Development Programme (MSE-CDP) with the following objectives: 1. Support sustainability of MSMEs by addressing common issues 2. Capacity Building of MSMEs for common supportive action 3. Create / upgrade Infrastructural Facilities in Industrial Estates / Clusters 4. Setting up of Common Facility Centres (CFCs) 5. Promotion of Advanced & Sustainable Manufacturing Technologies. Tamil Nadu Small Industries Development Corporation Limited (TANSIDCO) is the Nodal Agency for implementation of centrally sponsored MSE-CDP scheme in Tamil Nadu. Under the scheme, TANSIDCO has facilitated implementation of more than 40 clusters throughout the State. Tamil Nadu is number one in India on implementation of 26 Industrial Clusters for MSMEs. 16 are in various stages of implementation.

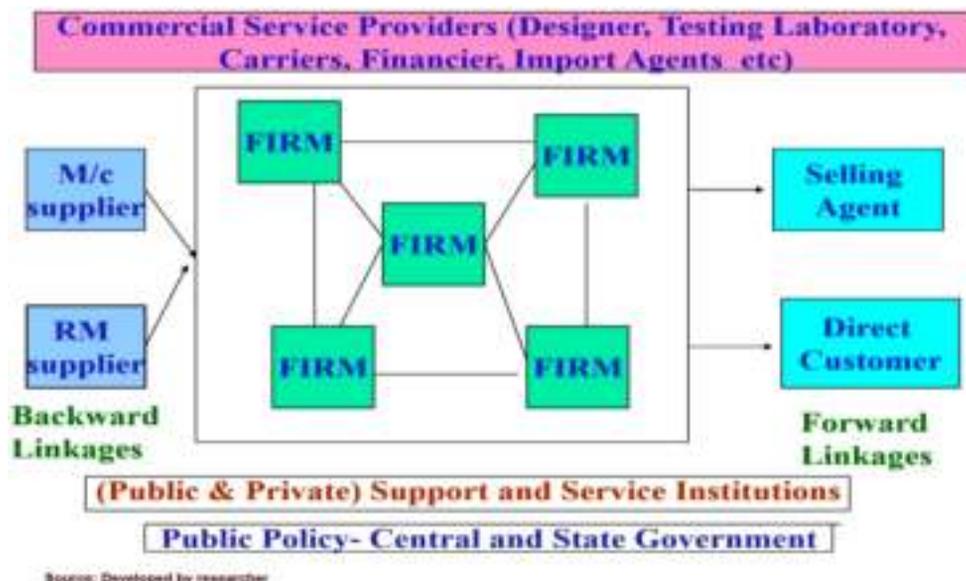
### TECHNICAL SURVEY

The completed CFC in Tamil Nadu are given in **Figure 2**[3].

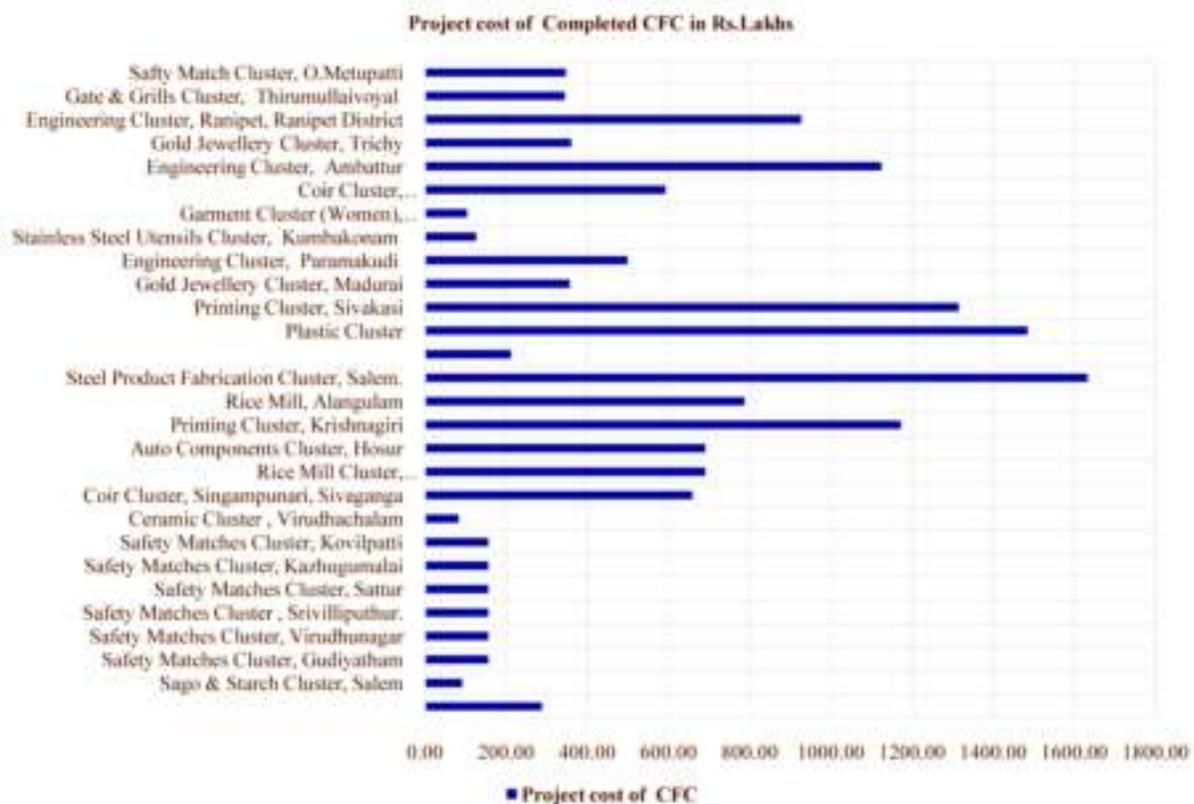
From the technical score and ranking of auto component manufactures, it is found that there is significant increase in technical efficiency of ACI after the CDA when compared to before CDA. The slack variables obtained clearly reveals the excess employment and net worth and no shortage of gross output. Government policy on CDA by intervention in interrelationships not only benefited Chennai Auto Cluster in general but also Chennai Auto Components Industries in particular[4].

There is increase in technical efficiency of not only Chennai auto cluster in general but also Chennai auto components industries in particular[5]. For sustainable development, the TC should strengthen infrastructure interrelationships, technology interrelationships, procurement interrelationships, production interrelationships and marketing interrelationships to decrease cost, increase productivity and efficiency to compete in the world market [6]. For inclusive growth and sustainable development, the inefficient ACC should increase their turnover and exports, as decrease in no. of enterprises and employment is practically not possible[7]. The variables are highly correlated and the inefficient industries should increase their gross output or decrease the fixed assets or employment [8]. The technical efficiency of LMC companies also increases significantly[9].

The Automotive Industries have fully utilized the Physical Infrastructure and Centralised Facilities by adopting CDA and now exporting their products to North America, South America, Europe, Australia, Africa and Asia. The value chain analysis models have been implemented in all the cluster units. This Cluster Development Approach (CDA) model can



**Figure 1** Cluster development approach



**Figure 2** Completed CFCs in Tamil Nadu

be implemented in industries of under developed and developing countries for cost reduction and productivity increase[10].

The variables are highly correlated, and for inclusive growth and sustainable development, the inefficient Engineering Industry at Hosur, Tamil Nadu should increase their Gross Value Added or decrease the employment or machinery[11]. The Chennai Automotive Industry Cluster Model demonstrates the fact that industrial units have utilised the physical infrastructure and centralised facilities by adopting cluster development approach[12]. There is need for Lead Acid Battery study on individual and cluster development approach.

### OBJECTIVES OF THE STUDY

The objective is

1. The objective is to study the Value Chain Analysis(VCA) of Lead Acid Battery Management Storage System for Sustainable Manufacturing of LAB in Chennai.
2. To study on LAB Cluster Model.
3. To find sustainable development of Lead Acid Battery Manufacturing enterprises.

### METHODOLOGY:

The methodology adopted is collection of primary data on manufacturing by supporting activities like Infrastructure, Human Resource Management, Technology Development Procurement, and Primary Activities for production like inbound logistics, operations, outbound logistics, sales/ marketing and service to get profit.

### TECHNICAL ANALYSIS

Value Chain Analysis



Figure 3 Value chain analysis

An individual firm to make profit should have support activities like firm infrastructure, Human Resource Management, Technology Development and Procurement and primary activities like inbound logistics, operations, outbound logistics, marketing, sales and services. As shown in **Figure 3**, in a cluster the firm infrastructure and HRM will be called as Infrastructure Interrelationships, Technology Development is called as Technology Interrelationships, raw material and machinery procurement is called as Procurement Interrelationships and the inbound logistics, operations and outbound logistics is called as Production Interrelationships, Finance, Marketing, sales and services is called as Marketing Interrelationships.

The value-chain concept as shown in **Figure 4** has been used to distinguish between cooperative strategies according to the type of resources pooled by the partners. This study is based on the value chain concept and integrated approach on cluster development (Porter). It has been discussed that Cluster Approach is a major motivating factor and enterprises are keen to accept the challenge to maximize their profits. Majority of enterprises are moderately satisfied with joint procurement of raw materials, marketing, production and finance.

### LAB CLUSTER MODEL

The LAB Cluster Model as shown in **Figure 5**, indicates the cluster level linkages of all actors namely, TIIC - Tamil Nadu Industrial Investment Corporation, SIDBI - Small Industries Development Bank of India, EXIM Bank - Export Import Bank, SIDCO - Small Industries Development Corporation, OE - Original Equipment, NATRIP - National Automotive Testing and R&D Infrastructure Project, ACMA - Automotive Components Manufacturers Association, AIEMA - Ambattur Industrial Estate Manufacturers Association, TACT- Tamil Nadu Association of Cottage and Tiny Industries, TANSTIA - Tamil Nadu Small and Tiny Industries Association, NSIC - National Small Industries Corporation, MSMEDI - Micro, Small and Medium Enterprises Development Institute, RTC- Regional Testing Centre, DIC - District Industries Centre, EEPC - Engineering Export Promotion Council, ITPO - Industrial Trade Promotion Organization, MOI- Ministry of Industry involved effectively in the formation and the supporting activities of Cluster. From the outcome of the present study, it is obvious that LAB Cluster at Chennai has significant interrelationships among the enterprises. One Location of the clusters plays a crucial role in the integrated study. Constant involvement of industrial units in the cluster will improve their performance. The costs of the industrial units have considerably reduced due to the intervention and the profit increased sizably. The policy planners can identify the parameters of industrial growth in different locations of the region using Cluster Development Approach. The outcome of Cluster Development Approach will attract the financial investors to concentrate more on specified industrial centres for investment. This will improve the economic status of the region for overall development. The Cluster Model indicates the cluster level linkages of all actors involved effectively in the formation and the supporting activities of LAB Cluster.

The total cost of conversion to hybrid two-wheeler is Rs.30,000 including controller, LAB, Hub motor etc. Government should give licence for use of hybrid vehicle where for every 100 km petrol engine may be used for 40 km and battery may be used for 60 km on the hybrid 100 cc two-wheeler.

### FINDINGS, SUGGESTIONS AND CONCLUSION

A Study conducted on the Value Chain Analysis(VCA) of Lead Acid Battery Management Storage System for Sustainable Manufacturing of LAB in Chennai, to study on LAB Cluster Model and to find sustainable development of



Support Activities	<b>Infrastructure</b>	The infrastructure need land, building of 1000 sqft area where 25% capital investment subsidy may be obtained from Government of Tamil Nadu under Capital Subsidy Scheme as announced in MSME Policy, 2021.			Infrastructure Interrelationships		
	<b>Human Resource Management</b>	HRM is requirement of 10 workers like 2 skilled, 3 semi-skilled, one each on helper, Manager, Accountant, Typist and Office Assistant where training on skill may be provided under Skill Development Training where Rs.2000 is refunded per employee for 6 months from Department of Industries and Commerce(DIC), Government of Tamil Nadu and Tamil Nadu Skill Development Corporation(TNSDC).					
	<b>Technology Development</b>	Technology development by using latest technology			Technology Interrelationships		
	<b>Procurement</b>	Procurement of raw materials like lead from Pondicherry in turn from Australia and sulphuric acid from local market,			Procurement Interrelationships		
	<b>Primary Activities</b>	<p>primary activities like inbound logistics like raw materials (lead – sulphuric acid), operations using sophisticated machinery like furnace for lead plate manufacturing cost of Rs.1,30,000, die cost of Rs.60,000, cell grading machine cost of Rs.90,000, punching machine of Rs.40,000, intersect welding machine cost of Rs. 2 lakhs, heat sealing of Rs.2 lakhs, gas welding machine of Rs.20,000, 5 hp compressor of Rs.60,000, battery leakage test machine of Rs.80,000, charger of Rs. 3,00,000 etc, amounting to the project cost of Rs. 15 lakhs where 25% machinery subsidy may be obtained from DIC,</p> <p>Outbound logistics cost of one LAB around Rs.2500 of 50 no's LAB per day for 25 days and 1250 nos per month,</p>	Marketing / sales of 1250 nos of LAB for hybrid two-wheeler vehicle (4 no's LAB *12 v) and Service station for LAB which exists in many places in Chennai.	Profit obtained on this VCA on manufacturing of LAB of 1250 no's is Rs. 8 lakhs per month.	PROFIT – Rs. 8 lakhs per month.		
		<b>Inbound Logistics</b>	<b>Operations</b>	<b>Outbound Logistics</b>		<b>Marketing / Sales</b>	<b>Service</b>
		<b>Production Interrelationships</b>				<b>Marketing Interrelationships</b>	
Source: Developed by Researcher							

Figure 4 Value chain analysis for LAB cluster

Lead Acid Battery Manufacturing enterprises.

The Government of India and Tamil Nadu policy on Cluster Development Approach is an important one for MSMEs. As per Value Chain Analysis and Cluster Map the profit earned per enterprises increases. There will be increase in Common Facility Centre utilisation after technology intervention. This leads to productivity increase due to adoption of cluster development approach. The cluster development is one of excellent concept for developing MSE's for that GOI and GOTN are supporting through TANSIDCO and MSME-DFO as implementing agency. All the departments in the State as well as Central are very Co-operative during the implementation of the project. The interrelationships / cluster

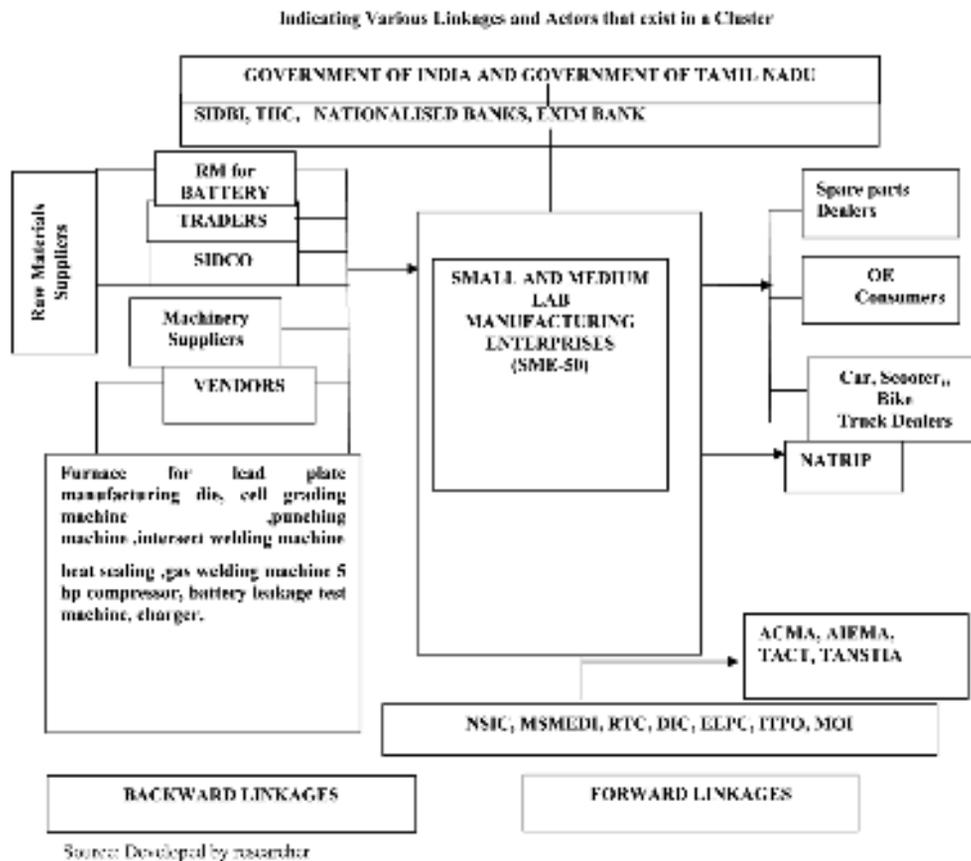


Figure 5 Lab cluster model

approach made by Cluster members to make use of interrelationships like Infrastructure, Procurement, Technology, Production and Marketing successfully.

#### ACKNOWLEDGMENT

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#### REFERENCES

1. <http://www.dcmsme.gov.in/schemes/New%20MSE-CDP.pdf> assessed on 31.07.22
2. Performance Study of Common Facility Centres, ITCOT, July 2022, pp.1
3. MSME Department, Policy Note 2021-22, pp 145-148
4. E Bhaskaran, The Technical Efficiency of Chennai Auto Industry Cluster, SAE Technical Paper 2011-28-0100, 2011, <https://doi.org/10.4271/2011-28-0100>
5. E Bhaskaran, Technical Efficiency of Automotive Industry Cluster in Chennai. J. Inst. Eng. India Ser. C 93, 2012, pp 243–249, <https://doi.org/10.1007/s40032-012-0029-x>
6. E Bhaskaran, The Productivity and Technical Efficiency of Textile Industry Clusters in India. J. Inst. Eng. India Ser. C 94, 2013, pp 245–251. <https://doi.org/10.1007/s40032-013-0073-1>
7. E Bhaskaran, E. Sustainable Development in Indian Automotive Component Clusters. J. Inst. Eng. India Ser. C 94, 2013, pp 81–84. <https://doi.org/10.1007/s40032-012-0039-8>



8. E Bhaskaran, The Productivity Analysis of Chennai Automotive Industry Cluster. *J. Inst. Eng. India Ser. C* 95, 2014, pp 239–249, <https://doi.org/10.1007/s40032-014-0120-6>
9. E Bhaskaran, Lean Manufacturing Auto Cluster at Chennai. *J. Inst. Eng. India Ser. C* 93, 2012, pp 383–390, <https://doi.org/10.1007/s40032-012-0035-z>
10. E Bhaskaran, The Quantitative Analysis of Chennai Automotive Industry Cluster. *J. Inst. Eng. India Ser. C* 97, 2016, pp 357–373. <https://doi.org/10.1007/s40032-016-0255-8>
11. E Bhaskaran, The Technical Efficiency of Engineering Industry Cluster at Hosur, SEDME (Small Enterprises Development, Management & Extension Journal, <https://journals.sagepub.com/doi/10.1177/0970846419852518>
12. E Bhaskaran, Qualitative Analysis and Impact Assessment of Chennai Automotive Cluster, <https://journals.sagepub.com/doi/abs/10.1177/0970846420180302>
13. TANSIDCO Coffee Table Book about CFCs in Tamil Nadu, 2020, pp-21-23
14. Performance Report of Cluster submitted to TANSIDCO during 2021.
15. Ministry of MSME, Government of India <https://cluster.dcmsme.gov.in/> assessed on 28.07.2022





# Material Selection in Engineering Design by Multivariate Analysis

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**Abstract:** Selection of material selection in engineering design takes a vital role in fulfilling all functional requirements as well as to make the element economically competitive in the market. The multi attributed decision-making (MCDM) methods are popular and being used for two decades to evaluate the alternatives. In some methods under MCDM, the alternatives are considered in  $n$ -dimensional Euclidian space where criteria or attributes of an alternative are considered as uncorrelated, but sometimes the attributes are highly correlated. For example, in product design, the material cost is highly correlated with the material properties. However, In the MCDM methods, there is some lack of precise analysis to address the correlation among the attributes. Therefore, in this paper, the alternatives are evaluated on Multivariate Analysis which a statistical analysis introducing the Mahalanobis Distance with Cosine Similarity. Choice of a gear material is considered as a case study and analysis shows the preeminent material is Carburised Steel which is consistent with the previous researchers work.

**Keywords:** Mechanical Design; Material Selection; Multi Attributed Decision-making; Multivariate Analysis; Mahalanobis Distance; Cosine Similarity

## INTRODUCTION

Engineering design is a sequential decision-making process. that requires a well trade-off between shape, materials, and manufacturing. Decision-making about material selection in engineering design takes a vital role in fulfilling all functional requirements as well as to make the element economically competitive in the market. Decision-making is the process of alternatives generation followed by alternatives evaluation. Typically, in the field of engineering design, Pugh Chart and Pahl and Beitz method are well-pronounced to evaluate the design alternatives. At the same time, multi-attributed decision-making (MADM) methods are being popular for two decades to evaluate the alternatives. In all the cases, the attributes of an alternative are considered as uncorrelated, but sometime the attributes are highly correlated. For example, in product design, the material cost is highly correlated with the material properties. However, In the above-mentioned methods, there is some lack of precise analysis to address the correlation among the attributes. The aim of this proposed paper is to overcome the above-mentioned discrepancy by introducing the Mahalanobis Distance from the domain of Multivariate Analysis along with cosine similarity to select a preeminent material.

## MATERIAL SELECTION AND METHODOLOGIES

In engineering design, Pahl and Beitz method and Pugh's method are generally used to evaluate the alternatives from performance ratings (decision matrix) of  $i$ th alternative with  $j$ th attribute [1,2]. The Pugh's method is a comparison method in which the alternatives are compared with the known datum alternative considering the equal weightage to the attributes. Pahl and Beitz method is a weightage sum method that requires normalized performance ratings with assigned weightage to the attributes. Due to the importance of reliability, in product design, the acceptability of the candidate materials is analyzed against multiple attributes rather than considering a single attribute. These two evaluation methods can be regarded as a multiple attribute decision-making process (MADM) where the decision space is discrete. There are also many MADM processes that are becoming popular due to its user-friendly nature to select the best alternative from the finite number of alternatives. Some of the popular MADM models in material selection point of view are:

- Scoring model that selects an alternative which deserves the maximum score, such as, MAUT [3], SAW [4], FUZZY logic [5] and AHP [6].
- Compromising model that skims off an alternative which is closest to the ideal solution, such as, TOPSIS [7] and VIKOR [8].



- Outranking model that arranges a set of performance relations among alternatives to acquire information on the best alternative, such as, ELECTRE [9] and PROMETHEE [10].

In the above discussion, the TOPSIS and VIKOR are widely used. In most of the cases, different types of normalization process are suggested and implemented [11], but the basic structure of overall performance analysis of the alternatives in all processes is same. Cables, et al [12] proposed a method, RIM (reference ideal method) where the only ‘ideal point’ is considered as a reference point (in case of TOPSIS, there is ‘ideal point’ and ‘negative ideal point’) and the outcomes are compared with TOPSIS and VIKOR methods. Lourenzutti and Krohling[13] introduced the Hellinger distance in TOPSIS (H-TOPSIS) whereas the original TOPSIS is based on Euclidean distance.

### GAPANALYSISANDAIM

From the above discussion, some of the methods [12,13] can be regarded to certain extent as a nearest neighbor search (NNS) approaches [14]. Nearest neighbor search is the finding of a point (a) in a given set which is nearer to a reference point or query point (q) in multi-dimensional Euclidean space where the axes are drawn right angle to each other. All the methods are structured with strong mathematical background and can be regarded as deterministic choice theory and choice is made taking the observed data with uncorrelated attributes. If there is correlation exists among attributes then the axes are no longer right angle to each other. Therefore, in maldistributed decision making, the alternatives should be considered in Multivariate space. At this point, very specifically, the aim of this paper is to select the preeminent material in design based on NNS on the basis of cosine similarity by introducing the Mahalanobis Distance from the domain of Multivariate Analysis [15]. If the points (alternatives) are mapped in the non-Euclidean n-dimensional space, then we can easily visualize and compare the points with the query point. The designers rather enjoy the spatial relationship which gives a confidence and courage under uncertainty.

### IMPLEMENTATION OF THE PROPOSED MODEL

The proposed approach does not consider the traditional NNS-methods, but the basic definition of the NNS i.e., searching the nearness of a set of points ( $a_{i=1,2,\dots,m}$ ) to a query point (q) by means of a distance parameter in multivariate space (n-dimensional non-Euclidean space) shown in **Figure 1**. In multivariate analysis, the query point can be considered as an outlier. From the material selection point of view, the absolute nearness or similarity between  $a_i$ (alternatives) and q(reference alternative) depends upon the length of the position vectors ( $|oa_i|$ ,  $|oq|$ ) and the angle between the vectors ( $\theta_i$ ). Cosine similarity is a popular approach[16,17] that investigates the similarity among alternatives and given by,

$$\cos \theta_i = \frac{oa_i \cdot oq}{|oa_i| \cdot |oq|} \quad (i = 1, 2, \dots, m) \quad (1)$$

Therefore, the comparison between  $a_i$  and q is the function of the length and orientation of the alternatives. Now the question is that which distance parameter should be considered, Euclidean distance ( $l_2$  norm) or Manhattan distance ( $l_1$  norm) or Mahalanobis distance. Our decision favours the Mahalanobis distance. Given a probability distribution o on  $R^n$ , with mean  $\mu = (\mu_1, \mu_2, \mu, \dots, \mu_n)^T$  and positive-definite covariance matrix S, the Mahalanobis distance of a point “x”= $(x_1, x_2, x_3, \dots, x_n)^T$  from o is,

$$d_M(a_i, o) = |oa_i| = \sqrt{(x - \mu)^T S^{-1} (x - \mu)} \quad (2)$$

and given an outlier query point "y"= $(y_1, y_2, y_3, \dots, y_n)^T$  from o is,

$$d_M(q, o) = |oq| = \sqrt{(y - \mu)^T S^{-1} (y - \mu)} \quad (3)$$

A set of alternatives (A) with performance ratings (D) is decided according to the design requirements. Performance is the measure of effectiveness in the form of attributes (E). Attributes are set according to the demands and desires of the design requirements and can be split up in benefit and cost attributes. As this paper investigate the nearness or similarity to the query point, the weightage to the attributes is not required. Therefore, a designer is free from assigning weightage to the attributes. The steps are followed to capture the preeminent alternative:

Step 1: A set of alternatives with performance ratings in the form of attributes.

$$A = \{a_i | i = 1, 2, \dots, m\} \quad (4)$$

$$E = \left\{ e_j \mid \begin{array}{l} j = 1, 2, \dots, n-r; \\ j = n-r+1, \dots, n \end{array} \right\} \quad (5)$$

benefit attribute
cost attribute

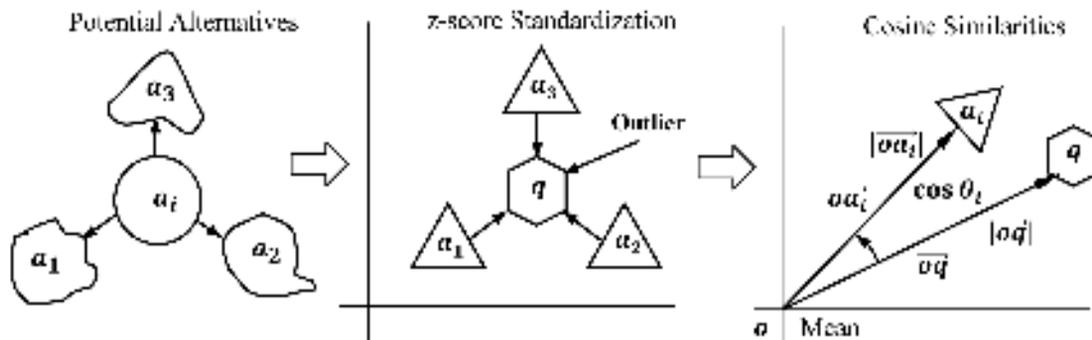


Figure 1 Spatial representation of alternatives and choice parameter in non-Euclidean space

$$D = \{d_{ij} | i = 1, 2, \dots, m; j = 1, 2, \dots, n\} \quad (6)$$

Step 3: z-score standardization of the performance rating matrix.

$$x_{ij} = \frac{d_{ij} - \mu^d_j}{\sigma_j} \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (7)$$

where, the mean,  $\mu^d_j = \frac{\sum_{i=1}^m d_{ij}}{N}$  and the standard deviation,  $\sigma_j = \sqrt{\frac{1}{N} \sum_{i=1}^m d_{ij}^2}$ .

Step 5: Query alternative q with standardized performance ratings.

$$q = \{y_j(\max x_{ij}) | j = 1, 2, \dots, n \quad r; y_j(\min x_{ij}) | j = n+1, \dots, n\} \quad (8)$$

Step 5: Mean of the distribution o from standardize z-score and of course it will be zero and o can be considered as an origin.

$$\bar{o} = \left\{ \mu^s_i \left( \frac{\sum_{j=1}^n x_{ij}}{n} \right) \mid i = 1, 2, \dots, n \right\} \quad (9)$$

Step 6: Mahalanobis distance in non-Euclidean  $R^n$  space following (2) and (3).

$$|\sigma \alpha_i| = \sqrt{(x_{ij} - \mu^s_j)^T S^{-1} (x_{ij} - \mu^s_j)} \quad (10)$$

$$|\sigma q| = \sqrt{(y_j - \mu^s_j)^T S^{-1} (y_j - \mu^s_j)} \quad (11)$$

Step 7: Cosine similarity following (1).

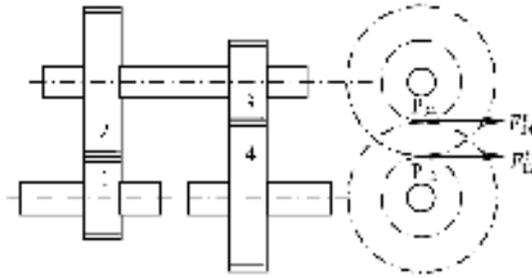
$$\cos \theta_i = \frac{\sum_{j=1}^n (x_{ij} - \mu^s_j)(y_j - \mu^s_j)}{|\sigma \alpha_i| |\sigma q|} \quad i = 1, 2, \dots, m \quad (12)$$

The value of  $\cos \theta_i$  lies between +1 and -1. The alternatives are ranked according to the maximum value of the  $\cos \theta_i$ .

#### A. Case Study: Selection of Gear Material

Gear reducers are used in all industries e.g., automobile, aerospace, marine gearboxes etc. They reduce speed and increase torque. An industrial gearbox is defined as a machine for the majority of drives requiring a reliable life and factor of safety. Spur gears are easier to manufacture and inspect than helical gears, and they can be rectified more easily at the assembly stage if required. In gear design, two types of failure are generally considered. First the bending failure due to the tangential load (F12, F34) through the pitch point (P12, P34) that causes bending stress (**Figure 2**). Second, the surface fatigue failure known as pitting due to the load along the line of action through the pitch point that causes contact stress. Higher core hardness at the pitch circle diameter can drastically reduce impact energy absorption characteristics of the material and that causes a micro crack on the teeth. From the above-mentioned discussion and multi-attributed decision-making point of view, all attributes can be categorized as:

- Benefit attribute: Surface hardness ( $e_1$ ), Surface fatigue limit ( $e_2$ ), Bending fatigue limit ( $e_3$ ), and Ultimate tensile strength ( $e_4$ ).
- Cost attribute: Core hardness ( $e_5$ )



**Figure 2** Two stage spur gear reduction unit

Some of the featured candidate materials in the ferrous domain for spur gear with performance ratings under specific condition are shown in Table 1 following the expression (4) to (6) [18]. The z-score standardize performance ratings are tabulated in **Table 2** following (7). From **Table 2** and following (8), the query alternative (q) with performance ratings and the mean (o) following (9) are given by,

$$q = [1.7104, 1.8474, 1.7657, 2.2003, -1.5052] \quad (13)$$

$$o = [0, 0, 0, 0, 0] \quad (14)$$

The overall performances of the alternatives are evaluated through the expressions (10) to (14) are also tabulated in **Table 2**.

## RESULTS AND DISCUSSION

The analysis shows the preeminent material is Carburized Steel as ranked 1 material in Table 2, which is a consistent result with the previous works and real-world practice. Speciality of this proposed approach, it does require weightage to the attributes that is the great advantage. Now it is the time to check the consistency of the ranking of the materials in Table 2 with previous works as:

- Proposed method with z-score standardization: 8-6-9-7-4-2-1-3-5;
- TOPSIS with vector normalization [19]: 9-8-6-5-4-2-1-3-7;
- PROMETHEE with max-min normalization [18]: 9-8-6-5-4-3-1-2-7;

Generally, the material properties are considered as discrete and average, but these are rather variable in nature. The true value cannot be known precisely (aleatory uncertainty). As the material selection takes place at the conceptual stage of the design process. It is further analyzed and check the suitability of the chosen material at the embodiment stage.

**Table 1** Performance ratings matrix (dij) of the case study

Alternatives (a <sub>j</sub> )	Surface Hardness	Surface Fatigue limit	Bending Fatigue limit	Ultimate Tensile Strength	Core Hardness
	e <sub>1</sub>	e <sub>2</sub>	e <sub>3</sub>	e <sub>4</sub>	e <sub>5</sub>
a <sub>1</sub> Cast iron	200	330	100	380	200
a <sub>2</sub> Ductile iron	220	460	360	880	220
a <sub>3</sub> S.G. iron	240	550	340	845	240
a <sub>4</sub> Cast alloy steel	270	630	435	590	270
a <sub>5</sub> Through hardened alloy steel	270	670	540	1190	270
a <sub>6</sub> Surface hardened alloy steel	585	1160	680	1580	240
a <sub>7</sub> Carburised steels	700	1500	920	2300	315
a <sub>8</sub> Nitrided steels	750	1250	760	1250	315
a <sub>9</sub> Through hardened carbon steel	185	500	430	635	185



**Table 2** Standardize performance ratings matrix, Mahalanobis distance cosine similarity and ranking of the case study

Alternatives	z-score standardization ( $x_{ij}$ )					$ \overline{oa}_i $	$ \overline{oq}_i $	$\cos\theta_i$	Rank
	$e_1$ (max)	$e_2$ (max)	$e_3$ (max)	$e_4$ (max)	$e_5$ (min)				
$a_1$	-0.8321	-1.1686	-1.7119	-1.2406	-1.1608	2.1220	5.4342	-0.5805	8
$a_2$	-0.7396	-0.8335	-0.6298	-0.3445	-0.7016	2.0307	5.4342	-0.3279	6
$a_3$	-0.6472	-0.6015	-0.7153	-0.4072	-0.2424	1.1776	5.4342	-0.6270	9
$a_4$	-0.5085	-0.3953	-0.3089	-0.8642	0.4464	2.4398	5.4342	-0.5559	7
$a_5$	-0.5085	-0.2921	0.1402	0.2111	0.4464	1.9755	5.4342	-0.1276	4
$a_6$	0.9477	0.9710	0.7391	0.9100	-0.2424	1.9728	5.4342	0.6610	2
$a_7$	1.4793	1.8474	1.7637	2.2003	1.4797	2.4203	5.4342	0.8877	1
$a_8$	1.7104	1.2030	1.0813	0.7186	1.4797	2.7628	5.4342	0.7684	3
$a_9$	-0.9014	-0.7304	-0.3303	-0.7836	-1.5052	2.5269	5.4342	-0.2136	5

**CONCLUSIONS**

Engineering design process is the judicious trade-off between shape, materials, and manufacturing that requires a wide range of organized decisions. Decision-making in engineering design allocates all the resources optimally while fulfilling all the design objectives. It is the versatility of the MADM approaches blended with mathematics and cognitions that different decision-making methods yield different rankings considering the same input data. The proposed method addresses the correlation between the attributes considering covariance matrix. Another advantage of this proposed method that it does not require weightage calculation of the attributes which gives relax to the designers. At the same time the proposed method need to be checked further in different field.

**REFERENCES**

1. K. Otto, K. Wood, Product Design: Techniques in Reverse Engineering and New Product Development, 1st ed. Pearson Education, 2001
2. G. Pahl, W. Beitz, Engineering Design. London / Berlin: The Design Council/Springer-Verlag, 1998
3. L. Yuan-pei, M. Qing-chun, L. Feng, X. Guang-xing, G. Zhi-dong, "Aircraft design material-selection Method based on MAUT theory," J Aeronautical Materials, vol. 30(3)L, pp. 88-94, 2010.
4. C. Kahraman, S. Birgun, V.Z. Yenen, "Fuzzy multi-attribute scoring methods with applications," In: Kahraman C., editor. Fuzzy Multi-criteria decision making, Theory and applications with recent developments, New York: Springer; 2008, pp. 187-207.
5. F.T.S. Chan, N. Kumar, M.K. Tiwari, H.C.W. Lau, and K.L. Choy, "Global supplier selection: a fuzzy-AHP approach," International Journal of Production Research, vol. 46, pp. 3825-3857, 2008.
6. S. Mujgan, M.S. Ozdemir, R.N. Gasimov, "The analytic hierarchy process and multi objective 0-1 faculty course assignment," Eur J Oper Res, vol. 157, pp. 398-408, 2004.
7. N. Gupta, "Material selection for thin-film solar cells using multiple attribute decision making approach," Mater and Des, vol. 32, pp. 1667-71, 2011.
8. S. Opricovic, and T. Gwo-Hshiung, "Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS," European Journal of Operational Research, vol. 156, pp. 445-455, 2004.
9. A. Shanian, A.S. Milani, C. Carson, R.C. Abeyaratne, "A new application of ELECTRE III and revised Simos' procedure for group material selection under weighting uncertainty," Knowledge-Based Systems, vol. 21, pp. 709-720, 2008.
10. A. Peng, K. Xiao, "Material selection using PROMETHEE combined with analytic network process under hybrid environment," Mater and Des, vol. 30, pp. 643-652, 2013;
11. K. Fayazbakhsh, A. Abedian, B.D. Manshadi, and R.S. Khabbaz, "Introducing a novel method for materials selection in mechanical design using Z transformation in statistics for normalization of material properties,"



- Materials & Design, vol. 30, pp. 4396-4404, 2009.
- 12 E. Cables, M.T. Lamata, J.L.Verdegay, "RIM-reference ideal method in multicriteria decision making," *Information Sciences*, vol. 337-338, pp. 1-10, 2016.
  - 13 R. Lourenzutti, R.A. Krohling, "The Hellinger distance in Multicriteria Decision Making: An illustration to the TOPSIS and TODIM methods," *Expert Systems with Applications*, vol. 41, pp. 4414-4421, 2014.
  - 14 M. Barrena, E. Jurado, P.M. Neila, P. C. Pachon, "A flexible framework to ease nearest neighbor search in multidimensional data spaces," *Data & Knowledge Engineering*, vol. 69, pp. 116-136, 2010.
  - 15 P. C. Mahalanobis, "On the generalized distance in statistics," *Proceedings of the National Institute of Sciences (Calcutta)*, vol. 2, pp. 49-55, 1936.
  - 16 P. Xia, L. Zhang, F. Li, "Learning similarity with cosine similarity ensemble," *Information Sciences*, vol. 307, pp. 39-52, 2015.
  - 17 G. Kou, C. Lin, "A cosine maximization method for the priority vector derivation in AHP," *European Journal of Operational Research*, vol. 235, pp. 225-232, 2014.
  - 18 P. Chatterjee, S. Chakraborty, "Material selection using preferential ranking method," *Mater. Des.*, vol. 35, pp. 384-393, 2012.
  - 19 A S Milani, A Shanian, R Madoliat and J A Nemes, The effect of normalization norms in multiple attribute decision making methods: a case study in gear material selection, *Struct. Multidisc. Optim.* 29, 2005, pp. 312-318.

# Comparative Analysis and Pros & Cons of Evaluation of Different Methods for Flange Leakage in Process Plant Critical Piping

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**Abstract:** For any industrial process plant, be it a thermal power station, or a refinery/petrochemical plant, or steel/non-ferrous metallurgical plant, the critical piping, which convey different process and utility fluids viz. hydrocarbons, steam, chemicals, toxic and flammable gases, or even water, are the arteries and veins of those installations, and constitute of approximately 20% to 35% of total plant cost. These piping systems operates at very high pressures and temperatures, and a single failure of a small part of these piping may lead to catastrophic failure and long shut down of the plant, and even may result into severe tragedy in terms of loss of human life, loss of property, and irreversible environmental degradation. These critical pipes are normally connected to nozzles of different static/rotating equipment such as towers, columns, furnaces, heat exchangers, pressure vessels, turbines, compressors, pumps, fans & blowers, etc., they tend to transfer large forces and moments on the nozzles of connected equipment, which often exceeds the allowable forces and moments for those pieces of equipment specified in respective codes & standards and/or guidelines of equipment manufacturers. Due to this, equipment nozzles are over-stressed and it often leads to misalignment of the equipment, and/or leakage from the nozzle flange. Also, in piping system of any process plant, there are innumerable valves, which, in majority cases, are installed in piping system between flanges. For critical piping of the industrial plants, pipe stress analysis per applicable codes are performed to ensure the code-compliant design of the piping with respect to allowable stress specified in relevant code. This also includes ensuring that neither of the nozzle flanges nor the counter flanges for valves are over-stressed causing flange leakage, as flange leakage is a matter of extreme concern & attention in process industry and it has a tremendous potential to cause severe hazard to plants & lives. Hence, the possibility of flange leakage needs to be investigated during the design stage and probability of leakage are to be minimized during operation of the plants. Pipe stress analysis methods and software commonly deal with three approaches of flange leakage analysis, viz. (i) Equivalent Pressure method based on ASME B16.5 pressure temperature tables, (ii) ASME BPVC Sec VIII Div. 1 Appendix 2 method, and (iii) ASME NC-3658.3 method each of which has their respective pros & cons. This paper intends to capture comparison of different approaches of flange leakage evaluation in piping stress analysis in order to ensure system integrity, safety and economy to the fullest extent.

**Keywords:** Plant; Piping; Flange; Leakage; Safety; Stress Analysis

## INTRODUCTION

In any industrial establishment, be it a thermal power station, or a refinery/petrochemical plant, or metallurgical plant, the critical piping, which convey different process and utility fluids such as hydrocarbons, steam, chemicals, toxic and flammable gases, or even water, play the role of arteries and veins of the respective installations, and constitute of approximately 20% to 35% of total plant cost, requires 30% to 40% of the erection labor, and consumes 40% to 48% of the engineering man-hours. The actual importance of piping installation, however, is far beyond these percentages. A complete piping system is composed of a large number of components. The failure of just one single component has the potential to shut down the entire plant or, worse yet, cause serious public safety problems [1]. These piping systems operates at very high pressures and temperatures, and a single failure of a small part of these piping may lead to catastrophic failure and long shut down of the plant, and even may result into severe tragedy in terms of loss of property, environmental degradation and loss of human life. These critical pipes are normally connected to nozzles of different static equipment such as towers, columns, furnaces, heat exchangers, pressure vessels, or rotating equipment such as turbines, compressors, pumps, fans and blowers, they tend to transfer large forces and moments on the nozzles of connected equipment, which often exceeds the allowable forces and moments for those pieces of equipment specified in respective codes and standards and/or guidelines of equipment manufacturers. Due to this, equipment nozzles are over-stressed and it often leads to misalignment of the equipment, and/or leakage from the nozzle-piping junction. Also, in piping system of any process plant, there are innumerable valves, which, in majority cases, are installed in piping system

between flanges. For critical piping of the industrial plants, pipe stress analysis per applicable codes are performed to ensure the code-compliant design of the piping with respect to allowable stress specified in applicable code. This also includes ensuring that neither of the nozzle flanges nor the counter flanges for valves are over-stressed causing flange leakage, as flange leakage can cause a major catastrophe such as environmental contamination, fire, or even a vapor cloud explosion which can destroy an entire plant, and even a habitation. Therefore, any and all phases of pipe and vessel flange engineering must be treated with complete competence and with the greatest amount of precision.

### PIPE STRESS ANALYSIS

A pipe stress analysis is, of course, an analysis of the stresses in the pipe. But when asked what they analyse, many engineers hesitate to answer. When the engineer began analysing piping systems in his 1950s and his 1960s, he had only one thing in mind. It was to calculate stress from thermal expansion. In other words, we checked the piping layout to determine if the piping system was flexible enough to accommodate thermal expansion due to temperature changes. This analysis is called a pipeline flexibility analysis. Since then, as technology has advanced, pipe stress analysis has included more than just flexibility checks. However, many engineers still refer to pipe stress analysis as flexibility analysis. However, focusing on thermal flexibility as the only consideration in a pipe stress analysis can result in an expensive and unsafe substandard design. For example, many engineers believe that adding flexibility to piping systems is a conservative approach. In practice, adding flexibility not only increases material cost and pressure loss, but also makes the pipe more prone to vibration. This is the biggest problem area for plumbing in service. If that is the picture, 1 is used to move liquid hydrocarbons between storage tanks and process equipment by centrifugal pumps. The stress analyst must

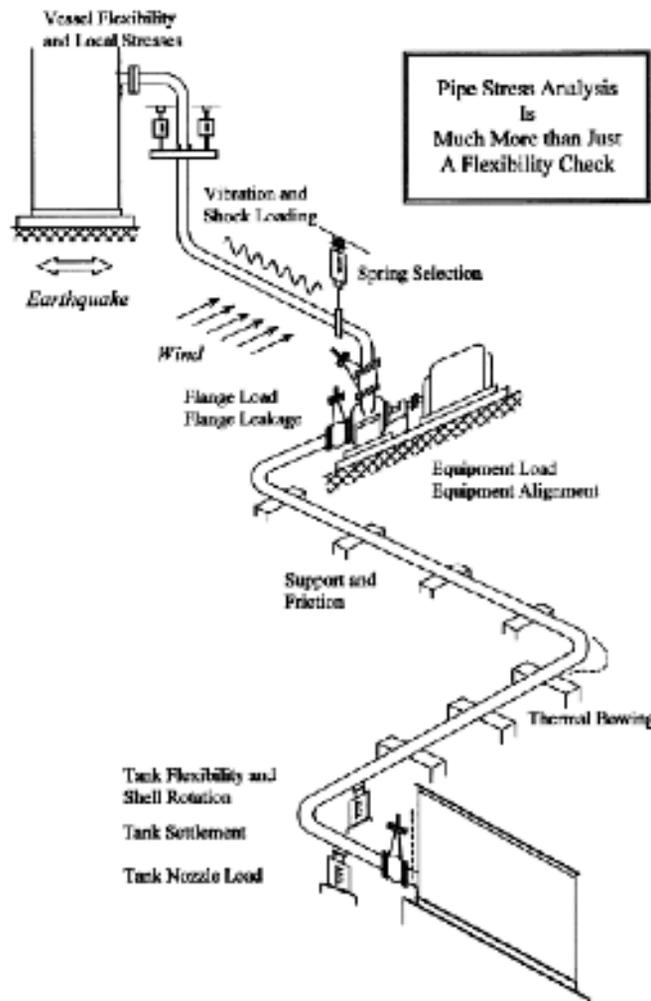
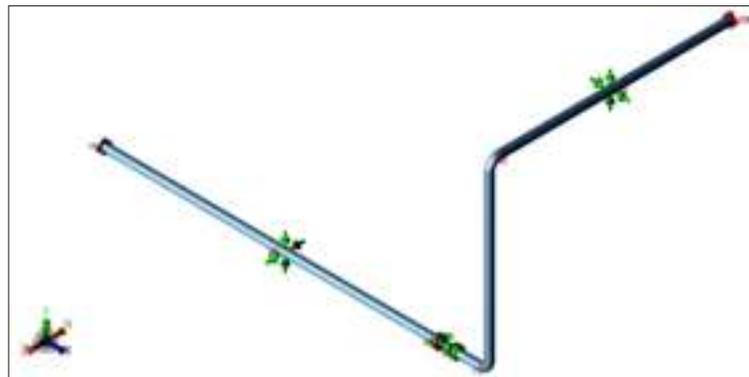


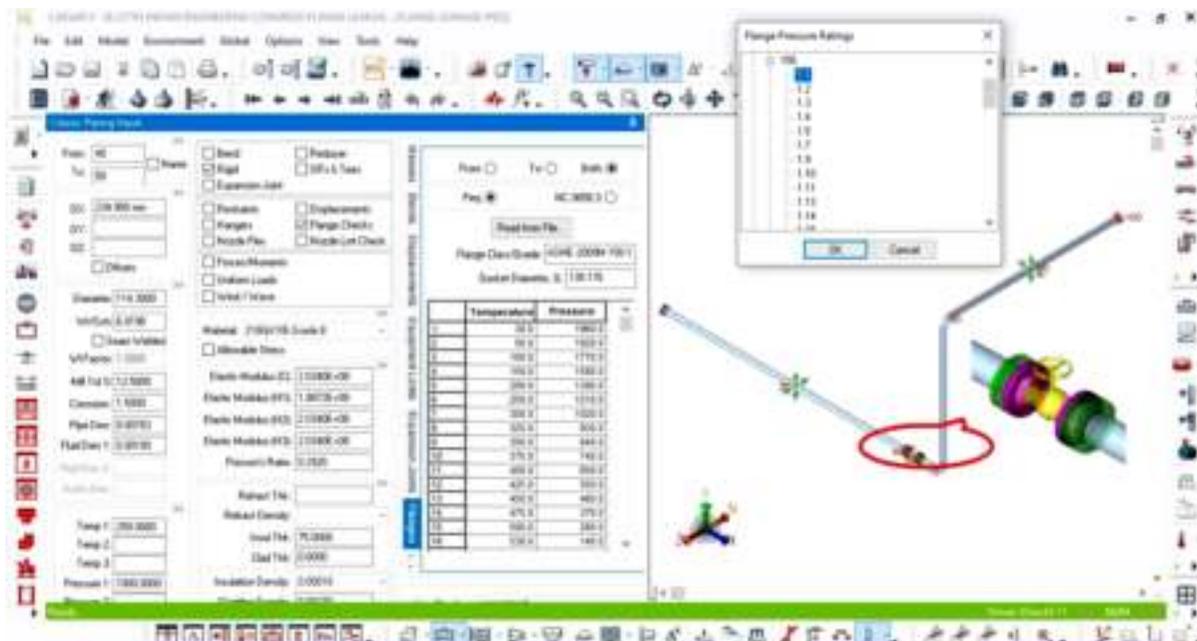
Figure 1 Tasks of pipe stress analysis



**Figure 2** A typical piping system for flange evaluation in CAESAR II

first address tank shell displacement and rotation due to hydrostatic deflection of the shell. This temperature-independent displacement and torsion have a significant effect on the connected pipeline. Moreover, the tank neck connection is by no means tight. Its inherent flexibility should be calculated and included in the analysis. After the pipe forces and moments at the socket connection have been calculated, it is necessary to evaluate whether they are permissible with respect to the tolerance limits. For pipelines connected to rotating equipment such as pumps, the pipe load must be kept within manufacturer's tolerances to avoid excessive vibration, wear and overheating of the equipment. Potential water hammer, pulsation, and other dynamic phenomena must also be considered in pipelines connected to rotating equipment. Again, for static device connections, flexibility and displacement at the connection should be included in the analysis. After calculating the pipe forces and moments at the joints, the local stresses in the tank should be evaluated to see if they are acceptable. Of course, if the structure is in an earthquake or hurricane area, earthquake and wind loads should be considered when designing the piping system.

There are many such items that are not usually called a piping flexibility analysis, but should be considered in a piping stress analysis. [1]



**Figure 3** Flange evaluation using equivalent pressure method



**Table 1** Flange peq report: equivalent pressure method operating case (W+T1+P1)

Node	Axial Force N	Bend. Mom. N-m	G/C mm	P Eq. kPa	Rating Temp. C	Allow. Pressure / Stress kPa	Ratio %	Result
40	733	1481	138.2	3908.39	250	1210.02	323	Fail
40	733	1481	138.2	3908.39	250	1210.02	323	Fail
50	733	1661	138.2	4255.08	250	1210.02	351.65	Fail
50	733	1661	138.2	4255.08	250	1210.02	351.65	Fail

### COMPOSITION OF A FLANGED JOINT

Nozzles of pumps, compressors, heat exchangers, pressure vessels & storage tanks, and valve bodies, all made with integral flanges in a special series of standard size-strength-bolting patterns, such as the American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME) Standard B16.5 and/or American Petroleum Institute (API) Standard 605 patterns. To form a suitably strong and pressure-tight joint that will not leak the fluid contents, the pipe end mating with the equipment flange must have a companion flange connected to it, matching with the specification and the pattern of equipment/valve body flange. Steel bolts compress a sealing gasket between the machined faces of the flanges, and the gasket blocks fluid flow under pressure. There are many types of gaskets, for the many different pressure-temperature-chemical exposure combinations they are intended to withstand. As long as the design pressure-temperature rating specified in applicable Flange Standard is not exceeded, and entire flange assembly is properly installed, the bolted flange-gasket sandwich joint will not leak or break. It is necessary that all persons affected by the use of flanged joints be aware that the integrity of the joint is adversely affected by external pipe-stress loads, such as bending moments, which always exist to some extent. The design engineer must take into account such loads, and may have to reduce actual fluid-pressure loading accordingly, or select a higher pressure-rating flange for the desired fluid max pressure, so that the flanged joint will not be overstressed. Along with these, the gasket must be rigid enough to allow a mechanically strong flange-to-flange joint assembly, yet it must be compressively stressed adequately to deform around the corners of the face ring and into the microscopic leakage paths in the flange faces, else fluid will come out from the joint. On the other hand, too much compression may rupture the gasket mechanically, destroying its functionality. So, the gasket manufacturer's minimum specified seating stress must always be applied to the gasket ring when the flange bolts are tightened down for system operation, but no disproportionately high bolt forces should be applied in gasket seating and compression.

The tightening torque of the high-strength steel bolts need to be applied by the pipe fitter very carefully and precisely, when making up the joint. Amount of torque is determined and specified by manufacturer for given type of gasket and the number, type and size of flange bolts specified for the intended duty. Resulting bolt stress in planned system operation would then usually be quite high, sometimes tending to bolt material's rupture point. The reason is to ensure that the combination of fluid pressure and pipe loads acting on the flange joint would not cause any tensile strain in the bolts beyond the pre-strained condition achieved with calibrated torque wrench during installation of the joint. Any additional bolt strain could let the flange faces separate and the gasket to tear apart/blow out [2].

The rules for correct bolting of pipe flanges can be summarized as follows: Flange gaskets should compress evenly to a certain stress level. Flange bolts must not yield when compressing the gasket [3].

### INTEGRITY OF FLANGED JOINTS

Flange leakage is a function of the relative stiffness of the flanges, gaskets, and bolts.

Generally, flanges used in process plants are manufactured to ANSI/ASME B16.5 or B16.47 standards. Flanges manufactured in accordance with this standard and used within the pressure and temperature limits specified therein are suitable for service without further pressure design analysis.

In some cases, flanges can be subjected to large external pipe loads (forces and moments) and cause excessive leakage. Typical concerns in such situations are:

- (i) How much external load can be termed as 'large'?
- (ii) How the flange joints subjected to both internal pressure and external loads can be evaluated? [4]

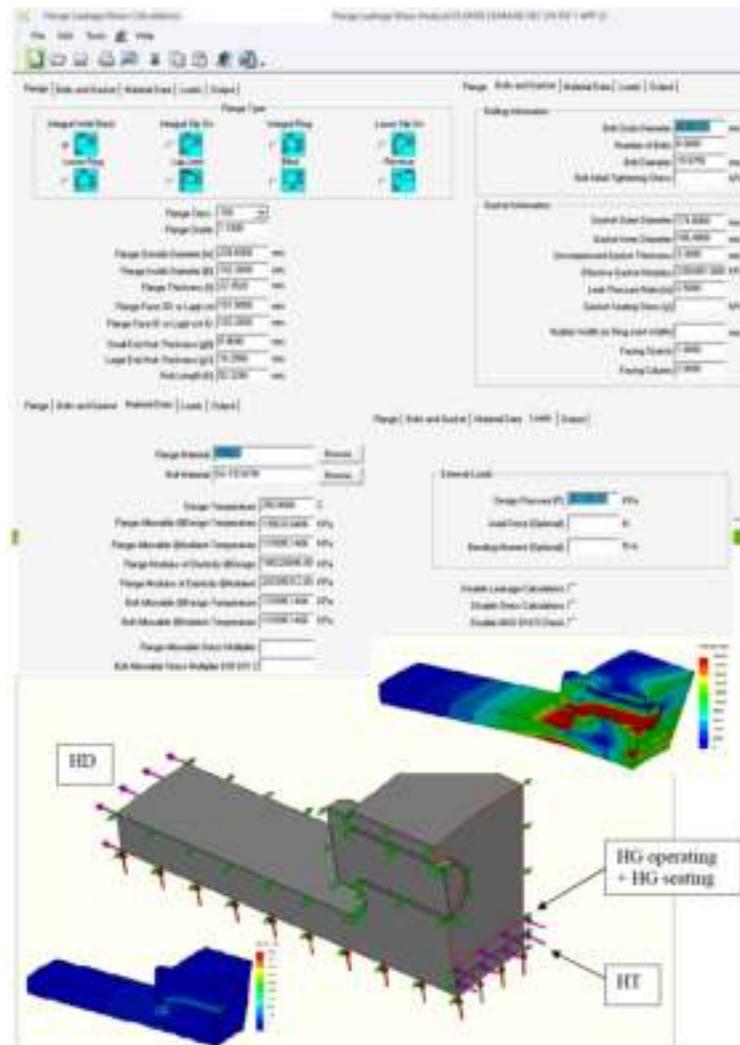


Fig. 4 Flange Evaluation using ASME SEC VIII DIV 1 APP 2 Method

**Figure 2** depicts a piping system, which is between two anchors, and is having a Gate Valve between a pair of flanges.

Line parameters are as below:

- Design Code – ASME B31.3
- Piping Material – Carbon Steel, as per ASTM A106 Gr. B
- Line Pressure – 1000 kPa
- Line Temperature – 250°C
- Pipe Installation Temperature – 21.1°C (70°F)
- Hydrostatic Test Pressure – 1500 kPa
- Pipe Size – 4" (100 NB), with outer dia. 114.3 mm
- Pipe Thickness – 6.02 mm (Sch. 40)
- Corrosion Allowance – 1.5 mm
- Coefficient of sliding friction between pipe support base and structure – 0.3



Table 2 Caesar II Analysis Report: Flange Leakage/Stress Calculations

FLANGE LEAKAGE/STRESS CALCULATIONS	
Flange Inside Diameter [B] (User to verify) .....	(mm.) 102.260
Flange Thickness [t].....	(mm.) 22.352
Flange Rating (Optional) .....	150.000
Bolt Circle Diameter .....	(mm.) 190.500
Number of Bolts .....	8.000
Bolt Diameter .....	(mm.) 15.875
Bolt Initial Tightening Stress .....	( KPa )
Uncompressed Gasket Thickness .....	(mm.) 3.300
Grade of Attached B16_5 ANSI Flange.....	1.100
Leak Pressure Ratio [m] .....	2.300
Effective Gasket Modulus .....	( KPa ) 2392481.000
Externally Applied Moment .....	(optional) ....( N.m. ) 0
Externally Applied Force .....	(optional) ....( N. ) 0
Pressure [P].....	( KPa ) 1000.000
Disable Stress Calculations (Y/N) .....	N
Flange Type (1-8, see ?-Help or Alt-P to plot) .....	1.000
Flange Outside Diameter [A].....	(mm.) 228.600
Design Temperature .....	C 250.000
Small End Hub Thickness [g0].....	(mm.) 5.969
Large End Hub Thickness [g1].....	(mm.) 16.256
Hub Length [h].....	(mm.) 52.324
Flange Allowable @Design Temperature .....	( KPa ) 135633.641
Flange Allowable @Ambient Temperature .....	( KPa ) 137895.141
Flange Modulus of Elasticity @Design .....	( KPa ) 188226896.000
Flange Modulus of Elasticity @Ambient .....	( KPa ) 203395312.000
Bolt Allowable @Design Temperature .....	( KPa ) 137895.141
Bolt Allowable @Ambient Temperature .....	( KPa ) 137895.141
Gasket Seating Stress [y] .....	( KPa )
Flange Allowable Stress Multiplier .....	1.000
Bolt Allowable Stress Multiplier (VIII Div 2 4-141) ...	1.000
Disable Leakage Calculations (Y/N) .....	N
Disable ANSI B16.5 Checks (Y/N) .....	N
Flange Face OD or Lapjt Cnt OD.....	(mm.) 157.000
Flange Face ID or Lapjt Cnt ID.....	(mm.) 102.260
Gasket Outer Diameter .....	(mm.) 174.800
Gasket Inner Diameter .....	(mm.) 106.400
Webbin Width .....	(mm.)
Facing Sketch .....	1.000
Facing Column .....	2.000
Flange Type: (Integral Weld Neck)	



Effective gasket width parameters:  
 Effective gasket seating width, b.....(mm.) 8.9526  
 Diameter of gasket load reaction, G....(mm.) 139.0749

SAFETY FACTOR SUMMARY for the different Flange Models  
 analyzed. (SAFETY FACTOR - Allowed/Actual)

	SAFETY FACTOR
Flexibility/Gasket Compression Model (Leakage) ..	51.82
ANSI B16.5/Equivalent Pressure (Stress).....	1.21
ASME Model Operating (Stress).....	4.13
ASME Model Seating (Stress).....	2.31

FLANGE FLEXIBILITY MODEL -----

BOLTED FLANGE CHARACTERISTICS:

Initial Tightening Stress in the Bolt (Not the seating  
 stress): 392456 KPa

Approximate Torque required to induce the above initial  
 stress: 122 N.m.

GASKET COMPRESSION:	COMPRESSION (mm.)
After Initial Boltup (Ci).....	0.1094469205
Loss-of due to Pressure (Cp).....	0.0019787969
Loss-of due to Applied Moment (Cm) ..	0.0000000000
Loss-of due to Applied Force (Cf)...	0.0000000000
Loss-of due to all loads (CL).....	0.0019787969
Initial minus all Losses (Ci-CL)....	0.1074681133
For Leak-Proof Joint (Creq).....	0.0068966062
Excess available (Ci-Creq) .....	0.1025503054

LEAKAGE SAFETY FACTOR: (If less than one then joint  
 leakage is predicted.) (Allowed/Actual)

Pressure Only (Ci-Creq)/Cp .....	51.82
Force Only (Ci-Creq)/Cf .....	99999.00
Moment Only (Ci-Creq)/Cm .....	99999.00
Pressure+Force+Moment (Ci-Creq)/CL .....	51.82

EQUIVALENT PRESSURE MODEL -----

Equivalent Pressure ( KPa ) .....	1000.00
ANSI B16.5 Flange Allowable Pressure Rating .	1209.34

STRESS SAFETY FACTOR: (If less than one then joint  
 failure is predicted.) (Allowed/Actual)



ANSI B16.3/Equivalent Pressure ..... 1.21

ASME SECT VIII DIV 1 STRESS MODEL -----

ACCORDING TO AOS APP 2-14, THE FOLLOWING RIGIDITY  
FACTORS SHOULD BE LESS THAN 1.0

ASME Rigidity Factor "J", Operating Case ..... 0.0492  
ASME Rigidity Factor "J", Seating Case ..... 0.1002

CALCULATED STRESSES ( KPa )

	OPERATING	ALLOW	SEATING	ALLOW
Longitudinal Hub ..	28319	203450	82341	206843
Radial Flange .....	25554	135634	56950	137895
Tangential Flange ..	13454	135634	29618	137895
Maximum Average ...	27102	135634	59661	137895
Bolting .....	33350	137895	0	137895

\*\*\* Indicates Failure for an item.

STRESS SAFETY FACTOR: (If less than one then joint  
failure is predicted.) (Allowed/Actual)

	OPERATING	SEATING
Longitudinal Hub ....	7.15	3.32
Radial Flange .....	5.24	2.42
Tangential Flange ...	10.05	4.66
Maximum Average .....	5.00	2.31
Bolting .....	4.13	99999.00

Pass

- k. Specific Gravity of Fluid – 1.0
- l. Valve Type – Gate Valve
- m. Material Group as per ASME B1.5/16.34 – 1.1
- n. Flange Type – Weld Neck Raised Faced
- o. Flange Rating – Class 150#
- p. Flange Thickness – 76.2 mm
- q. Gasket Dia. – 138.176 mm
- r. No. & Dia. of Bolts – 8 nos. Stud Bolts of 5/8” UNC or M16, 90 mm Long

Variation in results in all of the analysis methods, viz. Equivalent Pressure method, ASME BPVC Sec VIII Div. 1 **Appendix 2** method, ASME NC-3658.3 method, and EN-1951 method are to be observed on this piping system model.

#### Equivalent Pressure Method

ASME B31.3 refers to **Appendix 2** of the ASME Section VIII Division 1 for the design of flanges. This procedure considers only internal pressure to determine the adequacy of flanges. It does not consider external loads. Traditionally, analysis of flanges under piping loads has been done by converting piping loads to an ‘Equivalent Pressure’ by famous



'Kellogg Equivalent Pressure Method', which can then be added to the actual system design pressure, the sum of which is then compared to the ASME B16.5 or B16.47 allowable pressures at design/operating temperature. Piping forces & moments are converted to equivalent pressure by applying the pipe them over an equivalent gasket area and an equivalent gasket section modulus respectively.

$$P_{total} = P + P_e < P_r \quad (1)$$

Where

$P_{total}$  = Total pressure acting on flange joint, lb/in<sup>2</sup> or N/mm<sup>2</sup>

$P_r$  = ASME B16.5 or B16.47 allowable, lb/in<sup>2</sup> or N/mm<sup>2</sup>

$P$  = System design pressure, lb/in<sup>2</sup> or N/mm<sup>2</sup>

$P_e$  = Equivalent pressure due to piping loads, viz. external force & moment, lb/in<sup>2</sup> or N/mm<sup>2</sup> =  $16M/\pi G^3 + 4F/\pi G^3(2)$

$F$  = Axial external force in tension, lb or N

$M$  = External bending moment, in-lb or N-mm

$G$  = Diameter at location of gasket load reaction, in or mm

This method is very quick and is typically used on piping systems comprising of large number of flanges during initial validation, but on the other hand this method gives highly conservative results, showing failure in flanges which actually have substantial reserve strength. However, it has long been used due to the lack of any quick and user-friendly method for evaluating flanges under piping loads. Since this method is deemed an over-conservative approach, normally there would be a large number of flanges which would fail in this method, and further analysis should normally be carried out in accordance with ASME Boiler & Pressure Vessel Code Section VIII Division 1. In the subject case study, it is observed that both of the flanges failed, as shown in the results indicated in **Table 1**, thus necessitating analysis vide other methods.

However, if all flange joints in a piping system pass under this method, substantial hour and effort in design engineering can be saved.

ASME BPVC Sec VIII Div. 1 Appendix 2 Method

ASME Boiler & Pressure Vessel Code Section VIII Division 1 **Appendix 2** provides a method of flange leakage evaluation. The calculations use three loads – HT, HG & HD and two conditions – seating and operating.

HD (Operating): HD is generated by the pressure on the pipe attached to the flange, and is calculated as Force = Pressure x Area, i.e.  $HD = \pi B^2/4$ , generated on center line of the pipe, but ASME rules change the moment arm depending on the attachment method. When finite element analysis (FEA) is performed, the load should be applied to the attached pipe and the FEA program would determine how the load is distributed.

HT (Operating): HT is generated by internal pressure acting on the gasket, at exposed edge of the gasket which attempts to stretch but is held in place by the flange faces, and flange faces push back. The force is zero at the outer diameter (OD) of the gasket (there is no pressure at gasket OD and thus no leakage). At inside edge, the pressure is the pressure inside pipe. HT is the average pressure along the length. ASME rules reduce the width of the gasket. This load is a design rule, not a predictor of actual flange stresses.

HG (Operating): HG operating is the force required to keep the flange sealed tightly against operating pressure. It is

**Table 3** Flange NC-3658.3 Report: ASME NC-3658.3 Method operating case (W+T1+P1)

Node	Tors. Mom. N-m	Bending Mom. N-m	G/C mm	$A_k$ mm <sup>2</sup>	Flange Stress kPa	Allow. Press./Stress kPa	Ratio %	Result
40	291	1481	190.5	1043	85879.1	203900	42.12	Pass
40	291	1481	190.5	1043	85879.1	203900	42.12	Pass
50	291	1661	190.5	1043	96291.3	203900	47.22	Pass
50	291	1661	190.5	1043	96291.3	203900	47.22	Pass

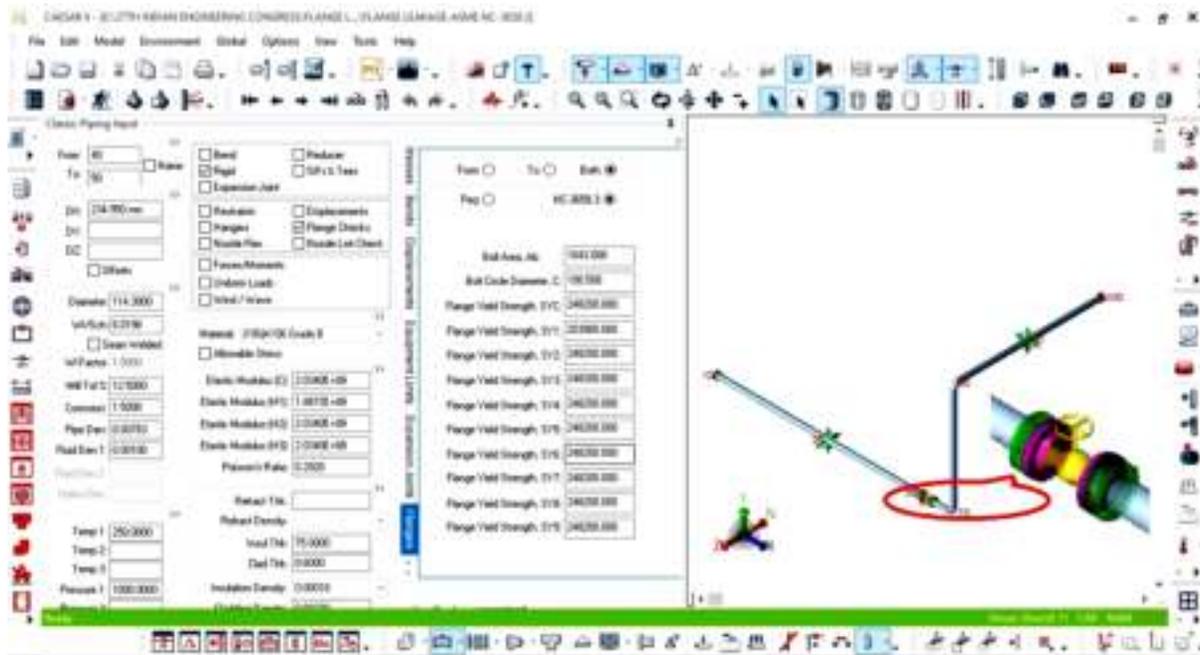


Figure 5 Flange evaluation using ASME NC-3658.3 Method in CAESAR II

generated by tightening the bolts, and calculated as  $\text{Load} = \text{Effective Area} \times \text{Gasket Factor 'm'} \times \text{Pressure}$ . If the flange is self-energizing, i.e. it does not need additional force to seal such as an O-ring) then  $\text{HG (Operating)} = 0$ . This load acts through the center of the gasket, but the gasket size is reduced by ASME rules to create an effective area. Correlation to real gasket properties is a bit difficult; this load and its moment arm constitute a design rule, not a predictor of actual flange stresses.

**HG (Seating):** HG seating is the force required to make the gasket seat onto the flange gasket face and be leak tight against a zero pressure. HG is based loosely on gasket physical properties, but the gasket area used is modified (reduced) from the actual gasket width because the code 'y' factors are too high. Correlation to real gasket properties is practically impossible; this load and its moment arm constitute a design rule, not a predictor of actual flange stresses. Force HG has an additional load added to it, which is called 'gasket destroying' or 'gasket crushing' force. Computed seating load on the gasket is increased to the average of the required bolt strength and the available bolt strength. This fallacy in code greatly influences to increase the required thickness of flanges far beyond the loads that the gasket can handle. Being the design engineer, when the seating loads are too large and are caused by extra bolt area, several options are available:

- 1) To make the bolts smaller in diameter or fewer in number, so that reduction in effective area of the bolts reduces this theoretical gasket crushing force.
- 2) To use weaker bolts, for same reason as above.
- 3) To make the flange thicker, if material cost is no constraint. This route is chosen when a custom Appendix 2 flange must mate up to standard flanges such as B16.5 series which seldom calculate to Appendix 2 rules.

Flanges designed by the ASME Section VIII Division 1 Appendix 2 method above may not be sufficiently rigid as far as flange ring rotation is concerned. With bolt loads applied to seat the gasket, flange ring rotation may happen which may affect the gasket seating surface and, in turn, gasket efficiency in controlling leakage. ASME Section VIII Division 1 recognizes this potential for flange leakage and has included a procedure for testing the flange rigidity for two types of flanges – integral hub type and loose ring type with and without hubs, with permissible ring rotations limited to  $0.3^\circ$  &  $0.2^\circ$  respectively, in the Appendix 2. To determine flange rigidity, flange rigidity index 'J' need to be calculated the where J must be  $< 1.0$ . Rigidity factors indicated as follows have been proven through extensive user experience for a wide variety of joint design and service conditions. Use of the rigidity index does not guarantee a leakage rate within



established limits. The use of the factors must be considered as only part of the system of joint design and assembly requirements to ensure leak tightness. Successful service experience may be used as an alternative to the flange rigidity rules for fluid services that are nonlethal and nonflammable and designed within the temperature range of -20°F (-29°C) to 366°F (186°C) without exceeding design pressures of 150 psi (1035 kPa). [5]

Flange Rigidity Factors are calculated as follows:

For integral-type flanges and optional type flanges designed as integral-type flanges:

$$J = 52.14VMO/LEgO2KIhO \quad (3)$$

For loose-type flanges with hubs:

$$J = 52.14VLMO/LEgO2KLhO \quad (4)$$

For loose-type flanges without hubs and optional flanges designed as loose-type flanges:

$$J = 109.4MO/Et3KL(\ln K) \quad (5)$$

Where

Nomenclature and terms of above equations are as per Mandatory **Appendix 2**, ASME Boiler and Pressure Vessel Code, Section VIII, Division 1.

SEC VIII DIV 1 APP 2

The same piping model used in Equivalent Pressure method is analyzed in ASME Section VIII Division 1 Appendix 2 method, and results are presented in TABLE II. The flanged joints are passed with high factor of safety.

### ASME NC-3658.3 Method

Evaluation of flanges for Non-Occasional Load Cases can be done using the ASME BPVC Section III Subsection NC-3658.3 Equation 12 method, as follows:

$$(250/21.7) \times Mfs / (C \times Ab) < \text{Min}(Sy, 250000 \text{ kPa}) \text{ in SI units} \quad (6)$$

Or

$$(36,000/3125) \times Mfs / (C \times Ab) < \text{Min}(Sy, 36000 \text{ psi}) \text{ in US customary units} \quad (7)$$

Where:

Mfs = Bending or torsional moment (whichever is greater) acting on the flange, in N-mm or in-lb

Sy = Yield strength of flange material at design temperature, in kPa or psi

C = Bolt circle diameter, in mm or in

Ab = Total cross-sectional area of bolts, in mm<sup>2</sup> or in<sup>2</sup>

The same piping model used in Equivalent Pressure method is analyzed in ASME NC-3658.3 method, and results are presented in **Table 3**.

From the results presented in TABLE III, it is observed the flanges failing exorbitantly under identical loading in Equivalent Pressure method are passed with high design margin in ASME NC-3658.3 method. Although this method requires a bit more effort in engineering stage, however gives much more optimized result compared to Equivalent Pressure method. On the other hand, the results obtained are on higher side compared to ASME BPVC Sec VIII Div. 1 Appendix 2 Method; however, considering the engineering hours involved in ASME BPVC Sec VIII Div. 1 Appendix 2 Method, ASME NC-3658.3 method would always be at a rational side, in case of plants/units numerous critical lines, because ASME BPVC Sec VIII Div. 1 Appendix 2 Method requires checking each flange joint individually.

Limitations associated with ASME NC-3658.3 method are:

- Derived from nuclear piping code, there has been lack of consensus in using this method in non-nuclear plant piping.
- Cannot be used in dynamic loading conditions; limit is doubled in dynamic loading (ASME BPVC Section III Subsection NC-3658.3 Equation 13, for Occasional Load Cases).
- Restricted to joints using flanges, bolting, and gaskets as specified in ANSI B16.5 that use bolting materials having



an S value at 100°F (38°C) greater than or equal to 20,000 psi (138 MPa).

## CONCLUSIONS

All of the three flange leakage analysis methods discussed above have their respective merits & demerits, pros & cons. Flange leakage analysis for critical piping systems for any process plant shall be done in accordance with the pipe stress analysis design basis for the subject project. Although Equivalent Pressure method is much simpler to use, high degree of conservativeness associated with this method leads to over design. On the other hand, in ASME BPVC Sec VIII Div. 1 Appendix 2 Method involves dedicated involvement and effort for analysis of each & every flange joint, thus requiring much more engineering effort and hours. ASME NC-3658.3 method stands in a mid-way between the two. However, for a large project involving numerous critical lines, Equivalent Pressure method can be adopted only if there all flange joints pass through this method, as well as there is no need of incorporating huge modification in piping layout and design in order to make the system fully stress compliant.

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## REFERENCES

1. Liang-Chuan (L.C.) Peng and Tsen-Loong (Alvin) Peng, Peng Engineering, Houston, Texas, USA, Pipe Stress Engineering, ASME Press, pp. 1-4.
2. James A. Wingate, Mister Mech Mentor Volume II - Applying the ASME codes: plant piping and pressure vessels, ASME Press, pp. 67-68.
3. George A. Antaki, Piping and Pipeline Engineering: Design, Construction, Maintenance, Integrity, and Repair, Marcel Dekker Inc., pp. 334.
4. Glynn E. Woods, P.E. & Roy B. Baguley, P.Eng., Practical Guidebook Series™, Volume 3 - 1997 CD-ROM Version, ASME B31.3 Process Piping, CASTI Publishing Inc., pp. 42, 44, 46
5. Mandatory Appendix 2, ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, ASME, 2-14, pp. 413



# Selection of Proper Expansion Joints in Large Diameter Piping System—Considerations and Pitfalls

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**Abstract:** For any industrial process plant, be it a thermal power station, or a refinery/petrochemical plant, or steel/non-ferrous metallurgical plant, the critical piping, which convey different process and utility fluids viz. hydrocarbons, steam, chemicals, toxic and flammable gases, or even water, are the arteries and veins of those installations, and constitute of approximately 20% to 35% of total plant cost. Expansion joints are installed in piping systems that convey high temperature fluids such as steam, feed water, hydrocarbons, or process and exhaust gases, to absorb thermal movement, to minimize forces on nozzles of equipment on which pipes are connected, to absorb vibration of any rotating equipment to restrict its transfer on the pipe, or to adjust misalignment between an equipment nozzle and its connecting piping caused during installation. A typical type of expansion joint for pipe systems is a bellow which can be manufactured from metal, plastic, or elastomer. In particular, proper selection of expansion joints for large diameter piping system is very critical, because, unlike smaller diameter piping, large diameter piping lacks inherent flexibility, and poses a challenge to piping design engineer to constitute a stable fluid conveying system. This paper intends to cover the design considerations for selection of expansion joints for large diameter piping, among different options, and the advantages of those along with the critical issues involved, with depicting a few practical examples.

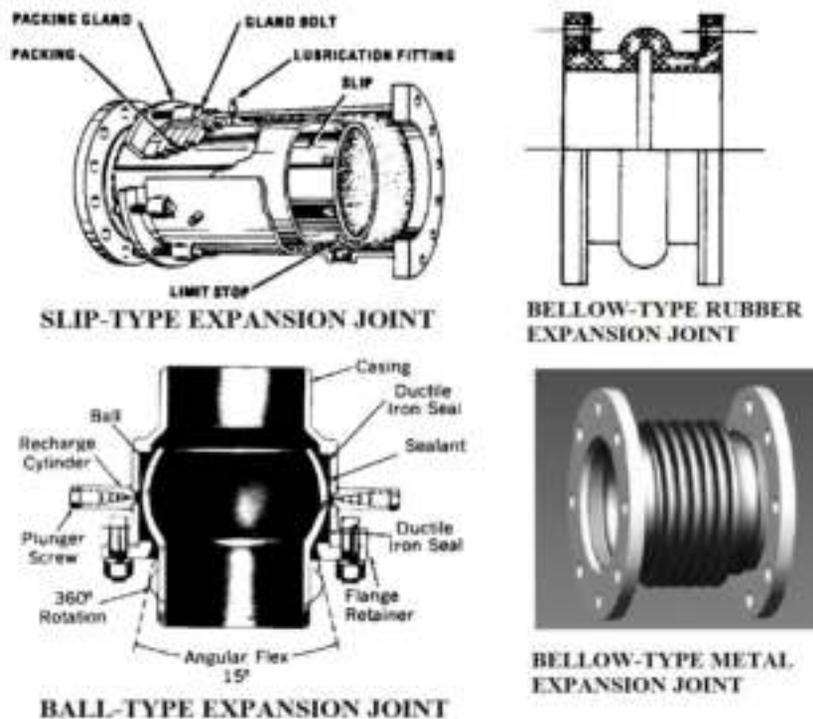
**Keywords:** Plant, Piping, Expansion Joint, Compensator, Safety, Stress Analysis

## INTRODUCTION

In any industrial establishment, be it a thermal power station, or a refinery/petrochemical plant, or metallurgical plant, the critical piping, which convey different process and utility fluids such as hydrocarbons, steam, chemicals, toxic and flammable gases, or even water, play the role of arteries and veins of the respective installations, and constitute of approximately 20% to 35% of total plant cost, requires 30% to 40% of the erection labor, and consumes 40% to 48% of the engineering man-hours. The actual importance of piping installation, however, is far beyond these percentages. A complete piping system is composed of a large number of components, failure of a single one of which, has the potential to shut down the entire plant or, worse yet, cause serious public safety problems [1]. These critical pipes are normally connected to nozzles of different static equipment such as towers, columns, furnaces, heat exchangers, pressure vessels, or rotating equipment such as turbines, compressors, pumps, fans & blowers, they tend to transfer large forces and moments on the nozzles of connected equipment, which often exceeds the allowable forces and moments for those pieces of equipment specified in respective codes & standards and/or guidelines of equipment manufacturers. In order to reduce the excessive loading on equipment nozzles/structures, as well as to adjust misalignment between an equipment nozzle and its connecting piping caused during installation, expansion joints are installed in piping systems. However, often expansion joints bring a set of unique problems in piping systems, and in many cases, those offset the piping problems which were intended to be resolved by installation of expansion joints.

## WHAT IS EXPANSION JOINT?

An expansion joint (also called compensator) is necessarily, but not limited to, a flexible piping component which absorbs thermal movement of a piping system and/or terminal movement of the connected equipment, along with adjusts misalignment between an equipment nozzle and its connecting piping caused during installation. A typical type of expansion joint for pipe systems is a bellow which can be manufactured from metal, plastic, or elastomer, although other types of expansion joints such as slip and ball type constructions are also available. Slip-type expansion joints comprise of a sleeve that telescopes into the body, having packing located between sleeve and body to control leakage. As a completely leak free seal cannot be ensured; thus these expansion joints are ruled out where zero leakage is a must. Packing is subject to wear due to cyclic movement of the sleeve due to expansion and contraction of connected piping, which necessitates periodic maintenance, either by compressing the packing by tightening a packing gland, or by



**Figure 1** Different constructions of expansion joints

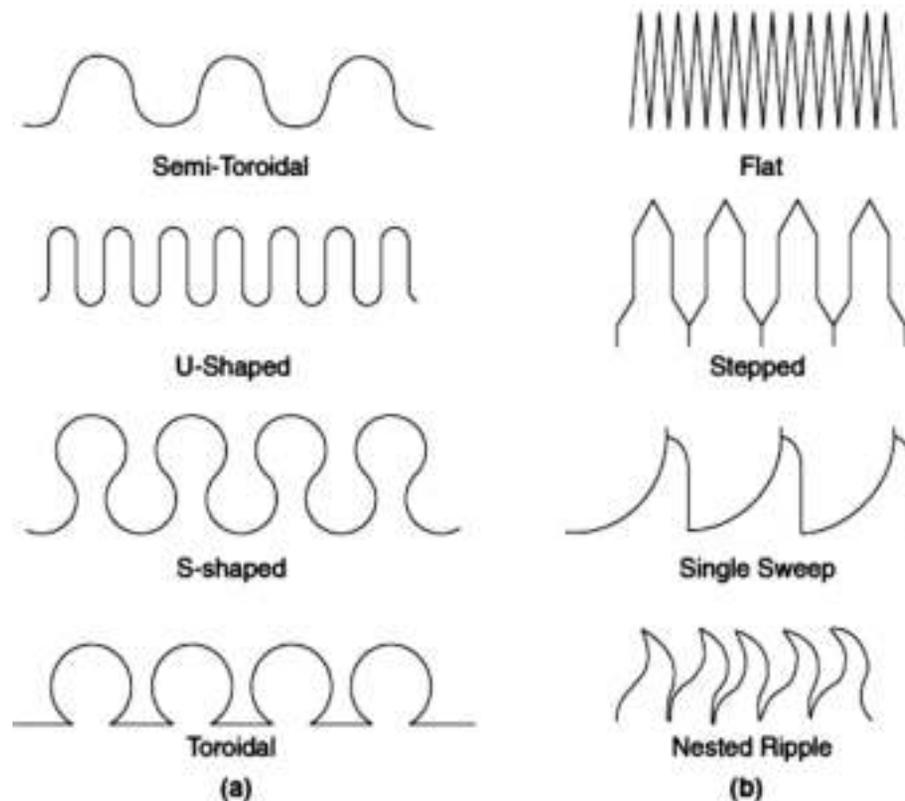
replacing or replenishing the packing. As the packing can wear out, some packing material may be picked up in the service fluid, which rules out the use of slip joints in systems where the fluid must be completely free from such contamination. These expansion joints are particularly suited for lines having axial movements of large magnitude, as these cannot absorb lateral offset or angular rotation which may cause binding, galling, and possibly, leakage due to packing distortion.

Ball-type expansion joints consist of a socket and ball with a sealing mechanism placed between them. Seals are made of rigid materials, and in some designs a pliable sealant may be injected into the cavity between ball and socket. The joints are capable of absorbing angular and axial rotation; however, they cannot accommodate axial movement. Therefore, an offset must be installed in piping route to absorb pipe axial movement.

Bellow-type expansion joints do not have packing which makes them free from potential leakage or fluid contamination problems of slip joints. Also, those do not require the periodic maintenance (lubrication and repacking) that is associated with slip joints. These joints absorb expansion and contraction by means of a flexible bellow which is compressed or extended. Those can also accommodate direction changes by various combinations of compression on one side and extension on an opposing side. Thus, those can absorb lateral offset and angular rotation of the connected line. However, they are not capable of absorbing any torsional movement. Typically, the metallic bellows are of corrugated metal construction and are welded to the pipe pieces. To provide the requisite flexibility, the metal bellows are considerably thinner (often less than 0.125 in (3 mm) thick) than the associated piping. Thus these expansion joints are susceptible to rupture by overpressure. These can also fail because of metal fatigue if the accumulated flexing/contracting cycles exceed the designed fatigue life (cyclic life) of the bellows or if the flexing/contracting extremes exceed the designed compression and extension limits.

Rubber bellows are similar in design to metal bellows expansion joints except that those are constructed of fabric and wire-reinforced elastomers. These are most suitable for use in cold water service where large movements must be absorbed (e.g., condenser circulating water).

Expansion Joint Manufacturers' Association (EJMA) publishes a handbook named Standards of the Expansion Joint Manufacturers Association. This book contains manufacturing standard practices as well as comprehensive and detailed



**Figure 2** Bellow configurations (a) formed bellows (b) fabricated bellows [5]

engineering methodology and data regarding pipe expansion joint types, installation layouts and locations, movements, forces, moments, cycle-life expectancy, and effects of corrosion, erosion, and testing. [2]

Process Plant Piping Code published by American Society of Mechanical Engineers ASME B31.3 has established an Appendix X, Metallic Bellows Expansion Joints. As stated in general paragraph of the appendix, it does not specify design details as those are the responsibility of manufacturer/OEM. Manufacturer's responsibilities, in Paragraph X302 include, based on the information given to them by the piping stress engineer:

- Design and supply of all piping and components within the end connections of the assembly.
- Specifying any need for supports or restraints external to their assembly.
- Determining the design conditions for all of their supplied components which do not come in contact with the fluid.

Stress engineer would provide the expansion joint manufacturer the following:

- Static design conditions, including a design temperature for the metal if other than that of the fluid
- Cyclic design conditions, including transient conditions separately
- Any other loads such as wind and seismic
- Properties of the fluid [3]

Design of a piping system with expansion joint requires significant knowledge of pipe stress analysis, as the responsibility of designing the main anchors and the intermediate anchors to the stress engineer. Although responsibility of parameters such as factors of safety, limits on the design stresses, fatigue analysis and testing lies with manufacturer, it does not relieve the overall responsibility off the stress engineer, who also requires to ensure whether the manufacturer has complied with all requirements stated in EJMA standard.

#### **WHY EXPANSION JOINT?**

In piping design, elbows, bends, and pipe expansion loops usually provide adequate flexibility for piping thermal

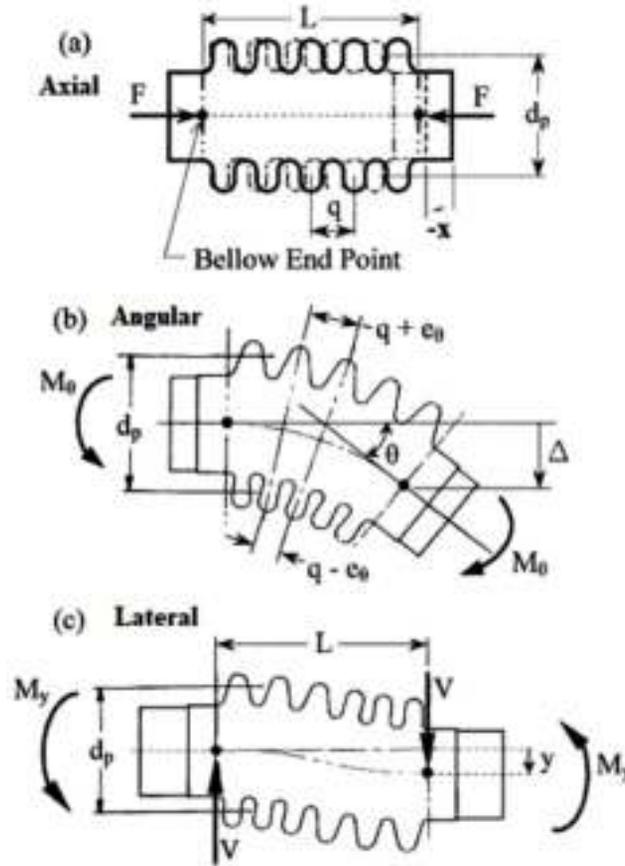


Figure 3 Bellows under deformation [1]

expansion and contraction, particularly for smaller diameter piping. However, in some cases this flexibility may not be enough. Expansion joints can be used as a solution for pipe expansion and contraction. Expansion joints should be avoided if possible, but sometimes the displacements and subsequent forces are too large to be absorbed by either the inherent flexibility of the piping or the load bearing capacity of the supporting structure to absorb the forces and moments imposed by the thermal expansion. Expansion joints for pressure piping are always fabricated of corrugated metal, and the additional forces imposed by the internal pressure acting on the annulus of the corrugations are absorbed by tie rods that bind the flanges together across the expansion joint. Amount of movement absorbed by expansion joints is actually not very much. Also, these movements are cumulative, so that if an expansion joint is rated to absorb certain amount of axial movement, that amount of axial displacement will be de-rated if it also has to take into account any parallel displacement which a pipe running adjoin may have. Due to the potentially large pressure thrusts produced by the corrugations of expansion joints, most applications require that the joints are required to be restrained with tie rods. This indicates that the best location for an expansion joint to accommodate thermal growth is probably in a line that is at right angles to the line that experiences the growth. In that way the expansion joint can deflect laterally rather than axially [4].

Use of Expansion joints in steam and condensate lines is generally to be avoided, except when extraction steam piping is routed through the condenser neck, an expansion joint must be provided in each line and located at the turbine nozzle.

Large diameter piping systems, especially those conveying gases, may require expansion joints as providing flexibility through layout and expansions loops may not be feasible due to space constraint, or if the system cannot afford significant pressure losses with the addition of elbows or bends.

In general, expansion joints are used for the following reasons:

1. Where space is inadequate to provide a conventional expansion loop, such as connection between two pieces of



**Figure 4** Bellow-type expansion joint classifications

equipment which are very close to each other.

2. Large dia. high-temperature, low-pressure piping requiring a huge expansion loop that would have been too expensive and occupy too much space to install. The flue gas line from a heater or from a cat-cracking unit of an oil refinery, or blast furnace gas, coke oven gas or mixed gas lines in iron and steel making plants are examples of this case.
3. Where thermal movements induce excessive stress in normal piping layout and arrangement
4. Where reactions to equipment terminals are in excess of allowable forces and moments specified by manufacturers/OEMs.
5. Where equipment allowable load is so low that it is impossible to meet no matter how large and extensive is the expansion loop that is provided, such as exhaust piping of a steam turbine.
6. Where reactions transmitted by pipe supports or anchors imparts large loads on supporting structures, beyond their load bearing capacity.
7. Lines which cannot tolerate higher pressure drop due to additional bends of expansion loop, particularly a vacuum line such as condensate line from power plant steam condenser
8. Process lines which require smooth and straight flow such as the catalytic cracking riser in an oil refinery.
9. To isolate vibration from a process machine to the piping and vice versa.
10. For the fit-up of a large-diameter piping to a machinery so that there is no misalignment between equipment nozzle and piping and also for ease of dismantling. This is for construction and maintenance purpose and does not serve as an expansion stress reduction device.

#### WHICH EXPANSION JOINT?

Most commonly used expansion joints are of bellow-type, and objective of this article is to focus on the design considerations and pitfalls of bellow-type metallic expansion joints only.

The term bellow is a generic one, as there are several fundamental types of bellows which are use. Use of a specific type of bellow is a function of the bellow manufacturer. Each manufacturer has its own tooling that is used for the common types of materials, and as the materials change, manufacturers may change the type of bellows to suit their design

**Table 1** Bellow-type expansion joint classifications [5]

Name	Description of Usage and Rationale
Single	Absorbs all movements of pipe section it is installed in
Double	Two single joints with a common connector rigidly anchored
Universal	Two sets of bellows acting as one joint to accommodate lateral movement larger than a single unit (where a double acts as two different singles)
Tied universal	Absorbs pressure thrust; will absorb no lateral movement external to the tied length
Swing expansion	Will absorb lateral and/or angular rotation in one plane only (a modification of hinged expansion joint)
Hinged	A single bellows to permit angular rotation in one plane only; note these should be used in double or triple combinations
Gimbal	Designed to permit angular rotation in any plane by use of a gimbal
Pressure balanced	Designed to take angular rotation and lateral movement while restraining the pressure thrust force

*Note: It is always good to determine the proper type to use in conjunction with the manufacturer.*

philosophy. There are two basic categories of bellows: (i) formed and (ii) fabricated. Within each category there are four shapes, shown in **Figure 2**, recognized by EJMA. In addition, there are several fundamental designs of bellows. Different degrees of freedom are associated with these different shapes which are used in different situations requiring the flexibility associated with the bellows.

A bellow-type expansion joint can work with three (3) fundamental movements (**Figure 3**):

- Axial movement: This is the movement that occurs along the axis of a straight piece of pipe not having any interactive pipe in other directions.
- Angular rotation. It is the bending of the centreline of pipe.
- Lateral movement: This can be in any direction that is perpendicular to the axis of the pipe

As indicated earlier, expansion joints have very little or no torsional resistance, and in case it is present in the system, special considerations would be required.

Bellow-type metallic expansion joints can be classified in eight (8) fundamental categories, listed in **Table 1**.

Above types are presented in **Figure 4**.

As the responsibility for the layout, anchors, guides, and supports lies with piping engineer and/or stress engineer, in developing the piping layout and arrangement so that an expansion joint will operate properly, there are four (4) basic concerns that should be addressed: [5]

- The friction force that the sliding pipe creates (weight of the length of pipe x the friction factor between the guides (supports) and that weight).
- The spring force that the bellows that act as a spring generates (spring rate of the joint x the displacement of the pipe over the total length of pipe); it is to be noted that this is the spring rate of the bellow as opposed to the spring rate of the convolutions. Expansion joint manufacturer would provide information of these spring rates. But in any case it is the expansion rate for the temperature and that spring rate.
- The pressure thrust force that the expansion joint generates; it is sometimes difficult to understand; its magnitude is surprising; It is more than the longitudinal force calculated using the pipe ID. Although lower diameter of the bellows is equal to the pipe ID, bellows extends some amount beyond that ID, which has a height h. By geometry the ID plus h is the mean diameter of convolute, which corresponds to effective area  $A_e$ . This area multiplied by the design pressure then becomes the pressure thrust. When expansion joints are used in piping, the pressure thrusts can no longer be balanced by tension in the pipe wall, and the pressure forces need to be resisted by pipe supports and anchors. Expansion joints do not have the capability to transmit large pressure thrusts. Restraints are required to be installed on both sides of the expansion joint to prevent the pressure force from pulling the joint apart (**Figure 5**). Pressure thrust developed in the expansion joint is equal to the internal pressure times the maximum cross-sectional area over which it is applied. Since an expansion joint increases the flexibility of a piping system, the flexibility (spring rate) of the expansion joint are to be incorporated in piping stress analysis. [2]
- The cycle life expectancy; which is total number of complete cycles expected from the expansion joint based on data



tabulated from tests performed at room temperature under simulated operating conditions. A cycle is one complete movement from full-open to full-closed to the full-open position. It is influenced by various factors, viz.

- Operating pressure.
- Operating temperature.
- Bellow material.
- Movement per corrugation.
- Thickness of the bellows.
- Centre-to-centre distance of the corrugations.
- Depth and shape of the corrugation.

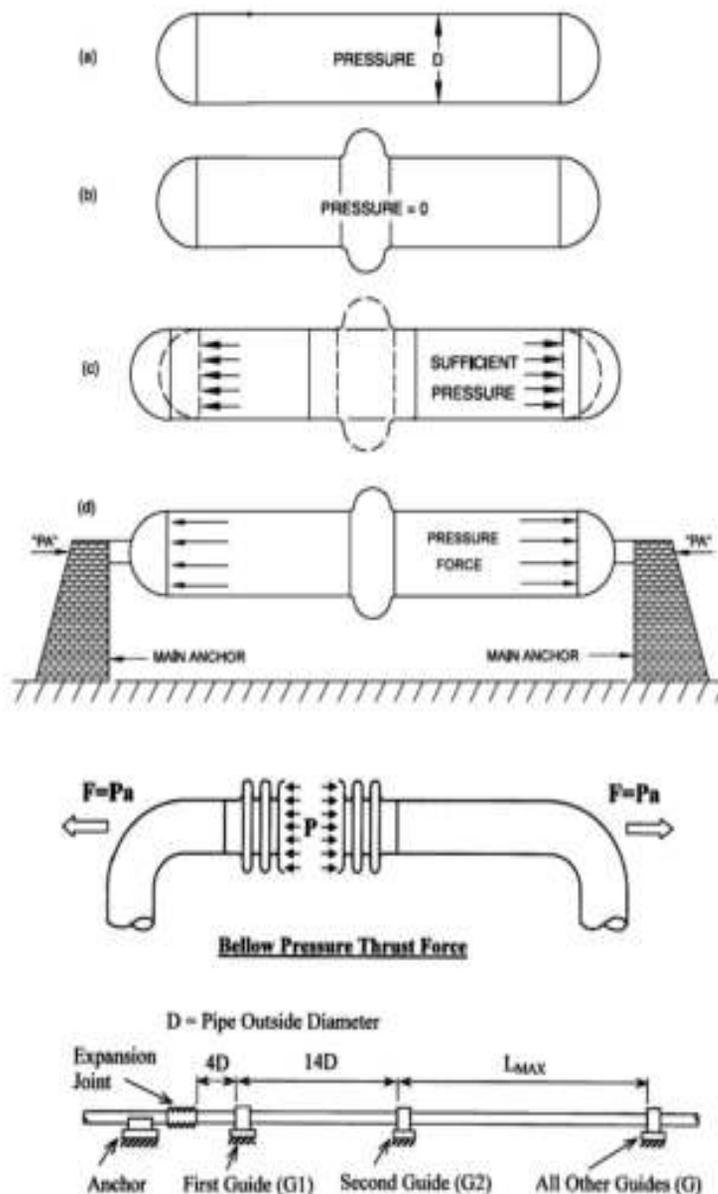
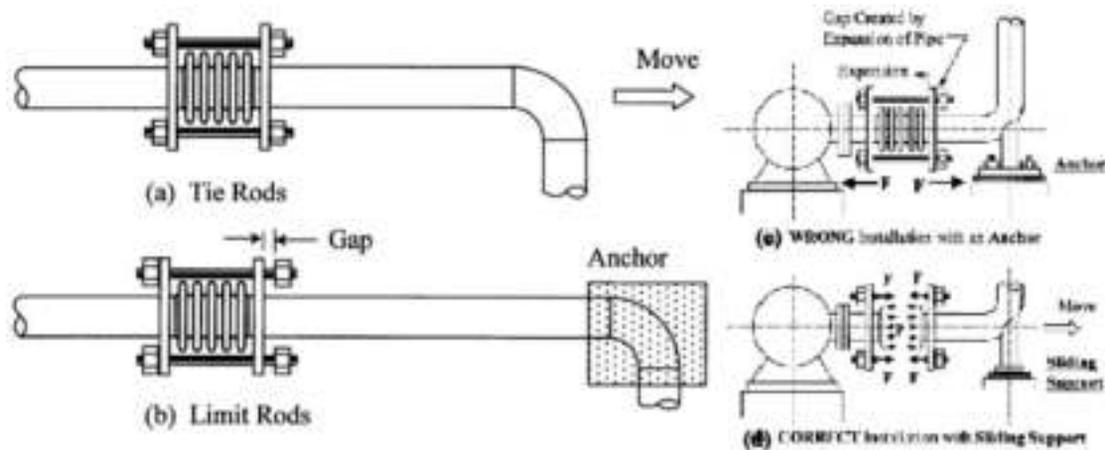


Figure 5 Bellows pressure thrust and restraining arrangement [1] [6]



**Figure 6** Bellow-type expansion joint installation considerations [1]

Any change in either of above factors would lead to change in the life of the expansion joint. However, experience has revealed that very few applications have a real need for high cycle-life design, which, otherwise, adds unnecessary costs to the project. [7]

### SELECTION OF AN EXPANSION JOINT FROM CATALOGUE

Every manufacturer has its own unique bellow shape, material, fabrication method, testing standard, and qualification procedure to manufacture a safe bellow for applications within their catalogue limitations. The stress engineer has to ensure that the characteristics such as spring rate, pressure thrust force, and so forth are included in piping stress analysis, and the calculated bellow deformations due to relative piping movements are within the limits specified by manufacturers. Manufacturer's experience and integrity to provide the required margin of safety are to be relied upon because they have mastered the art of design and manufacturing of bellow-type expansion joints through the years of practice.

Before using the catalogue, it is important to note that the data found in the catalogue varies greatly from manufacturer to manufacturer. The catalogue of the specific expansion joint intended for the service must be referred.

From the catalogue, a preliminary selection should be made based on pressure rating and required movements. Otherwise, this selection process can be entrusted to the manufacturer by providing the design parameters such as pressure, temperature, expected movements, and so forth. The stress engineer shall then incorporate the pressure thrust force and spring rates, either from the catalogue or from the manufacturer, into the stress analysis model of the piping system under design. If the equipment reaction, pipe stress, or the movement exceeds the allowable value, a longer bellow or other arrangement should be tried. The process needs to be repeated until all reaction forces, pipe stresses, and bellow movements are within the allowable range. [1]

### SPECIAL CONSIDERATIONS FOR INSTALLATION OF EXPANSION JOINTS

#### Direction of Anchor Force

This is an extremely important factor. To achieve the safest and most economical design, the strongest orientation of the anchor is always aligned with the direction of the anchor force, which is apparent in most cases; yet, intermittently, it can deviate according to the modes of operation.

#### Tie Rods and Limit Rods

Expansion joints are often fitted with tie rods and limit rods. THESE ARE DIFFERENT!!! Although referred interchangeably (and of course, erroneously!) even by industry veterans, their purposes and functions are different. Tie rods are installed to absorb the longitudinal pressure thrust force, thereby preventing the bellow from being overstretched by pressure during normal operation, and eliminating the requirement of anchor to withstand pressure thrust. Limit rods, on the other hand, are installed to safeguard the bellow from being overstretched during the event of anchor failure or pipe buckling. A misjudgment of the purpose of tie rods and limit rods can lead to piping failure or



**Table 2** Pitfalls for Bellow-type expansion joints [8]

Pitfalls	Name	Cause	Remedial Measure(S)
PITFALL # 1	FATIGUE FAILURE	Being a thin-walled pressure enclosure subjected, pressure transients and significant tensile/compressive metal strains, it cannot have eternal life, and is expected eventually to rupture at the natural end of its fatigue life, losing all capacity to contain fluids, and repairs are not possible because the convolute material reaching ultimate stress	<ol style="list-style-type: none"> <li>1. To correctly specify number of thermal and pressurization cycles, as well as the range of temperatures and pressures in those cycles</li> <li>2. Scheduled maintenance and replacement</li> </ol>
PITFALL # 2	UNPLANNED FAILURE	Due to internal/external erosion/corrosion, from excessive strains caused due to inadequate piping support-restraint-anchor-guide provisions, process upsets (temperature/pressure excursions) and from accidental mechanical damage.	<ol style="list-style-type: none"> <li>1. Internal/external erosion/corrosion are hidden by insulation and lagging, requiring frequent maintenance inspection, along with inspection provisions properly in place.</li> <li>2. Inadequate pipe support-restraint-anchor guide provisions are engineering errors, and to be avoided by engaging qualified pipe stress, pipe support, and interfacing structure engineers for piping system and support design</li> <li>3. Timely &amp; accurate recording &amp; reporting of process parameters are to be enforced</li> </ol>
PITFALL # 3	FAILURE TO PROVIDE ADEQUATE RESTRAINT AGAINST PRESSURE THRUST FORCES	Tie rods cannot absorb the pressure thrust UNLESS the expansion joint's end flanges are in full & firm contact with outer pair of stop nuts. Standard uncompensated bellow-type expansion joints cannot eliminate the unbalanced pressure thrust forces from piping system	<ol style="list-style-type: none"> <li>1. All stop nuts must be locked tight</li> <li>2. In case of regular uncompensated bellows, two pipe ends farthest from the expansion joint must be rigidly restrained and immovable by means of separate structure external to piping, so that bellow would be forced to compress by same magnitude of axial thermal growth of line, and the external structure must be able to absorb full pressure thrust</li> </ol>

equipment operational difficulty/failure **Figures 6 (a) - 6 (b)**.

#### Improperly Installed Anchors

Many piping engineers seem to automatically place an anchor or anchors in an expansion joint installation. The anchor is required in most bellow expansion joints those are not tied with tie-rods. An anchor placed at the piping that has a tied expansion joint is an invitation to an operational problem, **Figures 6 (c) -6 (d)**.

#### PITFALLS WITH BELLOW-TYPE EXPANSION JOINTS

There are three (3) major pitfalls associated with selection, design and installation of bellow-type expansion joints, presented as detailed in **Table 2**. [8]

#### CONCLUSIONS

It is evident that each stage of selection, design, manufacturing and installation of expansion joints in process plant piping MUST be dealt with careful and meticulous engineering, with engagement of qualified & competent personnel, adhering to statutory guidelines and manufactures' recommendation.

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## REFERENCES

1. Liang-Chuan (L.C.) Peng and Tsen-Loong (Alvin) Peng, Peng Engineering, Houston, Texas, USA, Pipe Stress Engineering, ASME Press, pp. 1-4, 209-245,
2. Mohinder L. Nayar, Piping Handbook, Seventh Edition, McGraw-Hill, pp. A.84-A.86, B.96, B.157-B.159, C.115, C.325
3. J. Phillip Ellenberger, P.E., Piping Systems & Pipeline ASME Code Simplified, McGraw-Hill, pp. 210-211.
4. Brian Silowash, Pipe Systems Manual, McGraw-Hill, pp. 220.
5. J. Phillip Ellenberger, Piping and Pipeline Calculations Manual - Construction, Design Fabrication and Examination, Second Edition, Butterworth-Heinemann, pp. 169-178.
6. Glynn E. Woods, P.E. & Roy B. Baguley, P.Eng., Practical Guidebook SeriesTM, Volume 3 - 1997 CD-ROM Version, ASME B31.3 Process Piping, CASTI Publishing Inc., pp. 53
7. Victor Helguero M., Piping Stress Handbook, Second Edition, Gulf publishing Company, pp. 358-359
8. James A. Wingate, Mister Mech Mentor Volume II - Applying the ASME codes: plant piping and pressure vessels, ASME Press, pp. 9-13.

# Utilisation of Water Body for Generating Green Energy — a Way Forward to Sustainable Development in Energy Sector

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**Abstract:** Increasing energy demand and limited fossil fuel resources make solar power the best source of free energy, an unlimited source that is also eco-friendly and sustainable. When solar projects are being implemented on land, the government and the project partners face problems such as land availability, land development and acquisition, substation capacity, evacuation, and timely clearances for the project on land and evacuation. These are obstacles to project completion. To address these issues, an innovative idea for installing solar power plants on canal tops, water bodies, lakes, dam backwaters, and reservoirs owned by the government has been proposed. The solar photovoltaic system is an existing renewable energy technology that is typically found on land surfaces. The floating solar system is a novel idea that uses available water bodies to install floating solar panels. This system integrates existing land-based photovoltaic technology with new floating photovoltaic technology. Despite the fact that environmentally friendly solar power generation has numerous advantages over other forms of electricity generation, the main constraint is obtaining land and the cost. A new era in solar power, i.e. floating solar power plants, will address this issue to some extent while minimizing disruption to the eco-system. This floating solar plant, which can be installed in any body of water, will not only reduce the cost of land but will also increase generation efficiency due to the cooling effect of water. This paper presents the installation of a floating solar power plant by utilizing inland water bodies in India and as a co-production center of a Thermal power plant by utilizing the thermal station water bodies.

**Keywords:** Floating Solar; Renewable Energy; Ash Ponds; Raw Water Lake

## INTRODUCTION

Fossil fuel emissions contribute to a variety of environmental impacts. Increasing natural disasters, rising sea levels, and accelerated erosion of coastal zones are some of these impacts. Climate change is likely to cause significant net damage costs over time, according to the Intergovernmental Panel on Climate Change (IPCC). Increasing energy demand and the exhaustion of fossil fuels prompt us to turn to renewable energy sources, which are not only the future unlimited source of energy but also environmentally friendly. Solar energy is virtually placed important role in eco-friendly renewable energy sources. The main issue with solar energy is the scarcity and high cost of land. A floating solar plant not only reduces the cost of the land but also increases the quantum of generation due to the cooling of modules in the water body. The floating solar system benefits by making use of the available space in the water bodies. This paper describes the installation of a floating solar power plant, in inland water bodies in India, as well as its use as a co-production center of a thermal power plant by utilizing the thermal station water bodies.

## NEED FOR THE FLOATING SOLAR SYSTEM:

Solar panels installed over a pond are naturally cooled, resulting in improved power production performance. The cooler environment also reduces the degradation of the system, allowing it to last longer. Floating solar system costs are slightly higher than that of roof-mounted and ground-based single-axis tracking solar systems and they use the same commercially available solar panels. Floating solar installations are eligible for central and state government grants and incentives like land based systems.

Solar panels, like other electronic goods, have lower power outputs as temperatures rise. The water, on the other hand, will cool the solar panels, ensuring their efficiency as temperatures rise. According to comparative experiments on a large-scale floating solar plant in Hyogo Prefecture, Japan, the power generation of floating solar can be increased by about 11% as a result of the water cooling effect [1].

Apart from generating electricity, the systems also benefit the environment. For instance, a solar power generation system can shade the water and reduce evaporation by up to 70%. The systems can also improve the quality of water.

**Table 1** Current installed capacity in various sector as on 30.09.2022

Sl.No	Sector	Power Generation (MW)
1	State	99,005
2	Central	1,01,966
3	Private	2,03,825
4	Total:	4,07,797
5	Total Fossil Fuel	2,36,086
6	Total Non Fossil Fuel	1,71,710
7	Total:	4,07,797

When bodies of water are exposed to sunlight, photosynthesis promotes the growth of organic matter, including algae. Algae growth is reduced by shading the water, lowering treatment and labour costs. As the floating power plant is built on water, it is simple to clean and reduces dust pollution.

### TOTAL INSTALLED CAPACITY OF ELECTRICITY IN INDIA

The power sector is one of the major driving factors for increasing the GDP of our Nation. The current installed capacity of the power generation in our country is tabulated (**Table 1**) for a glance as per the Ministry of Power, Government of India [4]. Solar power generation occupies about 29% of renewable Energy sources.

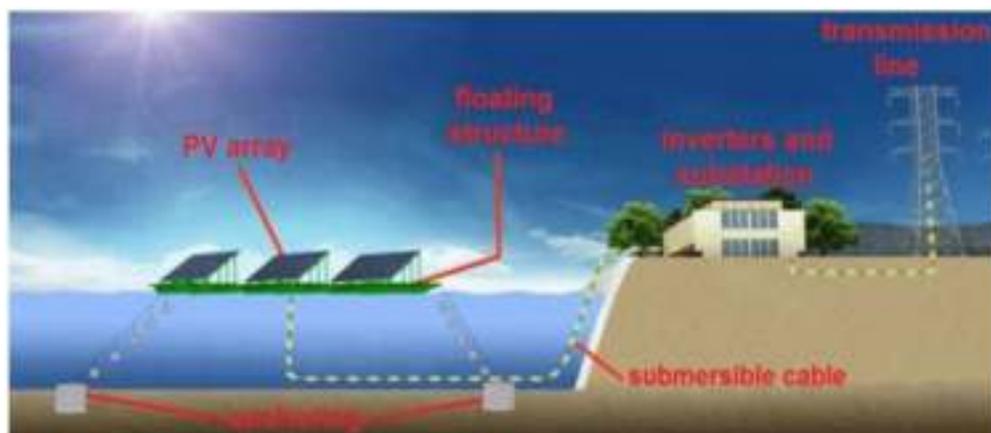
### OBJECTIVE OF FLOATING PV SYSTEM

India is the seventh largest country in terms of land area and is gifted with nearly 300 days of sunshine per year. Hence, solar energy has a lot of potential in India.

PV systems that are installed over the surface of drinking water reservoirs, quarry lakes, raw water/ash pond lakes of thermal power plant irrigation canals, and tailing ponds are named as floating solar arrays. France, India, Japan, South Korea, the United Kingdom, Singapore, and the United States are among the countries that have such systems [8,9]. As the land cost is more expensive by using the ideal facility, the structures of PV arrays are built on water bodies and generate power. On contrary, the water body cannot be used for other recreational purposes. Floating arrays, unlike most land-based solar plants, will be safe because they are hidden from public view. Due to water cooling the panels, floating solar achieve higher efficiencies than land-based PV panels. A special coating protects the panels from rust and corrosion[13].

### COMPONENTS OF FLOATING SOLAR PV SYSTEM

The PV floating power generation system is a hybrid of PV plants and floating technology. This combination represents a novel technological development in the renewable energy sector. It is similar to existing PV plants as a new generational concept, but it floats in bodies of water. This system consists of a floating system, mooring system, PV system, and underwater cables, etc.



**Figure 1** Outline of floating PV plant



**Figure 2** Floating solar plant functioning courtesy from Google images

### **Floating System/Pontoon/Floating Structure**

A pontoon is a flotation structure with sufficient buoyancy to float on water while supporting a heavy load. The structures are built in such a way that it can carry a large number of panels.

### **Mooring System**

Any permanent structure in which a floating structure is attached for tying up is a mooring. A floating structure is moored to prevent it from floating away from the desired location. An anchor mooring block, generally a solid concrete block immersed in the location, secures the position of a floating structure in its place without tying the floating structure to shore[14]. **Figure 4** shows the mooring system of the floating solar plant.

### **Solar Module**

A single solar module can only generate a limited amount of power, and most installations include a series of modules. A photovoltaic system basically consists of a panel or array of solar modules, a solar inverter, and, in some cases, a battery and/or solar tracker, as well as interconnection wiring. Generally floating solar systems are used with crystalline solar PV modules.

### **PV System**

PV generation gadgets for the floating system consists of electrical junction boxes, inverters, string monitoring boxes, transformers, etc.,

### **Underwater Cables**

Solar DC cables are specifically designed for outdoor uses. This cable provides resistant to UV radiation and extremely high temperature fluctuations, and they are generally withstood abnormal weather conditions. The cables are used to transfer the power generated from modules to the power system.



**Figure 3** Full view of water body at thermal station

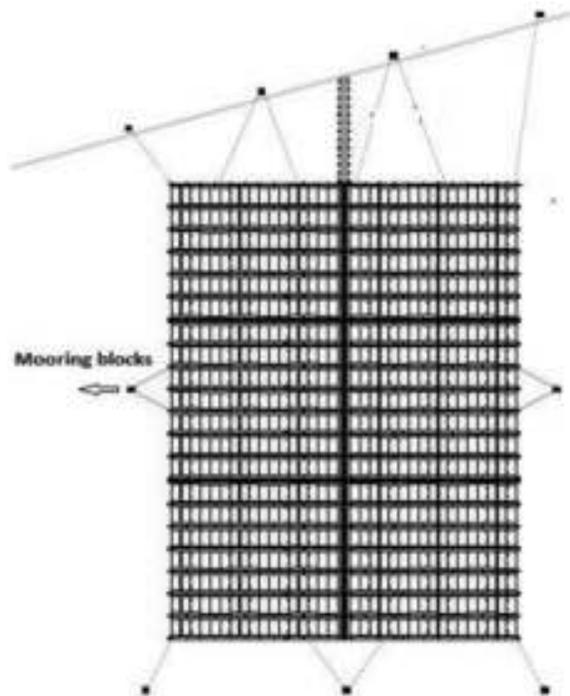


Figure 4 Setting of mooring arrangements

## MAJOR SOLAR POWER PLANT PROJECTS IN INDIA

India has come a long way in its pursuit of environmentally friendly power generation. However, the challenges posed by the rapid depletion of fossil fuel reservoirs and greenhouse gas emissions continue to rise. The situation warrants a significant shift to a renewable energy source.

The Government of India prioritizes solar projects for meeting the country's energy needs. It aims to generate 500 GW of renewable energy by 2030, with solar power accounting for 300 GW of that total [15].

### Major Indian Solar Power Projects: Ground-based Solar Power Plants

The largest solar power projects in the country have been built in Rajasthan, Andhra Pradesh, Karnataka, Madhya Pradesh, and Tamil Nadu.

- (i) Rewa Ultra Mega Solar 2020 (750 MW): It is the first Indian solar project to break the grid parity barrier, and it is Asia's largest single-site solar plant, covering 1,550 hectares.
- (ii) Bhadla Solar Park Project (2245 MW): The Bhadla Solar Park is one of the world's largest solar power plant projects, spanning over 14,000 acres. It is situated in the Rajasthan district of Jodhpur, in Bhadla. It involves a huge investment of about Rs. 10,000 crores.
- (iii) Kurnool Ultra Mega Solar Project (1000 MW): The Kurnool Ultra Mega Solar Project, with a total area coverage of 5932 acres, is located in the Panyam Mandal of Kurnool district, Andhra Pradesh.  
The Central and State governments, as well as Solar Developers, have invested approximately Rs. 7,000 crores in the solar park.
- (iv) Pavagada Solar Park Project (2050 MW): It is one of India's major solar power projects. Pavagada Solar Park, completed in 2019, spans 13,000 acres in Pavagada, Karnataka. The solar power park has a capacity of 2050 MW.
- (v) NP Kunta Ultra Mega Solar Park (1500 MW): This solar park covers 7924 acres of land in Anathapuram, Andhra Pradesh. It is one of India's Ultra Mega Solar Parks.

### India's Largest Floating Solar Power Project Commissioned

Floating solar power plants are categorized into 3 types based on the maximum power generation capacity. For example:

- (i) Small Size Power Plants (up to 100 kWp): In Kolkata 10 kW is also known as the first solar power plant in India.



- (ii) Medium Size Power Plants (100 to 500 kWp): A 2 MW project by Greater Visakhapatnam Smart City Corporation Limited (GVSCCL) at Vishakhapatnam. In Kerala 100 kW, plant is operated by NTPC. In Neyveli, Tamil Nadu 200 kW project was installed by NLCIL.
- (iii) Large Size Power Plants (above 1500 kWp): NTPC has set up the 100 MW plant through BHEL at Ramagundam, Telangana in 2022.

#### **SETTING UP OF FLOATING SOLAR SYSTEM AS A CO-PRODUCTION CENTRE BY UTILIZING WATER BODIES OF THERMAL POWER STATION**

By utilizing the water body at power stations, floating solar systems can be installed at thermal power plants water storing pools. This could serve as a co-production hub and the small quantity also serves as the auxiliary services of the thermal plant.

Every thermal power plant will have water storage pools and ash ponds. These bodies of water can be used for floating solar systems, which would provide a synergistic benefit. Water evaporation during the hot summers costs the plant a significant loss. Floating solar paves the way for doubling the benefits of water conservation by 50-70% and saving in the land (roughly 2.5 acres/MW) in addition to green energy generation. Moreover, humidity in the water body provides a cooling effect to the solar panels, increasing their efficiency and life.

The simple example provides a guideline for the installation of 200 kW capacities floating solar plant. The installation of the 200 kW floating solar PV system requires modules covering an area of around 2000 m<sup>2</sup> with sufficient buoyancy. The approximate installation cost will be Rs. 100 Lakhs.

The 200 kW floating solar plant may necessitate four 50 kW inverters, a transformer, and an HT breaker. As shown in **Figure 5**, the solar modules are mounted on floaters made of High Density Polyethylene (HDPE) material pipes. This plant's anchoring/mooring system consists of bottom anchoring via dead weight concrete blocks as shown in **Figure 4**.

A special High Modulus Polyethylene (HMPE) rope connects the entire floating system to the balancing reservoir bed. For real-time generation details, electrical equipment such as inverters, transformers, HT panels, and SCADA (supervisory control and data acquisition) can be connected through the use of an online portal (IoT).

#### **ENVIRONMENTAL IMPACT OF FLOATING SOLAR PLANT OVER COAL BASED THERMAL POWER PLANT**

The major direct environmental benefit is the reduced land requirement. Furthermore, the installation of floating solar panels reduces evaporation from water bodies, assisting in water conservation. It is estimated that water evaporation can be reduced by 70% per year. The water body beneath of these solar modules helps in the maintenance of the ambient temperature of the modules and thus it improving their efficiency and generation.

The power generated by a floating solar plant with a capacity of 1 MW is approximately 1500 MW per year. Similarly, approximately 800-1000 tons of coal consumption can be avoided per year [18]. Also, it is possible to avoid approximately 1500 tonnes of CO<sub>2</sub> emissions per year [16].



**Figure 5** Shows the view of floating solar plant at the thermal station lake



**Table 2** The approximate percentage utilization of water body respective installation capacity and avoidance of CO<sub>2</sub> emission

Sl.No	Percentage Utilization of Water Body	Approx. Installation Capacity in GW	Approx. Avoidance of CO <sub>2</sub> Emission in Tones per Year
1	1	75	$112.5 \times 10^5$
2	5	375	$576.5 \times 10^5$
3	10	750	$1125 \times 10^5$
4	20	1500	$2250 \times 10^5$
5	25	1875	$2812.5 \times 10^5$
6	30	2250	$3375 \times 10^5$
7	40	3000	$4500 \times 10^5$
8	50	3750	$5625 \times 10^5$

The plant, designed with cutting-edge technology and environmentally friendly features, is obviously to protect the aquatic ecosystem while producing clean power.

### SCOPE FOR UTILIZING AVAILABLE WATER BODIES IN INDIA

There is an abundant scope for covering water body available in India. As per the Department of Water resources, Ministry of Jal Shakthi, Government of India the Inland Water resources of the country are classified as rivers and canals; reservoirs; tanks and ponds; beels, oxbow lakes, derelict water; and brackish water. Other than rivers and canals, total water bodies cover all area of about 7 M.Ha. Of the rivers and canals, Uttar Pradesh occupies the First place with the total length of rivers and canals as 31.2 thousand km, which is about 17% of the total length of rivers and canals in the country. Other states following Uttar Pradesh are Jammu and Kashmir and Madhya Pradesh. Among the remaining forms of the inland water resources, tanks and ponds have maximum area (2.9 M.Ha.) followed by reservoirs (2.1 M.Ha.) [17].

The total area of inland water resources is, thus, unevenly distributed over the country with five states, namely, Orissa, Andhra Pradesh, Gujarat, Karnataka and West Bengal accounting for more than half of the country's inland water bodies.

As the resources availability is more, the installation of floating solar plants is very much necessary for producing huge amount of green energy. **Table 2** shows the approximate installation possibilities in the available water bodies in India. One hectare of water body can be approximately installed with 1 MW capacity of green energy floating solar plant. For the available 7.5 M.Ha the percentage utilization of water body, the possible capacity installation in Giga Watt (GW) and avoidance of CO<sub>2</sub> emission are shown in the following table.

### BENIFITS

- (i) No excavation/mining is required to produce energy.
- (ii) Conservation of valuable land and turning unused water bodies into profitable solar power plants.
- (iii) Area occupation would be around 80 % of the land PV plants.
- (iv) Reduce water evaporation by 70% and thereby savings in water.
- (v) Efficiency and life of the solar panel are increased due to the cooling effect of water.
- (vi) The existing facility in the thermal power plant may be used for the installation and power evacuations.
- (vii) Reduction in carbon helps to protect the Earth.

### CONCLUSION

India is rapidly approaching its renewable energy target by launching numerous large solar power projects. It has risen to fifth place on the list of countries with the highest solar power production. Due to a lack of suitable land for the installation of solar power generating plants, unused available water bodies will facilitate the installation of floating solar plants, adding to the eco-friendly Green energy.

Another advantage of the system is the cooling effect caused by its proximity to water. This improves the performance of solar photovoltaic panels by 5-10%, resulting in significant cost savings over time. Other benefits include lower grid interconnection costs, less water evaporation, improved water quality, and reduced algal blooming. As a viable alternative to solar installations on land, India has made progress in floating solar power by utilizing available water body resources.



This paper attempts to emphasize the importance of utilizing available water bodies for the installation of floating solar plants in India, as well as giving due consideration to installing as a co-generation centre by utilizing other existing water bodies and infrastructure facilities in thermal power plants.

## REFERENCES

1. Young-Kwan Choi, A Study on Power Generation Analysis of Floating PV System Considering Environmental Impact, International Journal of Software Engineering and its Applications, vol.8, no.1, 2014, pp 75-84.
2. N Krishnaveni, et al, A Survey on Floating Solar Power System, International Journal of Current Research and Modern Education, ISSN (Online): 2455-5428 & Impact Factor: 3.165, 2016.
3. Mehebab Alam and Mandela Gain, Floating Solar Photovoltaic (FSPV): An Innovative Novel Technology in Competitive Energy Market, Presented in 32nd Indian Engineering Congress, Chennai, Technical Volume, 2017, pp 216-223.
4. <https://powermin.gov.in/en/content/power-sector-glance-all-india>
5. A Sahu, N Yadav and K Sudhakar, Floating Photovoltaic Power Plant: A Review, Renewable and Sustainable Energy Reviews, Elsevier, 66815-824, 2016.
6. Sujay S Patil (Desai), M M Wagh and N N Shinde, A Review on Floating Solar Photovoltaic Power Plants, International Journal of Scientific & Engineering Research, vol. 8, issue 6, June 2017.
7. Lalit Solanki, Seminar Report on Floating Solar PV Station, National Institute of Technology, Kurukshetra, 2020.
8. Kyocera, Partners Announce Construction of the World's Largest Floating Solar PV Plant in Hyogo Prefecture, Japan. SolarServer.com. 4 September 2014.
9. Running Out of Precious Land. Floating Solar PV Systems May be a Solution. EnergyWorld.com. 7 November 2013.
10. Vikram Solar Commissions India's First Floating PV Plant. SolarServer.com. 13 January 2015.
11. Sunflower Floating Solar Power Plant in Korea. CleanTechnica, 21 December 2014.
12. Short of Land, Singapore Opts for Floating Solar Power Systems. CleanTechnica, 5 May 2014.
13. Erica Goodemay, New Solar Plants Generate Floating Green Power, New York Times, 20 May 2016.
14. Elbert S Maloney and Charles Frederic Chapman, Chapman Piloting: Seamanship & Small Boat Handling (62 Ed.), Hearst Marine Books, ISBN 978-0-688- 14892-8, 1996.
15. <https://www.solarsquare.in/blog/solar-power-plant-projects/>
16. <https://www.freeingenergy.com/environmental-impact-coal-water-co2-so2-mercury-pollution/>
17. <http://jalshakti-dowr.gov.in/water-bodies>
18. [https://cea.nic.in/old/reports/others/thermal/tppd/acq\\_norms.pdf](https://cea.nic.in/old/reports/others/thermal/tppd/acq_norms.pdf)





# Effect of Aluminium Powder Mixed Vegetable Oil and Silver Coated Copper Electrode on Electrical Discharge Machining of Inconel 718

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**Abstract:** Powder Mixed Electrical Discharge Machining (PMEDM) mostly encounter choice for machining the hard materials with job features like intricate shapes with greater accuracy and those materials are difficult to cut in conventional machining processes. In Electric Discharge Machining Process (EDM), dielectric fluid and its properties play an important role in material removal mechanism and it leads some environmental issues. Now a day's vegetable oils are tried as dielectric fluid for improvement of sustainability in EDM process. In this comparative experimental study, effect of Aluminium powder suspended palm oil dielectric and silver coated electrode on electrical discharge machining characteristics of Inconel 718 is focused. Current and Pulse on time were considered as input parameters. Effect of input parameters along with Aluminium powder suspended Palm oil dielectric fluid and silver coated electrode were investigated on EDM characteristics such as Material Removal Rate (MRR), Tool Wear Rate (TWR) and Wear Ratio (WR). Results clearly indicated that addition of powder to dielectric and coating on electrode has significantly improved MRR and reduced TWR compared to conventional Electrical Discharge Machining. Wear Ratio is calculated to find the optimal machining condition.

**Keywords:** Powder Mixed Electrical Discharge Machining; Vegetable Oil; Aluminium Powder; Silver Coated Electrode; Inconel 718; Wear Ratio

## INTRODUCTION

Electric Discharge Machining (EDM) is a competitive alternative for machining Ni-based super alloys as it is one of the thermal types of non-traditional machining processes having capability to machine any electrically conductive materials into desired shape with required dimensional accuracy irrespective of material's mechanical strength. EDM uses contact-free removal mechanism resulting low process forces of EDM are capable of creating burr-free micro structures with very high aspect ratios which would be very expensive or even impossible to achieve by conventional processes.

In electrical discharge machining, Dielectric fluid plays a significant role which affects the quality of machined components. Generally, oil based dielectrics, water based dielectrics, powder additives mixed dielectrics, and gaseous dielectric fluids are in practice for different EDM applications [1]. Associated problems with the usage of hydrocarbon based dielectric fluids over longer duration of time are hazardous emissions, disposal of contaminated dielectric fluid, skin problems, etc. [2]. Therefore, in order to reduce or avoid such drawbacks, hydrocarbon dielectrics are required to replace by water based, vegetable oil based, and gaseous dielectric fluids.

Which also supports in promoting green manufacturing in EDM process. Furthermore, sustainability approach can be incorporated in EDM process keeping in view various economic, environmental, and social considerations. These include higher productivity rate, minimum wastage, reduction in toxic fumes, and implementation of safety aspects etc. [3-5]. Disposal of waste generated leads to pollution problems on land and air, prolonged exposure to contaminated emissions affect working personnel's health in number of ways, and fire/radiation hazards are also associated with this advanced machining method [6].

EDM has been used in manufacturing of aerospace components such as fuel system, engine, impeller and landing gear components where high temperature and high stress conditions prevail. However, the EDM method also has limitations in machined performance (MP) and surface quality (SQ). For example, the material removal rate (MRR) is low when



compared to other methods and machining surface has many defects. Therefore, since the advent of the EDM method is until now, lot of research has been carried out to improve the MP and SQ. About four decades ago, researchers reported on the effect of powders mixed in insulating liquid on the machining process and surface quality of workpieces. Thus, the conductive powder particles are mixed in the insulating solvent of the EDM process, which is called the PMEDM process. This is a good solution to improve the MP and SQ. The presence of conductive powder reduces the ability in electric insulation of the dielectric liquid, varies the gap of the electric discharge between the tool electrode and the workpiece electrode, and electric discharges occur in many locations [7]. Moreover, the electric discharge process becomes stable and even, is enlarged, sparks in electric discharge process are less in the amount of energy, and the craters are formed shallower. As mentioned above, the presence of conductive particles changed and improved the discharge process. This has impacted the MP and SQ processed by the PMEDM process [8].

From the review of past research work, it is evident that Aluminium Powder Mixed EDM and palm oil as dielectric has strong potential in enhancing the Material Removal Rate (MRR) and Tool Wear Rate (TWR). However, the criteria for powder material selection, based on specific requirements and application, are still unknown. The aim of this work is to study the effect of Aluminium powder mixed vegetable oil and Silver coated copper electrode on EDM characteristics namely Material Removal Rate (MRR), Tool Wear Rate (TWR) and Wear Ratio (WR) by varying process parameters such as Peak current and Pulse on time.

### MATERIAL AND METHOD

Due to its excellent mechanical properties (high hardness, high temperature resistance and not easy to deform) and wide applications in industry, Inconel 718 is selected as the test materials. 36 small blocks were cut from the Inconel 718 plate using Wire EDM process. Dimension of each sample is 14 mm × 14 mm × 10 mm.

Copper, Silver coated copper electrodes are used in this Electrical Discharge Machining experimentation. Shape of the electrodes is cylindrical with approximately 12 mm dia. and 100 mm length. By using electroplating process Silver coating is made on Copper electrode with thickness about 0.010 mm and length 20 mm. Palm oil, Aluminium powder suspended palm oil were two types of dielectrics are used for carrying out the comparative study. Concentration of Aluminium metal powder- 325 mesh in kerosene is 3g/lit.

A set of experiments were conducted to study the performance measures of different experimental conditions in Electrical Discharge Machining process. According to literature survey, current and pulse on time has most influence in Electrical Discharge Machining of Inconel 718. So, Current and Pulse on time with three levels were selected in this experimentation as shown in **Table 1**. **Table 2** gives other constant parameters which are fixed while machining. The four experimental conditions for this comparative experimental study on Electrical Discharge Machining of Inconel 718 are listed in the **Table 3**. Whole experiments were carried out on a model ARD ARTM30D Die-sinking EDM setup.

After performing EDM of different experimental conditions for chosen input parameters peak current (6A, 9A, 12A) and pulse on time (120 μs, 300 μs, 500 μs), results were tabulated in **Table 4**. Calculations of Performance measures such as Material Removal Rate (MRR), Tool wear rate (TWR) and Wear Ratio (WR) are

#### Metal Removal Rate (MRR)

Material removal rate is nothing but the metal removed from the work piece for a particular period at given machining condition. This is expressed as

$$\text{Material Removal Rate (MRR)} = \frac{(W_i - W_f)}{t} \quad (1)$$

Where, 'MRR' - is g/min, 'Wi' - is the weight before machining the work piece-g, 'Wf' - is the weight after machining the work piece-g, and 't' - is the time for machining i.e. 7.5min.

#### B. Wear Ratio (WR)

WR is the ratio of Tool Wear Rate and Material Removal Rate which is helpful while selecting optimal experimental condition.

$$\text{Wear ratio} = \frac{\text{MRR}}{\text{TWR}} \quad (2)$$

**Table 5** gives wear ratio values of EDM using copper electrode, silver coated copper electrode, Aluminium powder mixed EDM using copper electrode and Aluminium powder mixed EDM using silver coated copper electrode.



**Table 1** Experimental plan

Parameters	Levels		
	1	2	3
Peak Current (A)	6	9	10
Pulse on Time ( $\mu$ s)	120	300	500

**Table 2** Other parameters

Parameters	Values
Gap Voltage (V)	60
Pulse off Time ( $\mu$ s)	50
Spark gap (mm)	0.1
Polarity	Positive

**Table 3** Experimental conditions

S.No	Experimental Condition
1	Copper electrode
2	Silver coated copper electrode
3	Powder suspended vegetable oil with copper electrode
4	Powder suspended vegetable oil with coated copper electrode

**Table 4** MRR for different conditions

Sample No.	Run	Current (A)	Pulse on time ( $\mu$ s)	MRR (g/min) for cu electrode	MRR (g/min) for silver coated cu electrode	MRR (g/min) for cu electrode with powder mixed dielectric	MRR (g/min) for silver coated cu electrode with powder mixed dielectric
1	9	6	120	0.008	0.009	0.010	0.011
2	4	6	300	0.009	0.012	0.014	0.015
3	1	6	500	0.013	0.014	0.016	0.016
4	6	9	120	0.04	0.043	0.052	0.058
5	2	9	300	0.092	0.098	0.110	0.114
6	8	9	500	0.108	0.112	0.130	0.128
7	3	12	120	0.121	0.150	0.159	0.169
8	5	12	300	0.212	0.227	0.238	0.265
9	7	12	50	0.249	0.256	0.264	0.261

**Table 5** Wear ratio for different conditions

Sample No.	Run	Current (A)	Pulse on time ( $\mu$ s)	MRR (g/min) for cu electrode	MRR (g/min) for silver coated cu electrode	MRR (g/min) for cu electrode with powder mixed dielectric	MRR (g/min) for silver coated cu electrode with powder mixed dielectric
1	9	6	120	0.375	0.244	0.119	0.090
2	4	6	300	0.444	0.0183	0.084	0.066
3	1	6	500	0.384	0.285	0.125	0.148
4	6	9	120	0.075	0.058	0.021	0.017
5	2	9	300	0.054	0.040	0.018	0.008
6	8	9	500	0.046	0.044	0.016	0.015
7	3	12	120	0.024	0.014	0.012	0.005
8	5	12	300	0.018	0.013	0.008	0.003
9	7	12	50	0.020	0.015	0.007	0.007

### C. Tool Wear Rate (TWR)

Tool wear rate is the material removed from the tool for a particular period at given machining condition. This is expressed as

$$\text{Tool Wear Rate (MRR)} = \dots \quad (3)$$

Where, 'Ei' - is weight of electrode before machining-g, 'Ef' - is weight of electrode after machining-g, and 't' - is time for machining each piece-7.5 min.

### RESULTS AND DISCUSSION

The influence of process parameters namely peak current (6A, 9A, 12A) and pulse on time (120 μs, 300 μs, 500 μs) on performance measures such as Material Removal Rate (MRR), Tool Wear Rate (TWR) and Wear Ratio (WR) using copper electrode, silver coated copper electrode, Aluminium powder suspended dielectric with copper electrode,

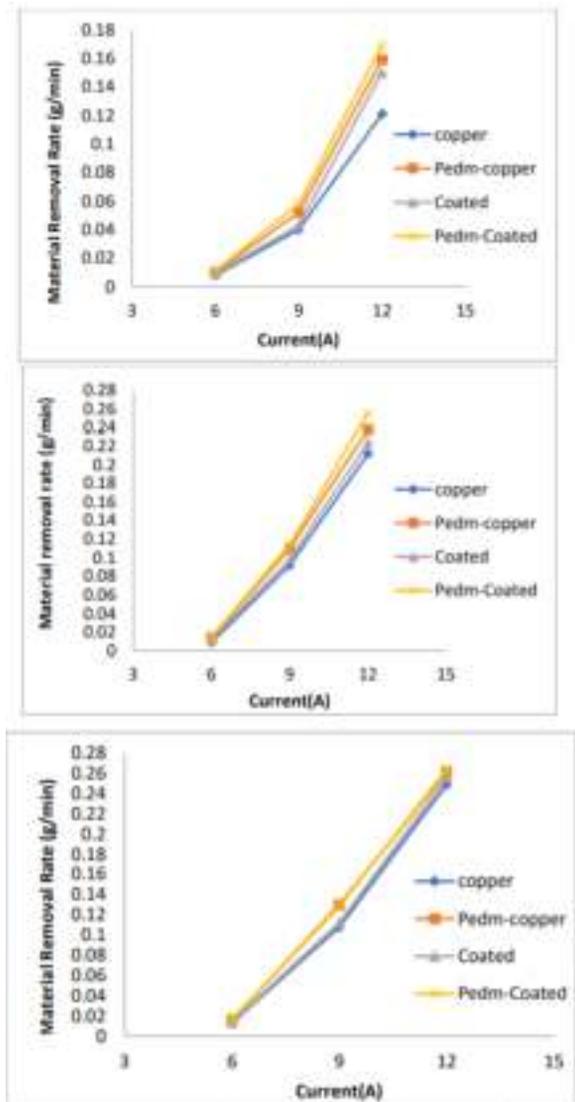


Figure 1 Effect of current on MRR at (a) 120 μs (b) 3000 μs (c) 500 μs pulse -on-time

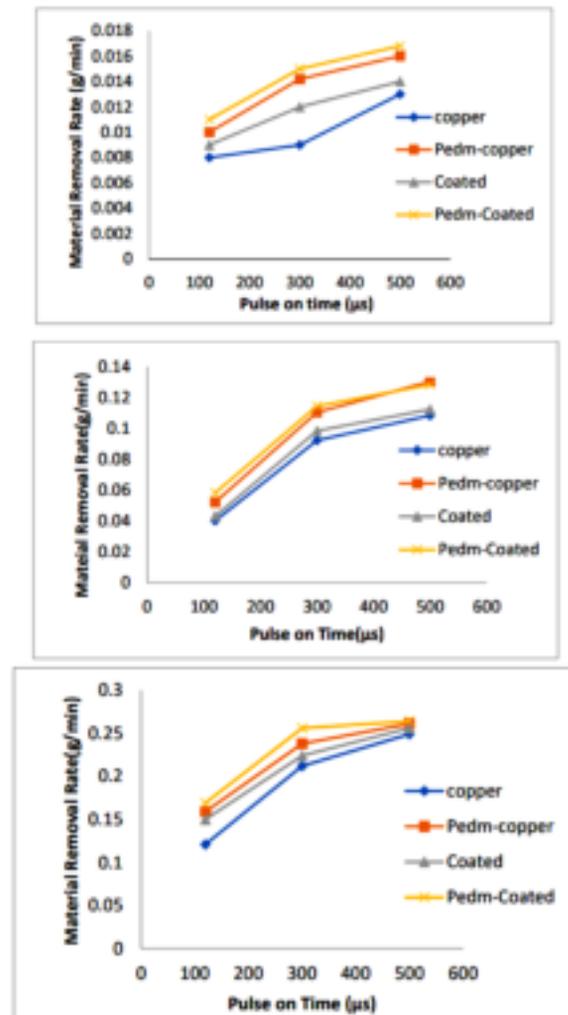
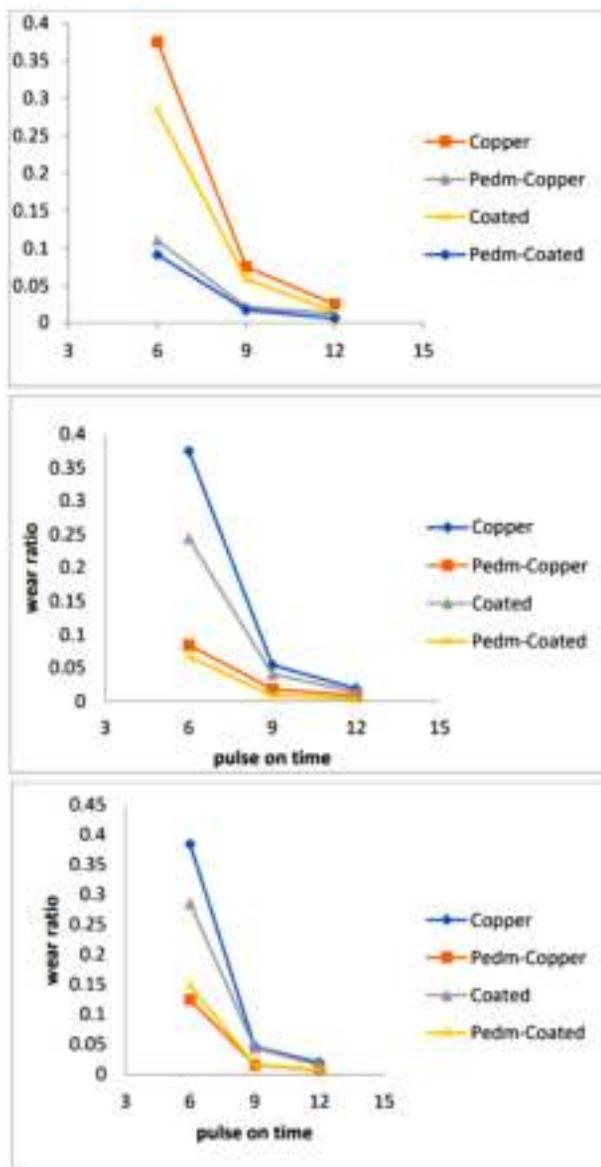
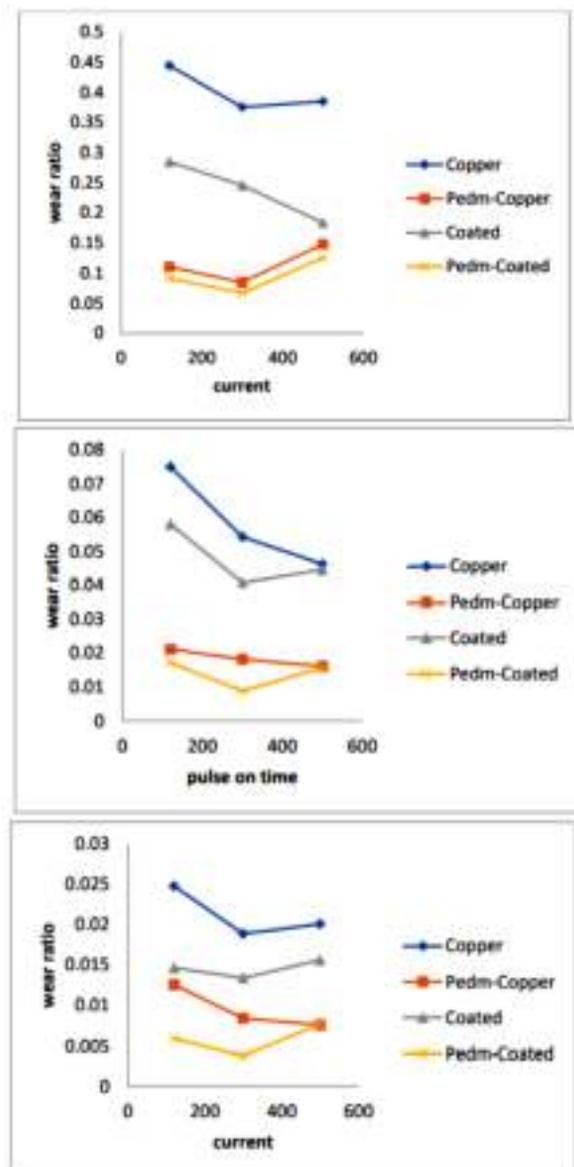


Figure 2 Effect of pulse -on -time on MRR at (a) 6 A (b) 9 A (c) 12 A current



**Figure 3** Effect of current on wear ratio at (a) 120µs (b) 300 µs (c) 500 µs pulse -on-time



**Figure 4** Effect of pulse -on-time on wear ratio at (a) 3 A (b) 6 A (c) 9 A current

Aluminium powder suspended dielectric with silver coated copper electrode are discussed in this section.

### A. 3.1 Effect of Process Parameters on MRR for Different Experimental Conditions

Graph as shown in **Figure 1 (a)-(c)** is plotted between current (6A, 9A and 12A) and material removal rate at constant pulse on time at 120 µs, 300 µs and 500 µs, respectively for different experimental conditions.

From above **Figure 1(a)**, it is observed that material Removal Rate (MRR) increased with increase in peak current. With increase in peak current, the discharge energy of the plasma channel increases causes temperature rises sharply that leads to rapid melting of work piece material at sparking area. Addition of Aluminium powder particles and Silver coating has significant improvement in Material Removal Rate (MRR). Overall Material removal rate is comparatively high for



Aluminium powder suspended Electrical Discharge machining using copper electrode at 12A of peak current as more electric charges are produced in Powder mixed EDM compared to conventional EDM. Material removal rate is comparatively low for Electrical Discharge machining using copper electrode. At low current, a small quantity of heat is generated and a substantial portion of it is absorbed by the surroundings, as a result, the amount of utilized energy in melting and vaporizing the electrodes is not so intense.

A Graph as shown in **Figure 2 (a)-(c)** is plotted between Ton and material removal rate at constant current 6A, 9A and 12A for different experimental conditions.

From **Figure 2**, it is evident that Material Removal Rate (MRR) increased with increase in Pulse on time. Average MRR at 12A is comparatively high for Powder Mixed Electrical Discharge Machining using Silver coated Copper electrode and comparatively low for Machining using Copper electrode. In PMEDM process after the first discharge, powder particles in IEG get energized and move rapidly along with ions and electrons. These energized powder particles collide with dielectric molecules and generate more ions and electrons. Thus, more electric charges are produced in PMEDM compared to conventional EDM. For low pulse-on time, the heating time of workpiece was so short that only a small part of material was melted.

### B. Effect of Process Parameters on Wear Ratio for Different Experimental Conditions

Graph as shown in **Figure 3 (a)-(c)** is plotted between current (6A, 9A and 12A) and wear ratio at constant pulse on time at 120  $\mu$ s, 300  $\mu$ s and 500  $\mu$ s respectively for different experimental conditions.

It is observed that as Wear ratio is directly proportional to Tool Wear Ratio and inversely proportional to Material Removal Rate it is desired to achieve less wear ratio. From **Figure 3**, it is clear that overall Wear Ratio is low for Powder mixed Electrical Discharge Machining using silver coated Copper electrode and high for Electrical Discharge Machining using Copper electrode.

Graph as shown in **Figure 4 (a)-(c)** is plotted between current (6A, 9A and 12A) and wear ratio at constant pulse on time at 120  $\mu$ s, 300  $\mu$ s and 500  $\mu$ s respectively for different experimental conditions. From **Figure 3**, it is observed that average Wear Ratio (WR) is comparatively low for Powder Mixed Electrical Discharge Machining using Copper electrode and comparatively high for Electrical Discharge Machining using silver Copper electrode.

### CONCLUSIONS

The effect of process parameters namely peak current (6A, 9A, 12A) and pulse on time (120  $\mu$ s, 300  $\mu$ s, 500  $\mu$ s) performance measures such as Material Removal Rate (MRR), Tool Wear Rate (TWR) and Wear Ratio (WR) using copper electrode, silver coated copper electrode, Aluminium powder suspended dielectric with copper electrode and Aluminium powder suspended dielectric with silver coated copper electrode were investigated through this Electrical Discharge Machining experimentation and the following conclusions were drawn.

- Material Removal Rate increases with increase in both peak current and pulse on time. For MRR the best process parameters are current at 12 A, pulse on time (Ton) at 500  $\mu$ s for Aluminium Powder mixed ED Machining using silver coated copper electrode.
- Tool Wear Rate increases with increase in both current and pulse on time. The best process parameters to obtain the minimum Tool Wear Rate are peak current at 12A for Aluminium powder electrode mixed ED Machining using plain copper and silver coated copper electrode
- The minimum of wear ratio 0.003 is economy which was obtained Aluminium powder mixed ED Machining using silver coated copper electrode of setting 12A of Peak Current, Pulse on Time 300  $\mu$ s.
- Optimal machining condition, is Aluminium powder mixed Electrical Discharge Machining using copper electrode.

### REFERENCES

1. Abbas, Norliana Mohd, Darius G. Solomon, and Md Fuad Bahari. A review on current research trends in electrical discharge machining (EDM). *International Journal of machine tools and Manufacture* 47, no. 7-8 (2007): 1214-1228.
- 2.. Chakraborty, S., V. Dey, and S. K. Ghosh. A review on the use of dielectric fluids and their effects in electrical discharge machining characteristics. *Precision Engineering* 40 (2015): 1-6.
3. Zia, Muhammad Kashif, Salman Pervaiz, Saqib Anwar, and Wael A. Samad. Reviewing sustainability interpretation



- of electrical discharge machining process using triple bottom line approach. *International Journal of Precision Engineering and Manufacturing- Green Technology* 6, no. 5 (2019): 931-945.
4. Singh, Nishant K., Pulak M. Pandey, K. K. Singh, and Manish K. Sharma. Steps towards green manufacturing through EDM process: a review. *Cogent Engineering* 3, no. 1 (2016): 1272662.
  5. Valaki, Janak B., Pravin P. Rathod, and Ajay M. Sidpara. Sustainability issues in electric discharge machining." In *Innovations in manufacturing for sustainability*, pp. 53-75. Springer, Cham, 2019.
  6. Leppert, Tadeusz. A review on ecological and health impacts of electro discharge machining (EDM). *AIP conference proceedings*, vol. 2017, no. 1, p. 020014. AIP Publishing LLC, 2018.
  7. Razak, M. A., A. M. Abdul-Rani, and A. M. Nanimina. Improving EDM efficiency with silicon carbide powder-mixed dielectric fluid. *International Journal of Materials, Mechanics and Manufacturing* 3, no. 1 (2015): 40-43.
  8. Jabbaripour, B., M. H. Sadeghi, Sh Faridvand, and M. R. Shabgard. Investigating the effects of EDM parameters on surface integrity, MRR and TWR in machining of Ti-6Al-4V." *Machining Science and Technology* 16, no. 3 (2012): 419-444.



# Study of Mechanical Properties, Microstructure and Wear behaviour of AL 6061 Metal Matrix Composite Reinforced with AISI 1060 Steel Chips

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**Abstract:** In this paper, mechanical properties and wear behavior of Al 6061 matrix composites reinforced with AISI 1060 steel machining chips was investigated. Steel machining chips with chip size range of 40  $\mu\text{m}$  and below were utilized to develop stir cast Al matrix composites having 2.5, 5 and 10 wt% of the chips as reinforcement. The Aluminium metal matrix composites (AMMCs) were produced through the Stir casting process, as it is one of the easiest and economical manufacturing process. The castings produced were subjected to various mechanical tests to determine the properties. The results were evaluated and also compared with the unreinforced Al6061 to understand the effect of addition of steel in improving the properties. To study the wear behaviour, the Design of Experiments (DOE's) were set with the help of Taguchi's L16 Orthogonal Array (OA) to reduce the number of experiments. From the results, an increase of 16.58% in the ultimate tensile strength of the composites is observed with the addition of steel chips. And due to increase in carbon content the % elongation is reduced. The compressive strength is observed to be increased by 7.7% with the addition of steel. The increase in % steel reinforcement has enhanced the hardness of composites by 22.5%. The composite castings produced were uniformly dispersed and no evidence of segregation was seen in the microstructure study. The optimum process parameters for minimum wear rate were 10% steel reinforcement, 20 N applied load & 100 rpm speed and, for minimum co-efficient of friction were at 5% steel reinforcement, 60 N applied load & 400 rpm speed.

**Keywords:** Al6061; AISI 1060 Steel Chips; Taguchi; Tensile Strength, Hardness; Wear Rate

## INTRODUCTION

Aluminum (Al) is most common metal used in many applications due to its light weight. Aluminum and its alloys are second important metal among engineering material, after steel material because of its low density, good electrical conductivity and heat and high resistance in corrosion environment. One of the most famous alloys 6061 boasts medium to high strength, excellent corrosion resistance, machinability and weldability. Al-6061 hails from 6000 series of aluminum alloys which uses magnesium (Mg) and silicon (Si) as primary constituents. The Al-6061 alloy strengthened by heat treating, which allows it to maintain medium-high strength in critical environments than normal aluminum alloys [1].

Metal Matrix Composite (MMC) is becoming an advanced material for aircraft applications by replacing conventional metals such as steel and aluminum due to its benefits. Various ceramic materials like SiC, Al<sub>2</sub>O<sub>3</sub>, B<sub>4</sub>C, TiB<sub>2</sub>, ZrO<sub>2</sub> and TiC are used as reinforcement in different micron sizes [2-11]. Reinforcement of ceramic materials in Aluminum Metal Matrix Composites (AMMC) can produce good mechanical and surface properties especially suitable for anticorrosion and excellent wear resistance with low density.

As every year, tons of industrial waste is produced in the form of machining chips and majority of them is steel machining chips, disposal and recycling of these chips is a major environmental as well as economical challenge. In this study, the steel machining chips were used as the reinforcement for AA6061 alloy to produce an Aluminium metal matrix composite to achieve sustainability. The investigations were done to evaluate the mechanical and tribological properties and microstructure. The comparison between the metal matrix composites produced with the base alloys was done and the results were analysed.

## MATERIALS AND METHODS

The matrix material selected was Aluminium alloy Aa6061 (circular rods of 1 inch diameter and 4 meter length) and the

reinforcement selected was AISI 1060 carbon steel powder of grain size of 40 microns. Stir casting (shown in **Figure 1(a)**) is one of the most suitable processing technique to fabricate Aluminium metal matrix composites, as it is an economical process and preferred for mass production. The matrix material (AA6061) was heated above its melting point. Then, the preheated reinforcement material was added slowly to the vortex, and after that, the molten composite melt was poured into the mould and allowed solidification. Then, the casting ingots of the various compositions were recovered from the moulds (shown in **Figure 1(b)**). The objective is to produce the composites of four varying percentages of steel reinforcement such as unreinforced AA6061, 2.5-wt% steel addition to AA6061, 5-wt% steel addition and 10-wt% steel addition to AA6061 and produce composites. The selection of mass or volume of AA6061 and AISI 1060 for each composition was done based on the calculations which are specified in the **Table 1**.

The ingots of various composition were machined according to the ASTM standards and tested for evaluating mechanical properties such as, tensile, % elongation and compressive strengths, hardness and microstructure. The wear behaviour of the various composition specimens was studied by varying the parameters. The design of experiments (DOE) i.e., Taguchi L16 OA was used to conduct the experiments. To optimise the responses, the signal-to-noise (S/N) ratios were calculated. The results of all the tests were evaluated and compared for understanding the changes in the properties due to the reinforcement of steel in the Aluminium metal matrix composites.

## RESULTS AND DISCUSSION

### A. Tensile Properties of the Cast AlMMC

From the tensile test, it was observed that with the increase in the percentage of steel reinforcement in the composites, there is an increase in the yield strength and the ultimate tensile strength of the composites compared to the unreinforced AA6061 as shown in **Table 2**. Further, it was observed that percentage of elongation at the point of failure is decreasing with the increase in the percentage of steel addition as shown in the Table 2. As the percentage of steel addition increases in the AA6061, its ductility decreases. And the carbon content present in the high carbon steel has imparted hardness and brittleness into the Aluminium alloy.

From the **Table 2**, it can be observed that the ultimate tensile strength or the tensile strength is almost same for 2.5% addition of steel, compared to the unreinforced AA6061. But from unreinforced AA6061 to 5% steel addition, there is a considerable increase in the tensile strength by 14.67%. And when compared with the 10% reinforcement to the unreinforced AA6061, there is an increase of 16.58% in the strength, which does not serve the purpose of reinforcement effectively. From the results, it was concluded that the desirable strength in AA6061 composites was observed at 5% reinforced.



**Figure 1** (a) Stir casting (b) Cast ingot recovered from the mould



**Table 1** mass calculation for various % steel reinforced composites

Type	% Steel reinforcement	AA6061			AISI 1060 mass addition (g)	Total mass (g)
		Density (g/cc)	Volume (cc)	Mass (g)		
I	0	2.7	456.04	1231.31	0	1231.31
II	2.5		445.9	1203.93	27.38	
III	5.0		435.77	1176.58	54.73	
IV	10.0		410.43	1108.16	123.15	

**Table 2** Mechanical properties of various composites

Composition	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	% Elongation	Compressive Strength (MPa)	Hardness (BHN)
Unreinforced AA6061	129	140	11.26	360	80
2.5% reinforced AA6061	135	140	4.89	364	84
5% reinforced AA6061	149	160	3.178	379	92
10% reinforced AA6061	160	163	2.1	388	98

### B. Compressive Strength of cast Al MMC

From the results obtained, it was observed that there is an increase in the compressive strength of the Aluminium metal matrix composite compared to the unreinforced AA6061.

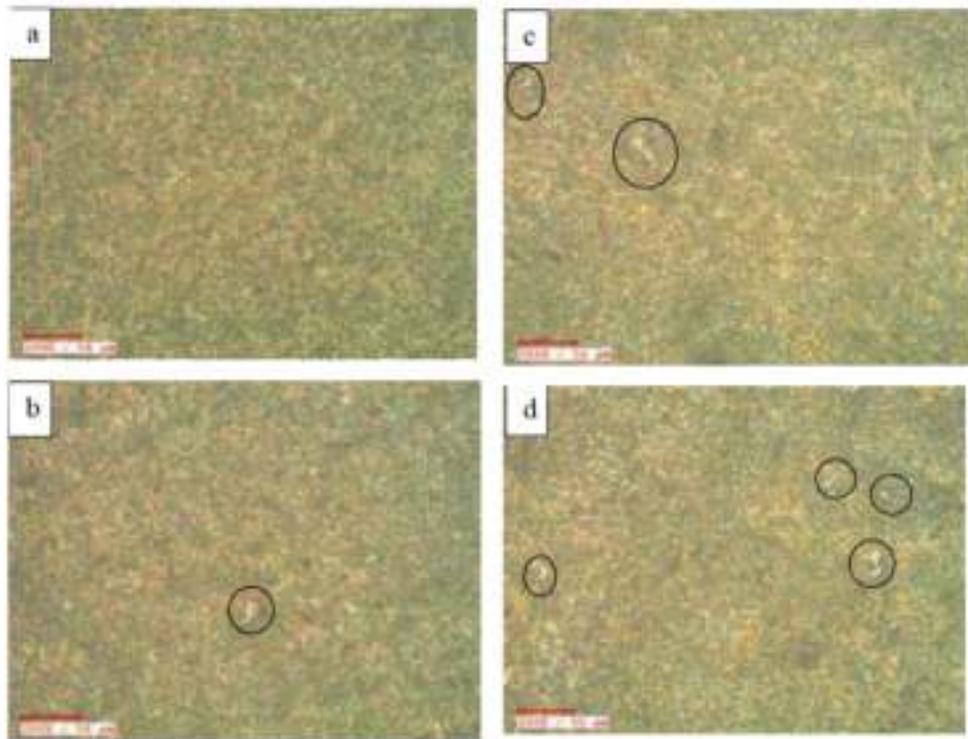
The compressive strength of the various compositions were as listed in **Table 2**. From the **Table 2**, it can be observed that the compressive strength of the 2.5% steel reinforced AA6061 is almost same as that of unreinforced AA6061 with just an increase of 1.13%. But from unreinforced AA6061 to 5% steel addition, there is a considerable increase in the compressive strength by 5.27%. And for the 10% steel reinforcement, there is an increase of 7.7% in the compressive strength. From this we can conclude that the compressive strength is increasing continuously as the % steel addition is increasing. The increase in the strength is attributed because of the presence of carbon content present in the high carbon steel reinforcement.

### C. Hardness Test of Cast Al MMC

From the results obtained, it was observed that there is an increase in hardness with the increase in the % addition of steel. This increase in hardness can be attributed to the addition of harder material steel to the soft material Aluminium to produce the composite. **Table 2** shows the Brinell hardness of the various composite specimens.

### D. Microstructure study of cast Al MMC

The microstructure study of all the four composites was done at 200X magnification. From these images (shown in **Figure 2**) it was clear that, the composite castings produced were evenly distributed all along the material. This can be attributed to effective stirring action and the use of appropriate process parameters. This uniform distribution also will improve the mechanical properties of the composites. And the steel particles also have an impact on improvement in hardness. The lighter particles are the AISI 1060 particles and the remaining darker particles are AA6061. No evidence of segregation was seen in all the composites. As well as there was no surface defect seen in all the specimens.



**Figure 2** Microstructure images of (a) Unreinforced AA6061, (b) 2.5%, (c) 5% and (d) 10% steel reinforced AA6061 at 200X magnification

#### E. Wear behavior Cast Al MMC

The results obtained from the wear testing done on the Pin-on-disc tester were utilised in evaluating the wear rate (g/min) and the co-efficient of friction are shown in the **Table 3**.

The pin wear rate was calculated using

$$\text{wear rate} = \frac{\text{initial mass} - \text{final mass}}{\text{time of sliding}} \quad (1)$$

#### F. Analysis of Wear Rate Response

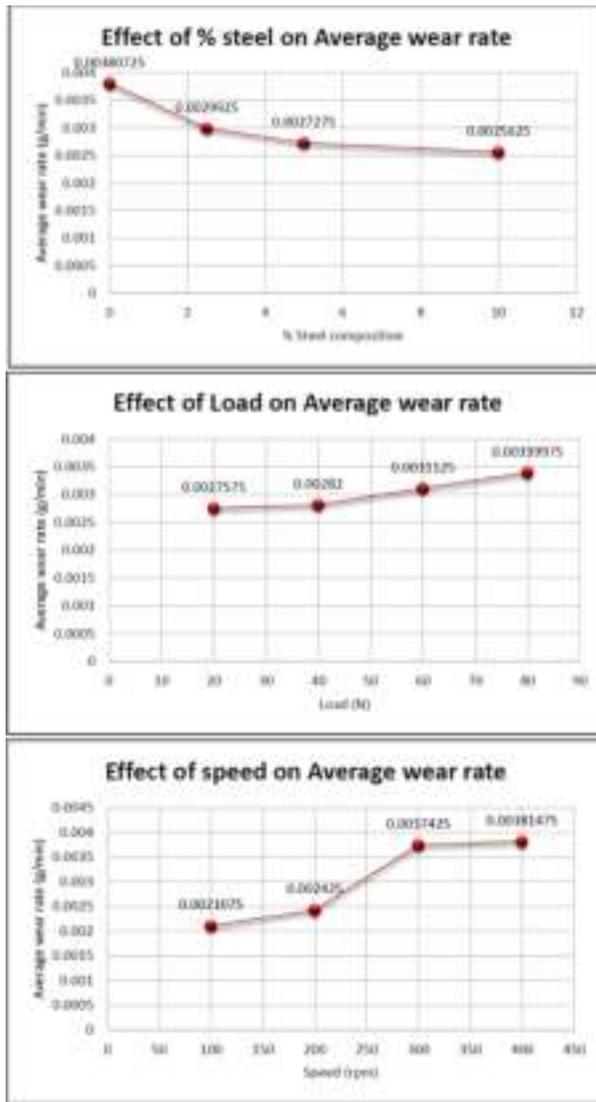
##### G. Effect of parameters on the wear rate

The graph plotted in **Figure 3(a)** shows that, the increase in the % steel reinforcement is continuously reducing the wear rate by 32.69%. From the graph shown in the Figures 3(b-c), it was observed that with the increase in load and speed, there is a continuous increase in wear rate i.e., up to 23.29% and 81% respectively.

H. Optimization of parameters for reducing wear rate The aim of the optimisation is to minimise the wear rate for the given input parameters. Taguchi's signal to noise ratio is the logarithmic function of desired output. Here mean refers to signal and standard deviation refers to noise. The ratio depends on the quality characteristic of the product/process to be optimized.

The signal to noise ratios for the wear rate are calculated (shown in **Table 4**) using the equation of 'smaller the better', as the pin wear rate is one of the responses which is to be as minimum as possible. Lower wear rate will permit the increase in the life of the pin (work piece), which means that the pin can be used for longer period of time without getting a change in the accuracy while machining.

From the **Table 4**, it can be concluded that speed has greater influence on the wear rate, followed by % steel



**Figure 3** Effect of % steel reinforcement (b) Effect of applied load (c) Effect of speed on average wear rate

**Table 3** Wear rate obtained from the wear test

Stal. Order	Composition (%)	Load (N)	Speed (RPM)	Wear rate (g/min)	S/N Ratio
1	0	20	100	0.00329	49.65
2	0	40	200	0.00288	50.81
3	0	60	300	0.00441	47.11
4	0	80	400	0.004649	46.65
5	2.5	20	200	0.00129	57.79
6	2.5	40	100	0.00218	53.23
7	2.5	60	400	0.00373	48.56
8	2.5	80	300	0.00477	46.43
9	5.0	20	300	0.00314	50.06
10	5.0	40	400	0.00357	48.95
11	5.0	60	100	0.00149	56.54
12	5.0	80	200	0.00271	51.34
13	10.0	20	400	0.00331	49.60
14	10.0	40	300	0.00265	51.54
15	10.0	60	200	0.00282	50.99
16	10.0	80	100	0.00147	56.65

**Table 4** Mean values of S/N ratio for wear rate

	% Steel reinforcement	Applied Load (N)	Speed (RPM)
Level 1	48.56	51.78	54.02
Level 2	51.50	51.13	52.74
Level 3	51.72	50.80	48.78
Level 4	52.19	50.27	48.44
Delta	3.64	1.51	5.58
Rank	2	3	1

**Table 5** % Contribution of the given factors

S.No	% Steel reinforcement	% Contribution	Rank
1	% Steel reinforcement	23.219	2
2	Applied Load (N)	13.481	3
3	Speed (RPM)	56.746	1
	error	6.554	

reinforcement and then applied load. Therefore, the optimum process parameters for minimum wear rate are 10% steel reinforcement, 20 N applied load and 100 rpm speed.

ANOVA test was conducted to determine the influencing factors in a regression study and is tabulated in **Table 5**. Based on ANOVA, the speed has 56.746% contribution, % steel reinforced has 23.219% contribution and applied load has 13.481% contribution, for obtaining minimum wear rate.

### CONCLUSIONS

After evaluating all the results obtained from the tensile test, compressive test, hardness test, microstructure study and the wear behaviour, few conclusions were drawn from the current study. The ultimate tensile strength increased up to 16.58% due to the steel reinforcement and also concluded that the desirable strength in AA6061 was observed at 5% steel reinforcement. The percentage of elongation at the point of failure is decreasing with the increase in the % steel reinforcement. The compressive strength increased continuously as the % steel reinforcement increased up to 7.7%



compared to the unreinforced AA6061. The hardness of composites (BHN value) increased with the increase in the % steel reinforcement and maximum is 98BHN at 10 - wt% steel reinforcement. From the microstructure study, it was observed that the reinforcement in the composite castings were uniformly dispersed and no evidence of segregation.

From the wear rate response, it was observed that the increase in % steel decreased the wear rate. Whereas, increase in the load and speed, increases the wear rate. And the speed has greater influence (56.746%) on the wear rate, followed by % steel reinforcement (23.219%) and then applied load (13.481%). And the optimum process parameters for minimum wear rate were observed at 10% steel reinforcement, 20 N applied load and 100 rpm speed.

## REFERENCES

1. Nagasai, B. Prasanna, C. H. Anusha, and A. Rajesh. Study on composites. *Materials Today: Proceedings* 47, 2021, : 4552-4557.
2. Li, Yong, and Terence G Langdon. Creep behavior of an Al-6061 metal matrix composite reinforced with alumina particulates. *Acta Materialia* 45, no. 11, 1997, 4797-4806.
3. Ehsani, R., and Reyhani S M Seyed. Aging behavior and tensile properties of squeeze cast Al 6061/SiC metal matrix composites. 2004, 392-397.
4. Mishra, Ashok Kumar, and Rajesh Kumar Srivastava. Wear behaviour of Al-6061/SiC metal matrix composites." *Journal of The Institution of Engineers (India): Series C* 98, no. 2, 2017, 97-103.
5. Maurya, Nagendra Kumar, Manish Maurya, Ashish Kumar Srivastava, Shashi Prakash Dwivedi, and Sandeep Chauhan. Investigation of mechanical properties of Al 6061/SiC composite prepared through stir casting technique. *Materials Today: Proceedings* 25, 2020, 755-758.
6. Gocer, Abdullah, and M. BakiKaramis. An Investigation on the Tribological Behaviors of Al 6061-B4C Metal Matrix Composites. *Protection of Metals and Physical Chemistry of Surfaces* 57, no. 3, 2021, 579-588.
7. Kumar, B N Anil, AbrarAhamad, and H. N. Reddappa. Impact of B4C reinforcement on tensile and hardness properties of Al-B4C metal matrix composites. *Materials Today: Proceedings* 52, 2022, 2136-2142.
8. Christy, T. V., N. Murugan, and S. Kumar. A comparative study on the microstructures and mechanical properties of Al 6061 alloy and the MMC Al 6061/TiB2/12p. *Journal of Minerals & Materials Characterization & Engineering* 9, no. 1, 2010, 57-65.
9. Selvaganesan, M., and S. Suresh. Production and characterization of Al 6061-TiB2 metal matrix composites." *International Journal of Engineering Research and Technology* 2, no. 11, 2013.
10. Chinnamahammad Bhasha, A., and K. Balamurugan. Fabrication and property evaluation of Al 6061+ x%(RHA+ TiC) hybrid metal matrix composite. *SN Applied Sciences* 1, no. 9, 2019, 1-9.
- 11, Raviraj, M. S., C. M. Sharanprabhu, and G. C. Mohankumar. "Experimental analysis on processing and properties of Al-TiC metal matrix composites. *Procedia Materials Science* 5, 2014, 2032-2038.



**MINING  
ENGINEERING  
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# Stability Assessment of Chain Pillars and Gateroads of Longwall Panel using 3D Numerical Modelling Technique

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**Abstract:** The chain pillars are developed between two longwall panels to provide support to the face and gateroads. The load on the chain pillars, face and neighbouring panel develops due to the retreating of the face and it causes reduction of the pillars stability. In order to excavate longwall panel successfully, the stability of the chain pillars and gateroads are required to be assessed and their optimum size need to be designed. Hence, 3D numerical modelling technique is applied to estimate stability of chain pillars and gateroads of a deep longwall panel of India situated at about 420 m depth. All numerical models are analyzed using Mohr's-coulomb failure criterion to determine safety factor of the pillars and workings. The paper also presents the stress distribution around the face, gateroads and chain pillars, and also discuss the vertical displacement developed in the longwall workings and abutment zone.

**Keywords:** Longwall; Chain Pillars; Gateroads; Safety Factor; Numerical Modelling; Stress

## INTRODUCTION

The longwall mining method is considered as the future for extracting a large portion of the coal from the deep underground coal mines. This method has high efficiency to produce the coal from the large panels as compared to the other conventional methods. The longwall panels are formed by driving series of gateroads and chain pillars and these structures will provide the service to the coal evacuation process till the panel gets completed. During the retreating of the face, the stress develops on the chain pillars, working face and adjacent panels and also excessive convergence and floor heaving occurs in the gateroads. As a result, the stability of the pillars, face and the gateroads may get deteriorated and tend to yield.

In order to extract the deep longwall panel with safety and productivity, the stability of the chain pillars and gateroads is required to be assessed and their optimum size needs to be designed. There are few studies were conducted on stability of the chain pillars, panels, longwall face and gateroads using theoretical methods, empirical methods and numerical methods and also the actual field data collected from the mine site. The abutment zone in the longwall face was also estimated using roof convergence and the induced stress data [1-2].

In this paper, the stability analysis of the chain pillars and gateroads of a deep underground coal mine of India is performed. Three-dimensional numerical model technique is applied to prepare the numerical model for deep longwall panel considering the lithology of the mine site. The size of the panel is 552 × 250 m situated at about 420 m depth. A 3D longwall panel consists of chain pillars, gateroads, longwall face, goaf, coal seam and other coal bearing strata. All the numerical models are analyzed considering the Mohr's-Coulomb failure criterion. The vertical displacements, principal stress distribution and vertical stress distribution profiles are obtained at the face, chain pillars and gateroads. Also, the safety factor of the chain pillars, intact coal seam and longwall face are estimated.

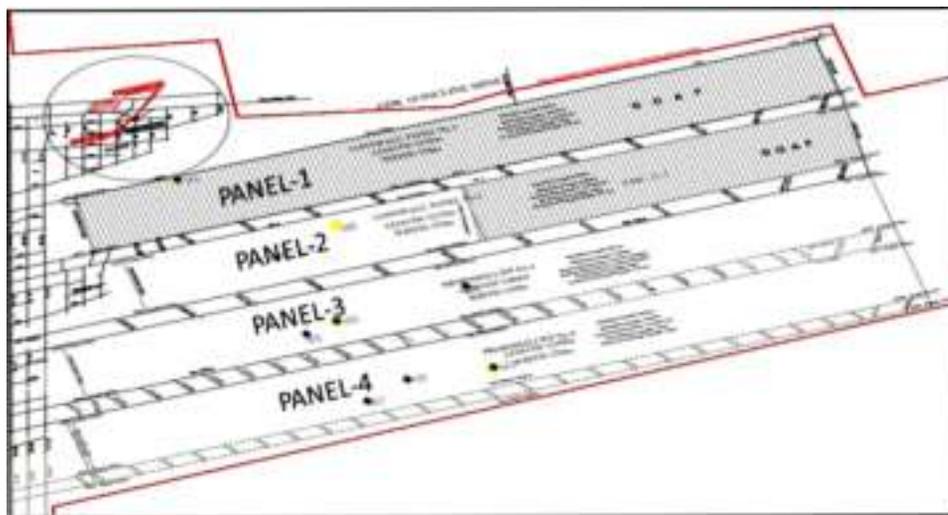
## DESCRIPTION OF THE MINE SITE

Adriyala Longwall Project (ALP) of the Singareni Collieries Company Limited (SCCL) is located in the Ramagundam Coal Belt of Godavari Valley Coalfields in Telangana State. The ALP section is being worked from the highwall in the no-1 seam of the OC-2 mine through punch entries. The entire project has 78.597 MT of extractable reserves within the depth range of 294–644 m and has 4 workable seams. The average depth and thickness of the coal seam and also the materials present above and below workable seams are listed in **Table 1**. The gradient of the mine is varying from 1 in 5 to 1 in 7 [3].

The longwall operation is going on in No. 1 seam which has thickness varies from 6.0 to 6.5 m. At present the panel no. 2 is under extraction and also the gate roads of panel No.3 are being developed with a Bolter Miner. **Figure 1** shows the

**Table 1** Details of the seams of ALP mine[4]

Sl. No	Seam	Depth (m)		Thickness(m)			Roof	Floor
		Min	Max	Min	Max.	Average		
1	ISeam	294	529	2.19	7.10	5.64	Grey SST	Grey Clay
2	IISeam	320	555	1.14	5.61	3.27	Grey SST	SST/Shale/Clay
3	IIISeam	394	625	7.10	11.08	9.40	Grey SST	Grey SST
4	IVSeam	406	644	1.32	4.29	3.66	GreySST	Grey /SST/Shale



**Figure 1** Plan showing ALP mine

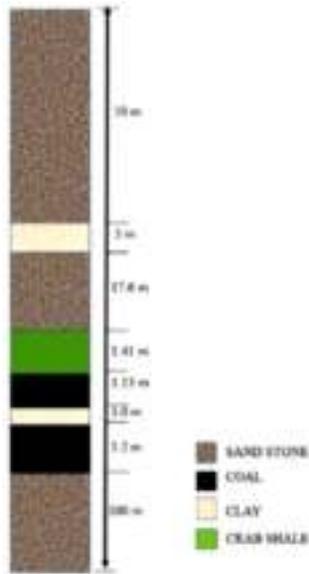
layout of the longwall panels. However, in this study, the stability analysis of the panel no. 1 is presented. The study panel has length and width of about 2340 m long and 250 m, respectively, and the height of the excavation is 3.2 m from the sandstone floor. The depth of the panel varies from 362 to 450 m with an average depth of about 420 m. The panel consists of chain pillars of 50 m for panel no. 1 and 63 m for panel no. 2. The width of the cross cuts is 5.2 m.

#### **DEVELOPMENT OF A NUMERICAL MODEL FOR THE STABILITY ANALYSIS OF CHAIN PILLARS AND GATE ROADS**

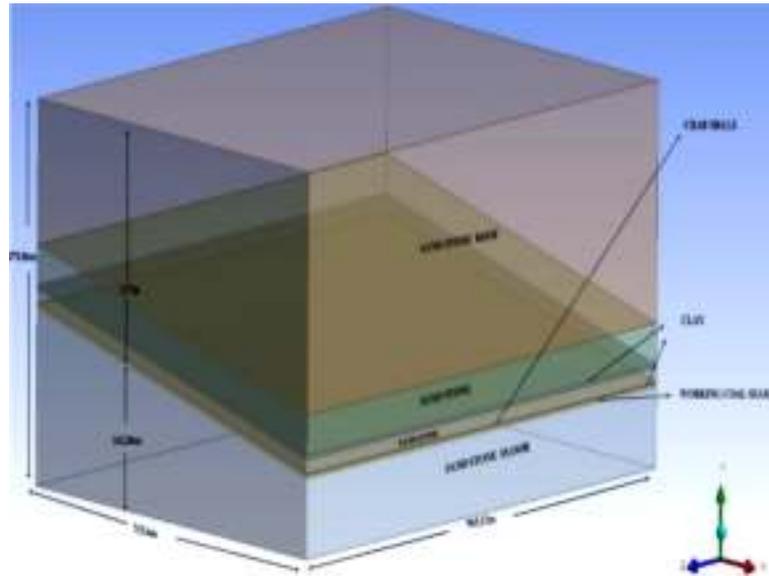
A full-scale 3D finite element models are developed using the lithology of the selected mine site given in **Figure 2**. Each FEM models consist of the longwall panel having chain pillars, gateroads, cross cuts, longwall face, coal seam, and surrounding strata (**Figure 3**). All the finite element models are analysed using Mohr's-coulomb failure criterion. The study longwall panel is developed with face of 250 m wide and length of 552 m and located at the depth of about 420 m. The four (4) chain pillars are developed along the panel length, and they are CP-1, CP-2, CP-3, and CP-4 of 100 m, 200 m, 200 m, and 50 m in length respectively. As mentioned above the size of the gateroads and crosscuts are considered as 5.2 m × 3.2 m. A 100 m goaf is considered from the setup room considering that the face has retreated to 100 m and 444 m intact coal seam. The height of the goaf is considered as 29.2 m from the roof of the workings assuming that the bulking factor is 1.2. **Figure 3** shows the 3D finite element model consisting of panel and other rock strata. **Figures 4 and 5** show the longwall panel describing the setup room and goaf (retreated of 100 m distance).

#### **Generation of Mesh and Boundary Conditions of Longwall Panel**

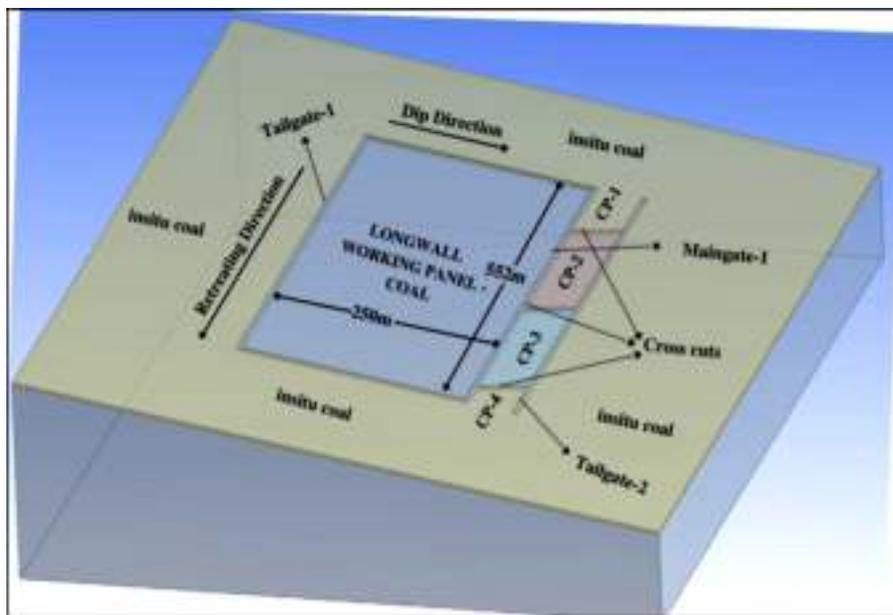
3D finite element model as shown in the **Figure 3** has been discretized to perform the stability analysis. **Figure 6** shows the meshed model of the longwall model and **Figure 7** shows the longwall panel consists of chain pillars, goaf and gateroads. The zone of interest especially at the face, chain pillars and gateroads is discretized with finer mesh to estimate the vertical displacement, the factor of safety and stress concentrations.



**Figure 2** Lithology of the mine site used for finite element model



**Figure 3** 3D finite element model of a deep longwall panel



**Figure 4** Longwall panel showing the chain pillars, gateroads and face gallery at setup room

3D FEM model is applied with a horizontal pressure of 1.5 (17.65 MPa) and 1 (11.76 MPa) times of vertical pressure in strikes (Z) and dip (X) directions, respectively. The gravity load of 9.81 N is applied to the model along vertical direction. The bottom of the model is constrained in all directions. The opposite sides of the faces applied the horizontal stresses are constrained in X and Z directions. Top of the model is applied 2.16 MPa which is equivalent of 103 m overburden as the overburden rock strata on the coal seam is considered as 420 m [5-6].

#### Material Properties

The material properties such as density ( $\rho$ ), young's modulus(E), compressive strength ( $\sigma_c$ ), poisson's ratio ( $\nu$ ), and

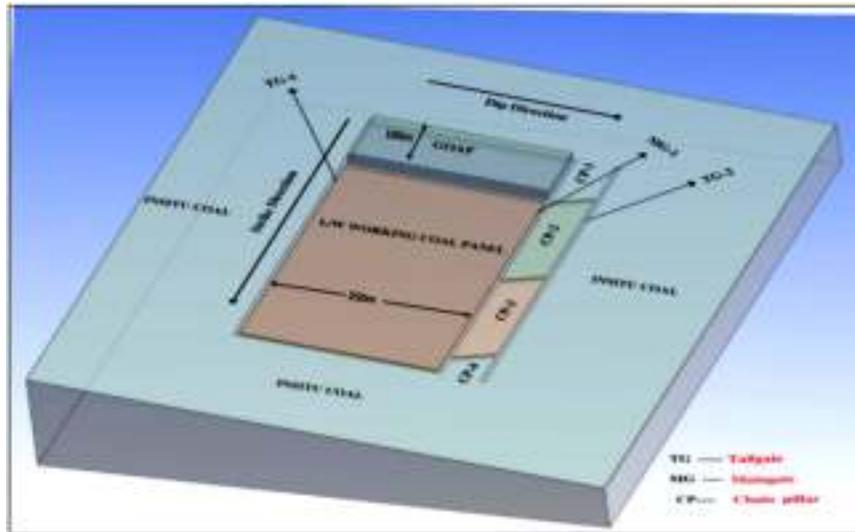


Figure 5 Longwall panel showing the chain pillars, gateroads, face gallery and goaf

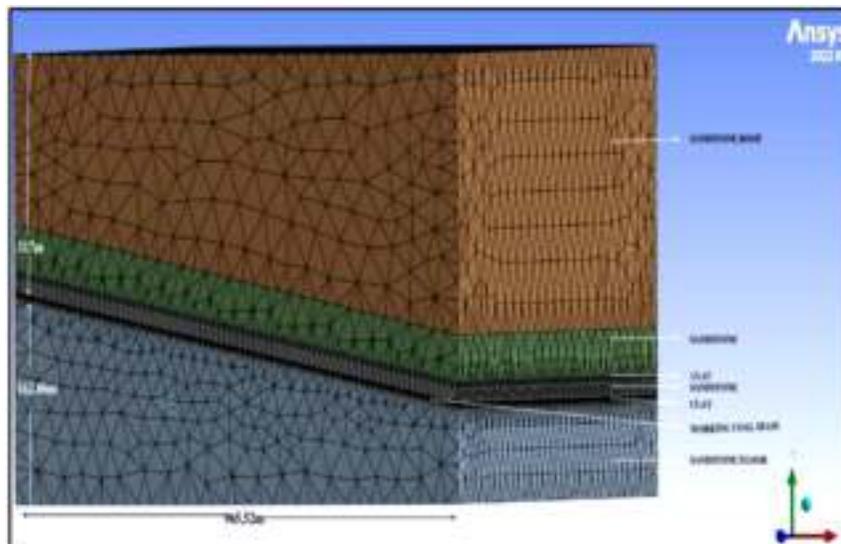


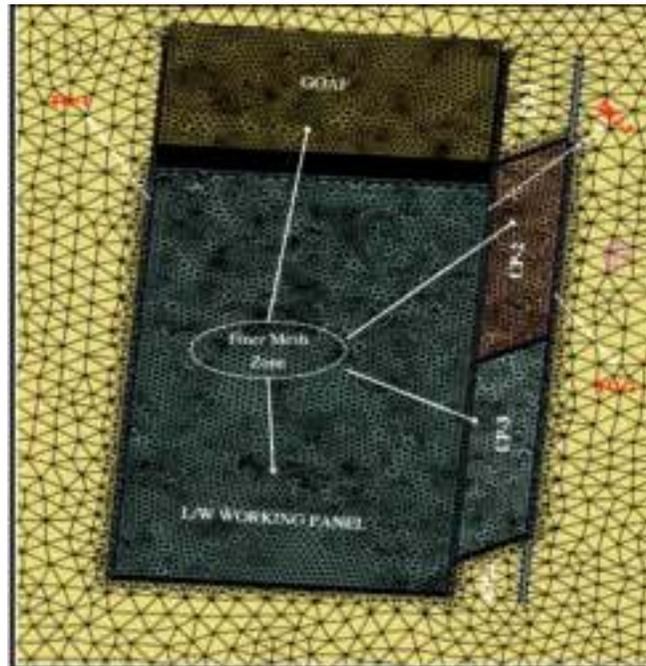
Figure 6 Finite element meshing for entire model

frictional and dilation angles of coal, sandstone, clay, and crab shale are collected from the ALP mine site and these values are converted to the rock mass properties using Rocklab software. The details of the material properties are shown in **Table 2**. Also, the modulus of elasticity of a goaf material is estimated using the study performed by Yavuz [7] and its material properties are shown in **Table 3**.

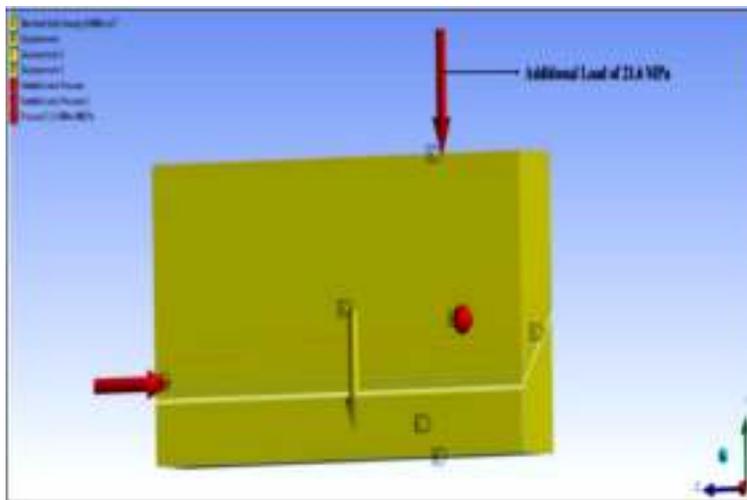
## RESULTS AND DISCUSSIONS

As mentioned earlier, all the numerical models are analyzed considering Mohr's – coulomb failure criterion to estimate the safety factor of chain pillars, panel and longwall face. The results in terms of vertical displacement profile in the gateroads, vertical stress concentrations on chain pillars and the intact panel, and principal stress distribution profiles on chain pillars, and intact coal seams are extracted and presented in this section along critical paths. **Figure 9** shows the paths considered for critical investigations.

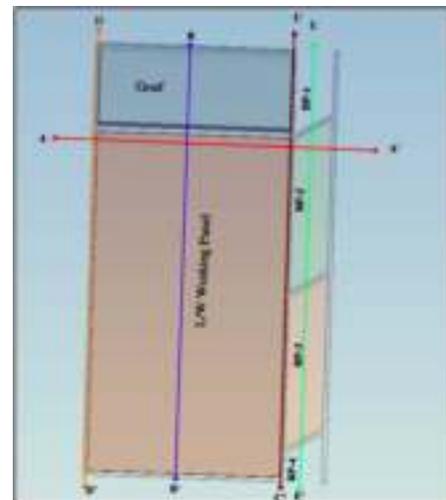
Path AA' is taken along the longwall face at a 5 m distance from the face, and path BB' is considered along the longwall



**Figure 7** Finite element for 100 m goaf



**Figure 8** Boundary conditions assigned for the model



**Figure 9** Different paths considered for the analysis

panel length which passes through the intact coal and goaf. Paths CC' and DD' are chosen in the roof of main gate and tail gate roadways respectively. Also, path EE' is taken on chain pillars.

#### Vertical Displacement in Gateroads

The vertical displacement profile of TG-1 and MG-1 is extracted along paths CC' and DD' of excavation models and insitu models. Then, vertical displacement obtained due to longwall workings is obtained and plotted in **Figure 10**. From this Figure, it is observed that displacements of 62 mm and 31 mm occurred near the face in MG-1 and TG-1 respectively. Then the displacement is found in decreasing trend as it moves towards intact coal. The low displacement in TG-1 is observed since this gate exists at the rise side.

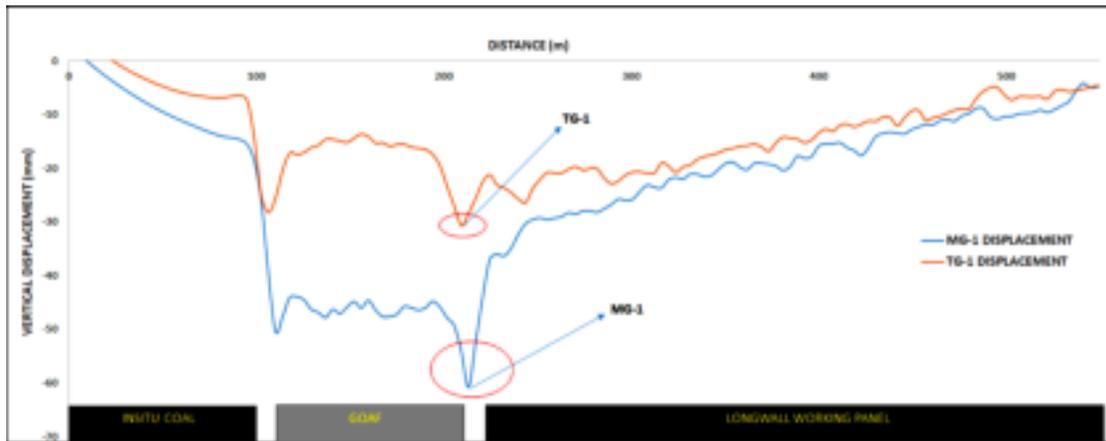


Figure 10 Vertical displacement distribution in gateroads

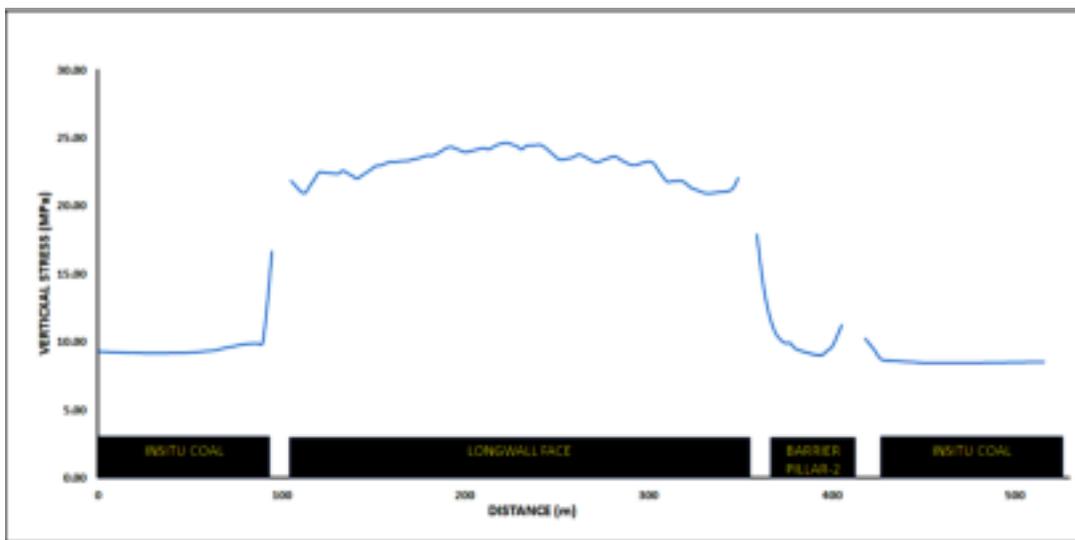


Figure 11 Vertical stress distribution on longwall working face

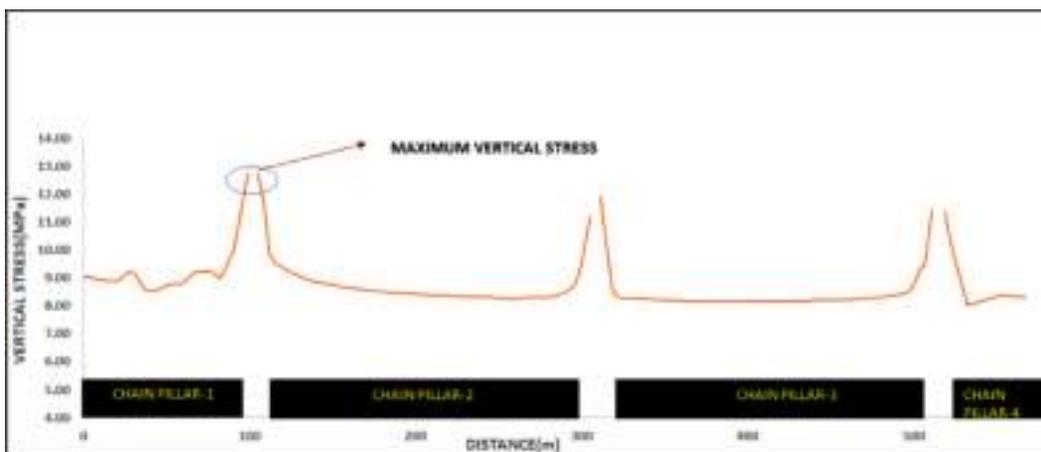


Figure 12 Vertical stress distribution on chain pillars

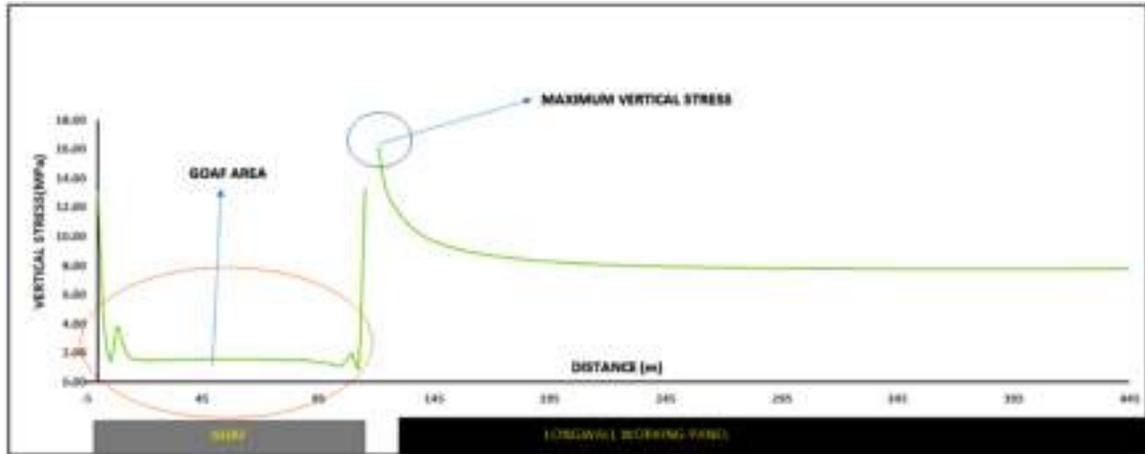


Figure 13 Vertical stress distribution on longwall panel

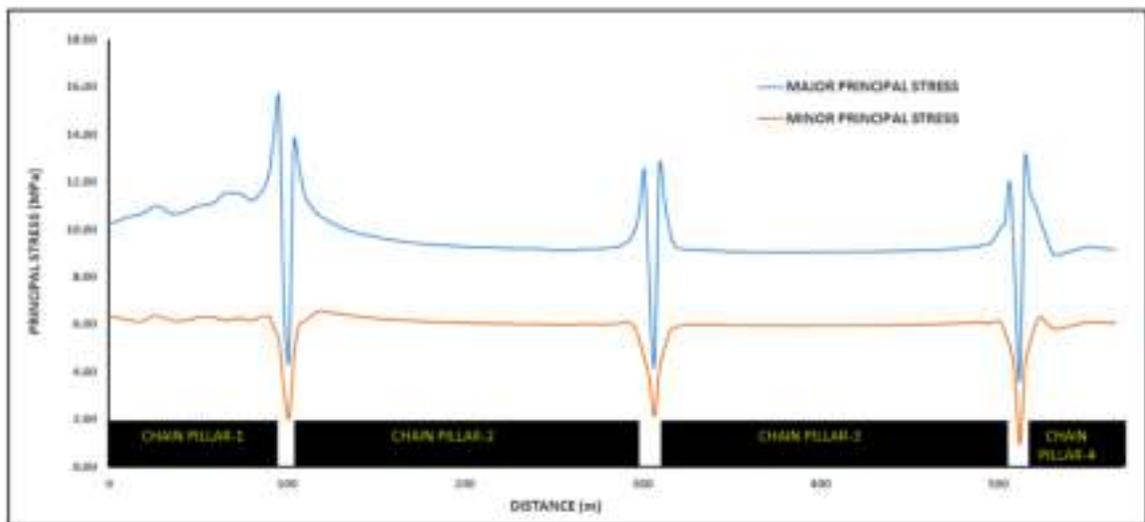


Figure 14 Principal stress distribution on the chain pillars

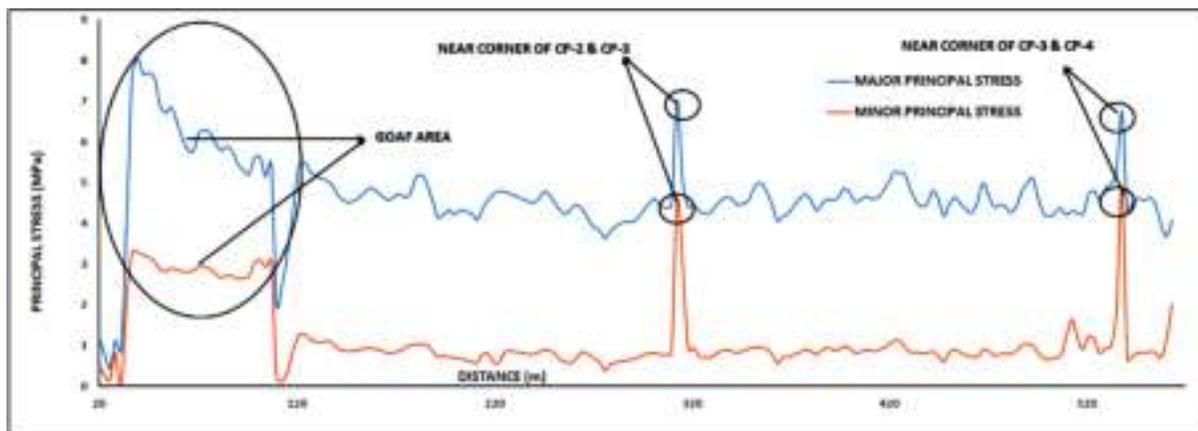


Figure 15 Principal stress distribution on the main gate (MG-1)

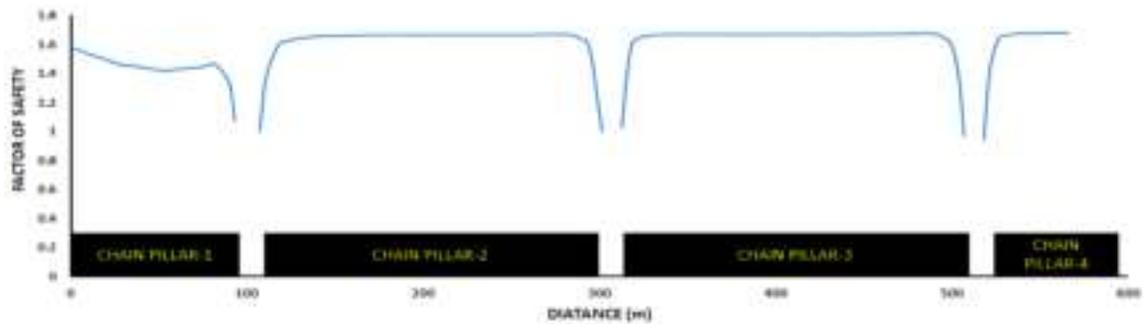


Figure16 Safety factor distribution of the chain pillars

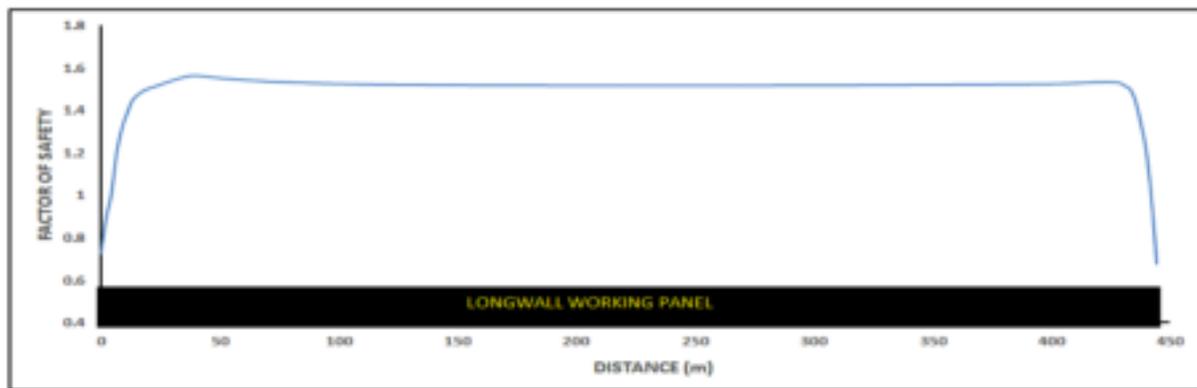


Figure 17 Safety factor distribution of the longwall panel

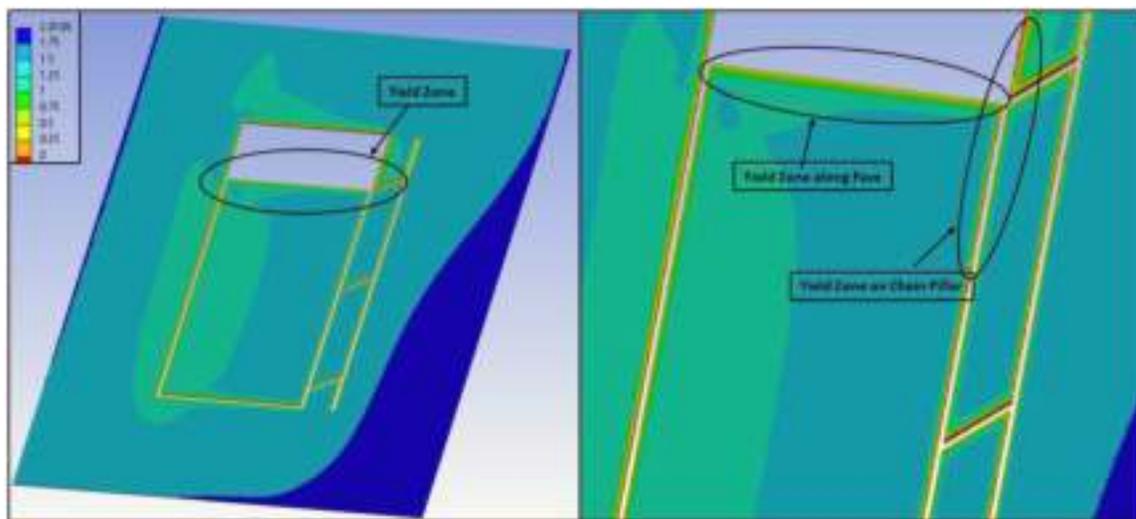


Figure 18 Yield zone in the chain pillars and longwall panel

### Vertical Stress Distributions

As mentioned above, vertical stress concentration on the longwall face and chain pillars is plotted along the paths AA' and DD' as shown in Figure 11. From this, it can be seen that vertical stress of 9.2 MPa develops on the intact coal of MG-1 side and that of 10.2 MPa on the TG-1 side. As expected the corner of the gateroads or chain pillars develops high-stress



**Table 2** Rock mass material properties applied in this study [6]

Rock Strata	Density $\rho$ (kg/m <sup>3</sup> )	Compressive Strength $\sigma_c$ (MPa)	Modulus of Elasticity E (GPa)	Poisson's Ratio ( $\nu$ )	Cohesion C (MPa)	Friction Angle $\phi^\circ$	Dilation Angle $\delta^\circ$
Clay	1100	2.582	1.278	0.35	0.811	27	18
Coal	1500	4.13	1.535	0.35	1.00	31	21
Sandstone	2147	7.643	5.132	0.28	1.461	38	19
Carb shale	1276	2.980	1.40	0.35	0.904	28	19

**Table 3** Goaf material properties

Material	Density, $\rho$ (kg/m <sup>3</sup> )	Modulus of Elasticity, E (MPa)	Poissons Ratio, $\nu$
Goaf	1920	96	0.30

concentrations up to 16.5 MPa. It is also observed that the vertical stress of 25 MPa developed at 5 m from the face due to the retreating operation of the face. The average stress of about 9 MPa develops on the chain pillar.

#### 4.2.1 Vertical Stress Distributions on the Chain Pillars

From the **Figure 12**, it is noticed that the average vertical stress of 9 MPa on CP-1 but the edges of the CP-1 and CP-2 develops the highest vertical stress around 13 MPa. This increase of the stress is mainly due to the presence of goaf and working panel gallery present beside the CP-1 and CP-2. The stresses of 12 MPa and 11.8 MPa are noticed at the edges of chain pillars CP-3 and CP-4 (**Figure 12**). As the high stress concentration develops in the chain pillars may yield the pillars specially at the corners.

**Figure 13** shows the vertical stress distribution on the longwall panel and goaf along the path BB. it can be seen that the maximum vertical stress of 16.17 MPa found at the corner of the longwall face and then decreases towards the intact coal and then reaches the in-situ condition of 7.77 MPa about 100 m from the longwall face. The stress at the face may deteriorate the face stability and tend for the failure. From this results, it can also be said that the abutment zone of about 100 m occurs in this panel.

#### Principal Stress Distributions

The major and minor principal stress distribution profiles on the chain pillars and gateroads are extracted from the numerical models and plotted along the paths CC' and EE' as shown in **Figures 14** and **15**, respectively. As seen previously, the chain pillar lying near the goaf develops the high principal stress concentration than the pillars lying away from the face or goaf. The major and minor principal stresses on CP-1 is found to be 10.5 MPa and 6.5 MPa, respectively. The average major and minor principal stresses occur on the CP-2, CP-3 and CP-4 is 9.72 MPa and 5.25 MPa, respectively.

Similarly, the average major and minor principal stress develops in the main gate (MG-1) is 6.5 MPa and 5.5 MPa near the goaf area and 4.5 MPa and 1.5 MPa away from the face respectively. The results of the principal stresses show that the yield of the gateroad occur.

#### Safety Factor of the Chain Pillars and the Longwall Workings

The safety factor of the chain pillars and the longwall working is calculated using the Mohr's-Coulomb rock mass failure criterion [8]. As previous, the paths BB' and EE' are considered for the estimation of safety factor values.

The safety factor of the chain pillars and panel indicates their condition and is defined as the ratio between the strength (R) of the working pillar to the stress (S) imposed on the pillar. It can be written as

$$FOS = R/S \quad (1)$$



$$FOS = \frac{\sigma_{th, \beta} - 2c_0 N_\beta}{\sigma_1} \quad (2)$$

A chain pillar/workingpanel is considered to be safe if FOS is greater than 1.0, where  $\sigma_1$  and  $\sigma_3$  are major and minor principal stress,  $N_\beta = \frac{1 + \sin \Phi}{1 - \sin \Phi}$  is the triaxial factor and  $c$  is cohesion, where  $\Phi$  is the angle of internal friction of the coal seam.

Using Equation (1), the factor of safety of the chain pillar and intact coal seam is estimated and plotted as shown in **Figures 16** and **17**. From the **Figure 16**, the maximum safety factor of 1.66 is noticed on the chain pillars and that of 0.67 is noticed on the corners of the chain pillars. It shows that corners of chain pillars CP-1 and CP-2 may lead to failure. About 1 to 1.5 m yield zone extends in the chain pillars (**Figure 18**).

From the **Figure 17**, it is observed that an average safety factor of 1.51 exists on the panel and the minimum of 0.72 is found exactly at the face edge. This is mainly due to the load exerted by the cutting of the web cut and goaf on the working face and may cause cracks/fractures on the face. This may finally lead to the yield zone in the longwall face. As seen from the **Figure 18**, it is observed that the about 1.5 m to 3 m yield zone develops in the longwall face. **Figure 18** shows the contour plot of the safety factor distribution around the chain pillars, longwall face and gateroads.

## CONCLUSIONS

The stability analysis of chain pillars and gateroads of a deep longwall panel of India is carried out considering Mohr's-Coulomb failure criterion by developing true 3D longwall panel using three dimensional finite element modelling technique. In the study, the maximum vertical displacement of 62 mm and 31 mm near the longwall face is observed in main and tail gateroads. Also, the average vertical stress of the 9 MPa is observed in the chain pillars and that of 16.17 MPa observed at the longwall face. The corners of the chain pillars and gateroads developed the high stress concentration and causing the yield at the chain pillars and the longwall face. The average safety factor of the chain pillars and intact coal/panel is found to be 1.52 and 1.6, respectively. It is also noticed that the corners of the pillars and the face yields about 1.5 to 3 m inside the pillars and longwall face.

## ACKNOWLEDGEMENT

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## REFERENCES

1. G S Esterhuizen, T Klemetti, M M Sears, et al. Assessing Longwall Gateroad Ground Response and Support Alternatives. *Mining, Metallurgy & Exploration* 38, 2021, pp 1739–1759, <https://doi.org/10.1007/s42461-021-00430-x>
2. Q Shi, G Xu, D Wang, et al. Chain Pillar Optimization at a Longwall Coal Mine Based on Field Monitoring Results and Numerical Model Analysis, *Arab J Geosci* 14, 2021, 2537, <https://doi.org/10.1007/s12517-021-08843-0>
3. A M Rao, S V S Ramalingeswarudu and G Venkateswarlu, Planning of Ventilation Requirements for Deep Mechanised Long Wall Faces—A Case Study of Adriyala Longwall Project of The Singareni Collieries Company Limited (SCCL), *Procedia Earth and Planetary Science*, 11, 2015, pp 548-556.
4. S R Islavath, D Deb and H Kumar, Numerical Analysis of a Longwall Mining Cycle and Development of a Composite Longwall Index, *International Journal of Rock Mechanics and Mining Sciences*, 89, 2016, pp 43-54.
5. S R Islavath, Stability of Continuous Miner Workings using Numerical Modelling Approach, *J Mines, Metals Fuels*, 8, 2019, pp 360-365.
6. S R Islavath, D Deb and H Kumar, Life Cycle Analysis and Damage Prediction of a Longwall Powered Support using 3D Numerical Modelling Techniques, *Arabian Journal of Geosciences*, 12(14), 2019, pp 1-15.
7. H Yavuz. An Estimation Method for Cover Pressure Re-establishment Distance and Pressure Distribution in the Goaf of Longwall Mines, *Int J Rock Mech Min Sci*, 41 (2), 2004, pp 193-205
8. D Deb and A K Verma. *Fundamentals and Applications of Rock Mechanics*, PHI Publications, New Delhi, 2016, pp 242-244.

# Challenges in Sustainable Mining and Green Mining Initiatives — NLCIL's Success Story

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**Abstract:** Sustainable mining can be developed and followed by adopting and integrating the requirements of Social and Environmental developments that will nullify the impact of mining over environment and make mining more environmental and people friendly. For achieving sustainability, what is required is that a mining should be economically viable, financially profitable technically efficient and environment friendly. Less consumption of water and energy, minimizing land disruption and waste production, preventing pollution in all forms and sticking to mine closure, reclamation and rehabilitation activities without fail will make mining sustainable. This paper analyses how these factors like adoption of technology in mining, water and energy consumption at low levels, land issues, preventing pollution, social and environmental responsibility and less waste production can contribute to the sustainability of mining in NLCIL. It describes about the good works being carried out by NLCIL in Reclamation and Restoration activities in a proper and scientifically proven way which is bringing back the land as nearer as to its original condition. Also it describes about how water management is being done in NLCIL's mines in all possible ways.

**Keywords:** Mining with BWE Technology; Environment Management; Sustainability; Reclamation; Rehabilitation

## NLC INDIA LIMITED (NLCIL)

NLC India Limited, a Navratna Govt. of India Enterprises, is the prime player of Lignite Mining and Power Generation in southern part of the country for about six decades. At present, NLCIL operates three opencast mines viz: Mine-I, Mine-1A and Mine II with total production capacity of 30.0 Million Tonnes Per Annum (MTPA) to meet the fuel requirement of linked four numbers of thermal power stations having total capacity of 3640 MW in Neyveli, Tamilnadu.

NLCIL is also operating a 2.1 MTPA capacity lignite mine at Barsingsar, Rajasthan to meet the demand of 250 MW power plant and one coal based thermal power plant of 1000 MW capacity (NLC Tamil Nadu Power Limited - NTPL) at Tuticorin, Tamil Nadu through its joint venture with TANGEDCO (Tamil Nadu Generation and Distribution Company). It is in the process of spreading its wings all over the country in the field with a dual objective i.e. Coal Mining and Power Generation. Apart from this twin objective, it has taken the lead in Solar Power and Wind Power also.

## MINE WATER MANAGEMENT

### Ground Water Management System

Mining of lignite from NLCIL's mines is faced with a unique hydrological problem due to the presence of powerful aquifers existing below lignite seam exerting an upward pressure of 5 to 8 kg/cm<sup>2</sup>. Depressurization of aquifer is being done to control the upward pressure of water for safe mining operations. If the pressure is not controlled it could affect the entire mining operations by flooding of mines. Therefore, the depressurization of this aquifer is essential during mining to maintain the pressure head constantly at the lignite bottom through pumping operations from strategically located pumping wells established in the lignite mines/ excavation zone. The pumping in Mines has been optimized to the minimum by keeping positive pressure and bringing the wells nearer to the deep cut position.

NLCIL is managing the Groundwater resources available in the region for sustainable development of Lignite Mining in the following ways:

- Monitoring of Groundwater level/Quality of the aquifers in the Neyveli Hydrogeological Basin.
- Conservation of Groundwater resources extracted from the Neyveli Hydrogeological Basin
- Enhancement of Groundwater resources through various artificial recharge methods in the Basin.

NLCIL has taken the following Groundwater conservation measures viz :



A number of observatory wells are also established in and around Neyveli region for monitoring purposes. The monitoring has been categorized into sixteen sectors spread over 3500 sq.km covering Neyveli hydrological basin. The groundwater level and quality of the entire hydro-geological basin is monitored periodically from the dug wells and tube wells.

In order to maintain the groundwater resources available in the basin, NLCIL is constantly involved in enhancing the ground water potential of the region through integrated studies viz: Rain Water Harvesting, Recharging deep seated aquifer through establishing of artificial recharge structures such as check dam, percolation wells, Infiltration wells and de-silting of reservoirs etc.

### **STORM WATER MANAGEMENT SYSTEM**

The NLCIL mine being “Open pit” receives water not only through rainfall but also seepage water. The entire water starts accumulating in the mines.

To manage the storm water, all the rain water is drained into one big sump established at the lowest level in the mine floor through well planned drainage system and then pumped out through pumping operations so as to maintain the water level within the sump. The storage capacity of established sumps is to handle the extraneous water from the catchment area of the mine and inside mine spoil dumps.

Sump dimension, number of sumps, catchment area, pondage area (water holding area) and quantum of precipitation are computed through a program by Geology & Planning division for each of the mine to plan the storm water control operations during Monsoon season.

The pumped out water and the storm water collected in mines is utilized for industrial units and domestic purposes. NLCIL has the best integrated water management by way of using mine ground water for thermal power station and using the mine waste water for domestic and industrial use after treatment. Part of rain water collected in the mine pit water let out by NLCIL in natural canals is fully utilized by local villagers for agricultural purpose. The livelihood of the people using mine water is better as they are harvesting in all seasons.

### **RAIN WATER HARVESTING IN DUMPS**

NLCIL’s successful initiative was land reclamation which started many years ago in areas where the quality of soil had deteriorated due to years of mining activity. NLC’s land reclamation policy has been successful, as different types of crops and vegetables are grown in and around the mine area.

Neyveli mines are located in cyclonic belt and receive an average annual rainfall of 1200 mm. The dump area received copious amount of rain fall during north east monsoon period every year. The runoff water if not controlled leads to soil erosion. So, when the dump area is levelled for reclamation, rain water harvesting structure in the mine dump soil is created in the depression available in the dump depending on the topographical favourableness. The number of rain harvesting structures made in the Mine-I dump are 13 nos.



View of sumps to collect seepage water and storm water



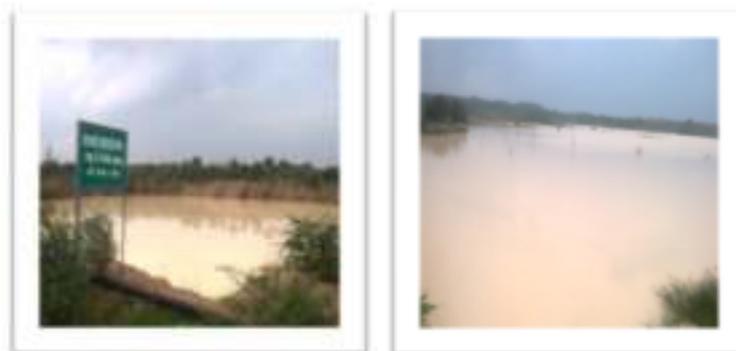
Utilization of Groundwater / Mine Water

Artificial lakes/ponds have been developed fully in Mine I of NLCIL in a total area of 52 hectares and original habitat formation is being brought. These water bodies have been formed in the afforested area which serves as a bowl for collecting rain water.

The entire overburden dump yards are prepared and made ready in such a way that rain water is stored in a natural way. Ponds are formed in the plain areas of OB high dumps are utilised. All the partially filled void areas on high dumps are converted into ponds of suitable sizes depending upon the respective catchment areas. The collected of rain water is used to provide greater stability for establishment of vegetation.

Water body formed by creating partially filled void and also strengthening the outer side by wide earth bund to store rain water.

These ponds are formed in series based on the ground profile and natural gradient, in such a way that the pond after getting filled with rain water will let out the surplus water into the successive pond and so on. The last but one pond will convey all the surplus water into the Mother Lake, which has considerable capacity to store the rain water.



Rain water harvesting structure which is created by excavating the dump soil and making a deep pit to store rain water

- Average size of small ponds is about 150 m × 150m × 2m.
- Mother lake dimensions: 600 m × 600 m × 4.0 m.

All the above ponds are provided with overflow arrangement through pre-stressed concrete pipes.

Further wild fruit trees are developed around these ponds, such as Amla, Badam, Naval, Sweet Tamarind, etc. These trees are developed to attract birds so as to maintain the Flora and Fauna of the high dumps. The ponds are formed not only for rain water harvesting but also for maintaining the moisture content of ground water.

The orchards having different varieties of fruit bearing trees and artificial lakes attract large number of birds and even migratory birds have been noticed in the reclaimed land. It is a habitat of more than 250 birds and diversified mammal population.

Artificial lake has also been developed in Mine I reclaimed area of 10 hectares and the area around this lake has been converted as park. It is harbouring the migrating birds as sanctuary.

In Mine-I, the lake has been formed in the afforested area which serves as a bowl for collecting rain water. The whole area around this lake has been converted as a park and picnic spot, planting flowering trees, fruit trees and rest shelters. A Mini Zoo has also been developed with spotted deer, rabbits, peacocks, lovebirds, parrot, doves, fowls, etc. besides boating facilities. Different kinds of fishes are also reared in the aquarium maintained in the park. Apart from this, a nursery has also been established. Flora Fauna has been developed very well and more than 250 species of birds are settled in this area.

#### **Rain Water Harvesting and Drip Irrigation System**

The rain water collected from one of the lakes, is pumped into a storage tank kept at an elevated area. From there it is used for cultivation vegetables through drip irrigation system. Due to this water is conserved, used in an efficient way and also made available throughout the year.

#### **Rainwater Harvesting in Township**

NLCIL has established the rain water harvesting in the drainage canals in Neyveli Township to enhance the ground water resources in the water table so as to help the surrounding villages with the assistance of Central Ground Water Board.



Views of lake formed in Mine I



Google Image showing the Rain water harvesting ponds in Mine-I dump area

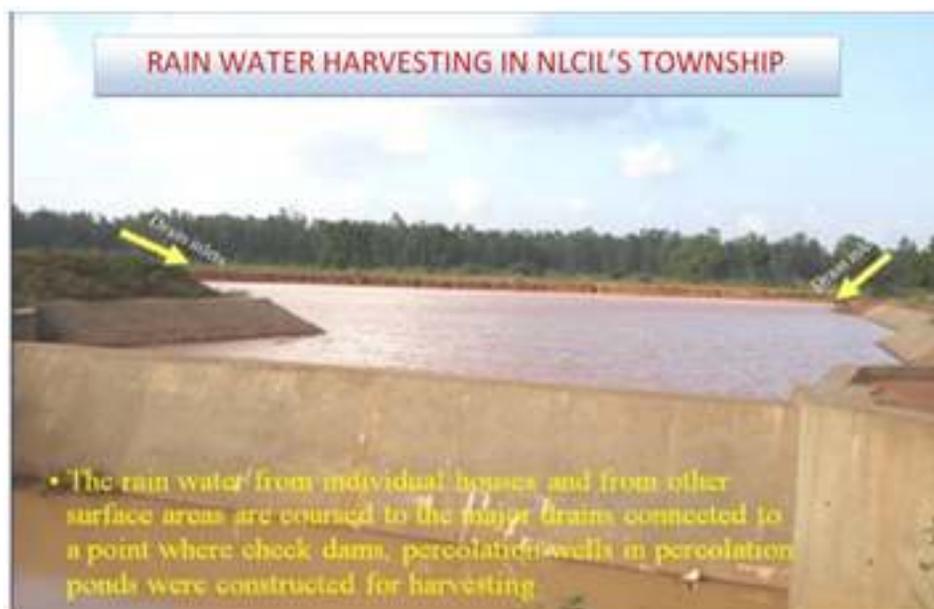


### Drip Irrigation using Rain water

NLCIL has also implemented the roof top rain water harvesting in office buildings where as for individual houses it was implemented by constructing an over flow weir at the junction where the major drains are discharging the runoff water. This has improved the water table conditions in the downstream side villages.

Recharging deep seated aquifer through establishing of artificial recharge structures such as check dam, percolation wells, Infiltration wells etc: NLCIL has completed construction of check dams in five locations nearby area across the Nallas and established percolation wells in the water storage area

NLCIL as a socially responsible corporate company continues to carry out development works with regard to water conservation in the surrounding villages, right from its inception, focusing on the socio economic development of the operating regions for achieving inclusive growth.



De silting and restoring water bodies

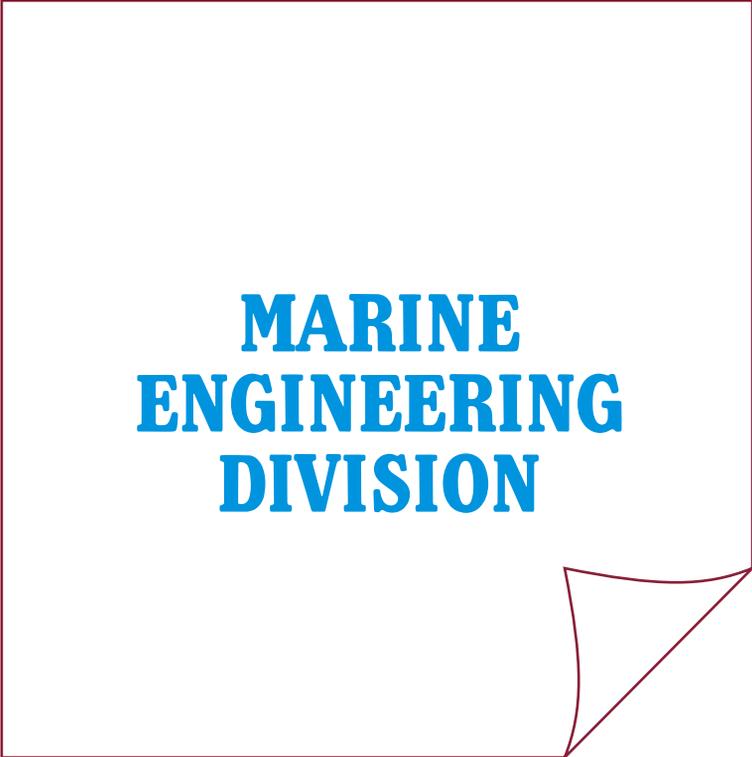


Various CSR works are carried out for the benefit of the population in the areas surrounding the operating localities, which include the Walaja Lake De-silting project undertaken in the Karaimedu village near Neyveli, by which, water holding capacity for irrigation has been increased by about 22.75 lakh cubic meters, providing direct irrigation to about 11,500 acres of land and benefitting about 60 villages in the region. Besides, continuous supply of water to nearby villages for irrigating over 23,000 acres of land is also continued in the Neyveli region.

Water spread area 1664 acres, total earth excavated is 21 lakhs cubic meter, additional capacity made 21 lakhs cubic meter, Project cost Rs.13.72 crores.

#### CONCLUSION

NLCIL Mines has developed an effective mine water control and ground water management system for sustainable development with integrated mining and industrial complexes at Neyveli. NLCIL Mines has developed effective Rain water harvesting system and due to this ecological system is being maintained. NLCIL's combination of biological and engineering methods has yielded fruitful results in reclamation and rain water harvesting in the Mined out areas. Natural regeneration of flora and inflow of fauna is persistent in the reclaimed and afforested areas. The increase in the floral diversity in the reclaimed areas resulted in increase of insect diversity in the reclaimed areas. NLCIL has successfully carried out and will be carrying out the responsibility of protecting the environment through sustainable mining practices along with water management systems.



**MARINE  
ENGINEERING  
DIVISION**



# Robotic Gesture Control for Autonomous Vessels

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**Abstract:** The safety of the crew is the most important aspect of any ongoing vessel. Many tasks on the ship pose a risk to the crew, and thus robots may be used to ensure the crew's safety without sacrificing the quality of the work. The elimination of human crews would allow ships to be built without ship facilities required for human activity, such as the bridge, or for human liveability, such as sleeping quarters, plumbing, mess halls, and electrical wiring, minimising weight and improving reliability. This would allow autonomous ships to be constructed lighter and with a smaller crew, thereby lowering fuel consumption and damage to the environment. It is planned to use a gesture control robot for this intent, which might control some of the ship operations from the shore with a confined crew on-board a vessel. These robots are used not only with gestures, but also with neural schemes, i.e. automatic response in the event of an urgent situation, rather than giving AI to the robot, which may supersede rules. Such robots will be far more beneficial in terms of safety, and the seafarers can indeed be reused once their voyage is completed. Internet of things (IoT) will be used for signal transmission from shore to ship as well as ship to shore when working on these gesture control robots. For capturing and sending the signal, Arduino or Raspberry Pi controllers can be employed and a set of instructions can be given ahead of time to conquer serious emergency instances. To accomplish this, a signal transmission station and a signal transmitting suit may be needed, which propagates a signal to the IoT cloud server where the signal is further transmitted to the centralised receiver plant on-board which contains a receiver and a decoder and sends signal to the robot comprised of a microcontroller like raspberry pi or Arduino which controls a motor and mimics our gesticulations. This paper presents a detailed study of an autonomous ship with multi-degree autonomy, as well as an examination of recent literature and the various gesture control mechanisms with numerous controllers.

**Keywords:** Gesture Control; Autonomous Vessels; Robotic Control; IoT; Raspberry Pi Controller

## INTRODUCTION

The maritime industry is rich in tradition, but there has recently been an intensification of technology advance from maritime leading manufacturers. New digital technologies, particularly in automation systems, have resulted in progressively complex and diverse user interfaces. During an operation, an operator must deal with a variety of processes, each with a unique interaction style[1].

On Dynamic Positioning (DP) ships, for example, the operator's job can be strenuous because he/she is expected to communicate with at least three distinct processes, each with a separate graphical user interface (GUI) and screen. Furthermore, he/she must direct radio communication, keep a watch on the propulsion system, and preserve continuous exploratory awareness of the vessel's surroundings. This poses a physical and psychological challenge, and if operators are given with excessive info, their cognition may bump up[2].

Physical exertion however still directly impacts the operator if the machinery is not properly positioned. To circumvent such troubles, a computer-controlled system was proposed and tested in the Rolls-Royce DP operator station using an interface with menus and buttons to automatically manage a ship's position and heading through utilising her own propellers and thrusters. At the point in time, autonomous ships are being researched in order to efficiently oversee most ship operational processes with a small crew. According to the International Maritime Organization, autonomous ships are known as Maritime Autonomous Surface Ships (MASS).

They are supposed to function in one of 4 types of autonomy, swapping among them interactively, as seen below[3]:

Degree 1 - "Ship with automated processes and decision support": Shipboard strategies and features are operated and controlled by mariners. A few activities may indeed be automated and unsupervised at times, yet there are always seafarers on board ready to take authority.

Degree 2 - "Remotely controlled ship with seafarers on board": The ship is monitored and operated from some other area. Seafarers are present on board to take command and perform the ship's systems and services.

Degree 3 - “Remotely controlled ship without seafarers on board”: The ship is operated and managed from a remote place. There aren’t any seafarers on board.

Degree 4 - “Fully autonomous ship”: The ship’s operating system can make judgments and decide actions on its own.

### HISTORY OF AUTONOMOUS SHIPS

Numerous autonomous cargo vessel initiatives were in the works as of 2019, the most renowned among which was the construction of the MV Yara Birkland, which has been originally planned to start trials in 2019 and functions in 2020. In Russia, the Autonomous and Remote Navigation Trial Project was launched by a group of companies affiliated with the Industry Association MARINET. Within the project scope, three operating ships were outfitted to be remotely controlled and capable of operating in remote mode while on actual commercial cruises. Shipping companies in the Great Lakes are also aggressively seeking this new tech in collaboration with various marine tech giants.

Since around 2020, Japan asserted to the IMO on its first MASS trial with the Iris Leader, and France reported on trials with the 80-m-long merchant ship “VN REBEL”, which was controlled remotely from the Polytechnic School in the Paris province. China confirmed on trials with the ship “Jin Dou Yun o Hao”, a 12.9-m vessel energised by an electrical plant and controlled by automatic navigation technology and remote control.

All through 28 commercial voyages in 2021, Russian companies tested autonomous guidance systems. Because of the encouraging results obtained, the Russian maritime officials have permitted any shipping company to adequately prepare its ships flying the Russian flag with autonomous navigation systems and use them in their routine operations as part of the national experiment, under certain restrictions.

Global sea - based business is anticipated to boost, as is maritime tourism. Furthermore, the lack of seafarers is expected to spur the incorporation of automated processes[4]. These systems are fitted in vessels to automate processes like navigation and propulsion using a variety of modules such as automated navigation, thruster control mechanisms, and sensor systems, and many more. The majority of these systems are currently used in numerous sectors and applications including aerospace and automobiles. Maritime industry players are investing heavily to figure out how to integrate these techniques and systems for the safe and cost-effective operation of unmanned ships[5]. The international autonomous ships business was worth USD 6.03 billion in 2018 and is anticipated to expand at a 13.5% CAGR throughout the projected time-frame (till 2025). **Figure 1** depicts the global market for autonomous ships.

In the near future, all sea-going vessels will have at least some degree of autonomy. Electronic controllers improve the effectiveness of any feedback control mechanism. Somatosensory interaction technologies such as touch interaction and gesture interaction are currently diversifying beyond game consoles and into smart phones, tablet computers, Desktop computers, wearable devices, as well as other sectors. Somatic sensory interaction technique, with touch interaction and gesture communication as the mainstream, will be a regular feature of electronic devices in the near future[6-7]. So it was decided to examine a low level of autonomy in which gesture control robots[8-9] controlled by a Raspberry Pi controller are used for specific ship functions, and the necessary technological specifications are covered in the section of the paper that follows.

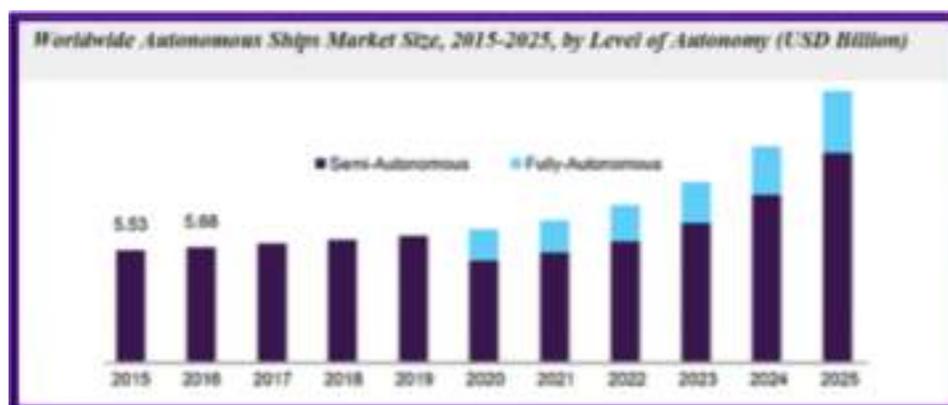


Figure 1 Global market size for autonomous ships[5]

## TECHNICAL ASPECTS FOR GESTURE CONTROL

The gesture control components/modules/units must include a battery pack to power the circuit, a gyro sensor and motion sensor (accelerometer), transmitting and receiving modules, and a suitable microcontroller. Each component is discussed briefly here.

### Battery Pack

It is preferable to use a Sodium-Ion battery for this work. The sodium-ion battery (NIB or SIB) is a form of rechargeable battery similar to the lithium-ion battery, but it utilises sodium ions ( $\text{Na}^+$ ) as charge carriers instead of lithium ions ( $\text{Li}^+$ ). Its underlying concept and cell construction are remarkably similar to those of commercially available lithium-ion battery groups, except that sodium substances are utilised in lieu of lithium substances. Sodium-ion batteries are considered to be an appealing potential substitute for the next-gen large-scale Electrical Energy Storage (EES) systems owing to their extensive availability and low price of sodium resources[10]. Besides this, SIBs have a smaller environmental footprint. They comprise non-flammable solid electrolytes with a high degree of protection. SIBs are bulkier and bigger than LIBs, but they are suitable for stationary energy storage systems where size and weight are less important[11].

#### *Sodium Ion Battery—Operating Principle*

Sodium-ion ( $\text{Na}$ -ion) batteries are solid-state batteries that transport ions through their core using solids rather than liquids. It entails of 3 parts: An anode composed of hard carbons; a cathode consisting of sodium-containing layered materials; and an electrolyte that enables the movement of electrons. Sodium ions swing wildly between the positive and negative electrodes[12]. The sodium-ion electrolyte serves as the carrier for this transfer. As a result, the battery is charged and discharged in a “rocking” swing. Whenever an external voltage is applied, electrons flow in the opposite direction at the same time to counteract this ionic flow[13]. **Figure 2** illustrates this concept.

### Gyroscope and Accelerometer

This work is a real-time surveillance/tracking system that allows humans to communicate with robots using gestures. Gesture recognition is split into three phases: image capture, image processing, and data extraction. All of these are done as vision-based tasks. Furthermore, the stability of robots while operating machineries for ship maintenance and overhauling can be supervised from ashore and can be self-stabilizing.

The consistency of the ship must always be affirmed while navigating for a correct spot and appropriate orientation in all

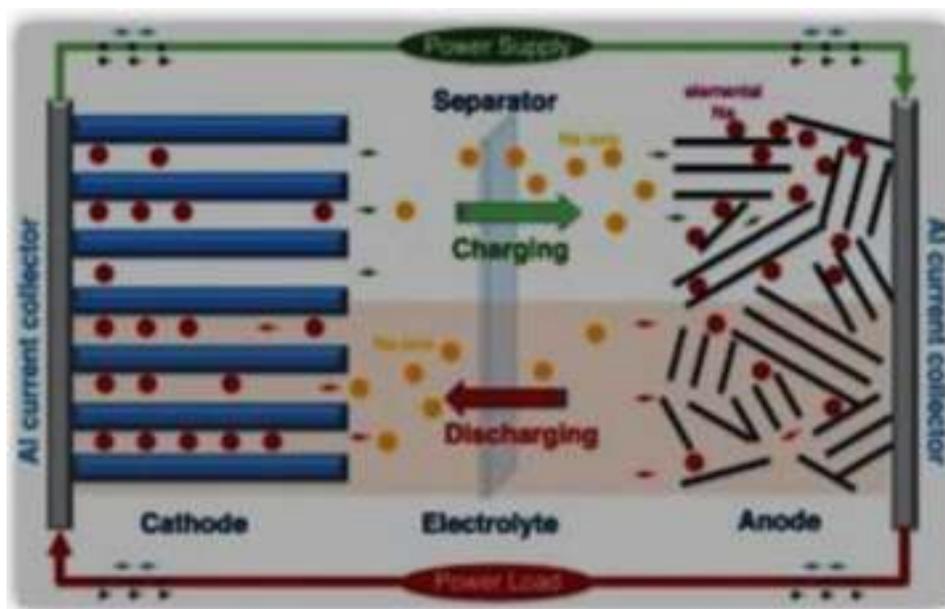


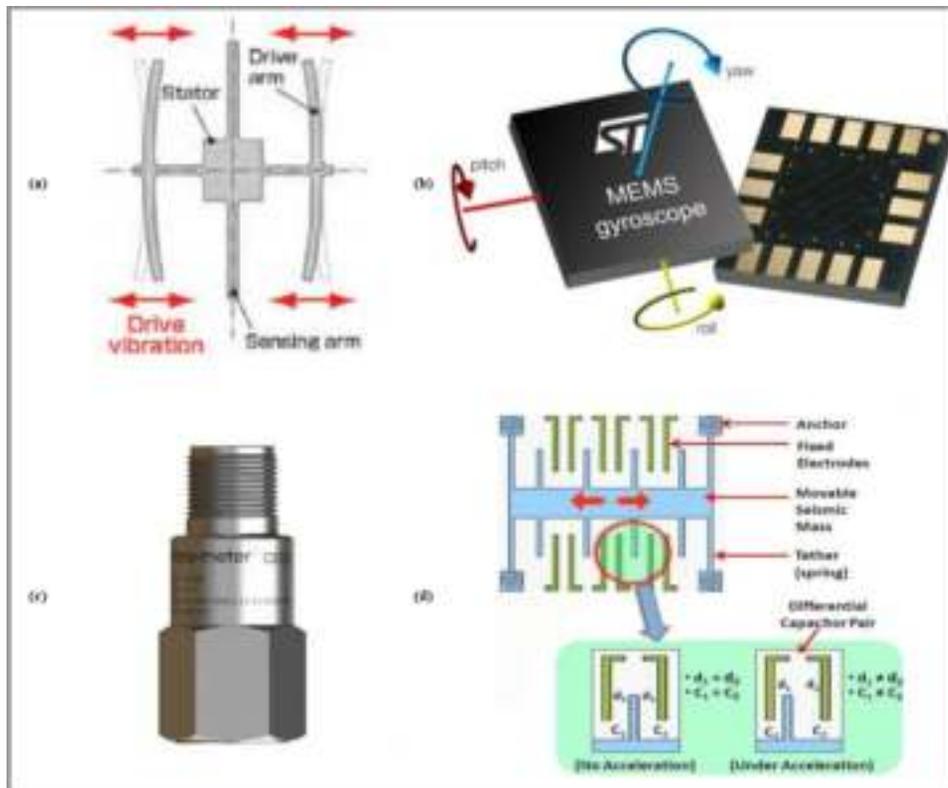
Figure 2 SIB working principle diagram[12]

motion sensing applications, particularly in the proposed work. Only then will position control be significantly more effective. The choice of sensors for this reason is critical. Numerous sensorial devices are utilised to calculate an object's location and direction. The gyroscope and accelerometer have been the most prevalent of such sensors. Even if they perform the same function, they quantify different things. If they are integrated into a single device, they could indeed produce a really impactful array of data.

A gyro is an apparatus that employs gravity to aid in assessing orientation. Its structure is made up of a freely rotating disc known as a rotor that is fitted onto a twisting axis in the centre of a relatively large and also more stable wheel/roller[14]. The rotor remains stationary as the axis rotates, indicating the central gravitational pull and hence which way is "down." The force applied to a vibrating element causes vibration gyro sensors to detect angular velocity. The accuracy, with which angular velocity is measured, on the other hand, varies markedly based on component material and structural variances. For a more accurate and reliable results, a high-accuracy MEMS gyro sensor with a better scale factor, high shock resistance, a fair temperature-frequency coefficient, good stability, and compact design may be chosen[15].

An accelerometer is a small device that senses non-gravitational acceleration. When the object into which it is embedded moves from a halt to any velocity, the accelerometer is configured to respond to the vibrations generated by the movement[16]. It employs microscopic crystals that are stressed when vibrations eventuate, and this stress generates a voltage, which is then used to produce a reading on any acceleration[17-18]. Because of its small size, a MEMS accelerometer can be used in this proposed work. **Figure 3** depicts a few gyro and accelerometer sensors available on the market[19].

In fact, the accelerometer is used to detect linear motion and tilt, whereas the gyroscope is used to trace all rotational movement patterns. Both are distinct motion sensors that have altered how humans communicate with various devices. The basic functions of gyroscopes authorise them to quantify an object's motion by rotation rate and are featured in many such devices while humans cannot recognise orientation[20].



**Figure 3** Gyro and accelerometers sensors on the market : (a) Vibration Gyroscope; (b) MEMS Gyroscope; (c) Piezoelectric Accelerometer; (d) MEMS accelerometer

## Internet of Things

Signal Transmitting and Receiving: IoT devices are nonstandard computing devices that can link to a network wirelessly and transfer data, like the numerous devices on the internet of things (IoT). The Internet of Things (IoT) entails providing internet access further than standard devices such as desktops, laptops, smartphones, and tablets to any number of historically “dumb” or non-internet-enabled physical machines and everyday objects. Such devices, which are implanted with technology, can communicate and collaborate via the internet. They can indeed be tracked and controlled wirelessly[21].

In its most basic form, IoT system layout shall consist of 3 tiers: Tier 1: Devices, Tier 2: Edge Gateway, and Tier 3: Cloud. Devices encompass networked objects such as sensors and actuators contained in IoT equipment, in particular those which link up to an Edge Gateway via protocols like as Modbus, Bluetooth, Zigbee, or proprietary protocols[22]. The Edge Gateway layer is comprised of sensor data gathering systems known as Edge Gateways, which offer features and functions such as data pre-processing and acquiring connectivity to the cloud via systems like Web Sockets. The last tier includes the cloud application designed for IoT. **Figure 4** depicts an example of how the Internet of Things is employed in collision avoidance by using Automatic Identification Systems on a seagoing vessel.

As gesture control is being used, signal transmission for the robots in the vessels is a big hurdle; the time delay must be limited to microseconds for instantly transferring the gestures. The entire action for a specific gesture can be separated into two — signal transmission and signal reception.

Transmitting the signal over such a long distance is too complicated since we need to install transmitting and receiving antennas as well as towers of about 300 m in height, which is a near-impossible task. To solve this problem, we will use the internet to broadcast the signal over a wide area, which is also known as Internet of Things (IoT). Because gestures must be genuinely and quickly transferred to the robot, a transmitting device, such as a wearable suit or a glove, must be designed to transmit a relevant signal to the robot so that it can fulfil the task as guided/instructed.



**Figure 4** IoT application: automatic identification systems for a marine vessel[23]

### Signal Transmitter

The transmitter is an electronic unit that converts sensor readings into a signal and sends it, either wired or wirelessly, to be acquired by a control device. The transmitting module contains an ADC for analogue to digital conversion and an encoder for encoding the four-bit data, which is then transmitted through an RF Transmitter.

### Signal Receiver

RF receivers serve as one of the simplest ways to integrate wireless control. It receives data sent by the gesture console, which functions similarly to the transmitter. An RF Receiver gets the encoded data and decoder IC deciphers it at the receiver section.

### Raspberry-Pi Controller

The data from the receiver is processed by a microcontroller, and the motors are controlled by a motor driver. The proposed work makes use of the “Raspberry Pi” microcontroller. It is a line of small single-board computers (SBCs) developed by the Raspberry Pi Foundation in collaboration with Broadcom in the United Kingdom. Because of its minimal price, extensibility, and open configuration, it is popularly used in many fields, including weather forecasting. It is commonly used due to its Compatibility with the HDMI and USB standards.

### Others

The controller is set to work based on the sensor throughput, and it sends the appropriate signal to the motors. The movement is powered by two DC motors. A motor driver is an integrated circuit (IC) that offers the required current to the motors. The entire assembly is held together by a metal chassis. Now, the robot mimics human actions based on the gestures of the controlling person. **Figures 5 and 6** display the entire signal transmitting and receiving assembly including the necessary controller and signal conditioning circuits.

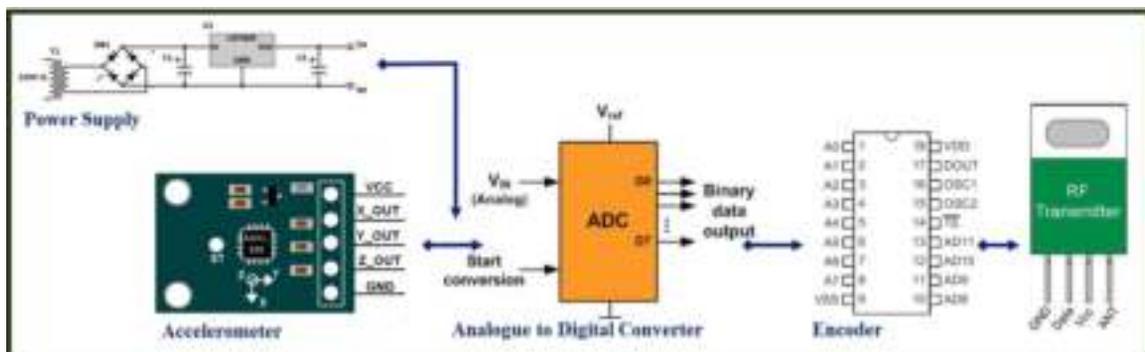


Figure 5 Transmitter circuit for gesture controlled vessel

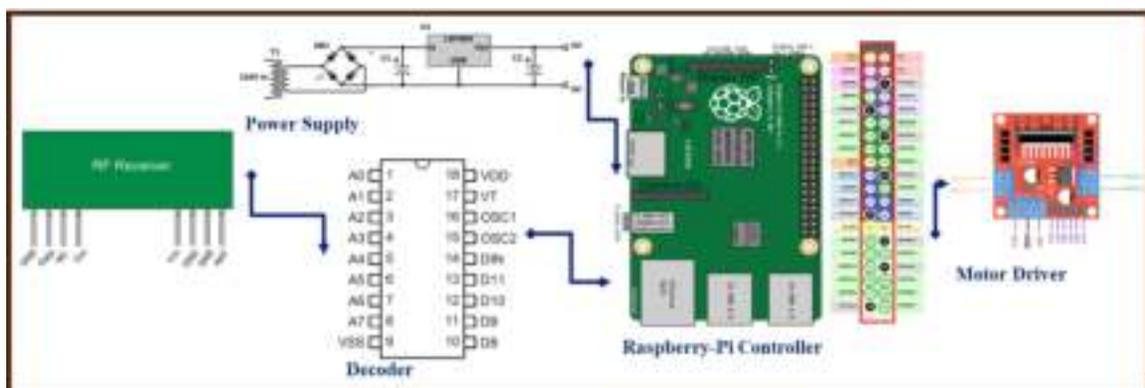


Figure 6 Receiver circuit for gesture controlled vessel



## CONCLUSION

A gesture is a nonverbal form of communication that involves perceptible physical movements or activities that deliver messages/information. There are multiple methods for capturing a human gesture that a machine can comprehend. A camera or a data glove can be used to record the gesture. Motions could also be collected using Bluetooth or infrared waves, as well as sound, touch, photonic, or vibration technology. Embedded systems for particular control features can be optimized to minimize device size and expense while increasing efficiency and reliability. It is intended to use a gesture control robot, primarily for vessel direction and motion controls. The various important control components have been thoroughly discussed. For the selection of sensors, controllers, and signal conditioning units, recent literature has been reviewed. With IoT as a platform, appropriate sensors and controllers are chosen for signal transmission and reception. A set of instructions is used by an embedded Raspberry-Pi controller to control the gestures.

## REFERENCES

1. F B Bjørneseth, M D Dunlop and E Hornecker. Assessing the Effectiveness of Direct Gesture Interaction for a Safety Critical Maritime Application. *International Journal of Human-computer Studies*, 70(10), October 2012, pp 729-745, <http://dx.doi.org/10.1016/j.ijhcs.2012.06.001>
2. F B Bjørneseth, M D Dunlop and J P Strand, Dynamic Positioning Systems: Usability and Interaction Styles. *Proceedings of the 5th Nordic Conference on Human-computer Interaction: Building Bridges*, October 2008, pp 43-52, <https://doi.org/10.1145/1463160.1463166>
3. M C Jo, A R Lee, Y D Kim and J S Seo, Study on the Potential Gaps and Themes Identified by IMO Regulatory Scoping Exercise (RSE) for the use of Maritime Autonomous Surface Ships (MASS). *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, 929(1), November 2020, p 012014.
4. E Ziajka-Poznańska and J Montewka, Costs and Benefits of Autonomous Shipping — a Literature Review, *Applied Sciences*, MDPIAG, 11(10), 2021, p 4553, Retrieved from <http://dx.doi.org/10.3390/app11104553>.
5. Autonomous Ships Market Size & Share | Industry Report, 2019-2025 (n.d.). *Autonomous Ships Market Size and Share | Industry Report, 2019-2025*. Retrieved November 9, 2022, from <https://www.grandviewresearch.com/industry-analysis/autonomous-ships-market>.
6. J Cui, L Cui, Z Huang, X Li and F Han, IoT Wheelchair Control System based on Multi-Mode Sensing and Human-Machine Interaction. *Micromachines*, 13(7), 2022, p 1108.
7. Xiaoci Chen, Shuyi Du, Xu Yang, Qinwen Li and Yuxiang Ma. Unmanned Boat Control System based on Gesture Interaction Technology, *Journal of Artificial Intelligence Practice*, 4, 2021, pp 78-80, doi: 10.23977/jaip.2020.040213.
8. D G Yuk and J W Sohn, User Independent Hand Motion Recognition for Robot Arm Manipulation. *J Mech Sci Technol* 36, pp 2739–2747, 2022, <https://doi.org/10.1007/s12206-022-0507-x>.
9. G Brantner, and O Khatib, Controlling Ocean One: Human–robot Collaboration for Deep — Sea Manipulation, *Journal of Field Robotics*, 38(1), 2021, p 28-51.
10. L Zhao, T Zhang, W Li, T Li, L Zhang, X Zhang and Z Wang, Engineering of Sodium-ion Batteries: Opportunities and Challenges, *Engineering*, 2022, ISSN 2095-8099, <https://doi.org/10.1016/j.eng.2021.08.032>.
11. N Tapia-Ruiz, A R Armstrong, H Alptekin, M A Amores, H Au, J Barker and R Younesi, 2021 Roadmap for Sodium-ion Batteries. *Journal of Physics: Energy*, 3(3), 2021, 031503.
12. W Lu, Z Wang and S Zhong, Sodium-ion Battery Technology: Advanced Anodes, Cathodes and Electrolytes. *Journal of Physics: Conference Series*, IOP Publishing, 2109(1), November 2021, 012004.
13. Kedia, Sodium-Ion batteries | An alternative to Li-ion batteries. *Evreporter*, February 24, 2022, Retrieved November 9, 2022 from <https://evreporter.com/sodium-ion-batteries-an-alternative-to-li-ion-batteries/>
14. V M N Passaro, A Cuccovillo, L Vaiani, M Carlo and C E Campanella, Gyroscope Technology and Applications: A Review in the Industrial Perspective, *Sensors (Basel)*, 17(10), 2017, 2284. doi: 10.3390/s17102284. PMID: 28991175; PMCID: PMC5677445.
15. IA Faisal, T W Purboyo and A S R Ansori, A Review of accelerometer Sensor and Gyroscope Sensor in IMU Sensors



- on Motion Capture, *J. Eng. Appl. Sci.*, 15(3), 2019, pp 826-829.
16. C C Yang and Y L Hsu, A Review of Accelerometry-based Wearable Motion Detectors for Physical Activity Monitoring, *Sensors (Basel)*,10(8), 2010, 7772-88. doi: 10.3390/s100807772. Epub 2010 Aug 20. PMID: 22163626; PMCID: PMC3231187.
  17. H Zeng and Y Zhao, Sensing Movement: Microsensors for Body Motion Measurement. *Sensors (Basel)*, 11(1), 2011, pp 638-660, doi: 10.3390/s110100638. Epub 2011 Jan 10. PMID: 22346595; PMCID: PMC3274064.
  18. T Gondo and R Miura, Accelerometer-Based Activity Recognition of Workers at Construction Sites, *Frontiers in Built Environment*, 6, 2020, 563353.
  19. Q Liu, Human Motion State Recognition based on MEMS Sensors and Zigbee Network, *Computer Communications*, 181, 2022, pp 164-172.
  20. A J Casson, A V Galvez and D Jarchi, Gyroscope vs. Accelerometer Measurements of Motion from Wrist PPG during Physical Exercise, *ICT Express*, 2(4), 2016, pp 175-179.
  21. Posey and Shea, What are IoT Devices? —Definition from TechTarget.com. *IoT Agenda*, March 1, 2022, Retrieved November 9, 2022, from <https://www.techtarget.com/iotagenda/definition/IoT-device>
  22. S Aslam, M P Michaelides and H Herodotou, Internet of Ships: A Survey on Architectures, Emerging Applications, and Challenges, *IEEE Internet of Things Journal*, 7(10), 2020, pp 9714-9727, doi: 10.1109/JIOT.2020.2993411.
  23. Use of AIS in Collision Avoidance and SAR Operation. *Use of AIS in Collision Avoidance and SAR Operation*, September 18, 2022, Retrieved November 9, 2022 from <https://www.seamanguide.com/2021/09/use-of-ais-in-collision-avoidance-and.html>

# Application of AFC for Marine Biofouling Control

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**Abstract:** Marine structures like jetties, platforms and sea water intake system components suffer massive and diverse biofouling. The settlement and accumulation of marine organisms on inanimate substrates could result in large penalties to the industries by posing restrictions to the water inflow and affect the hydrodynamics thus impair the intended performance these systems and structures.

In Madras Atomic Power Station (MAPS), the sea water intake system screens, which act as barriers for the entry of marine organisms into the sea water cooling systems, persistently experience severe biofouling. Conventional control methods like, chlorination, has limitations in their applications to the open sea water system and also on its discharges to the marine environment.

To overcome the biofouling and associated concerns in the intake sea water system of MAPS and to protect the marine structures from these influences, one of the contemporary technologies of application of anti fouling coating (AFC) is employed to the intake water system screens.

The AFC applied screens performance was significantly superior with less dense and significantly low population of bio-organisms on the screens thus highlighted effective marine bio-fouling control on these screens. The low level attachments were easily getting detached with gentle wash or pressure. Also, due to the inherent self polishing nature of the coating, the surfaces remained smooth thus controlling further attachments. All these resulted in extended life of these intake screens with superior integrity to satisfy the intended objectives of these screens in the intake sea water system.

**Keywords:** Biofouling; Marine Structures; Intake Sea Water System; Anti Fouling Coating

## GENERAL

Biofouling of sea water intake system components has been a common concern for coastal power plants and also for the Madras Atomic Power Station (MAPS). The sea water for the MAPS requirement is drawn from the Bay of Bengal through a 'morning glory' type of intake, 16 m in dia, to the pump house located about 450 m away from the onshore.

The sea water intake system screens, which are provided as the barrier for the entry of marine organisms into the cooling water system, recurrently suffer from severe biofouling.

In the intake system, there are 16 openings each of about 2.9 m × 1.76 m in size, through which sea water enters the sub-sea bed tunnel. Each opening has screens called trash racks. These trash racks experience severe biofouling which reduces the inflow of water and cause low levels in the on-shore pump house which has a direct impact on the plant operation. Thus it necessitates recurrent cleaning and maintenance works on these screens. These works include, physical lifting-up of heavy structures, laborious manual cleaning and maintenance on a rotation basis.

The sea water chlorination programme with low level continuous chlorination and alternate day's booster dosing is employed by the plant. However, due to factors like, continuous inward flow of high inventory seawater, water turbulences due to wave breaks, varying sea weather conditions and open system, the chlorination efficacy is not adequately realized at the intake system and the intake screens experience severe biofouling.

Several years experience indicated that coal tar epoxy coating renders temporary protection and the screens recurrently suffer massive fouling. To overcome the biofouling and associated concerns in the intake system of MAPS, the contemporary technology of application of Anti Fouling Coating (AFC) is employed to these screens, based on various experimental studies.



## FOULING PROTECTION TECHNOLOGIES

The sequence of biofouling generally includes an initial accumulation of adsorbed organics, the settlement and growth of bacteria creating a biofilm matrix and the subsequent succession of micro and macrofoulers.

Biofouling could create corrosive environment due to their life cycle and their ability to generate decomposition products, which is called microbiologically induced corrosion (MIC). The control of MIC is a key outcome for the development of a successful coating which inhibits the attachment of biofouling.

Growth of marine organism would start immediately when the surface is exposed to seawater. To keep the surfaces fouling-free requires periodic cleaning with high pressure water washing (HPWW) or mechanical hard brush cleaning. The intensity of cleaning required might be higher thus there lies a potential for damaging the surfaces and increasing the roughness of the surface due to repeated washing. This would increase the likelihood of recurrent fouling and loss of integrity of the surfaces and structures.

Fouling protection technologies provide fouling free surface. One of the current common technologies widely employed for fouling protection of surface is by application antifouling coating (AFC).

### Antifouling Coating (AFC)

It contains active biocide which is released steadily with the water inflow/impact and provides fouling free surface. The release of biocide depends on water flow and accordingly the type of antifouling is selected with due consideration to the service requirements.

Antifouling coating is commonly classified as Hydrating, Hydrolysing and Hybrid type. Among the above, hydrolyzing (chemical reaction in seawater, self-smoothing effect) is considered to be the most effective even for static structures. In this type, fresh antifouling layer is continuously exposed and available for fouling protection.

Self polishing Hydrolyzing type Antifouling forms partly hydrophobic surface. When antifouling surface is exposed to seawater, Biocide leaches out at a controlled rate from the antifouling film and provides fouling protection at the surface. This is a continuous process and always fresh layer of antifouling gets exposed for fouling protection.

Anti fouling coatings make a valuable contribution to the sustained operational efficient sea water systems, achieved by the release of active ingredients (or biocides) which prevent the settlement of marine fouling organisms. The success of this process depends on the nature of biocide used, the biocide release mechanism and the polishing and smoothing action of the coatings technology employed.

## APPLICATION OF ANTI FOULING COATING TO SEA WATER INTAKE SCREENS

A commercial anti fouling coating (AFC) was considered based on the encouraging results obtained through several pilot scale studies. This AFC falls under self polishing copolymer (SPC) group where the acrylic copolymers are with hydrolysable pendant groups like, silyl acrylate, zinc or copper acrylate polymers. Hydrolysis of the pendant groups and the dissolution of the hydrolysed polymer release the incorporated biocides and lead to a self polishing surface which is self smoothing.

Accordingly, some newly fabricated screens were applied with this AFC and a few other screens were applied with the regular coal tar epoxy coating (Non-AFC) and these gates were exposed to sea water in the intake system for about two years.

During the periodical inspections, it was noted that the coal tar epoxy coated gates were getting massively fouled with dense population of bio-organisms adhering to the metal structure and they were hard to get removed on mechanical cleaning wherein the AFC applied gates were scarcely fouled and were loosely held onto the metal structure and easily getting dislodged by gentle pressure.

The typical photographs of these AFC and Non-AFC screen gates after an exposure period of ~2 years are shown in **Figures 1(a)** and **1(b)**. The AFC applied screens BEFORE and AFTER cleaning are shown in **Figures 2(a)** and **2(b)** and the typical photographs of Non-AFC applied gates BEFORE and AFTER cleaning are shown in **Figures 3(a)** and **3(b)**.

## RESULTS AND DISCUSSIONS

The following are some of the key results and observations on AFC and Non-AFC applied screens of intake sea water system:

- The performance of AFC applied screens was significantly superior than Non-AFC applied gates with effective



**Figures 1 (a)** AFC applied screen **(b)** Non-AFC applied screen



**Figures 2 AFC applied screen (a)** before cleaning **(b)** after cleaning



**Figures 3** Non-AFC screen (a) before cleaning (b) after cleaning

control on biofouling on these gates thereby ensuring intended inflow of sea water to the plant operational requirements.

- The AFC applied screens had considerably lesser population and lesser density of bio-organisms on them and were loosely held.
- With gentle pressure the fouling on the AFC screens was getting dislodged wherein for the Non-AFC screens higher pressure or metallic scrapping was to be adopted to dislodge the fouling adhering to them.

**Table 1** Summary of the observations and results

Description	Gates with Coal Tar Epoxy Coating	Gates with Anti Fouling Coating
Biofouling control	Less effective with high dense and higher population of bio-organisms on the screens	Very effective control with less dense and very low population of bio-organisms on the screens
Sea water inflow to pump house	Restriction in the inflow due to severe biofouling	No constraints on inflow due to considerably low level biofouling
Ease of cleaning	Hard cleaning with metal scrapping/high pressure	Easy to dislodge the foulants with gentle pressure
Frequency of surface cleaning	Once in two months on rotation	About 4-5 months on rotation
Surface finish after cleaning	Rough surface with loss of material due to mechanical scrapping	Smooth surface-finish due to the inherent self-polishing nature of the coating
Cost of coating materials	~ Rs.10,000/6 months (Recurrent in nature as these gates are to be recreated every 6-7 months in the life span of ~3-5 years.)	Rs.1.5lakhs (One time application for the entire life of the gate which is more than 6-8 years)



- The mechanical methods of cleaning adopted for Non-AFC screens were resulting in loss of coating and physical damage of the screens which were becoming weaker sites for further degradation and damage or corrosion of the screens. Thus, for these gates every 6-7 months reapplication of coal tar epoxy coating was done to extend their life span wherein such requirement did not arise with the AFC applied gates.
- The ease of cleaning of AFC applied screens was much simpler and post cleaning, the gates were looking almost like a fresh one due to the inherent self polishing nature of the AFC.
- The anti-corrosion life of AFC applied gate is 10-12 years wherein for the Non-AFC applied gate, it may be 5-6 years with every 6-7 months reapplication of coal tar epoxy coating.
- As per the literature, the expected anti-fouling life span of this AFC applied gates are more than 5-7 years under the given environmental and process conditions wherein the coal tar applied did not have any anti-fouling properties.

The summary of the observations and results is shown in **Table 1**.

### **CONCLUSIONS / REMARKS**

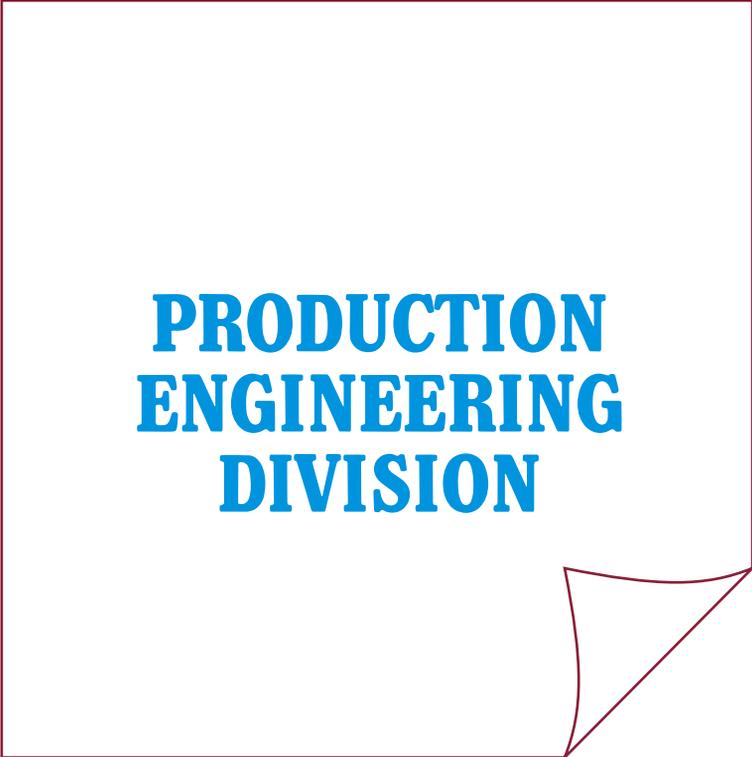
To overcome the severe biofouling and associated concerns in the intake system of MAPS, one of the contemporary technologies of application of Anti Fouling Coating (AFC) is employed to the intake water system screens which highlighted its effectiveness in exercising control on biofouling and corrosion of these intake structures thereby ensuring intended inflow of sea water to the plant operational requirements.

The AFC applied screens performance was remarkably superior with less dense and very low population of bio-organisms on the screens highlighting very effective bio-fouling control. The low level attachments were easily getting detached and due to the inherent self polishing nature of the coating the surfaces remained smooth thus controlling further attachments. All these were resulting in extended life of the intake screens with better integrity to satisfy the intended objectives of these screens in the intake sea water system.

### **ACKNOWLEDGMENT**

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**PRODUCTION  
ENGINEERING  
DIVISION**



# Sustainability of 3D Printing in Manufacturing Industries

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**Abstract:** 3D printing has turned into a remarkable point in today's innovative exchange. In this paper, will focus at the additive manufacturing or 3D printing and the various materials used in 3D printing and their properties which become a notable topic in technological aspects. We will go into the history of 3D printing and study about the process of 3D printing and what materials used in the manufacture of 3D printed objects and select the best materials among them which are suitable for our 3D printing machine. It is inevitable that the capabilities that come with 3D printing and the way in which technology is evolving will enable businesses to adopt this new way of producing products or parts and it is likely that this adoption is going to grow well in the future. Also see the focal points and burdens of 3D printing and will also watch the various applications that is being utilized today.

**Keywords:** Design; Process; Materials; 3D Printing; Additive Manufacturing

## INTRODUCTION

When the first Stereo Lithography Apparatus (SLA) machine was developed, a sustainable resolution to reduce waste and production cycle has come around[1]. From the fabrication of complicated jet engine parts to simple cups, 3D printing is being regarded as an alternative and more efficient way to develop new product. At present the global market for 3D printing is good worth when compared to that of 2014[2]. Due to a competitive advantage in materials efficiency and less processing procedures, 3D printing has both the technological and economic benefits. It still presents a trend of fast increase in the basic theory exploration and technology development. Although several surveys about 3D printing have been documented[3], and almost all the survey on 3D printing has always focussed on categories, processes, quality and cost benefits and environmental impact.

Unlike traditional manufacturing processes, 3D printing starts from modelling, going through printing and finishing, it saves the traditional processes of casting, forging and rough machining without reducing the final part quality. Difference of processes in 3D printing and traditional manufacturing is shown in **Table 1**.

Gradually, by the early 2010s, the terms 3D printing and additive manufacturing evolved senses in which they were alternate umbrella terms for AM technologies, one being used in popular vernacular by consumer - maker communities and the media, and the other used officially by industrial AM end use part producers, AM machine manufacturers, and global technical standards organizations. Both terms reflect the simple fact that the technologies all share the common theme of sequential-layer material addition/joining throughout a 3D work envelope under automated control (**Figure 1**).

The most common 3D printing processes are: [**Figure 2**]

1. Stereolithography (SLA), which is a vat photopolymerization technology
2. Fused deposition modelling (FDM), which is a material extrusion technology
3. Selective laser sintering (SLS), which is a powder bed fusion technology [4]

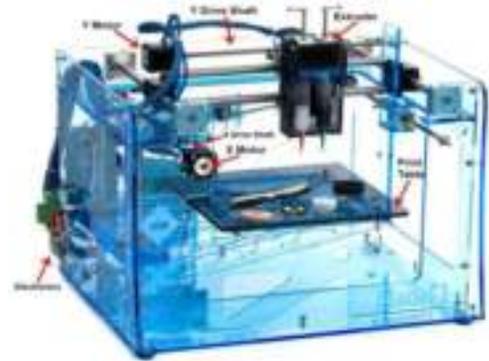
## GENERAL PRINCIPLES

### A. Modelling

3D printable models can be created with the help of CAD design packages or via 3D scanner. The manual modeling process of preparing geometric data for 3D computer graphics is similar to method sculpting. 3D modeling is a process of analyzing and collecting data on the shape and appearance of an object. Based on this data[4-5], 3D models of the scanned object can be produced. Both manual and automatic creations of 3D printed models are very difficult for average consumers. That is why several market-places have emerged over the last years among the world. The most popular are Shape ways, Thingiverse, My Mini Factory, and Threading.

**TABLE 1 DIFFERENCE OF PROCESSES IN 3D PRINTING AND TRADITIONAL MANUFACTURING**

Items	3D printing	Traditional manufacturing
Forming method	Additive	Subtractive
Materials	Powders, Filament and Tapes, etc.	Block, Bar, Plate, etc.
Efficiency	Higher	Lower
Production Waste	Less	More
Built time	Hours to days	Days to months
Cost	Higher	Lower
Life cycle	Shorter	Longer
Required employees	Ordinary workers	Skilful workers
Suitable applications	Making prototypes, Complex shapes	Batch production



**Figure 1 3D Printer**

### 3D PRINTER MATERIAL

#### A. Acrylonitrile Butadiene Styrene [ABS]

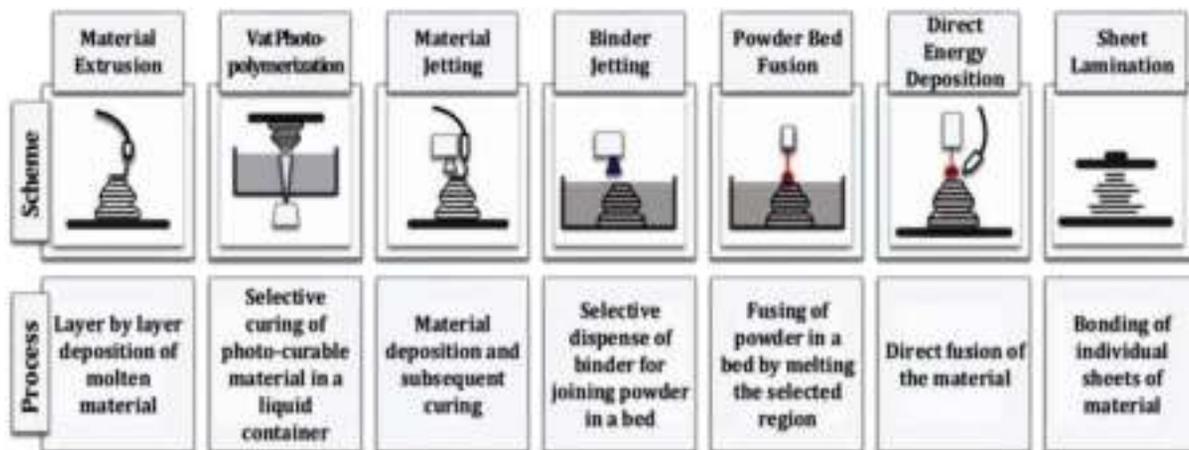
One of the most widely used material since the inception of 3D printing. This material is very durable, slightly flexible, and lightweight and can be easily extruded, which makes it perfect for 3D printing[10]. It requires less force to extrude than when using PLA, which is another popular 3D filament. This fact makes extrusion easier for small parts. The disadvantage of ABS is that it requires higher temperature. Its glass transition temperature is about 105°C and temperature about 210 - 250°C is usually used for printing with ABS materials. Also another drawback of this material is quite intense fumes during printing that can be dangerous for pets or people with breathing difficulties. So 3D printers need to be placed in well-ventilated area. Also good advice is to avoid breathing in fumes during printing considering the cost of 3D materials ABS is the cheapest, which makes it favorite in printing communities until now.

#### B. Poly Lactic Acid [PLA]

Poly lactic acid (PLA) (is derived from corn and is biodegradable) is another well-spread material among 3D printing enthusiasts. It is a biodegradable thermoplastic that is derived from renewable resources. As a result PLA materials are more environmentally friendly among other plastic materials[5]. The other great feature of PLA is its biocompatibility with a human body. The structure of PLA is harder than the one of ABS and material melts at 180 – 220°C which is lower than ABS. PLA glass transition temperature is between 60 – 65°C, so PLA together with ABS could be some good options for the projects.

#### Technical Specifications

- o Density - 1.3 g/cm<sup>3</sup> (81 lb/ft<sup>3</sup>)



**Figure 2 Types of 3D printing technologies and processes**



- Elastic (Young's, Tensile) Modulus - 2.0 to 2.6 GPa ( $0.29$  to  $0.38 \times 10^3$  psi)
- Elongation at Break - 6.0 %
- Flexural Modulus - 4.0 GPa ( $0.58 \times 10^3$  psi)
- Flexural Strength - 80 MPa ( $12 \times 10^3$  psi)
- Glass Transition Temperature -  $60^\circ\text{C}$  ( $140^\circ\text{F}$ )
- Heat Deflection Temperature At 455 kPa (66 psi) -  $65^\circ\text{C}$  ( $150^\circ\text{F}$ )
- Melting Onset (Solidus) -  $160^\circ\text{C}$  ( $320^\circ\text{F}$ )
- Shear Modulus- 2.4 GPa ( $0.35 \times 10^3$  psi)
- Specific Heat Capacity - 1800 J/kg-K
- Strength to Weight Ratio - 38 kN-m/kg
- Tensile Strength : Ultimate (UTS) - 50 MPa ( $7.3 \times 10^3$  psi)

### C. High Impact Polystyrene [HIPS]

HIPS filament is made from a High Impact Polystyrene material and it is another example of support 3D materials. This material is well spread in food industry for packaging. It is also used to pack CD discs and to produce trays in medicine naturally this filament has bright white color and it is also biodegradable so there is no adverse effect when it is put in tight contact with a human or animal body. HIPS filaments have curling and adhesion problems, which can be reduced by using a heated bed during the printing. HIPS material that can also be used as support structure during the printing and then dissolved in a colorless liquid hydrocarbon Solution.

#### 3D Printing Process

##### Printing

Before printing a 3D model (**Figure 3**) from STL file, it must be processed by a piece of software called a "slicer" which converts the 3D model into a series of thin layers and produces a G-code file from .STL file containing instructions to a printer. There are several open source slicer programs exist, including, Slic3r, KISSlicer, and Cura. The 3D printer follows the G-code instructions to put down successive layers of liquid, powder, or sheet material to build a model from a series of cross-sections of a model[6]. These layers, which correspond to the virtual cross sections from the CAD model, are joined or fused to create the final shape of a model. The main advantage of this technique is its ability to create almost any shape or geometric model. Construction of a model with existing methods can take anywhere from several hours to days, depending on the method used and the size and complexity of the model. Additive systems can typically reduce this time to very few hours; it varies widely depending on the type of machine used and the size and number of models being produced.

##### Finishing

Although the printer-produced resolution is sufficient for many applications, printing a slightly oversized version of the object in standard resolution and then removing material with a higher-resolution process can achieve greater precision. As with the Accucraft iD-20 and other machines Press Release. International Manufacturing Technology shows some additive manufacturing techniques are capable of using multiple materials in the course of constructing parts.

#### A. Selective Laser Sintering

Selective laser sintering (SLS) (**Figure 4**) was developed and patented by Dr. Carl Deckard and academic adviser, Dr. Joe Beaman at the University of Texas in the mid-1980, under the sponsorship of DARPA[2]. Deckard was involved in the resulting start-up company DTM, established to design and build the selective laser sintering machines. In the year 2001, 3D Systems the biggest competitor of DTM acquired DTM. The most recent patent regarding Deckard's selective laser sintering technology was issued on January 1997 and expired on Jan 2014[4]. Selective laser sintering is a 3D-printing technique that uses a laser as the power source to sinter powdered material (mostly metal), aiming the laser at points in space defined by a 3D model, binding the material to create a solid structure. Selective laser melting uses a comparable concept, but in SLM the material is fully melted than sintered, allowing different properties (crystal structure, porosity).

#### B. Fused Deposition Melting

Fused deposition modeling (FDM) (**Figure 5**) method was developed by S. Scott Crump in the late 1980s and was





traditional methods which takes months to develop their idea and thus the companies which adopts 3D printing will have an edge over their competitors.

2. Reduces Production Cost: The parts and tools are manufactured through additive manufacturing techniques using 3D printing and thereby reduces the manufacturing cost when compared to the traditional machining[14].
3. Reduces Risk : Under 3D printing to print test a prototype is cheaper than to redesign or alter an existing mould.
4. Market Demand: The prototype model can be exhibited in the Trade fair shows to witness the demand and buyer's response before going into actual production.
5. Customize to the Individual needs.t: With 3D printing, one can personalize, customize a part to uniquely fit to their need and elaborate their idea in the new world.
6. Enhance Creativity: In the modern digital world the creativity and imagination are without limitations. With the help of 3D printing the idea, concept and simple blue print can march towards production with much ease.
7. Early Breakthroughs: Due to the speed of the 3D printing the product developer can make break throughs at an early state which is inexpensive and helps to produce better products with minimum cost.

## VI. APPLICATIONS

1. The designing can be challenging in traditional methods hence Engineers opt for 3D printing and it is mostly preferred by Aeronautics and Aerospace Industries.
2. The 3D printing is widely used in the medical and dental industries for metal casting of dental crowns and in the manufacture of tools to make dental aligners.
3. In the Jewellery sector the new designs enabled by 3D CAD and 3D printing has paved way for 3D printed Jewellery making eliminating the traditional steps of jewellery making.
4. 3D Printing processes had been staple application for architectural models as it fast, easy and economically feasible for producing models using 3D CAD and BIM.
5. 3D printed accessories are playing a vital role in the fashion industries. Headpieces, shoes, hats and bags had made the way globally.

## CONCLUSION

3D printing technology has the potential to open doors in product development, manufacturing and distribution for pharmaceutical companies. It could help fulfill the promise of personalized medicine, a concept that is growing in popularity within the industry and it will be the future of the manufacturing process. Improvement in production speed, the scaling up pf printing processes and the development of material compatible with a variety of 3D printing techniques will provide even more opportunities for environmental applications.

## ACKNOWLEDGMENTS

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## REFERENCES

1. C Hull, Stereolithography: Plastic Prototype from CAD Data without Tooling, Mod Cast 78, 1988, p 38.
2. Bloomberg Businessweek, 3D Printing, Materials & Services: Global Market Size 2014-2018, May 19-May 25, 2014, p S4, <http://www.statista.com/statistics/315363/global-marketfor-3d-printing-and-services/>
3. S H Huang, P Liu, A Mokasdar and L Hou, Additive Manufacturing and its Societal Impact: A Literature Review, International Journal of Advanced Manufacturing Technology, 67, 2013, pp 1191–1203.
4. Manoj Kundu and Arnab Mandal, Additive Manufacturing Process (3D Printing): A Critical Review of Techniques, Applications & Future Scope, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, 11(10), October 2022.
5. Yee Ling Yap, Swee Leong Sing and Wai Yee Yeong. A Review of 3D Printing Processes and Materials for Soft Robotics.



6. W E Frazier, Metal Additive Manufacturing: A Review, *Journal of Materials Engineering and Performance*, 23(6), 2014, pp 1917-1928.
7. F L Bourhis, O Kerbrat, L Dembinski, J Y Hascoet and P Mognol, Predictive Model for Environmental Assessment in Additive Manufacturing Process, *Procedia CIRP*, 15, 2014, pp 26 – 31.
8. P Mognol, D Lopicart and N Perry, Rapid Prototyping: Energy and Environment in the Spotlight. *Rapid Prototyping Journal*, 12(1), 2006, pp 26-34.
9. R Huang, M Riddle, D Graziano, J Warren, S Das, S Nimbalkar and E Masanet, Energy and Emissions Saving Potential of Additive Manufacturing: The cCase of Lightweight Aircraft Components. *Journal of Cleaner Production*, 2015.
10. E Bryce, How a 3D Printer Gave a Teenage Bomb Victim a New Arm – and a Reason to Live, January 19, 2014.
11. Burke, 3D Printing is the Future, But Safety Comes First. *Information Week*, January 16, 2014.
12. J Falconer, Formlabs Creates Blu-ray Based Prosumer 3D Printer, September 26, 2013.
13. S Kaur, How is “Internet of the 3D Printed Products” Going to Affect Our Lives?, 2012.
14. *IETE Technical Review*, 29(5), pp 360-364

# A Study for Fabrication of an Affordable Motorized Lower Limb Exoskeleton System (Wearable Device) for Paraplegic Person

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**Abstract:** In this work, detailed study is carried out towards the fabrication of an affordable motorized lower limb exoskeleton (LLE) a wearable device for paraplegic people. To measure movement of hip, knee and ankle angles goniometer is used. Spring balance has been used to find the holding torque of the joints to estimate the required motor torque. Solidworks software is used to draw the 3D CAD model. Ansys software is used to performed structural analysis of the designed parts. Finally, fabrication of the exoskeleton is done with steel frame, stepper motor and linear actuator.

**Keywords:** Lower Limb Exoskeleton; Solid Works; ANSYS; Linear Actuator; Stepper Motor; Arduino

## INTRODUCTION

As per the Indian Census of 2011[1], there are about 2.68 cr people with disability of motion, among which paralytic people comprising a major part of it. Majority of the cases of paralysis arise due to strokes, and estimates of 2015 show that India has a total of approximately 1.8 million cases of stroke annually, the number rising each year. Owing to their low incomes, majority of these paralytic patients opt for manual wheelchairs as a means to restore their mobility. However, the annual wheelchair has these pose a few limitations such as use on uneven terrain and limited independent to move. Whereas, the motorized lower limb exoskeleton system gives more freedom to move these paraplegic persons as compare to these wheelchairs.

An exoskeleton, is a wearable robotic device that can be help human being to support and protect their body part[2]. Paraplegic person (paralyzed from the waist down), who have only partial or no use of their legs or lower body may use exoskeleton device. Due to various reasons, if any damage to the nervous system like road accident, pressure stroke, nerve injury, Parkinson's disease, or even genetic disorders, may lead to a person losing his or her muscle function, as a result the ability to move is hampered. Thus, the need is to develop a cheaper and affordable lower limb motorized exoskeleton system for paraplegic person, which can restore mobility in a much better way, and simultaneously act as a means of rehabilitation. It can also be used for physiotherapy purpose.

Mobility is a fundamental part of an individual's daily life. In general, lower limb exoskeletons[3] are used for rehabilitation and assisting human activity. In this study, gait analysis has been done with the help of goniometer. Spring balance is used to find out the required motor torque for hip and knee joints. Designed a 3D CAD model for the system to support hip, knee and ankle joint of human legs. Investigation has been done for the suitable and affordable material for this device with subject to availability. Static structural analysis has been done to the all designed parts of the exoskeleton device in ansys software to determine failure. Final testing has been done with one healthy person.

## METHODOLOGY OF STUDY

### Gait Analysis

Measurements of hip angle, knee angle and ankle angle movement for one step of walking with the help of goniometer[4] for a person weighing 70 kg and height of 167 cm.

Hip, knee and ankle joint measurement while walking for one step.

### Experiment for Finding the Holding Torque

To find out the holding torque of hip motor, experiment has been carried out with a spring balance [5].

**Figure 7** shows the experiment of holding load of one leg, while in standing condition = 7 kg

Length of the leg from hip to fastened area = 80 cm



**Figure 1** Hip angle while backward movement

**Figure 2** Hip angle while forward movement

**Figure 3** Knee angle while forward movement

**Figure 4** Knee angle while backward movement

**Figure 5** Ankle angle while backward movement

**Figure 6** Ankle angle while forward movement

**Table 1** Hip angle measurement while walking of one step

Position	Standing	Forward	Backwards
Hip angle	180°	150°	190°
Knee angle	180°	146°	160°
Ankle angle	93°	80°	115°

Therefore, minimum holding torque required by the hip

$$\text{Motor torque} = \text{distance} \times \text{load} = 80 \times 7 = 560 \text{ kg-cm}$$

One may take 3-time higher torque value to find the motor for safe operation.

$$\text{Therefore, torque of the hip motor} = 560 \times 3 = 1680 \text{ kg-cm} = 16.8 \text{ kg-m}$$

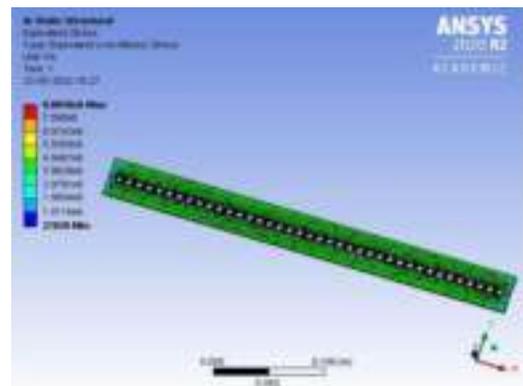
To find out the holding torque of knee motor, same experiment has been carried out with the spring balance with considering knee to foot part of the leg, in sitting condition.

With this experiment holding load is 5.5 kg shown in **Figure 7** by the spring balance.

Length of the leg from knee to fastened area = 37 cm



**Figure 7** Estimate the load of one leg with the help of spring balance



**Figure 8** Adjustable link middle (part no.11)

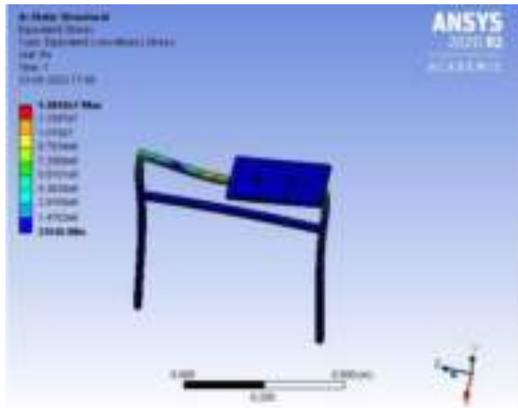


Figure 9 Stand (part no.2)

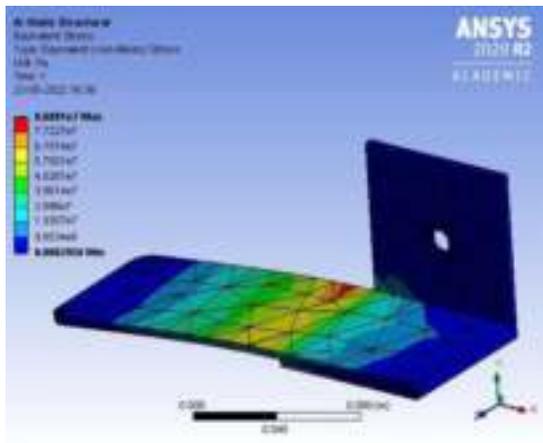


Figure 10 Ankle and foot support (part no.7)

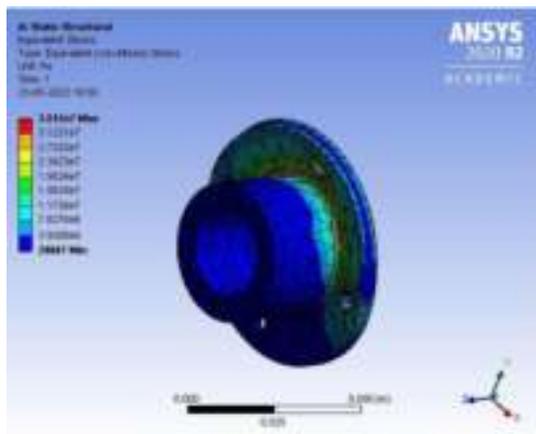


Figure 11 Flange coupling (part no.8)

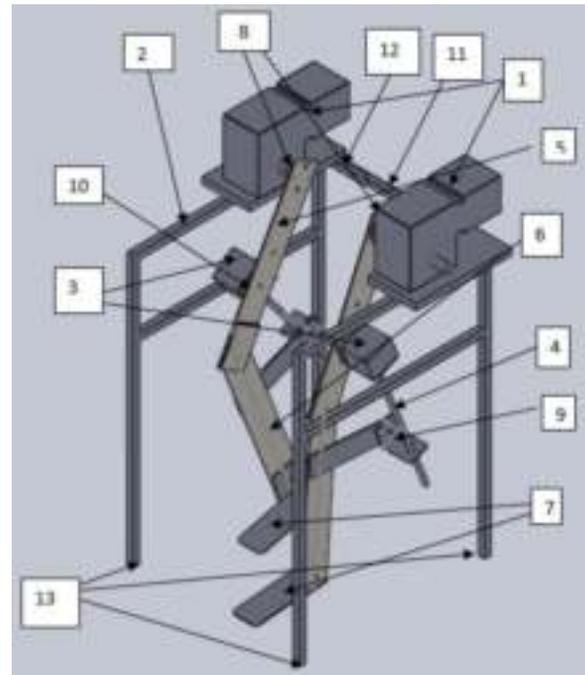


Figure 12 Final 3D CAD model assembly of the device  
 1. Stepper Motor, 2. Stand, 3. Stepper Motor, 4. Lead Screw, 5. Upper Link, 6. Lower Link, 7. Ankle and Foot Support, 8. Flange Coupling, 9. Lower link Bracket, 10. Upper link Bracket, 11. Adjustable link Middle, 12. Adjustable link Right (Left), 13. Position for Wheels (4 nos)



Figure 13 Final prototype of hip-knee exoskeleton



The minimum holding torque required by the knee motor torque = distance  $\times$  load =  $37 \times 5.5 = 202.5 \text{ kg-cm} = 20.025 \text{ kg-m}$   
One may take 3-time higher torque value to find the motor for safe operation.

Therefore, the knee motor torque =  $202.5 \times 3 = 607.5 \text{ kg-cm} = 60.75 \text{ kg-m}$

According to the Farries, et al., 2012[6] the maximum hip and knee joints torques required for stair ascent and descent with the exoskeleton are found to be 0.75 Nm/kg and 0.87 Nm/kg, respectively. The peak hip and knee joint power was shown to be 0.65 W/kg and 0.85 W/kg, respectively. Considering a reasonable upper bound for subject body mass as 90 kg (~ 200 lbs), a gait assistance exoskeleton with stair ascent and descent capability would need to provide maximum absolute joint torques of 68 Nm and 78 Nm at the hip and knee joints, respectively, and peak joint powers of 59 W and 77 W at the hip and knee joints, respectively.

Consider the experimental data of Farries, et al. literature and subjected to availability stepper motors and linear actuator have been selected. Two stepper motors for hip joints with torque 1740 kg-cm to support both legs. Two lead screw based linear actuator whose torque 300 kg-cm with 450 mm stroke length have been selected to support to knee joints.

### ANALYSIS

Static structural analysis has been done for the parts of the exoskeleton device in Ansys software. Considering one end fixed with applied a ramp up load of 500 N and solve with equivalent stress solution. The material has been selected as Structural Steel, in Ansys workbench.

### FINAL 3D CAD MODEL

Overall dimensions of the device

1. Height of the stand (part no.2) = 840 mm
2. Adjustable distance (part no.11 and 12) = 600 mm
3. Leg length from hip joint to ankle joint (part no 5 and 6) = 880 mm
4. Height of wheel with adjustable link (part no.13) = 70 mm

### PROTOTYPE DEVELOPMENT AND TESTING

The developed prototype is a hip knee exoskeleton system[7]. The device has been manufactured and tested in the laboratory with one healthy subject. It has been supported the hip and knee joint effectively. For controlling the device arduino board, stepper motor driver, dc power source 24 V have been used. To stop in emergency condition and safety one emergency push button switch has been installed in the device.

### COST ESTIMATION

**Table 2** Cost Estimation of the hip knee exoskeleton device

SL No	Parts	Cost (INR)
1	Stepper Motor (for hip joint), 1740 kg-cm torque – 2nos	68000
2	Stand	2000
3	Flange coupling 2 nos	500
4	Upper link-2 nos	200
5	Lower link-2 nos	200
6	Stepper Motor (Knee Joint)-2 nos	33000
7	Lead screw -60 cm -2 nos	900
8	Lead screw coupling-2nos	500
9	Stepper motor driver-4 nos	16000
10	Arduino Board	700
11	Electrical wire-50 mtrs	500
12	SMPS-48V, 10 Amp	7000
13	Labour Cost	10000
Total Cost of Manufacturing (INR)		1,39,500

Cost estimation has been done with the actual price of the components after completion of the manufacturing.

**AVAILABLE EXOSKELETON DEVICES AND THEIR COST**

**Table 3** shows the some of the available Motorized Exoskeleton System or Robotic suits are most commonly used as a walking or mobility assistance device by the military, physical therapists helping patients for rehabilitation of Paraplegic Person (paralyzed from the waist down), who have only partial or no use of their legs or lower body[7].

**COST COMPARISON**

As per **Table 3** available Motorized lower limb exoskeletons are costlier. Outcome of this study is a wearable motorized hip knee exoskeleton for lower limb with an affordable price which will be suitable for low income people. As per the estimation shown in **Table 2**, the total manufacturing cost of this device is Rs. 1,39,500 only. If compare the price with the existing motorized exoskeleton system, it is very less and affordable. This cost can be lower if this device will be manufactured in a large scale.

**CONCLUSION AND FUTURE WORK**

**Table 3** Cost and application of available motorized exoskeleton system

Name	Cost	Application
EKSO	\$100,000+	clinics only
HAL5	\$20,000	qualifying patients only
Honda Walking Assist	\$375 monthly	bulk sale only - supports upper legs only
Indego	\$80,000	an adjustable lower-limb exoskeleton that enables therapists to deliver task-specific gait training for stroke and spinal cord injury patients.
ReWalk	\$77,000	Walking assistance system that uses powered leg attachments to enable paraplegics to stand upright, walk and climb stairs.
SuitX Phoenix	\$40,000	test pilots only



**Figure 14** Arduino control board



**Figure 15** Linear actuator-based stepper motor (part no.3,4) (image source:<https://steppermotors.bholanath.in/>)



**Figure 16** Stepper motor for hip joint (part no.1)



**Figure 17** Stepper motor driver



**Figure 18** Rewalk exoskeleton [Ref.7]



The prototype of affordable motorized lower limb exoskeleton system will be a very helpful product for paraplegic persons. It also can be helpful for physiotherapy. If mass production will be made for this device then the cost of the product could be within 1 lakh, which is very economical price. The mathematical modelling of lead screw actuator mechanism to find out the knee gait cycle with motor torque may be considered. Studies may be extended to make the device using light weight material like carbon fibres. Studies can be possible to develop proper control system for this device.

#### ACKNOWLEDGEMENT

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#### REFERENCES

1. A Mishra, A N Nagarkar and N M Nagarkar, Challenges in Education and Employment for Hearing Impaired in India", *Journal of Disability Management and Special Education*, vol. 1, no. 1, January 2018
2. A M. Dollar and H Herr, Lower Extremity Exoskeletons and Active Orthoses: Challenges and State-of-the-Art, *IEEE Transactions on Robotics*, vol. 24, no. 1, February 2008, pp 144-158.
3. D S Pamungkas, W Caesarendra, H Soebakti, R Analia and S Susanto, Overview: Types of Lower Limb Exoskeletons, *Electronics*, 8, 2019, 1283.
4. A Roaas and G B Jandersson, Normal Range of Motion of the Hip, Knee and Ankle Joints in Male Subjects, 30–40 Years of Age, *Acta Orthopaedica Scandinavica*, vol 53, 1982-issue 2, July 2009, pp 205-208.
5. J Narayan, M Dowarah, S Bhawsinghka and S K Dwivedy, Experimental Investigation and Dynamic Analysis of a Lower Limb Exoskeleton System, 2nd International Conference on Advancements in Automation, Robotics & Sensing, PSG College of Technology, Coimbatore, 2018.
6. R J Farris, H A Quintero and M Goldfarb, Performance Evaluation of a Lower Limb Exoskeleton for Stair Ascent and Descent with Paraplegia, 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2012, pp 1908-1911, doi: 10.1109/EMBC.2012.6346326.
7. X Tu, J Huang and J He, Leg Hybrid Rehabilitation based on Hip-knee Exoskeleton and Ankle Motion Induced by FES, 2016 International Conference on Advanced Robotics and Mechatronics (ICARM), 2016, pp 237-242.

# Sustainable Development in Wood Pressed Oil Cluster through Industrial Cluster Development Approach

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**Abstract:** Tamil Nadu is number one in India on implementation of 26 Industrial Clusters for MSMEs. 16 are in various stages of implementation. The objective is to study on linear programming techniques like cost minimisation and profit maximisation of Wood Pressed Oil Manufacturing enterprises, which are formed by 30 wood pressed oil manufacturers namely Wood Pressed Oil Clusters (WPOC) in the Chengalpattu District of Tamil Nadu by adopting Cluster Development Approach (CDA). The methodology adopted is collection of Primary input data like Employment in no's ( $E_i$ ), Investment in Machinery in Rs. Lakhs ( $M_i$ ), and output data like Turnover in Rs. Lakhs ( $T_i$ ) and Profit in Rs. Lakhs ( $P_i$ ) where  $i = 1, 2, 3, \dots, 30$ , from 30 Micro Manufacturers of WPOC and secondary data from WPOC and Government of India and Tamil Nadu. The data were analyzed using Descriptive Analysis (DA), Correlation Analysis (CA), Regression Analysis (RA) and Structural Equation Modelling (SEM) before and after Cluster Development Approach. If Common Facility Centres are created by purchasing machineries under Micro Small Enterprises Cluster Development Programme (MSE-CDP) of Government of India like wooden cold press oil, testing lab, dehusking, compressor with dryer, filter, tank, solar drying equipment's, by product packing like cake making etc. there is possibility of increase in average  $E_i$ ,  $M_i$ ,  $T_i$  and  $P_i$  from 15% to 30% after CDA. By Correlation Analysis it is found that there exists high degree of relationship between variables. The regression equation obtained is  $P_i = 3.00 - 0.13 E_i + 0.250 M_i$  and  $P_i = -0.42 + 0.25 T_i$ , where the null hypothesis is rejected and alternate hypothesis is accepted that is when one unit of employment increases there is decrease in turnover; however when there is one unit increase in Investment in Machinery the turnover increases and when one unit increase in turnover there increase in profit. To conclude there will be sustainable development in the WPOC due to cost reduction in manufacturing by adding value addition to the product and also diversify their product thereby increasing their profit after CDA and also to compete in the global market.

**Keywords:** Sustainable Development; Oil Cluster; Cluster Development Approach

## INTRODUCTION

A cluster is a group of enterprises located within an identifiable and contiguous area (to a large extent) or a value chain that may go beyond a geographical area and producing same / similar products / complementary products / services, which can be linked together by common physical infrastructure facilities. It must address their common challenges which is the core reason to take up the project under this scheme. The essential characteristics of enterprises in a cluster are — (a) Similarity or complementarity in the methods of production, quality control and testing, energy consumption, pollution control, etc., (b) Similar level of technology and marketing strategies / practices, (c) Similar channels for communication among the members of the cluster, (d) Common market and skill needs and/ or (e) Common challenges and opportunities that the cluster faces[1].

Ministry of MSME, GoI runs various schemes targeted at providing credit and financial assistances, skill development training, infrastructure development, marketing assistance, technological and quality upgradation[2]. One such Scheme offered by the Ministry to enhance the competitiveness of MSMEs is Micro and Small Enterprises Cluster Development Programme (MSE-CDP) with the following objectives:

1. Support sustainability of MSMEs by addressing common issues;
2. Capacity Building of MSMEs for common supportive action;
3. Create / Upgrade Infrastructural Facilities in Industrial Estates / Clusters;
4. Setting up of Common Facility Centres (CFCs);
5. Promotion of Advanced and Sustainable Manufacturing Technologies, Tamil Nadu Small Industries Development Corporation Limited (TANSIDCO) is the Nodal Agency for implementation of centrally sponsored MSE-CDP scheme in Tamil Nadu. Under the scheme, TANSIDCO has facilitated implementation of more than 40 clusters



throughout the State. Tamil Nadu is number one in India on implementation of 26 Industrial Clusters for MSMEs. 16 are in various stages of implementation.

## TECHNICAL SURVEY

The completed CFC in Tamil Nadu are given in **Figure 1**[3].

the technical score and ranking of auto component manufactures, it is found that there is significant increase in technical efficiency of ACI after the CDA when compared to before CDA. The slack variables obtained clearly reveals the excess employment and net worth and no shortage of gross output. Government policy on CDA by intervention in interrelationships not only benefited Chennai Auto Cluster in general but also Chennai Auto Components Industries in particular[4].

There is increase in technical efficiency of not only Chennai auto cluster in general but also Chennai auto components industries in particular [5]. For sustainable development, the TC should strengthen infrastructure interrelationships, technology interrelationships, procurement interrelationships, production interrelationships and marketing interrelationships to decrease cost, increase productivity and efficiency to compete in the world market [6]. For inclusive growth and sustainable development, the inefficient ACC should increase their turnover and exports, as decrease in no. of enterprises and employment is practically not possible [7]. The variables are highly correlated and the inefficient industries should increase their gross output or decrease the fixed assets or employment [8]. The technical efficiency of LMC companies also increases significantly [9].

The Automotive Industries have fully utilized the Physical Infrastructure and Centralised Facilities by adopting CDA and now exporting their products to North America, South America, Europe, Australia, Africa and Asia. The value chain analysis models have been implemented in all the cluster units. This Cluster Development Approach (CDA) model can be implemented in industries of under developed and developing countries for cost reduction and productivity increase[10].

The variables are highly correlated, and for inclusive growth and sustainable development, the inefficient Engineering Industry at Hosur, Tamil Nadu should increase their Gross Value Added or decrease the employment or machinery[11]. The Chennai Automotive Industry Cluster Model demonstrates the fact that industrial units have utilised the physical infrastructure and centralised facilities by adopting cluster development approach[12]. Wood Pressed Oil Manufacturing enterprises, propose to get funding of Rs.15.00 crore of the Project Cost where 60% from Micro Small Enterprises Cluster Development Programme (MSE-CDP) of Government of India of Rs. 9.00 crore, 20% from Government of Tamil Nadu of Rs.3 crore and 20% from Special Purpose Vehicle of Rs. 3 crore which are formed by 30 wood pressed oil manufacturers namely Wood Pressed Oil Clusters (WPOC) in the Chengalpattu District of Tamil Nadu by adopting Cluster Development Approach (CDA).

## OBJECTIVES OF THE STUDY

The objective is

1. To study on linear programming techniques like cost minimisation and profit maximation of Wood Pressed Oil Manufacturing enterprises.
2. To find significant relationship between employment, investment in machinery, turnover and profit Wood Pressed Oil Manufacturing enterprises.
3. To find sustainable development of Wood Pressed Oil Manufacturing enterprises.

## METHODOLOGY

The methodology adopted is collection of Primary input data like Employment in no's ( $E_i$ ), Investment in Machinery in Rs.lakhs ( $M_i$ ), and output data like Turnover in Rs. lakhs ( $T_i$ ) and Profit in Rs. lakhs ( $P_i$ ) where  $i = 1,2,3...30$ , from 30 Micro Manufacturers of WPOC and secondary data from WPOC and Government of India and Tamil Nadu [13-15]. The data were analyzed using Descriptive Analysis (DA), Correlation Analysis (CA), Regression Analysis (RA) and Structural Equation Modelling (SEM) before and after Cluster Development Approach.

### Technical Analysis

#### *Physical Performance and Financial Performance*

The physical and financial performance is shown in **Figure 2**.

If Common Facility Centers are created by purchasing machineries under Micro Small Enterprises Cluster Development

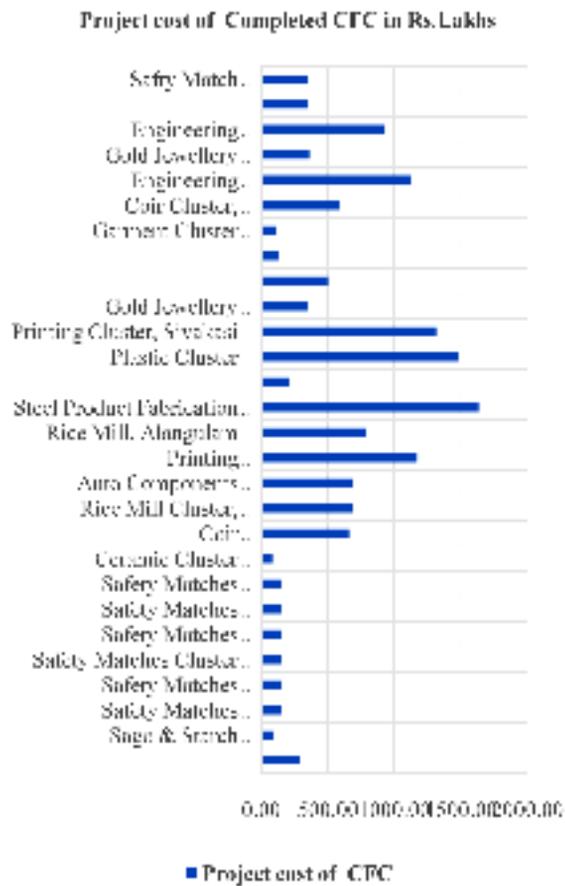


Programmed (MSE-CDP) of Government of India like wooden cold press oil, testing lab, dehusking, compressor with dryer, filter, tank, solar drying equipment's, by product packing like cake making etc. there is possibility of increase in profit and reduction in cost.

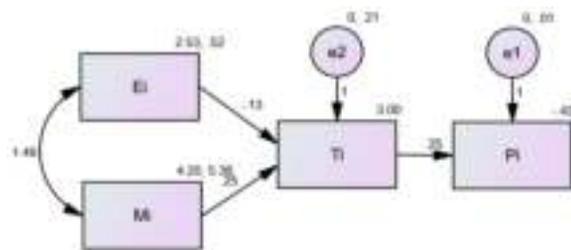
**Descriptive Analysis**

The Descriptive Analysis is given in **Table 1**.

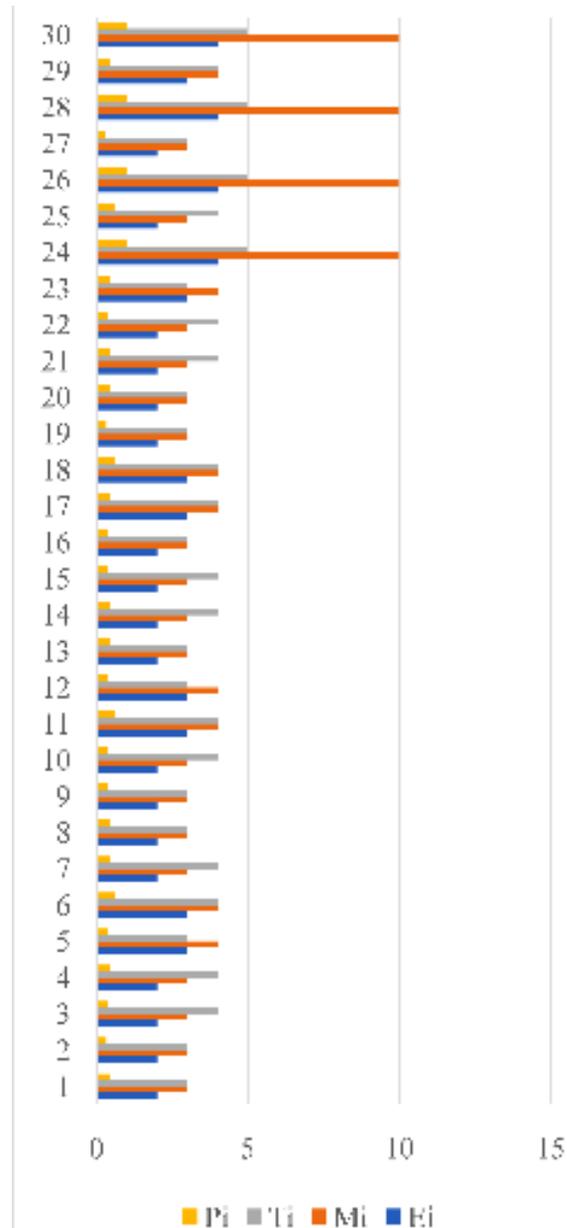
The mean value of employment, investment, turnover and profit indicates that there is growth in all variables. By DA it is found that the average Ei is 3 no's, average Mi in cold press oil extraction machinery is Rs. 4.2 lakhs, average Ti is Rs.3.7 lakhs and average Pi is Rs. 0.51 lakhs before cluster development approach.



**Figure 1** Completed CFCs in Tamil Nadu



**Figure 3** Structural Equation Modelling (SEM)



**Figure 2** Physical and financial performance



### Correlation Analysis

The Correlation Analysis is given in **Table 2**.

#### Null Hypothesis 1

There is no significant relationship between dependent variable turnover and independent variable employment.

#### Alternate Hypothesis 1

There is significant relationship between dependent variable turnover and independent variable employment.

As per **Table 2**, Correlation Coefficient  $R = 0.633$ ,  $p = 0.000 \leq 0.05$ , null hypothesis is rejected at 5% level. There is significant relationship between turnover and independent variable employment.

**Table 1** Descriptive analysis

		Ei	Mi	Ti	Pi
N	Valid	30	30	30	30
	Missing	0	0	0	0
Mean		2.53	4.20	3.73	0.51
Std. Error of Mean		0.13	.42	0.12	0.03
Median		2.00	3.00	4.00	0.45
Mode		2	3.00	4.00	0.45
Std. Deviation		0.730	2.35	0.69	0.20
Variance		0.53	5.54	0.47	0.04
Skewness		1.01	2.12	0.41	1.63
Std. Error of Skewness		0.43	0.43	0.43	0.43
Kurtosis		-0.30	2.9	-0.77	1.72
Std. Error of Kurtosis		0.83	.83	0.83	0.83
Range		2	7.00	2.00	0.70
Minimum		2	3.00	3.00	0.30
Maximum		4	10.00	5.00	1.00
Sum		76	126.00	112.00	15.45

Source: Computed Data

**Table 2** Correlation analysis

		Ei	Mi	Ti	Pi
Ei	Pearson Correlation	1	0.898**	0.633**	0.832**
	Sig. (2-tailed)		0.000	0.000	0.000
	Sum of Squares and Cross-products	15.467	44.800	9.267	3.690
	Covariance	0.533	1.545	0.320	0.127
	N	30	30	30	30
Mi	Pearson Correlation	0.898**	1	0.733**	0.937**
	Sig. (2-tailed)	0.000		0.000	0.000
	Sum of Squares and Cross-products	44.800	160.800	34.600	13.390
	Covariance	1.545	5.545	1.193	0.462
	N	30	30	30	30
Ti	Pearson Correlation	0.633**	0.733**	1	0.827**
	Sig. (2-tailed)	0.000	0.000		0.000
	Sum of Squares and Cross-products	9.267	34.600	13.867	3.470
	Covariance	0.320	1.193	0.478	0.120
	N	30	30	30	30
Pi	Pearson Correlation	0.832**	0.937**	0.827**	1
	Sig. (2-tailed)	0.000	0.000	0.000	
	Sum of Squares and Cross-products	3.690	13.390	3.470	1.271
	Covariance	0.127	0.462	0.120	0.044
	N	30	30	30	30

\*\*Correlation is significant at the 0.01 level (2-tailed).

Source: Computed data



#### *Null Hypothesis 2*

There is no significant relationship between dependent variable turnover and independent variable Investment in Machinery.

#### *Alternate Hypothesis 2*

There is significant relationship between dependent variable turnover and independent variable Investment in Machinery.

As per **Table 2**, Correlation Coefficient  $R = 0.733$ ,  $p = 0.05 < 0.05$ , null hypothesis is rejected at % level. There is significant relationship between dependent variable turnover and independent variable Investment in Machinery.

#### *Null Hypothesis 3*

There is no significant relationship between dependent variable profit and independent variable turnover.

#### *Alternate Hypothesis 3*

There is significant relationship between dependent variable profit and independent variable turnover.

As per **Table 2**, Correlation Coefficient  $R = 0.827$ ,  $p = 0.000 < 0.05$ , null hypothesis is rejected at 5% level. There is significant relationship between dependent variable profit and independent variable turnover.

#### Structural Equation Modelling

The structural equation modelling is done using AMOS and is given in **Figure 3**.

#### **Regression Analysis**

#### *Null Hypothesis 4*

There is no significant relationship between dependent variable turnover and independent variables like employment and investment in machinery.

#### *Alternate Hypothesis 4*

There is significant relationship between dependent variable turnover and independent variables like employment and investment in machinery.

Regression Equation is given in Equation (1)

The Structural Equation (1) is

$$P_i = 3.00 - 0.13 E_i + 0.250 M_i \quad (1)$$

$$p = 0.00 < 0.05, R^2 = 0.540, r = 0.735,$$

The null hypothesis is rejected and alternate hypothesis is accepted that is there is significant relationship between dependent variable turnover and independent variables like employment and investment in machinery.

When one unit increase in employment there is decrease in turnover by 0.125 units and for one unit increase in investment in machinery there is 0.250 unit increase in turnover. The histogram diagram for Employment, Investment in machinery and turnover is given in **Figures 4** and **5**.

#### **Null Hypothesis 5**

There is no significant relationship between dependent variable profit and independent variable turnover.

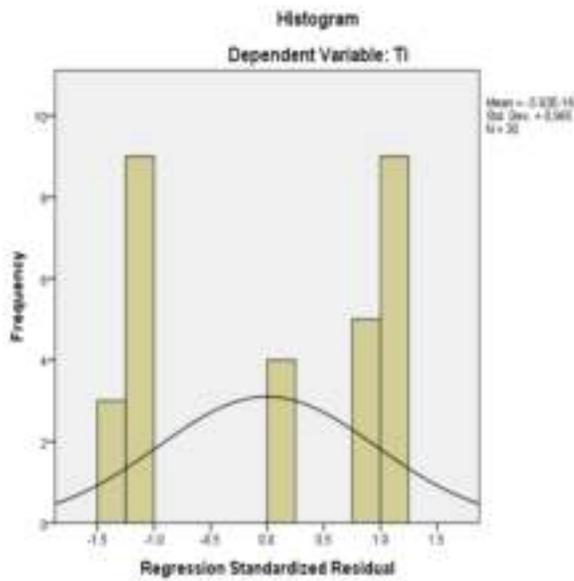
#### **Alternate Hypothesis 5**

There is significant relationship between dependent variable profit and independent variable turnover.

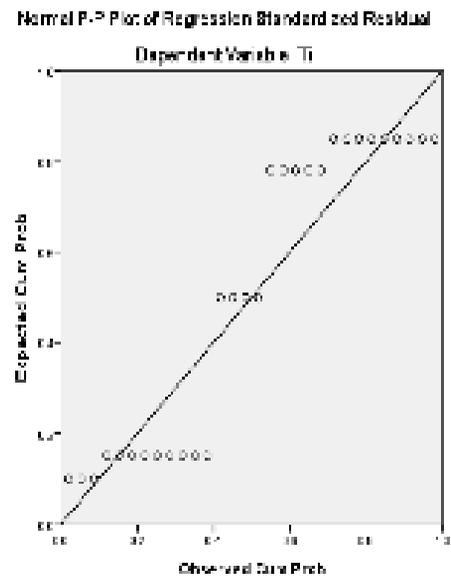
$$P_i = -0.42 + 0.25 T_i \quad (2)$$

$p = 0.00 < 0.05$ ,  $R^2 = 0.683$ ,  $R = 0.827$ , The null hypothesis is rejected and alternate hypothesis is accepted as per Equation (2) that is there is significant relationship between dependent variable profit and independent variable turnover. When one unit increase in turnover there is increase in profit by 0.25 units

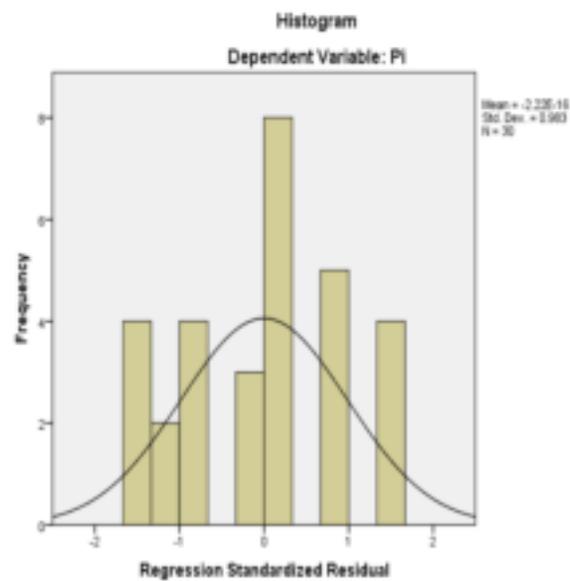
The histogram diagram for turnover and profit is given in **Figures 6** and **7**.



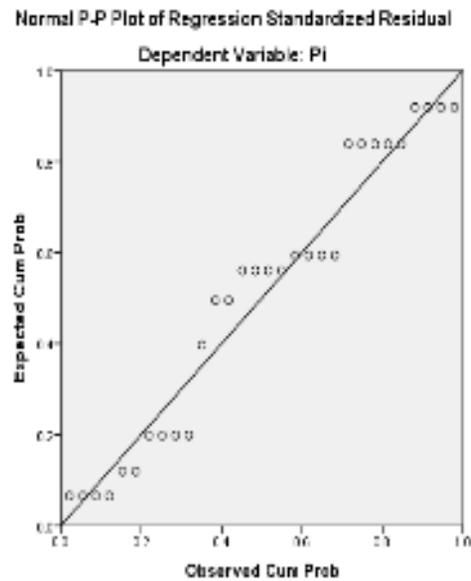
**Figure 4** Histogram for employment, investment in machinery and turnover



**Figure 5** Histogram for employment, investment in machinery and turnover



**Figure 6** Histogram for profit and turnover



**Figure 7** Histogram for profit and turnover

### FINDINGS, SUGGESTIONS AND CONCLUSION

A Study conducted on the Wood Pressed Oil Cluster in Chengalpattu district of Tamil Nadu. Physical Performance is an increasing trend for employment and Investment in machinery and also for Financial Performance like Turnover and Profit. The mean value of employment, Investment in machinery, turnover and Profit indicates that there is will be growth in all variables after cluster development approach. There exists a significant positive relationship between employment and Investment in machinery and also for Financial Performance like Turnover and Profit.

Higher dependent variables like turnover and profit are associated with higher independent variables like employment



and investment after cluster development approach. Employment and investment in machinery significantly predicts turnover and profit.

The Government of India and Tamil Nadu policy on Cluster Development Approach is an important one for MSMEs. As per Value Chain Analysis and Cluster Map the profit earned per enterprises increases. There will be increase in Common Facility Centre utilisation after technology intervention. This leads to productivity increase due to adoption of cluster development approach by experimental group.

The cluster development is one of excellent concept for developing MSE's for that GOI and GOTN are supporting through TANSIDCO and MSME-DFO as implementing agency. All the departments in the State as well as Central are very Co-operative during the implementation of the project. The interrelationships / cluster approach made by Cluster members to make use of interrelationships like Infrastructure, Procurement, Technology, Production and Marketing successfully.

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### REFERENCES

1. <http://www.dcmsme.gov.in/schemes/New%20MSE-CDP.pdf> assessed on 31.07.22
2. Performance Study of Common Facility Centres, ITCOT, July 2022, pp.1
3. MSME Department, Policy Note 2021-22, pp. 145-148
4. E Bhaskaran, The Technical Efficiency of Chennai Auto Industry Cluster, SAE Technical Paper 2011-28-0100, 2011, <https://doi.org/10.4271/2011-28-0100>
5. E Bhaskaran, Technical Efficiency of Automotive Industry Cluster in Chennai. J. Inst. Eng. India Ser. C 93, 2012, pp 243–249, <https://doi.org/10.1007/s40032-012-0029-x>
6. E Bhaskaran, The Productivity and Technical Efficiency of Textile Industry Clusters in India. J. Inst. Eng. India Ser. C 94, 245–251, 2013, <https://doi.org/10.1007/s40032-013-0073-1>
7. E Bhaskaran, Sustainable Development in Indian Automotive Component Clusters. J. Inst. Eng. India Ser. C 94, 81–84, 2013, <https://doi.org/10.1007/s40032-012-0039-8>
8. E Bhaskaran, The Productivity Analysis of Chennai Automotive Industry Cluster. J. Inst. Eng. India Ser. C 95, 239–249, 2014, <https://doi.org/10.1007/s40032-014-0120-6>
9. E Bhaskaran, Lean Manufacturing Auto Cluster at Chennai. J. Inst. Eng. India Ser. C 93, 2012, pp 383–390, <https://doi.org/10.1007/s40032-012-0035-z>
10. E Bhaskaran, The Quantitative Analysis of Chennai Automotive Industry Cluster. J. Inst. Eng. India Ser. C 97, 2016, pp 357–373, <https://doi.org/10.1007/s40032-016-0255-8>
11. E Bhaskaran, The Technical Efficiency of Engineering Industry Cluster at Hosur, SEDME (Small Enterprises Development, Management & Extension Journal), <https://journals.sagepub.com/doi/10.1177/0970846419852518>
12. E Bhaskaran, Qualitative Analysis and Impact Assessment of Chennai Automotive Cluster, <https://journals.sagepub.com/doi/abs/10.1177/0970846420180302>
13. TANSIDCO Coffee Table Book about CFCs in Tamil Nadu, 2020, pp-21-23
14. Performance Report of Cluster submitted to TANSIDCO during 2021.
15. Ministry of MSME, Government of India, <https://cluster.dcmsme.gov.in/> assessed on 28.07.2022





**TEXTILE  
ENGINEERING  
DIVISION**



# Unveiling of Knitting Science Opened Up a New Horizon of Manufacturing Value Added and Speciality Knitted Products

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**Abstract:** Knitting is the unique technique of manufacturing textile fabrics and shaped products by inter-looping of one or one set of yarn(s), which started its journey about 3000 years ago and presently about 25% out of total textile fabric consumption is contributed by knitting. Since the inception, knitting had been considered basically as an art of fabric manufacture and the science aspects of knitting remained unexplained over the millenniums. With the introduction of primitive engineering and technology aspects in knitting, science was there but as mystery. Science aspects of knitting started to be unveiled and visualized by the knitters only about eighty years back. In knitting Technology, combination of science and engineering not only deals with manufacturing of machinery, tools and apparatus, but also it helps in engineering (designing) a textile product having the desired functional properties out of variety of yarns which are basically non-engineering materials.

The fundamental knowledge derived from the initial study of knitting science confirms that – (i) loop length and loop shape are the most important parameters of a knitted fabric for governing its physical and functional properties, (ii) loop length is finalized in machine state, and does not change during relaxation, but loop shape changes and (iii) robbing back is an important phenomenon in knitting which deals with the mechanics of loop formation and plays the important role in determining loop length. In the meantime, lots of scientific studies had been carried out on knitting technology and contributed for the advancement in knitting machines and products. The author of the paper had also the opportunity to carry out in-depth studies on the science aspects of the barren field of double jersey knitting. He developed computerised model of double jersey loop formation under both synchronised and delayed timing, and validated the predicted output of the model in terms of loop length and knitting force obtained under actual situation.

Thereafter, the understanding of mechanics of knitting along with developments in other branches of science / engineering and technology, the knitting technology has flourished beyond our imagination. Knitting is no more confined in the production of traditional inner and outer wears, but can produce any product as per requirement, which are not possible in other fabric manufacturing technology.

So, knitting is a unique technology in the sense that it is more versatile than other techniques of fabric formation including weaving, knitting can produce shaped and seamless garments as well various types of technical textiles including artificial human body parts for improving lifestyle. Knitting is an eco-friendly process due to lower power consumption, heat and noise generation, minimum wastage of raw material etc. Above all, due to incorporation of various electronic control devices, artificial intelligence and IoT, knitting technology has achieved Industry 4.0 status.

**Keywords:** Knitting; Science; Loop Length; Product

## INTRODUCTION

Knitting is the unique technique of manufacturing textile fabrics and shaped products by inter-looping of one or one set of yarn(s), which started its journey about 3000 years ago and presently about 25% out of total textile fabric consumption is contributed by knitting. Since the inception, knitting had been considered basically as an art of fabric manufacture and the science aspects of knitting remained unexplained over the millenniums. With the introduction of primitive engineering and technology aspects in knitting, science was there but as mystery. Science aspects of knitting started to be unveiled and visualized by the knitters only about eighty years back. In knitting technology, combination of science and engineering not only deals with manufacturing of machinery, tools and apparatus, but also it helps in engineering (designing) a textile product having the desired functional properties out of variety of yarns which are basically non-engineering materials.



## BACKGROUND

The fundamental knowledge derived from the initial study of knitting science confirms that — (i) loop length and loop shape are the most important parameters of a knitted fabric for governing its physical and functional properties; (ii) loop length is finalized in machine state, and does not change during relaxation, but loop shape changes; and (iii) robbing back is an important phenomenon in knitting which deals with the mechanics of loop formation and plays the important role in determining loop length. In the meantime, lots of scientific studies (1 to 5) had been carried out on single jersey knitting technology and contributed for the advancement in knitting machines and products. The author of the paper had also the opportunity to carry out in-depth studies on the science aspects of the barren field of double jersey knitting (6 to 8).

## SCIENCE, ENGINEERING AND TECHNOLOGY

Science, Engineering and Technology are often confused with each other, all three are closely related but mean different things. “Science is the study for the knowledge of the natural world as it is, engineering is creating new tools, devices, and processes based on scientific knowledge, and technology is the sum total of all the engineered tools, devices and processes available.

There is a saying – “Scientists study the world as it is, Engineers create the world that has never been, and Technologists practically implement the creations of the Scientists and Engineers for the benefits of the inhabitants in the world”. The ultimate goal of the three is to create knowledge and products that solve natural phenomenon real life problems and improve human life.

Genesis of knitting sciences — [1947 onward by Pierce, ..... strengthened by Munden in 1959, ..... Knapton & Munden in 1966 ..... Wray & Burn in 1976 ..... Ray & Banerjee in 1992 .....].

## SCIENCE ASPECTS OF KNITTING

### Objectives of Studying Knitting Science

The main objectives of studying knitting science are:

- ❖ To identify various input parameters which influence the knitting process;
- ❖ To learn about the parameters/particulars of the fabrics which are important in end use;
- ❖ To gain an insight into the mechanics of loop formation;
- ❖ To optimize input parameters for desired output (fabric/product);
- ❖ To redesign the machine parts in order to achieve higher productivity and more control of human being on knitting;
- ❖ To engineer knitted fabrics and products.

### Fields of Study

- ❖ Fabric parameters like loop length (l), Courses per inch (cpi), Wales per inch (wpi), stitch density (S), etc;
- ❖ Fabric constants like KC, KW, KS, etc;
- ❖ Fabric tightness factor (TF);
- ❖ Geometry of the knitting zone;
- ❖ Robbing back (R.B.%) of yarn;
- ❖ Yarn tension profile inside knitting zone and its measurement;
- ❖ Factors governing loop length in fabric.

### Knitting Constants

It was observed by Munden that the basic knitted fabric parameters are inter-related, and based on value of one, the values of other parameters can be predicted (calculated) for single jersey fabrics irrespective of their different values of loop length, courses per inch, wales per inch as well as the deviation of machinery and yarns used in manufacturing those fabrics. Moreover, the relationship between loop shape and loop length may be expressed in the form of simple equations. The scientific relationships of the knitted fabric parameters as Constants are given below.

- Course constant,  $K_c = cpi \times l$
- Wale constant,  $K_w = wpi \times l$
- Stitch density constant,  $K_s = K_c \times K_w = S \times l^2$



**Table 1** Knitting constants of single jersey fabrics for cotton

Types of Constants	Dry Relaxed	Wet Relaxed	Fully Relaxed
Kc	5.0	5.3	5.5
Kw	3.8	4.1	4.2
Ks	19.0	21.6	23.1
R	1.3	1.3	1.3

- Loop shape factor,  $R = \frac{K_c}{K_w} = \frac{cpi}{wpi}$

The different knitting constant values are shown in **Table 1**.

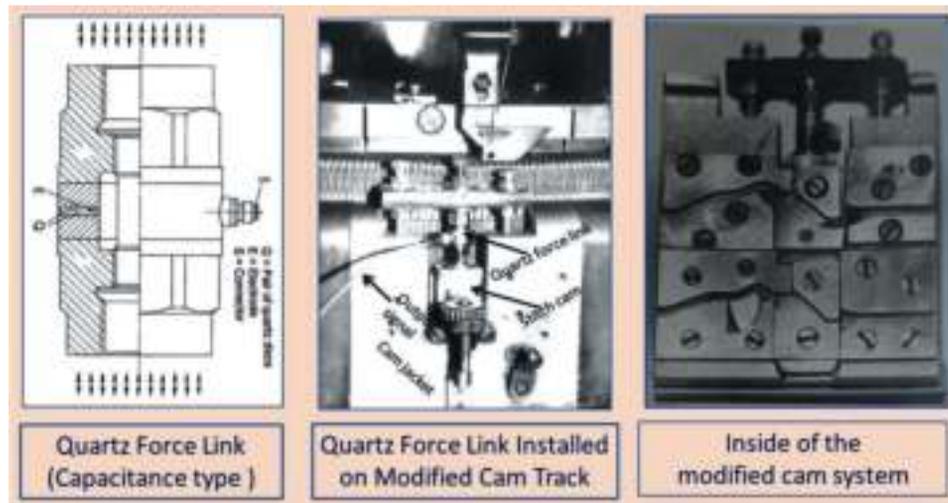
### MECHANICS OF LOOP FORMATION

Mechanics of loop formation in knitting deals with movement of yarn around sinkers and needles under the control of cam system as well the forces acting on yarn and knitting elements during loop formation. The mechanics of loop formation can be studied either through mathematical modeling or by measurement of knitting forces to understand the sciences of knitting. A good number of mathematical models and knitting force measurement systems had been developed and reported in research journals since 1966 for single jersey knitting. The double jersey loop formation is much complicated as it takes place in three dimensional planes using two sets of needles under the control of two cam systems, and hence no such report of mechanics of loop formation for double jersey knitting was available till 1992. Ray and Banerjee attempted first to study the mechanics of 1×1 rib loop formation in circular dial and cylinder type machine for calculating gradual development of loop length from the point of yarn catching as well as the forces developed in the cam surfaces.

They developed computerised model of double jersey loop formation under both synchronised and delayed timing, and validated the predicted output of the model in terms of both loop length and knitting force obtained under actual situation.

### STEPS TAKEN FOR THE STUDY OF KNITTING SCIENCE IN DOUBLE JERSEY KNITTING MACHINE

1. Two different Double Jersey Machines made of MS/ Raj International of India and MS/ Mellor Bromley of Germany were chosen for the study;
2. The Different features and functions of the knitting machines were identified and measured;
3. Some preliminary experiments were carried with random selection of machine, yarn and process parameters for gathering some knowledge on the effects of variables on loop length;
4. Movement of yarn during loop formation as well as the configuration of loop at different stages of loop formation were observed with the help of travelling microscope and mirror reflection;
5. Development of geometry of knitting zone under both synchronised and delayed timings;
6. The mathematical modelling of the loop formation process for both Synchronized timing and Delayed knitting timing were done with the help of computer software. The user-friendly programmes were written in PROFORT incorporating total nineteen variables which could be varied individually or in combination;
7. As the complete rib loop is made in 3-dimensional planes, the final loop at knitting point was considered to be constituted of 13-parts. The model predicts the profile of loop length and yarn tension (Cam force) over the total loop forming cycle. The profile of length of loop at various points inside the knitting zone reflects the extent of robbing as well as phases of occurrence of robbing back;
8. The frequency of loop formation was calculated from machine and process parameters;
9. In order to study the yarn tension development (cam force) during one complete loop formation, it was needed to move some needles in a separate path from the other needles. For the purpose one set of cam assembly was designed and manufactured in the workshop, similar to the existing one and fitted on the Mellor Bromley Machine;
10. There was a need of fitting one Sensor (Transducer) for generating signals of the cam force. For the purpose, Quartz Force Link (Capacitance type) made of Kistler Instrumente AG, Switzerland was procured of desired frequency (up to 2500 Hz);
11. The Sensor was fitted on the stitch-cam without hampering the normal knitting process. So, to accommodate the sensor, the cam jacket was partly cut and removed (**Figure 1**). In order to eliminate the effect of line voltage on the signal, the sensor was isolated from the metallic parts of the machine using nonconducting material like bakelite;



**Figure 1** Sensor fitted on the stitch cam of the new cam track

12. As the sensor generates the signal in pico-Coulomb, the same is magnified and converted in to volt by the Charge Amplifier for output;
13. For the purpose of importing the data from the Charge Amplifier to the computer, necessary software (programme) was written in Turbo-Pascal language;
14. Considering the necessity of storing and analysis of data, the Analog signal generated by the sensor was sent to a digital computer through Analog to Digital Conversion Card (ADC) of 16 channels, 0 to 5 Volts;
15. Properties (tenacity, elongation, bending rigidity, and coefficient of friction between yarn to yarn and yarn to metal of different yarns were measured;
16. The input yarn tension was also measured in every situation with the help of portable digital yarn tensiometer;
17. The efficacy of the total cam force measurement system was tested in various terms by – (a) using function generator, (b) applying vertical and angular force on the sensor, (c) applying sudden impact of hard body and soft body, (d) presence of noise etc. before carrying out the experimental studies;
18. The digital values stored in the computer were then plotted in graph for analysis of the cam force for a complete duration of loop formation;
19. Loop length and other structural parameters of the knitted fabrics produced with variable machine, process and yarn during knitting force measurement were also measured;
20. The robbing back values for all the combination of knitting were also calculated;
21. The developed Models were then validated in terms of both loop length and cam force.

#### **IMPORTANT OBSERVATIONS**

1. The validation of the proposed mathematical model was found to be well matching with the experimental loop length of the knitted fabrics irrespective of the combination of variables;
2. The predicted number of peaks and the average values of the cam force profile were same as found in the experimental values. But there were some deviations in the nature of trend of rise and fall between the predicted and measured cam forces. The causes of such deviation were investigated and found that the probable causes may be – (a) frictional force of cast-off loop, (b) wear and tear of the used stitch cam surface, etc. which could not be incorporated in the model;
3. The peak yarn tension inside knitting zone may be about 8-10 times of yarn input tension;
4. Robbing Back also occurs in double jersey knitting, and that too in two phases, but the extent (10 to 15%) is lesser than single jersey knitting;
5. For the same stitch cam setting and other variables, loop length is higher in case of synchronized timing, whereas the cam force is higher in case of delayed timing;



6. Number of variables is more in double jersey knitting than single jersey knitting in order to control loop length as well as to engineer knitted fabric;
7. Both loop length and yarn tension are influenced by the yarn composition and properties like — fibre, twist, coefficient of friction, elongation, bending rigidity etc;
8. Loop length and yarn tension also depend on — delay timing, machine gauge, vertical and horizontal gaps between two beds, stitch cam angle and settings etc;
9. Such understanding is essential for optimizing input parameters for desired output and redesigning the machine parts in order to achieve higher productivity as well as to produce a knitted fabric with a pre-determined loop length;
10. Thus, the length of loop decided and the yarn tension developed inside KZ are the two crucial parameters to be considered in studying the mechanics of the loop forming system.

#### **OUTPUT OF UNDERSTANDING OF KNITTING SCIENCE {DEVELOPMENTS IN TERMS OF MACHINE, PROCESS AND PRODUCTS}**

- ❖ Better quality product;
- ❖ Higher rate of production at higher speed/working width;
- ❖ Optimization of input parameters of yarn (Fibre), machine and process for desired output;
- ❖ Product diversification for speciality products including human body parts;
- ❖ Redesigning of machine parts in order to reduce industrial hazards;
- ❖ Newer type of knitting machines with automation and more control on machine;
- ❖ Seamless garments;
- ❖ Scopes of using electronic devices including CAD & CAM;
- ❖ Protection of environment (lower carbon foot print).

#### **JOURNEY TOWARDS VALUE-ADDITION AND INNOVATION IN KNITTING**

- ❖ Knitting out of many techniques of fabric manufacture has the maximum potential for producing value-added innovative fabrics and products suitable for technical applications and fashion garments.
- ❖ With the advent of science and technology in one hand and remarkable change in our lifestyle due to multi-disciplinary approach on the other, scenario of knitting (machine, process & products) has passed through significant changes.
- ❖ Very sophisticated knitting machines are now available.
- ❖ In fact, the production of value-added innovative fabrics for ever changing fashion, fully fashioned (shaped) garments, spacer fabrics and various technical fabrics including medical textiles are the results of exploration of knitting science only.

#### **FASHION GARMENTS AND TECHNICAL TEXTILES**

- ❖ Knitting is no more confined in the production of traditional inner and outer wears.
- ❖ With the dramatic developments in science and technology including medical branch in the last fifty years our lifestyle has been changed.
- ❖ To fulfill the diversified requirements of textiles in today's context, knitting technology has been playing a key role in the production of fashion particularly shaped (seamless) garments where comfort is the main criteria in addition to its aesthetic appearances in one hand and technical textiles (swimwear, spacer fabric, medical textiles etc.) on the other where functional properties of the products are the prime requirements.
- ❖ The engineering of fabric for specific end uses is now the buzz word to the fabric manufacturers.
- ❖ Out of all techniques of fabric manufactures, knitting has the highest scope for fabric engineering with the understanding of knitting science on account of its following advantages/features.

#### **TYPES OF MACHINES USED IN THE PRODUCTION OF INNOVATIVE PRODUCTS**

1. Flatbed weft knitting : Single jersey and double jersey
2. Circular weft knitting : Single jersey and double jersey
3. Warp knitting : Tricot and Raschel (single and double needle bar)



Figure 2 Knitted innovative technical textiles

## CONCLUSION

Thereafter, the understanding of science aspects of knitting including mechanics along with developments in other branches of science/engineering and technology, the knitting technology has flourished beyond our imagination. Knitting is no more confined in the production of traditional inner and outer wears, but can produce any product as per requirement, which are not possible in other fabric manufacturing technology.

So, Knitting is a unique technology in the sense that it is more versatile than other techniques of fabric formation including weaving. Knitting can produce shaped and seamless garments as well various types of technical textiles including artificial human body parts for improving lifestyle (**Figure 2**). Knitting is aneco-friendly process due to lower power consumption, heat & noise generation, minimum wastage of raw material etc. Above all, due to incorporation of various electronic control devices, artificial intelligence and IoT, knitting technology has achieved Industry 4.0 status.

## REFERENCES

1. F T Peirce, Geometrical Principles Applicable Designs of Functional Fabrics, Textile Research Journal, 17, 1947, pp 123-147
2. D L Munden, The Geometry and Dimensional Properties of Plain Fabrics, Journal of Textile Institute, 50, 1959, pp T448-571.
3. J J Knapton and D L Munden, A Study of the Mechanism of the Loop Formation on Weft Knitting Machinery, Part I: The Effect of Input Tension and Cam Setting on Loop Formation, Textile Research Journal, 36, 1966, pp1072-1080.
4. G R Wray and N D Burn, Transducers for the Precision Measurement of Weft Knitting Forces, Part I to III, Journal of Textile Institute, 67, 1976, pp 113-128 & 189-209.
5. S Ghosh and P K Banerjee, Mechanics of the Single Jersey Weft Knitting Process, Textile Research Journal, 60, 1990, pp 203-211.
6. S C Ray and P K Banerjee, Mechanics of 1×1 Rib Loop Formation on a Dial and Cylinder Machine: Part I: Modeling of 1×1 Rib Loop Formation, Indian Journal of Fibre and Textile Research, 28, 2003, pp 185-196.
7. S C Ray and P K Banerjee, Mechanics of 1×1 Rib Loop Formation on a Dial and Cylinder Machine: Part III: Validation of the Model, Indian Journal of Fibre and Textile Research, 28, 2003, pp 246-259.
8. S C Ray, Fundamentals and Advances in Knitting Technology, Woodhead Publishing UK and India Pvt. Ltd., 2011.

**INTERDISCIPLINARYP**





# Role of Engineers in Creating a New India

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**Abstract:** This paper briefly discusses the national developmental goals for achieving self-reliance derived from the 17 Sustainable Development Goals (formulated by the United Nations in 2016). It discusses how these goals could be achieved and the important role played by engineers to ensure a sustainable future.

**Keywords:** Development Goals; Engineers' Role; Manufacturing

## INTRODUCTION

India is the second most populous country in the world with a population of about 1.4 billion in 2022. The poverty rate in India is estimated to be 10.2% based on consumption per capita cut off line of \$1.9/day, according to a World Bank Report of April 2022. The development of India that began in 1950 when India became a republic has a long way to go before India could be considered to be a self-reliant developed country. In achieving this goal, engineers have an important role to play as much depends upon India's domestic industry.

## SUSTAINABLE DEVELOPMENT GOALS ADOPTED BY UNITED NATIONS

In 2015, the United Nations adopted 17 sustainable development goals (SDGs) that came into effect on 1 January 2016. These are listed in **Annexure**. These goals are also relevant to the growth story of India. Prime Minister Narendra Modi has succinctly summarised these while formulating the mantra "sab ke saath, sab ka vikas ...". Out of 17 SDGs, engineers have a direct role to play in working towards and achieving 12 of these SDGs.

## IMPORTANT NATIONAL GOALS

The following are the important goals from the national perspective:

- to develop and maintain human settlements, viz. public, and private buildings, roads, railways, bridges, tunnels etc. for intra-city and intercity transportation, water supply and underground sewerage, solid waste disposal systems, power and other forms of energy supply in urban and rural areas;
- to develop infrastructure including buildings to cater to education, health, banking, food distribution and other needs of the population;
- to develop airports, sea ports and container terminals to meet needs of international trade and travel;
- to meet the needs of society: food, shelter, health, education, employment, social security and other needs;
- to ensure inclusive growth and reduce inequality in educational opportunities and distribution of resources;
- to build, operate and maintain factories for production of goods needed by the population and for defence;
- to equip and train defence forces.

Engineers have an important role to play in the achievement of the above goals by engaging in manufacture of high quality goods required by citizens as well as for defence of the country so that the country becomes self-reliant.

## ROLE OF SCIENCE AND MATHEMATICS

Since the dawn of civilisation human being have been curious about natural objects and natural phenomena. Some of these persons, after detailed study and contemplation understood some aspects of nature and formulated theories about them. Some of these "scientists" went further and developed new materials and processes. Many engineering marvels of today had their beginning in the work of scientists. But their work was limited in their scope and was confined to the "laboratory".

## ENGINEERING

As a natural extension of the work of scientists, engineers and technologists devised methods to make new materials and



products on a scale that would be useful to man. Engineering is all about giving a practical shape to discoveries and inventions made by scientists. Some engineers and technologists went further to make new products that were not found in nature and devised ways to use them by giving them different shapes.

### **Engineering in the Ancient World**

Sun-dried mud bricks were made in the Middle East in 7500 BCE and fired bricks were made in China around 4400 BCE. The Egyptians were the first to invent mortar using the material gypsum as a base. The Romans later developed the concept further, using a mixture of lime, water and sand which is the process still used today. The ancient city of Pompeii was built using bricks and mortar

Engineering, even in ancient times, was not limited to building. Archimedes of Syracuse (287-212 BCE), a Greek mathematician, physicist, engineer, astronomer and inventor from the ancient city of Syracuse in Sicily is also credited with designing innovative machines such as his screw pump, compound pulleys and defensive war machines to protect his native Syracuse from invasion.

The modern world today is essentially the creation of engineers, architects and town planners supported by politicians and bankers.

Engineers study the properties of natural and man-made materials and how to use them to construct and/or fabricate useful innovative products. Engineers have been quick to adopt developments in Science and Mathematics and turn new knowledge into products and services needed by society. Engineering has made a steady progress and developments have taken place in various spheres. It is no longer limited to Civil, Mechanical, Electrical engineering. New disciplines such as Electronics and Telecommunication engineering, aeronautical engineering, agricultural engineering, robotics, mechatronics, biotechnology etc. have come up and have applications in the fields of surveying, molecular biology, orthopaedics, dentistry, cardiology, life sciences and so forth. Although there is an urban-rural divide, modern products have penetrated rural areas. In modern medicine also, medical test equipment devised by engineers are used extensively. In modern warfare, small and heavy weapons devised by engineers are used. The war between Russia and Ukraine that is currently in progress amply demonstrates how advanced weaponry can keep even a major power like Russia at bay.

If a country has to reduce poverty amongst its citizens (SDG -1), it should invest in construction and manufacturing industries. These industries provide good employment opportunities for labour. These activities will increase the gross national product. Surplus manufactured products may be exported to earn foreign exchange. Before embarking on a large manufacturing project, it would be desirable to carry out market surveys to ascertain if there is a market for products manufactured.

Before setting up a factory, it would be prudent to carry out a market survey to determine the extent of demand for the product proposed to be manufactured and existing competition. This task has to be carried out by agencies that have specialised in market research.

### **Detailed Project Report**

The next step is to select the products to be manufactured and get a detailed project report [DPR] to be prepared. The report should contain details of the following:

- (a) Land with adequate water, power and logistic support for setting up a factory should be made available.
- (b) The DPR should examine alternative designs and manufacturing processes available, supply chain for inputs, human resources required and financial plan.
- (c) The layout of the factory should be prepared and machinery for manufacturing and materials handling equipment should be identified.
- (d) Manuals should be prepared for operation and maintenance of machines before undertaking training of personnel.
- (e) Human resources department should carefully select the persons ensuring that selected personnel have the necessary qualifications and skill sets and can be trained to install, operate and maintain the manufacturing plant and control other manufacturing operations.
- (f) If any materials required for use in the manufacturing process are to be outsourced, it has to be ensured by meticulous planning that the supply chain is reliable. Any disruption in the supply chain will adversely affect manufacturing output and affect the bottom line.
- (g) Requirement of working capital has to be planned and adequate cash flow should be organised by tying up with banks.



- (h) Setting up a manufacturing plant today, particularly if they have to comply with Industry-4 norms, is a complex process and requires specialised knowledge. To compete with manufacturers from developed countries, the plant has to be modern and comply with international standards. If quality products are not produced, customers may look to other suppliers and the factory may run into financial difficulties. It may even face closure.
- (i) The market for many products is volatile and designs have to be frequently updated to make improvements in products and thwart competition. Manufacture of some products or models may have to be given up all together. Factories may require retooling existing machines or installation of new machines. As it is expensive to install new machines every few years, it may be a good idea to set up smart factories with flexible manufacturing systems so that the factory could be used to manufacture a wide range of products. Personnel may also have to be retrained for making new products. If these are not done, the factory may go out of business sooner than later.

### **INDIA'S MAKE IN INDIA INITIATIVE**

When the government at the centre announced the "Make in India" initiative, about 8 years ago, it created the impression that Indian Engineers would get a chance to work in the industry as designers, innovators and builders of new factories making India a manufacturing power house that could compete with China. But the Government of India had other ideas. They invited foreign manufactures to invest in India and set up factories and other facilities in India in sharp contrast to what the Chinese are doing. Probably, the government did not have enough confidence in the capability of Indian engineers and businessmen!

### **ENERGY REQUIREMENTS**

For thousands of years man used gravity, manual labour and animal power to perform various tasks such as agricultural operations, transportation, water supply, domestic chores and so on. But with these sources of power, productivity was low. During the first industrial revolution, external and internal combustion engines were used as power sources for driving various machines. These machines used fossil fuels that were abundant. But towards the end of the 20th century, it was realised that there was a downside to the use of fossil fuels as a source of energy. Burning fossil fuels also caused climate change and consequent environmental damage on a global scale.

### **PETROLEUM PRODUCTS**

India is the third largest consumer of petroleum products in the world worth about US\$ 152 Billion and imports it from various countries including Russia, Saudi Arabia and Iraq. Petroleum is an important source of energy for the transportation sector. Burning fossil fuels including petroleum products has an adverse impact on the environment. Availability and price of oil also depends upon geo-political factors such as war. Considering all these factors, using fossil fuels cannot be sustained over the long run. India has to diversify into using renewal sources of energy. In order to support manufacture of goods a lot of power is needed.

### **SOLAR ENERGY**

India is blessed with a good amount of sunlight because of its geographical location. To harvest solar energy that is abundant, India has taken the initiative to establish the International Solar Alliance as a founder member. It has solar installed capacity was 60.813 GWAC as of 30 September 2022[3]. Solar power generation in India ranks fourth globally in 2021. During April 2019 to March 2020, 50.131 GWh of electricity were generated. This is going to increase further and is a step in the right direction.

### **NUCLEAR ENERGY**

The other alternative available to meet its energy needs is nuclear energy. India already has 8 nuclear power plants with a total installed capacity of 7.38 GW.

### **Defence Production**

In modern warfare sophisticated weapons are used. For India to be self-reliant, it has to design and manufacture advanced weapon systems in India in sufficient quantities within a short time frame. India has been relying for a very long time on armaments imported from Russia and more recently from the west. This situation has to change. New technologies such as drones have been effectively used in the recent war in Ukraine. India should also produce such weapons. India must provide sufficient funding to universities and private companies to design and develop fighter jets, destroyers, tanks and other weapon systems. This is a continuing process, so that our weapons could match the best in the world.



## **AGRICULTURAL AND CHEMICAL ENGINEERING**

India is more or less self-sufficient in its requirement of food, except perhaps in items such as cooking oil. But to feed our ever-increasing population we have to increase food production by undertaking major and minor irrigation projects, build factories for production of fertilizers and make machines to help the farmer in his farming operations. Engineers have an important role to play in all these areas.

## **MEDICAL EQUIPMENT**

Hospitals also need many engineering products such as syringes, beds, X-Ray, Ultrasound, CAT and MRI scanning equipment, equipment for use in operating theatres instruments for use in dentistry and so on. These should be manufactured and distributed on a large scale so that the cost of medical treatment is brought down to the level at which the common man could afford it.

## **USE OF INFORMATION TECHNOLOGY IN EDUCATION AND TRAINING**

In order to cope with the increasing number of students wanting admission to various courses, we have to use Information and communication technologies to prepare and disseminate educational materials as well as video lectures delivered by experts. Examinations may also be conducted online. The government's initiative in starting the Swayam programme available through the Internet and DTH television is commendable.

## **CHANGES IN LIFESTYLE**

There was a time in India, when life style was simple. Bicycles were used by most people. But at present motorised transport is very common and users of bicycles are rare. This has resulted in a sharp increase in the import of petroleum products. Luxury cars which consume a large amount of fuel are imported resulting in greater outflow of foreign exchange. A large amount of gold is also imported into the country. People are encouraged to undertake pilgrimages and attend melas. These activities also consume fuel and other resources that could better used for other productive activities.

## **GOVERNMENT POLICY ON POPULATION**

The phenomenal increase in population of India has resulted in greater demand for housing, water supply, power, food, transportation etc. While the support of the government to "soshit, vanchit, peedit" (exploited, deprived and oppressed classes) is laudable, there should be policy of not allowing their numbers to increase. Only those who can support their progeny and give them a better life should be allowed to have children. Although this may appear to be a drastic step, these are necessary if India has to develop into a vibrant economy. Engineers by themselves cannot achieve the goals, unless the government also re-engineers its policies.

## **EDUCATIONAL POLICY**

India has a large number of engineering colleges, but some studies have shown that the quality of education is not uniform. It is necessary to revamp the syllabus and improve the quality of education so that graduate engineers can make a significant contribution towards the achievement of SDGs.

## **CONCLUSION**

As India is still a developing country and has to achieve SDGs formulated by the United Nations. Indian engineers can achieve these goals to make India a developed country by 2030. India could become a manufacturing power house and not depend upon foreign collaboration and investment in various sectors of the economy.

## **ANNEXURE**

### **Sustainable Development Goals**

The new Goals and targets will come into effect on 1 January 2016 and will guide the decisions we take over the next fifteen years. The particular goals in achieving which engineers have a role to play have been italicised.

- Goal 1. End poverty in all its forms everywhere;
- Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture;
- Goal 3. Ensure healthy lives and promote well-being for all at all ages;
- Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all;
- Goal 5. Achieve gender equality and empower all women and girls;
- Goal 6. Ensure availability and sustainable management of water and sanitation for all;



- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all;
- Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all;
- Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation;
- Goal 10. Reduce inequality within and among countries;
- Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
- Goal 12. Ensure sustainable consumption and production patterns;
- Goal 13. Take urgent action to combat climate change and its impacts\*;
- Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development;
- Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss;
- Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels;
- Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development.

#### REFERENCES

1. Sutirtha Sinha Roy and Roy Van Der Weide, Poverty in India Has Declined Over the Last Decade but not as much as Previously Thought, World Bank Policy Research Paper 9994, April 2022.
2. Transforming Our World: the 2030 Agenda for Sustainable Development, <https://sdgs.un.org/2030agenda>.
3. Owlcation.com.
4. Wikipaedia.
5. Wikipaedia.





# Role of Engineers for Creating a Sustainable and Self Reliant India

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Article# 01: Relevance of Science Engineering and Technology to Civilization / Nation / Society

Observation of nature and its dynamics leads to Science, application of Science is Engineering and enhancement of Engineering is Technology. When a rarest of rare, human intellect is able to add distinct value to Technology, then it becomes an Innovation (completely transforms civilization as a whole).

Invention of Integrated Circuit (Microchip) Led to Microprocessors, Miniaturization and Paved the Way for Industry 3.0/4.0

Engineering is the only discipline of human civilization, which is completely nature based and thus Sustainable. It is the only discipline which is Universal (Laws of Gravity / Laws of Planetary Motion are the same without time/ space limitations).

Even without Farming, animals are fed by the process of photosynthesis. Engineering is required to manage water resources for crops, manufacturing of Pesticides / Manures, Mechanisation (Tools, Equipment, Transportation, Harvesting, Storage)

Animals don't take vaccine, don't take medicine and are sustained just by natural immunity.

Engineering is largely required for development of Hospital Infrastructures, Diagnostic Equipment (X-Ray, Computer Tomography, Nuclear Magnetic Imaging).

Pharma Industry and Major portion of Healthcare is also Engineering

Bioinformatics (Bio-Technology with Information Technology and its applications — Culture of Biological Virus in conventional Laboratories and subsequent arrival of right vaccine conventionally takes 2 years. The same can be done using Bioinformatics in 2 weeks with improved accuracy / reliability at a fraction of cost and at zero risk).

Education largely needs Infrastructure, which all can be provided only by Engineering.

Defence sector is also largely dependent on Engineering.

Other disciplines including economy, insurance, banking need Engineering.

Therefore, the only discipline that sustains human civilization directly (all forms of mechanized transport, buildings, power, comforts like, ac, lift, mass communication), indirectly (all other disciplines) and is coherent with nature (Ecosystem, Environment, Cosmos) Engineering thus ensures sustainability all means.

Universally, invariably, unquestionably, undoubtedly, it is by instinct / values / virtues, that Engineering is the only, discipline and only Engineers can Ensure / Create a Sustainable Self-reliant civilization (India).

Article #2: **Inspirational / Motivational Fellow Humans / Institutions**

(i) Sainik School, Amaravathinagar — the school, the author of this article K Manikandan got educated, was conceptualized by the then Defence Minister of India, Sri Krishnan Menon to impart Highest ethics, morals, values, leadership qualities, comradeship, friendship, unity in diversity, perpetual competitive spirits, die hard patriotism, in addition to CBSE education, so that the Cadets become Officers in the Indian Armed Forces .

Each Day, every school activity reminds the cadet — you are imparted complete training to achieve anything that your brain can conceive and when it so demands, you be ready to sacrifice your life for India.

(ii) The Thiagarajar College of Engineering, Madurai. The author graduated from this Institution, whose alumni have contributed distinctly, immensely to India's Space Programs, Missile Systems, many critical Technologies, and lead many Research / Education Institutions.



(Notably Nambi Narayanan who worked on liquid / cryogenic fuel system for satellite launch vehicles, Sivathanupillai, MD BrahMos Missile System, which is cruise type and uniquely with manoeuvrable trajectory.

- iii. Dr Kalam and his Indian vision 2020– Blueprint / Document for optimised development of India / welfare of Indians.
- iv. A Better India A Better World by Infosys founder N R Narayanamurthy, an analytical report for Technology-based Development of India
- v. Madurai, the native place and Tamil, the mother tongue of the author:

The archaeological survey of India has Scientifically established that Keeladi excavations have so far, confirmed that the civilization dates back to 6th Century BC and Madurai is one of the very few cities in the world to have continuous civilization for more than two and half Millennium. Lord Shiva is recorded to have performed 64 divine dramas at Madurai and even today related rituals are practiced.

Madurai, the abode of Sri Meenakshi Amman, has rich culture, traditional values and the name is derived to mean Divine nectar. Thousands of years ago, the city has been planned in square shape with all infrastructure intact.

The Tamil language is phonetic and more than 3000 years old. Grammar for Tamil language was formed 2700 years ago. Kaniyan Poongundranar declared 2600 years ago, Yaadhum Oorey Yaavarum Kelir, meaning all humans are my brethren and I belong to all places. Thirukural, compilation of similarly composed 1330 short couplets, with 7 words, each covering all aspects of human civilization– applicable universally, and relevant without time barriers. Father of our nation, Mahatma Gandhi is said to have learned Ahimsa from Leo Tolstoy who himself referred Thirukural, for his Ideologies.

Tamil Poet Bharathi, has composed a song to mean, we have to adopt / bring artistic values from all over the world. By that logic we adopt Technology / Expertise from all times / all places and use them to benefit India, Indians.

vi. Arvind Eye Care System, was started in a humble way in 1976 by Army Ophthalmic veteran Dr. Venkitaswamy at Madurai. It has grown into one of the largest eye care systems in the world (both qualitatively, quantitatively adopting unique philosophy - all patients get equal world class treatment - at zero cost for poor, affordable cost for middle class and the rich willing pay to compensate the poor.

vii. Delhi Metro Rail Corporation - Covering 350 Kms in 20 directions (10 lines),executed in 3 phases within 2 decades is successful in all 4 fronts - most competent Technology, all Environment / safety issues followed during construction, best affordable service to people and ensuring financial viability at the same time.

viii. General Sir Arthur Cotton - defying many challenges including impeachments in British Parliament, he transformed perpetual floods of Godavari, Krishna River Basins into rice bowl of India by designing /implementing Canals, Dams, Hydraulic structures. Many of his unfulfilled in land navigation in Peninsular India are worth taking up for execution and relevant even today.

ix. Alfred Nobel - highest awards, mostly for contributions to human civilization, mostly Engineering discoveries for more than 120 years through estate formed out of his lifetime savings. Most of the transformations of human civilization during 20th,21stCenturies can be attributed to him.

x. CERN– conseil Europeen pour la Recherche Nucleaire- world’s premier Research Institution in Fundamental Physics Research and its, findings need to be replicated and would be useful in finding solutions to certain issue of human civilization.

xi. NASA – pioneers in Aerospace, Aeronautics, Space Administration, Cryogenic fuels for satellite launch vehicles, reusable space shuttles, successful launches of voyagers that have completed their design mission and left the solar system.

xii. MIT - Massachusetts Institute of Technology, MIT contributes significantly for sustaining the Super power status of the United States of America - in Technology, Defence, Economy for more than a Century consistently. MIT has also 98 Nobel recognitions in core fields of human development. Indian Institutes of Technology, IITs conceptualised from MIT , to develop India by Technology have Zero Nobel recognition in 7 decades and contributions of cream IIT ians to India's development remains to be answered.

Article #3:Affiliation of the author with the Institution of Engineers(India):

On 15 & 16 October 2017, Manikandan represented, National Waterways Development Technology, NAWAD TECH,



and presented a Technical Paper on Inland Navigation with 9 m draft assured by National Smart Waterways Project at the National Convention on Inland Waterways organised by IE(I), Kolkata and held at Maritime University, Kolkata. Er Mukherjee at the Headquarters of IE (I), Kolkata received and arranged hospitality and formal procedures relevant.

On 28-08-2021, Manikandan presented his blueprint for finding the most optimized, sustainable solutions of issues of India, by combination of Technology & Expertise, through zoom organised by Tamil Nadu State Centre, IE (I).

Attended zoom meeting organised by IE (I) Telengana, along with Water Board Chiefs of six Metro Cities, to resolve water related issues— floods during monsoons and drought during summers. Did find a viable solution.

During 36th Indian Engineering Congress, “Abhiyanta Bandhu 2021”, released on 26-12-2021, at Vigyan Bhavan, New Delhi, had the Technical article by Manikandan and Thiruchelva, in their native language Tamil.

The article was improved version of the blueprint to find sustainable, optimized solutions to issues of India by Utmost Technology and Human Intelligence.

Article #4: Emotional bonding with Sir M Visvesvaraya: Manikandan had studied about all the contributions of Sir M Visvesvaraya, whose birthday on 15 September is observed as Engineers' day and visited his native / birth place Muddenahalli, near Chikkaballapur, Bangalore.

Also made visit to the Almamater of Sir MV - College of Engineering, Pune, the weirs designed by Sir MV at Khadkvasla Dam, functional even today and the Krishnaraja Sagar Dam across River Kaveri designed by Sir MV.

Article #5: Conferences, Webinar meetings attended to enhance competency.

During May 2013, on behalf of NAWAD TECH, National Seminar on Smart Waterways project was organised at New Delhi.

Presented the Smart Waterways Project to Public Works Department, then at Irrigation Management Training Institute, Tiruchirappalli three times to trainee Engineers. Explained in various forums, including Polytechnics, Engineering Colleges.

Feb 26 - 28, 2020, attended Roorkee Water Conclave held at IIT Roorkee and interacted with global experts on Water Resources Engineering & Management.

During August & September 2020, attended 12 days INSPIRO webinar organised by National Design and Research Forum, NDRF and 5 days webinar on let's fly. Environment, Ocean Resources, Civil Aviation, Defence were the topics covered and discussion were on Aerospace, Navigation Systems Biotechnology, Health, application of Artificial Intelligence, Robotics. Dr Dilli Babu, from Defence Research and Development Organization, Sri. Mayilswamy Annadurai, Chandrayan-1, concluded the last two days of the webinars.

On 5th and 6th August 2022, the author presented Technical Paper on Technology and Expertise-based solutions at the Central University of Kerala, Kasaragod.

Attended 3 days Bangalore Tech Summit, on 16th, 17th & 18th November 2022 and utilized the opportunity to update knowledge / competency on Nano Technology, 6G Communication Technology Biotechnology, Mass Rapid Transits Systems, Aviation and discussed with relevant competent professional / officials.

Article #6: Strengths of India: -

India's diverse culture, tradition, history, civilization are quite known. Warfare Techniques, Water Resources Management (Kallanai Dam built 2000 years ago across River Kaveri Near Tiruchirappalli is still operational). Temple Architecture (In the Sun Temple, Konark, the Sun God's chariot is driven by Seven Horses, implying the Seven Colours of Sunlight - VIBGYOR, Centuries before Spectrometer. Fourteen Gopurams at Srirangam Temple with different Dimensions have centreline in millimetre accuracy. 18 Tons single stone above the Thanjavur Big Temple, aqueducts / bath tanks / sunlight passing into the Gopuram, all at Hampi, seat of Vijayanagara Empire have no parallels. So many testimonials in Agriculture, Textiles, Architecture, Astronomy, Ayurveda, Mathematics, Arts, Crafts, Culture, Heritage, Literature, Metallurgy, Health care, Surgery, Yoga, Education (Takshashila, Nalanda Universities).

India of today: we have a large population with professionals, skilled, semiskilled human resource.

We have 1100-millimetre average annual rain fall and 4000 billion cubic meter of water. India as 7,500 km of coastline, fertile river basins and we lead in many agriculture products including sugarcane, dairy products, forest resources. India



has enough cultivable lands, metals ,mineral resources.

#### Article #7: About the Author

K Manikandan had his Secondary School Education, from Sainik School Amaravathinagar (1976-83) and graduated in civil engineering from the Thiagarajar Collage of Engineering of Madurai (1983-87)

Started his professional carrier as Site Engineer in Small Projects in Tamil Nadu — Combined Water Supply Project along with Tamil Nadu Water Supply and Drainage Board (TWAD), Execution of Highway Projects compying with standards of Ministry of Surface Transport (MOST) and Construction of residential buildings.

Overseas /Multinational Project Execution with Global Standards, Procedures started with 24” 32Km Oil & Gas Pipeline Projects for clients including Petroleum Development Oman, Occidental Petroleum Mukhaizna (USA)

Then returned to India and was involved as full execution in - charge (Senior Project Execution Engineer) for the 1 Million Metric Tons per Annum Sodium-based Uranium Ore Processing Plant, for the Uranium Corporation of India Limited, Pulivendula, Kadapa, Andhra Pradesh. India was restrained under Nuclear Non-Proliferation Treaty to import Uranium when the necessity was critical (India was planning to expand Atomic Power Generation and Development of Indigenous Nuclear Submarines).

Then Manikandan joined Phase XI Projects as Resident Manager at the Indira Gandhi Centre for Atomic Research, Kalpakkam (The Project Scope included constructions of world class Library /Academic Block on Nuclear Science, 14 story Engineering Building, Earthquake resistant Nuclear Reactor after Fukushima catastrophe, Automated Vehicle Surveillance Security Systems for the Central Industrial Security Force).

Demise of the only daughter who succumbed to congenital in test in aldeformity after 2 critical surgeries and 7 years hospitalisation brought Manikandan’s personal life and professional carrier to a standstill. After reasonable break, he took up position as Senior Construction Manager for Larsen and Toubro’s Polyethylene Project at Jubail, Kingdom of Saudi Arabia (part of SADARA -Saudi Aramco’s 32 products from Crude, combined project and at \$ 20 billion - largest infrastructure project ever , in the world )

Since 2015, Manikandan on national interest, associated himself with the National Waterways Development Technology, Madurai under the leadership of Professor A.C. Kamaraj and his Expert Team (Retired Superintending / Chief Engineers from PWD), focused in networking of Indian Rivers concept to resolve all water related issues of India. During his honorary association with the NAWAD TECH team. Manikandan was exposed with working Engineers of PWD, Central Water Commission, River Basins of India, Research/Academic Institutions in water Resources Engineering & Management. In addition, he had global exposure in Effluent Treatment methods , recycling, re use, conservation of water resources.

Finding the necessity of cross disciplinary expertise in resolving any critical issue of our nation, Manikandanre located to Bangalore in the year 2020. After visiting Research/ Academy Institutions in India, Manikandan formed his own organization Chelvamani. (Institutions visited - Indian Institutes of Technology, Indian Institute of Science, Centre for Development of Advanced Computing, National Institute of Construction Management and Research, Central Power and Water Research Station).

Chelvamani is derived from names of Manikandan’s partner for Life / Profession/Career Dr S R Thiruchelve, M Tech, PhD., (Environmental Engineering) and Er K Manikandan.

Chelvamani is registered under clause #42, Intellectual Property Rights (Government of India) to carry out Research/ Innovation in all relevant branches of Engineering / Technology.

#### Article #8: Critical issues of India to be addressed

Ensuring adequate water for all purposes (Drinking, domestic, agriculture purposes, industrial purposes, inland navigation and miscellaneous ).

Affordable, accident free, pollution free, comfortable, convenient, faster public transportation system.

Energy generation to satisfy domestic needs, industrial needs and public utilities by replacing fossil fuel with sustainable renewable green energy system.

Affordable, suitable housing - using environment friendly composite materials, with faster construction methodologies.



Proactive, comprehensive Risk/ Disaster Management System(Natural / Manmade).

Environment enhancement and control of all kinds of pollutions, waste disposal, recycle reuse conservation of resources, protection of eco system .

Bridging the gap in Space Research, Civil Aviation, Aeronautics, Indigenous Defence Capabilities.

Providing world class infrastructure for enhanced Education, Healthcare, Research and Development scope in all domains of expertise with Globe Competency.

Industrial growth, economic development and employment generation for all.

Article #9: Only Engineers can Create a Self-relevant and Sustainable India

Only Engineering has all the curriculum in coherence with all forms of nature and its dynamics. Morals, ethics, leadership qualities, analytical / reasoning capabilities, societal/national/ human values and essential ingredients for a complete human are only with Engineers.

By design, by instinct, by default, it is only engineers who define/ ensure / sustain / lead civilization with due regards to all forms of nature- Ecosystem, Environment, Cosmos.

All forms of infrastructure are directly engineering based -houses, community and commercial structures, transportation on / under land on /undersea, air , space, generation of electricity, communication systems, industries, water supply, treatment and recycle of waste, all forms of additional comfort like air conditioners, lifts, entertainment, games and sports, visual effects, imagery and luxurious necessities are completely Engineering based.

All other domains - economy, health care, education, civil administration, defence, internal security, enforcement, agriculture, law and order largely depend on Engineering.

Self-reliance is ensured when we need not depend on external resources and we comply with nature's designs.

India has enough resources of all kinds (natural / human) and by adopting comprehensive, fool proof resource management systems, India can very well be self-reliant in all domains.

Sustainability is ensured by factoring dynamic issues like quantum of resources, time, demography, nature and its dynamics, global changes.

Issue: 1

Water is the most essential substance for sustenance of life/ life systems in addition to ensuring civilization. India has annual availability of 4000 Billion Cubic Meters, from all sources. By adopting the best and optimum, sustainable water resource management systems, we can fulfill all water needs of India (complete analysis of hydrological cycle – mountain hydrology including glacial dynamics, glacial lake outburst floods, landslide lake out burst floods, hydro geology including geotechnical engineering, aquifers(confined and unconfined), aquicludes, aquitards, seismic studies, ground water resource management by making use of contour canals which will act both as storage and for transmission of water, then atmospheric hydrology).

Hydroinformatics (Hydrology + Information Technology) can be used design irrigation projects in very short time with very high accuracy. Isotope Hydrology can be applied relevantly both in quality assurance and quantity management.

Simulation, modelling, imagery can be used to evaluate projects with no loss before actual execution of projects. Big data can network all the hydrological data centres of India for effective and faster management. Technologies including Artificial Intelligence, Robotics, Machine Learning, 3D Printing, Dedicated Satellite, drones, remote sensing Technique, advance flood warning system can be utilized relevantly.

Sir General Arthur Cotton, probably the one who has the most credit for knowledge and application of water resources of India declared, "India has enough water for all its conceivable purposes — ten times over". He proposed many inland navigation canal systems, which are relevant and applicable even today.

Best technologies are available for quality assurance— water quality treatment, recycle, reuse and conservation.

Issue: 2

Food , Nutrition, Preventive Health Care : Geographical Information Systems, Land Use, Bigdata, Digital Surveys,



Satellite Imagery, Crop Rotation, effective Water Resources Management and ensuring fertility and water availability for fallow land, India with 3.3 million Sq. km. area, can be ensured of nutritious and healthy food all times.

Issue: 3

Public Transport Systems : Automated Vehicle Network System will reduce accident to zero. Green hydrogen, electric power vehicles will reduce pollution to zero.

Technologies like computational fluid dynamics, parallel reality, passenger digital identity, block chain technology can ensure most comfort in all forms of mechanized mobility on land, sea, air, space.

Issue: 4

Affordable housing and faster constructions: Composite materials, glass fibre reinforced gypsum, bamboos, plastic waste admixture added floor tiles and construction blocks to be largely used and building methodologies like Building Information Modelling, 3D Printing can ensure cheap houses for all.

Issue: 5

Green hydrogen from biomass has been developed at Indian Institute of Science, Bangalore. Nuclear fusion technology is nearing feasible stage and it is also possible to generate electricity in space and transmit to earth wireless.

Issue: 6

Core/Critical Technologies that will optimise human civilization in all domains : This is saturation level of development possible by man: Industry 5.0:

- Quantum computing
- Nano Technology
- Black Holes, Dark Energy and origin of universe.
- Ocean resources management.

# Engineering Education in Vernacular Language – Key to Sustainable Self-Reliance for India

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**Abstract:** India's technological and scientific heritage is evidenced by several ancient engineering marvels. This exceptional inherent potential of India's scientific thoughts and engineering excellence need to be rekindled for sustenance and self-reliance.

In the pre-independence era, colonial ruler established industries to suit their needs. Some of those industries were of Industry 1.0 age. Post-independence, India set up some industries but all with foreign origin machines and technologies. Such industries were of Industry 2.0 age. At present India is going to embrace Industry 5.0. Brain drain deprived India from the merit of a sizeable portion of pass-outs from these institutions. Since independence, in 75 years industry standard jumped from 2.0 to 5.0 but skill level is limping hard to catch. From the language learning to engineering education to get adopted to fast changing technology – everything is foreign. Parallel to the industry, society has also changed from Society 1.0 to 4.0 with Society 5.0 knocking at the door.

Incremental Industry age along with inability to meet pollution control measures has caused closure of several industries resulting in blockade of a substantial amount of capital; a large amount of assets are rotting; vast land is lying unutilized. All round sincere and truthful effort for sustenance and self-reliance is the need of the hour.

The heritage of engineering marvel culminated with updated knowledge base need to be used to formulate Appropriate Technology specific to India. Top-down and Bottom-up approaches shall ensure presence of 'Appropriate' at all levels starting with Engineering Education, Application and Adaptation emphasising life-quality instead of growth-oriented life-standard. Sustenance is a practical aspect and therefore outcome based. Engineering education for sustainable self-reliance should enable easy grasp, critical and systematic thinking and bring creativity amongst the learners. Imparting engineering education in understandable vernacular is essential for assimilation and suitable application of knowledge. Syllabus based course learning is exemplified by certificates but translating the learning towards fulfilment of real-time society's requirements in real term needs competence. Knowledge, Skillset and Aptitude for application shall constitute cognitive domain of competence. All engineering products are result of convergence of technologies so transdisciplinary knowledge is essential. Pedagogy with vernacular needs to be implemented gradually. India has considerable numbers of retired engineers; this bank of accumulated knowledge needs to be utilized in conjunction with stakeholders to ascertain industry and society requirements. Existing engineering education content needs modification and practical application oriented with emphasis on skill development. Engineering colleges should produce engineers who are ready to accept challenges and deliver results – if required, a longer than normal period of induction training may be given to make the candidate suitable for the specific industry. Gradual but steady change in curriculum and pedagogy is the imperative.

**Keywords:** Industry; Society; Engineering Education; Vernacular; Appropriate Technology; Sustainable Self-Reliance

## ABBREVIATIONS

AICTE	All India Council for Technical Education
BOSS	Bharat Operating System Solutions
GUI	Graphic User Interface
HMI	Human Machine Interface
HRD	Human Resource Development
IoT	Internet of Things
MOOC	Massive Open Online Course
NEP	National Education Policy



NME-ICT National Mission on Education through Information Communication Technology  
OS Operating System

## INTRODUCTION

Monolithic rock cut temple at Ellora, Qutub Minar – the non-rusted iron pillar standing straight as it is for centuries, stepped wells along with serene statues and aesthetic sculptures as an ingenious way of solving the perennial water shortage by alloying philosophical and spiritual thoughts are the ample proof of ancient engineering marvels of India. These heritage engineering works speak for extraordinary scientific knowledge, culture and thinking and capacity to translate those thinking in real terms for the long-time benefit of citizens, without hampering the ecological balance. Thinking involves words or rather it is impossible to think and reason without words, i.e., language. Engineering is application of science by using scientific principles. Therefore, Engineering involves ability to think, learn and reason, enabling capacity development for knowledge and understanding. Language is the basic of Engineering and Technology. India possessed her own Engineering languages which had been uprooted giving room to foreign language. Operation and maintenance, of high-capacity foreign origin complicated designed mining machineries produced through convergence of technologies, at remote places or in underground mines shows inheritance of engineering aptitudes by native Indians. This inherited engineering excellence need to be rekindled through the native language.

## BRIEF HISTORY OF ELIMINATION OF INDIAN LANGUAGE FROM HIGHER EDUCATION

The school system in India prioritising English as the medium of education was brought by Lord Thomas Babington Macaulay in the year 1835 through a document famously known as ‘Minute by the Hon'ble T. B. Macaulay, dated the 2nd February 1835’. Few lines from this Minute are quoted below:

“It seems to be admitted on all sides, that the intellectual improvement of those classes of the people who have the means of pursuing higher studies can at present be affected only by means of some language not vernacular amongst them.” [1]

The system of Gurukul was shown the path of extinction and some sort of so-called organized education system came into being.

75 years after independence, ‘Self Reliance’ has been a talking point in India. Arousal of this awareness itself indicates desire to change from the prevailing subservient linguistic environment in India’s education system. Sustainability is today’s buzzword in whole of the world; understandably technology oriented present-day civilization has threatened the very existence of humanity. While technologically advanced countries are facing only the ‘sustenance’ problem, India is required to tackle sustainability as well as becoming ‘Self-Reliant’. The shining edge is that, for India ‘Self-Reliance’ shall automatically endow ‘Sustainability’ and therefore should not be viewed as separate and should not be treated in isolation. About 115 years ago, Sri Aurobindo had visualised impact of intellectual subordination to foreign culture on the future of India. His such thought was:

“Two oriental nations have come powerfully under the influence of western ideas and felt the impact of European civilization during the nineteenth century, India and Japan. The results have been very different. The smaller nation has become one of the mightiest powers in the modern world, the larger in spite of greater potential strength, a more original culture, a more ancient and splendid past and a far higher mission in the world, remains a weak, distracted, subject and famine-stricken people, politically, economically, morally and intellectually dependent on the foreigner and unable to realise its great possibilities. It is commonly said that this is because Japan has assimilated Western Science and organization and even in many respects excelled its teachers; India has failed in this all-important task of assimilation. If we go a step further back and insist on asking why this is so, we shall be told it is because Japan has “reformed” herself and got rid of ideas and institutions unsuited to modern times; while India clings obstinately to so much that is outworn and effete.”

## PRESENT SCENARIO

Time changes everything. Industry, Society and Human Generation — all are changing. Apart from historical wars and colonial rule, India is also required to deal with the accumulated problem arising from different combinations of Industry, Society and Generations as shown in the **Figure 1** given here.

India is having all the versions of Industry from bullock cart to 5g mobile network, all the versions of Society up to Society 4.0, all the generations defined by birth cohort boundaries as mentioned in the **Figure 1**. Society 5.0 is coming up in the form of Smart Cities. In addition to above varieties, India is having remarkable demographic variations, necessitating inclusivity. Engineering and Technology spans beyond geographical boundaries and not limited by time.

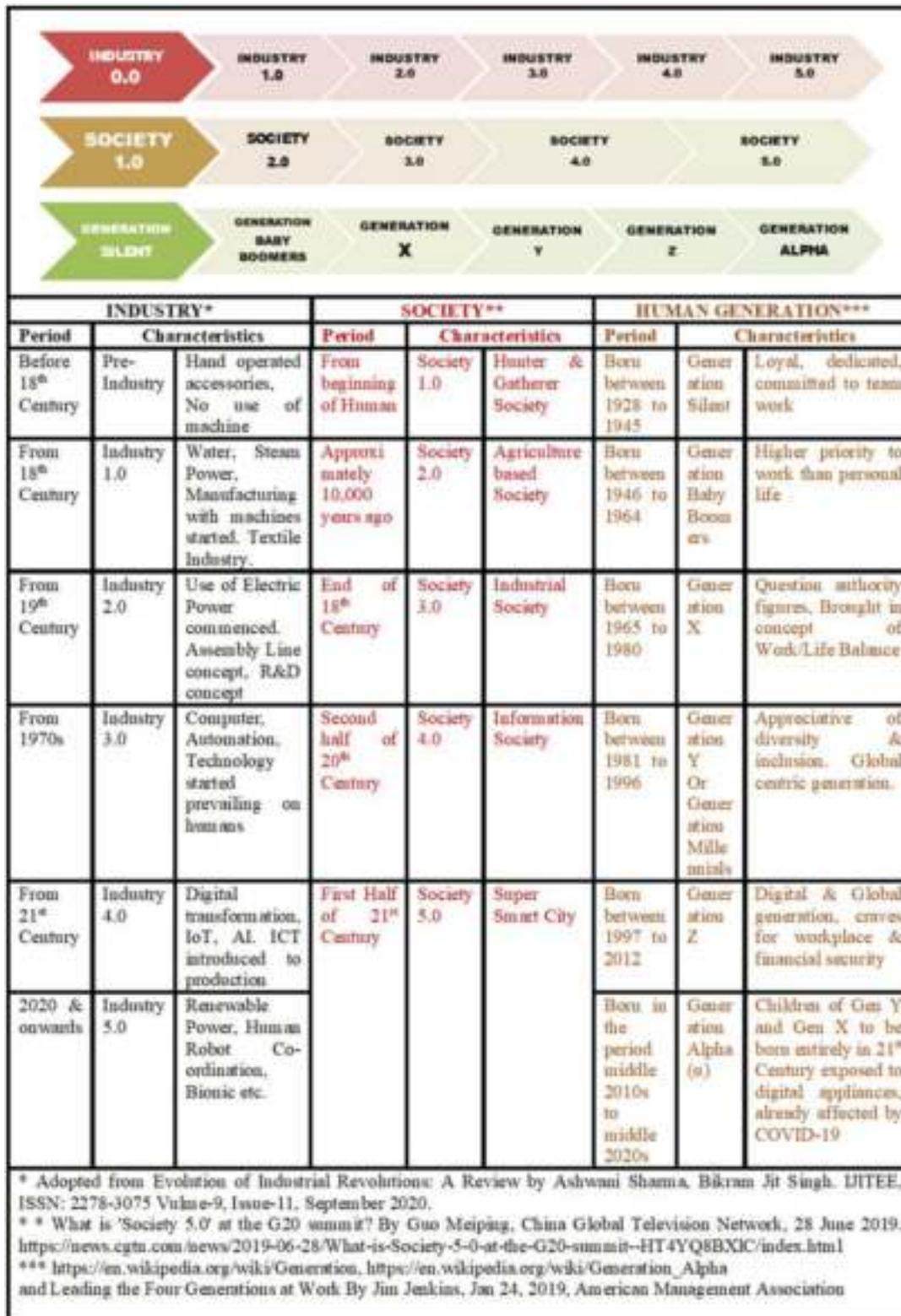


Figure 1 Different ages of industry, society and generation



Engineering education must therefore acknowledge diversity and also embrace inclusivity.

To deal with the sustainability and self-reliance, India needs to deal technical issues in its own way as far as possible ingeniously. From Engineering point of view, first Appropriate Technology needs to be evolved, upgraded and enriched.

### APPROPRIATE TECHNOLOGY

The principle followed by Benjamin Franklin – “That, as we enjoy great advantages from the inventions of others, we should be glad of an opportunity to serve others by any invention of ours; and this we should do freely and generously” [3] shall be the pathway for Appropriate Technology. Appropriate Technology for India shall be that technology which encompasses inclusivity, specific to cater to the need of a community or locality, having scope for application and use in other areas with no or minor modifications, shall be environment friendly, shall have a reasonable life span not likely to be declared as surplus or obsolete and lastly technology solutions should be indigenously available not requiring any import.

In the technology arena, first and foremost priority is to provide a framework for aligning Indian Engineering thoughts with Chip-based technology. Bharat Operating System Solutions (BOSS GNU/Linux) need to be made more user friendly and accommodative comparable with other OS. Intangible part of chip-based technology, that is software need to be developed in Indian languages. As all native Indian languages had Sanskrit origin, so an OS with Sanskrit language is proposed. A separate BOSS GNU/Linux for non-defence sector and Indus OS for Smartphone application or similar OS need to be developed with Government support and patronage of elite Engineering Institutions. A separate electronic factory need to be opened where Computers and other peripherals shall be manufactured, tested with developed indigenous OS and Software. This is to be done on war footing basis to catch up with the global advancement in computer sector. Indigenous development of proven OS with compatible software shall make Indian industry self-sufficient in IoT, HMI, GUI devices and Control systems.

Other than above, methodology for Appropriate Technology shall include the followings as minimum:

1. To identify the necessity of community
2. To list down the ethical, cultural constraints towards fulfilling the need. It may be caste or religion-based separation within a locality. The solution may require gender-based solutions also.
3. To determine probable technical solutions of the need
4. To weigh pros and cons of each of the probable solutions with due consideration of feasibility of easy implementation, longevity and lifecycle
5. In case of reluctance of acceptance of the solutions, to go for inculcating the benefits, setting example by initial one or two acceptance.
6. To impart training for operation and maintenance of the system
7. To transfer the installed system to the community for whom it is meant for.

#### Example

In a remote village, there is no toilet system, people defecate in open. It causes health problem and also having demoralising effects especially for the adults. People wanted a toilet system. While going for solution, it was found that there is water scarcity and no electricity. Vacuum toilet (**Figure 2** given here) can be a solution to this problem. Water may be fetched from village pond; solar battery can be used as a stand-alone source of electricity.

Appropriate Technology can be made applicable through top-down and bottom-up approach. In the above example, Bottom-up approach includes villagers coming with the justified needs, providing land, providing access to water, operating and maintaining the system after installation and providing feedback. Need for Self-Reliance comes from within, so bottom-up approach is key for successful application of Appropriate Technology. Top-down process involves government funding, resource allocation, design of the system and monitoring the installation. Possible up-gradation and improvisation also comes under top-down approach.

There are several Appropriate Technological applications which shall give self-reliance as well as sustainability, such as Rain water harvesting, Renewable Energy Harnessing, Drainage water recycling, Compost fertilizer etc.

Appropriate Technology has got a wide application in converting wastes to resources. Considering Food waste alone –

- According to the Brihanmumbai Municipal Corporation (BMC)’s Environment Status Report 2020-21, of the 6,500-6,800 metric tonnes of solid waste generated daily by Mumbai, as much as 72.6% is food waste.[4]

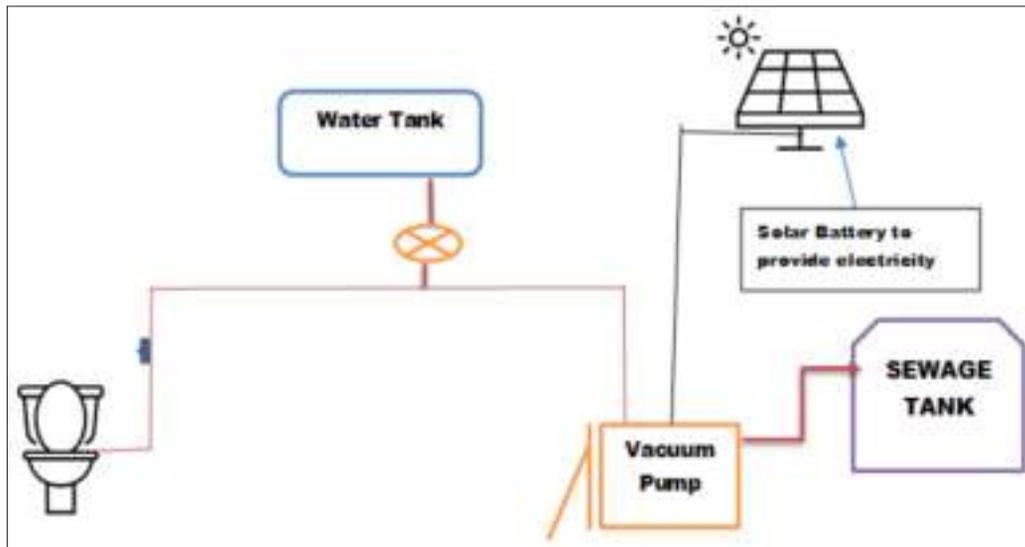


Figure 2 Vacuum toilet

- According to UNEP Food Waste Index Report 2021, with Confidence in Estimate labelled as ‘Medium Confidence’, in India Estimated Household Food Waste is 50kg/capita/year which comes to 6,87,60,163 tonnes Household Food Waste per year.

According to UN News – Global Perspective Human Stories dated 17 May 2019, “Padmanaban Gopalan takes advantage of geolocation technology by allowing restaurants and individuals to log into his “No Waste Food” app, where “they can find the nearest community that can take their food, instead of throwing it in the bin — and so far, Mr Gopalan’s provided meals for more than 900,000.”[5]

Alternate Technology for channelising such Food Waste may be placement of high-capacity large refrigerators, powered by renewable energy sources. Dietary technology may be used to make the people understand intake of food suitable to meet the calorie requirement.

Correct understanding of issues resolvable through Appropriate or Alternate Technology shall come only when Engineers are competent in application of acquired knowledge and understand the society needs.

## ENGINEERING EDUCATION

Computers are success, humans are now subordinated to computers because and only because, behind every computer there is a thinker who has thought what the computer would think. Similar is the case for Engineers; an Engineer is to think what a machine would think, what a technology would think, speak and deliver. Thinking is done by language; mother tongue is the language by which a person thinks. Education in general is a matter of transfer of knowledge from teacher to student. Pedagogy of Engineering Education should enable a student to think. Complexity of Indian Engineering education sector has been discussed above. Necessity of determining and thereafter implementing Appropriate Technology has also been emphasised. The enormity of the problem related to use of language medium can be guessed from the following mentioned in the Introduction of AICTE-Technical Book Writing and Translation Scheme Document:

### Introduction

The local language communication in India is vital for effective developmental action. According to Census of India, 122 major languages and 1599 other languages out of which 30 languages are spoken by over a million native speakers in different parts of India. Therefore, a need arises to promote original book writing with latest developments on technical subjects incorporated and as per AICTE’s Model Curriculum therein in 11 regional languages listed below[6].

World-renowned mathematician, educational-technology visionary, a founding faculty member of the MIT Media Lab, Professor Emeritus Seymour Papert said – “No knowledge is entirely reducible to words, and no knowledge is entirely ineffable”[7]. This saying shall be the pathway for teaching Engineering to students in vernacular medium.



### No Language is Complete

Engineering deals with man-made items. No language is complete to in describing the man-made items. English language uses many Latin phrases like *in situ*, meaning ‘in the place’ widely used Geological Engineering. Symbols are also borrowed from other languages, mostly, from Greek. So, there is no reason to think own mother tongue as inferior to any foreign language.

### Using Indian Language for Engineering Education

As per Para: 20.6 of NEP, ‘Technical education includes degree and diploma programmes in, engineering, technology, management, architecture, town planning, pharmacy, hotel management, catering technology etc., which are critical to India’s overall development.’

For all these programs, there are 8902 AICTE approved Institutions with total intake of 3004199 students. According to AICTE Press Release dated 3rd January 2022 – “AICTE has introduced “AICTE Technical Book Writing and Translation” in 12 scheduled Indian regional languages leading to overall increase in GER, enhanced Learning outcomes, Strengthening Innovation and Research opportunities for the students. Based on a survey, 19 institutions, across 10 states in 6 different languages have come forward towards commencement of UG in regional languages from the current academic year.” [8] This small leap is a giant step forward to remove pre-conceived notion of inferiority of India’s native languages. It is just the beginning, some more works are to be done.

### MTB-MLE

Mother Tongue-Based Multilingual Education (MTB-MLE) needs to be implemented in Engineering colleges. Teaching staff need to be trained in MTB-MLE. Special attention to be given for terms essentially having engineering implications, like Hysteresis Loop, Tribology, I/O system etc. Engineering Symbols of other than English alphabet are also to be made acquainted with their use and epistemological significance. All these nitty-gritties do have learning Engineering subjects. Nothing preliminary should be treated as insignificant as otherwise base shall remain weak.

Keeping in view all the foregoing discussions, Curriculum, Pedagogical and Didactic Approaches for Engineering Education in vernacular language are proposed:

#### (i) Curriculum

Science subjects and mathematics in last school level education are to be retained with further improvisations, advancement and application oriented. Curriculum is to be divided in Core programs and Frontier Area of Learning. Usually, these are divided as compulsory subjects and optional subjects in syllabus. In general curriculum should be –

- (a) Student-centred
- (b) Aim to make the basics very strong
- (c) Contextualized and relevant
- (d) Flexible enough to accommodate local culture, social norms and ethics
- (e) Transformative – transfer from localized outlook to national and global perspective
- (f) Usable and implementable with pedagogical and didactic approaches mentioned below.

Curriculum should

- (a) Aim to make the basics very strong
- (b) Adhere to Mother Tongue-Based Multilingual Education system.

Fast change in job market requirements necessitate corresponding skill-set development, and therefore Curriculum should be flexible to accommodate Short-, Medium- and Long-term programs; Short term programs are intended for enrichment and fine-tuning of emerging skill-set requirements, Medium term shall take care forecasted skill-set requirement in near future, Long term shall focus on core learning and comparatively long-lasting technology like engineering in infrastructure developments.

#### (ii) Pedagogical Approach

Sustainability and Appropriate Technology, both, demand inclusivity. Learner groups may differ in terms of age, educational background, ideologies, ethnicity, culture etc. Collaborative model of pedagogy shall be effective in such heterogenous group. Based on the fact that everyone has got something to contribute, by sharing one’s skill, experience



and knowledge, each member of the group plays asymmetric role. No single person can be an expert. Embarking on innovation driven economy shall be immensely facilitated by sharing of knowledge.

Engineering education involves theoretical, practical classes and project work. For students in engineering colleges teaching through vernacular language medium, Spiral Progression Approach (SPA) along with Vertical Learning and Horizontal Learning shall be most suitable. Biggest benefit of SPA is that it eliminates barrier of language to a great extent.

- (a) Boosting cognitive development
- (b) Exposure of the students to wide variety of concepts, ideas, engineering disciplines enabling total learning experience
- (c) Mastering a subject through incremental complexity

Vertical Learning involves learning a subject in more and more hierarchical complexity. Horizontal Learning involves learning subjects of other disciplines but in the same level. Backed by strong base of fundamentals, SPA in conjunction with Vertical Learning and Horizontal Learning provides the most comprehensive and holistic pedagogy for Engineering Education in Vernacular Language. For example:

A group of students are given a commonly known appliance, say a domestic refrigerator. It is known that a refrigerator cools. Learning shall start with questions, answers of which shall give the learning. More the inquisitive questions, larger shall be the learning. It may be seen that detailed and in-depth study of a refrigerator shall take a student to thermodynamics, electrical engineering, electronics, insulation technology, metallurgy, mechanical engineering and so on. As shown in the **Figure 3**, SPA is a progressive method of learning; every participant student is allowed to comprehend as much as he/she is capable of and can progress further as incremental complexity is integrated in it. Seamless review enables teacher to intervene and augment the deficiencies if competence level acquired becomes less than the benchmark. Thus, SPA enables a student to attain level-wise as well as total competency. Project-Based Learning, Inquiry-based Learning, Learning through Interactive sessions all these are included in SPA.

#### (iii) Didactic Strategies

Enrichment of education by leveraging proven technology is essential. MOOC can be used in the following scenarios for students undergoing Engineering courses in Vernacular Language:

- Students shy of vernacular language background
- Facing discrimination because of vernacular medium
- Having knowledge but in need of translation augmentation
- Understanding International Standards, Protocols used in real-time Engineering and co-relating the same with the syllabus-based learning
- Soft-skill development

Guidelines given by AICTE are to be followed for deciding appropriate E-learning ecology for Engineering Education in vernacular medium. 'MOOCs an Initiative Under NME-ICT Programme — Guidelines for Development and Implementation of MOOCs' of Department of Higher Education under Ministry of HRD is most suitable for this purpose.

#### (iv) Utilizing Experiential Knowledge

One year's working experience is equivalent to ten years' classroom learning, if not more. India is having vast reserve of retired Engineering professionals. Most of such retired Engineers are from the Generation Baby Boomers and has passed through Industry 1.0 to Industry 4.0 age. All these Engineers were educated in English medium. To cope up with different transitional phases, they had undergone lot of trainings and refresher courses. On one hand they had worked with foreign origin machines of different countries on the other hand they had to lead and were part of a team consisting of fellow countrymen of various demographic origins. This potential of accumulated knowledge is capable of teaching indigenous people. AICTE and other concerned bodies are required to create a pool of willing retired engineers from this bracket and utilize their experiences in conversing and delivering education in vernacular language. A model of such transfer of experiential knowledge for Appropriate Technology and also for Engineering Education is given in **Figure 4**.

Learners from higher age groups will not feel shy in learning from persons senior to them. This and wide experience base shall ensue a fruitful interactive session not only for transfer of knowledge but also shall give an edge to the normal

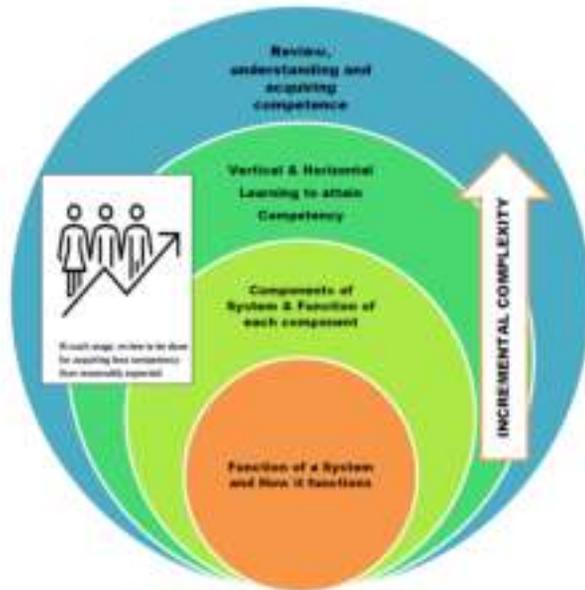


Figure 3 Spiral progression approach

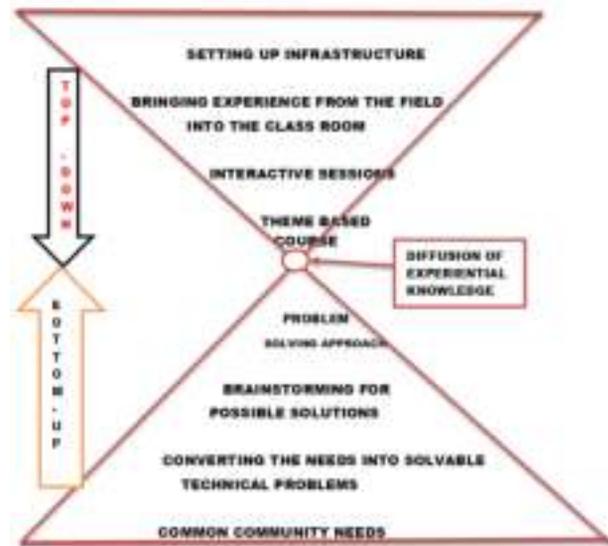


Figure 4 Using experiential knowledge

curriculum-based learning.

## CONCLUSION

India is blessed with seed of talented visionary Engineering exemplified by spirituality oriented, aesthetically sensed heritage engineering marvels. To attain sustainable self-reliance, this seed needs to be planted in the soil of vernacular languages of India. Process of bringing that seed from the isolated cold storage has started, it needs cultivation, nourishment through synergistic approach of intellects harnessed from deep reserve of experiential knowledge. Prioritisation of development of own OS, Software and Hardware, appropriate for use with Indian languages, holistic consideration for change in curriculum and pedagogy need to be prioritised and positive efforts for writing books in Indian languages shall pave the way for all-inclusive Engineering Education in vernacular language.

## REFERENCES

1. [http://www.columbia.edu/itc/mealac/pritchett/00generallinks/macaulay/txt\\_minute\\_education\\_1835.html](http://www.columbia.edu/itc/mealac/pritchett/00generallinks/macaulay/txt_minute_education_1835.html)
2. The Bourgeois and the Samurai, Sri Aurobindo Archives and Research, vol 2, no 1, April 1978, pp 1 & 89.
3. The Autobiography of Benjamin Franklin the Harvard Classics with Introduction and Notes, Charles W Elliot (ed) LLD presented by Project Gutenberg
4. Mid-day, Mumbai, 16th October 2022. <https://www.mid-day.com/lifestyle/food/article/why-india-in-general-and-mumbai-in-particular-needs-to-worry-about-food-loss-23194415>
5. <https://news.un.org/audio/2019/05/1038701>
6. <https://www.aicte-india.org/sites/default/files/fds/28.06.2021%20TBW%20SCHEME%20DOCUMENT.pdf>
7. Seymour Papert, Mindstorms – Children, Computers and Powerful Ideas, p 96
8. <https://www.aicte-india.org/sites/default/files/Press%20Release%20NEAT%20CELL%2003.01.2022%20%20>



# Role of Engineers for Creating a Sustainable and Self Reliant India

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**Abstract:** Scientists study the world as it is, engineers create the world that never has been.

Engineers can play an important role in sustainable development by planning and building projects that preserve natural resources, are cost-efficient and support human and natural environments. A closed-loop human ecosystem can be used to illustrate the many activities of engineers that support sustainable development.

This compilation covers, quite in detail about role of engineer in creating Sustainable and self reliant India, by upgrading skills, productivity, competitiveness and technology leadership.

**Keywords:** Engineers; Sustainable Development; Ecosystems & Environmental Pollution; Society & Economic Resources; Global Challenges; Self Reliant

## SUSTAINABLE DEVELOPMENT

### Introduction

The earth's population is rapidly increased day by day. The earth is full and we have no new geographical horizons to move to. As a result of this, there is a failure to meet the needs of the current world population due to constant depletion of the limited natural resources. Thus, there is a call to adopt the practice of sustainability and sustainable development.

### Definition

Sustainable development is defined as ‘‘a constraint upon present consumption in order to ensure that future generations will inherit a resource base that is no less than the inheritance of the previous generation’’.

### Four Pillars of Sustainable Development

The term sustainability is broadly used to indicate programs, initiatives and actions aimed at the preservation of a particular resource. Sustainable development refers to four distinct areas: Human, Social, Economic and Environmental sustainability.

1. Human => Well being, Creativity, Identity & diversity
2. Social=> Human rights, Justice & Participation
3. Economic=> Material prosperity, Education & Employment, Fair trade
4. Environmental=> Ecological balance, Efficient use of natural resources, Renewable energy

### Human Sustainability

Human sustainability aims to maintain and improve the human capital in society. Investments in the health and education systems, access to services, nutrition, knowledge and skills are all programs under the umbrella of human sustainability. Natural resources and spaces available are limited and there is a need to balance continual growth with improvements to health and achieving economic wellbeing for everyone. In the context of business, an organisation will view itself as a member of society and promote business values that respect human capital. Human sustainability focuses on the importance of anyone directly or indirectly involved in the making of products, or provision of services or broader stakeholders (the human capital of the organisation). Communities around the globe may be positively or negatively affected by business activities, or impacted through methods used to source raw materials. Human sustainability encompasses the development of skills and human capacity to support the functions and sustainability of the organisation and to promote the wellbeing of communities and society.

### Social Sustainability

Social sustainability aims to preserve social capital by investing and creating services that constitute the framework of



our society. The concept accommodates a larger view of the world in relation to communities, cultures and globalisation. It means to preserve future generations and to acknowledge that what we do can have an impact on others and on the world. Social sustainability focuses on maintaining and improving social quality with concepts such as cohesion, reciprocity and honesty and the importance of relationships amongst people. It can be encouraged and supported by laws, information and shared ideas of equality and rights. Social sustainability incorporates the idea of sustainable development as defined by the United Nations sustainable development goals. The principle of sustainable development addresses social and economic improvement that protects the environment and supports equality, and therefore the economy and society and the ecological system are mutually dependent.

### **Economic Sustainability**

Economic sustainability aims to maintain the capital intact. If social sustainability focuses on improving social equality, economic sustainability aims to improve the standard of living. In the context of business, it refers to the efficient use of assets to maintain company profitability over time.

Maintaining high and stable levels of economic growth is one of the key objectives of sustainable development. Abandoning economic growth is not an option. But sustainable development is more than just economic growth. The quality of growth matters as well as the quantity.

### **Environmental Sustainability**

Environmental sustainability aims to improve human welfare through the protection of natural capital (e.g. land, air, water, minerals etc.). Initiatives and programs are defined environmentally sustainable when they ensure that the needs of the population are met without the risk of compromising the needs of future generations. Environmental sustainability, places emphasis on how business can achieve positive economic outcomes without doing any harm, in the short- or long-term, to the environment. An environmentally sustainable business seeks to integrate all four sustainability pillars, and to reach this aim each one needs to be treated equally.

The principle of the four pillars of sustainability states that for complete sustainability problems to be solved in relation to all four pillars of sustainability and then need be maintained. Although in some cases these may overlap, it is important to identify the specific type of green business to focus on, as the four types present unique characteristics. Businesses need to make a strategic decision about it so as to effectively incorporate the chosen approach into their policies and procedures.

### **Global Challenges**

Many countries are facing global challenges. These global challenges are affecting business organizations as external factors; SD is a concept employed to address these challenges; SD can be applied in business organizations through corporate social responsibility (CSR), corporate governance (CG) and sustainability policy and practices and embedding CSR, CG and sustainability concepts at a strategic level is an effective response to global challenges.

### **Telecom in Sustainable Development**

Sustainability is an important topic that is being addressed urgently worldwide. With telecom operators' climate-related commitments and the ICT sector's expanding energy footprint, there is a need to do more and transform faster.

Telecom companies, worldwide, are already in the process of implementation of carbon neutrality targets which are primarily set for 2030 and 2050. Achieving these climate-reduction targets will require a mix of behavioural change, regulation, legislative commitments and technology advancements.

The mobile industry was the first to fully commit to the United Nations' Sustainable Development Goals (SDG) in 2016 and has since been a forerunner in climate action. Thanks to continued investment in infrastructure and the resilience of networks, the mobile industry continues to achieve its highest impact on SDG.

With technological progress benefiting humanity across different verticals, the telecoms sector is a key player in building a sustainable, resilient and quality ecosystem. To deliver the common 2030 agenda, it is increasingly important for telcos, among other industries, to embed principles of sustainability at their core.

Strong Environmental, Social and Governance (ESG) initiatives bring an advantage by putting a spotlight on climate change and sustainability. In fact, an analysis showed that actively addressing and demonstrating consistent performance in sustainability leads to higher market valuations.

It is certain that connectivity has become a necessity for today's generation. Hence, now is the time to use the momentum



of advocating for environmental sustainability to rethink telecom operations and value creation. By responding to the telecom sector's sustainability challenges, including becoming carbon neutral and bridging the digital divide, digital transformation and innovative solutions can support the transition to a low-carbon, digital economy.

Digital companies, including those that produce and sell ICT equipment, operate telecommunication networks and provide software and other IT services, have become prominent in the race to eliminate harmful greenhouse gas (GHG) emissions.

By definition, the concept of sustainability assumes that resources are finite and should be used strategically to remain available for future generations. Nowadays, telcos are facing increasing pressure from customers and investors to be sustainable, with customers opting for companies that are sustainable and environmentally responsible.

## **CORE ENGINEERING: NEED OF THE HOUR**

### **Energy Efficiency**

Energy costs represent 20–40% of telecoms OPEX. This trend will intensify as 5G takes hold, increasing the average data usage by 4× in 2025. In 2022 alone, the average usage per Smartphone is expected to surpass 15 GB.

Taking this high demand into consideration, one area where the mobile industry can play a significant role is in decarbonising energy systems. Minimizing energy consumption and maximizing the use of sustainable energy sources at ICT sites requires a transition toward smart energy systems (SES) and a holistic approach to energy management.

Network infrastructure energy efficiency is a priority for operators as networks (RAN, base stations, etc.) represent 90% of energy consumption. Moreover, the massive increase in the amount of data traffic over mobile wireless communication brings the challenge of supplying reliable and clean energy to end-users.

The ability to stabilize power on demand is critical for handling the 4G network, 5G transition, edge computing and IoT, and beyond. With the urgency of achieving carbon dioxide (CO<sub>2</sub>) reductions to meet net-zero deadlines, the telecom sector is shifting towards a strong commitment to sustainable business practices.

Sun setting 2G and 3G legacy systems are said to contribute 15% of reduced energy consumption. Major operators, worldwide have already announced plans to retire these older networks and make way for newer generations.

### **Renewable Energy**

Net-zero commitments have been made by telcos and enabled by a rapid substitution of renewable energy in place of fossil fuels. IoT penetration is also around 35% in solar and 10% in wind, and is set to increase steadily as a result of commitments to renewable that will connect a majority of grids by 2050.

Unsurprisingly, the use of renewable energy has been found to bring significant reductions in CO<sub>2</sub> emissions. Major operators across the world are turning to renewable sources for their energy use and are aiming to make their entire consumption green.

### **Waste Reduction**

While the average replacement cycle for mobile devices has trended longer in many markets over the past few years, the disposal of billions of devices every year carries a sizable e-waste footprint. Global e-waste is estimated to grow further to 74 million tonnes by 2030, with only a small fraction being recycled.

Recycling efforts are a visible strategy for mitigating the impact of e-waste as well as putting downward pressure on the resource-intensive production of new devices. In terms of emissions, a carbon-neutral economy is the goal, while in terms of waste, the goal is one of a circular economy. This is based on the principles of designing out the waste and pollution, keeping products and materials in use, and regenerating natural systems.

Telco and IT equipment are a major share of e-waste where 80% is discarded in landfills, burned or illegally traded every year. By 2025, the telco targets to reuse or recycle 500,000 mobile phones, modems and other devices each year and increase the network waste recycling rate to 85%.

### **Green Telcos**

Moving ahead, operators are uniquely capable to empower households and businesses across sectors to become more involved in environmental strategies. Beyond providing connectivity, enabling sustainability through telecommunications is an even higher goal, one that is lucrative in the fast-paced digital transformation scene.



Sustainability metric is necessary to know which sectors and products to target in B2B strategies, particularly in deploying vertical use cases such as transportation, automation, remote working and smart applications. Overall, reduced energy consumption, adoption of renewable energy sources and the implementation of a carbon reduction strategy are the three vital elements that must work in tandem for a telco to be considered green.

### **10 Paths to Achieving Sustainability in Telecom and Wireless**

1. Green design for 5G mobile telecommunications infrastructures
2. Adopting innovative technology
3. Analyzing possible use of renewable sources, such as solar
4. Designing energy efficient components for data centres
5. Implementing power-saving modes in base stations
6. Improving backup power sources
7. Optimizing cooling equipment and thermal management via energy engineering solutions
8. Reducing power requirements via small cells
9. Providing real time monitoring and analysis of data centre energy output
10. Planning for future equipment expansion

### **Scope**

The telecommunication sector should be supplied with sustainable energy sources. Depending on the locations of the sites, the cell towers should collect the power from appropriate sustainable energy sources. Testing labs like Idea should be set up in more places to have proper testing of equipments. Training should be given to the engineers to design and manufacture in line with sustainable development. Adhering to the government sustainable development policy and conducting sustainability programs across India at regular intervals.

### **SELF RELIANT INDIA**

#### **Definition**

Self-reliance means being a larger and more important part of the world economy. The concept requires policies that are efficient and resilient, and encourage equity and competitiveness.

Self Sufficiency and Self Reliance are virtues in isolation. In a nation's context the apex objective should be a road map for: being a Technology Leader, making all people move up the skill ladder; be competitive so that world is after you to get your goods; create enough job opportunities for all; all people to be much above poverty line (per capita income). The mantra to achieve this is – Skills, Productivity, competitiveness and Technology Leadership.

The developing countries like India can strengthen themselves and boost up the economy which is now called “self-reliant India”. The only meaning is to manufacture the maximum products in our country with indigenous resources. There are several ways India can be self-dependent, but several ways should have a systematic approach.

**Research and Analysis:** Research is most important because we should know where we stand. We directly can't boycott any product suddenly instead of that there should be a proper research, as to where we stand on selective things such as mobiles, automobiles, etc. We should analyze which are the raw materials that we import and from which countries our international relations are strong.

**Promoting Local Products:** Now, the 2nd step should be promoting locally available products / raw materials and Indian manufactured products, this is how imported product sales can be reduced.

**Creating demand and infrastructure:** Requirements to manufacture and develop indigenously by an indigenous company, such as Infrastructure, Research and development centre, skill development centres should be setup.

The use of technology should be prominently done in India because this is the age, where the world is changing and wholly dependent on technology. As India is an IT hub and Information Technology should be wisely used as it helps each and every sector. Similarly, the defence sector also plays an important role, and this sector is important as the defence equipment which is being used in our country is mostly imported. Here, the government needs to innovate the existing manufacturing sector and develop some new advanced manufacturing units.

There is a clear path to lead India to global leadership in engineering and technology and become self-reliant in these



spheres. The country has the resources, the institutions and the mindset too. Engineers do need to work towards a fusion of our positive achievements. This is the essential condition for India's path towards self-reliance and emergent role in global engineering and technology. With the seamless engineering and technology capabilities, tempered by the social and political systems, Indian engineers can be the harbinger to the development of economy of the country in the post-pandemic regime.

#### **FIVE PILLARS OF SELF RELIANT INDIA/AATMANIRBHAR BHARAT**

Five pillars of Aatma Nirbhar Bharat – Economy, Infrastructure, System, Vibrant Demography and Demand.

**Economy** — To build a type of economy that is sufficient enough to take a Quantum jump rather than growing and changing incrementally.

**Infrastructure** — To create more and more Infrastructures within the country that become the spotlight and identity for modern India.

**System** — To create a system that runs on technology and can fulfil the needs and dreams of 21st-century requirements. The present system would be entirely upgraded, unlike the past conditions.

**Demography** — The vibrant demographic is the present millennial in the country who are ambitious enough to bring the nation to a global level and upgrade it from a developing to a developed country. Being the world's largest democracy, the vibrant demography would be given chances to come up and be part of a self-reliant India.

**Demand** — To create a demand cycle, there has to be proper supply there for Atma nirbhar Bharat, aims to create a proper cycle of demand and supply chain within the economy, which will boost the needs of the country to be harnessed at its fullest.

**Scope** — India is a country that is blessed with an abundance of engineering talent, which if combined with cutting-edge knowledge resources, a solid education foundation, and the right kind of zeal can enable us to make the best of the plethora of opportunities that await us.

#### **CONCLUSION**

Engineers are the backbone for successful implementation of all the schemes launched by the Government and should provide the thrust and motive required for accelerated growth of the economy in a sustainable environment. Sustainable development and Self Reliant India can be achieved with the following various meaningful schemes launched by Government of India, with focused areas

1. Swachh Bharat Abhiyan-the 'Clean India Mission' is a nationwide campaign with focus on sanitation for all;
2. Ayushman Bharat Yojana – 'Healthy India' is a flagship scheme with a focus to achieve universal health coverage;
3. Sashakt Bharat – an initiative for 'Empowered and Resilient India for helping the underprivileged to have access to nutrition, child health, education, sanitation, drinking water, electricity and housing;
4. Samagra Bharat – for an 'Inclusive and Entrepreneurial India';
5. Sanatan Bharat – for a 'Sustainable India' and
6. Sampanna Bharat -the 'Prosperous and Vibrant India' for inclusive and sustainable growth.

#### **REFERENCES**

1. International Journal of Advance Research in Science and Engineering, vol 7, no 7, Special Issue, April 2018
2. <https://www.futurelearn.com/info/courses/sustainable-business/0/steps/78337>
3. <https://www.telecomreview.com/articles/reports-and-coverage/6372-sustainability-the-path-to-being-green-telecoc>
4. <https://www.daijiworld.com/chan/exclusiveDisplay?articlesID=5379>
5. <https://37iec.org/theme-of-the-congress/>





# Students Focusing on Industrial Engineering Should Enhance their Soft Skills to Create Sustainable Social Innovation

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**Abstract:** The industry regards students of the NBA diploma programme. The fifth academic semester's mandatory subject, Social Practice, aims to build projects with a social impact focused on the SDGs. This research examines how students evaluate their proficiency in various soft skills obtained in the Social Practice course and how they view its significance in industrial engineering to increase student engagement. The participants were asked to assess their level of competence in 20 soft skills developed by various research in diploma engineering education. The poll acknowledges the value of developing specific soft skills, particularly teamwork, reasoning, and meeting deadlines, to support professional advancement. SDGs 4 and 9 must emphasise sustainability because they are not related to the student's projects.

**Keywords:** Diploma Engineering; Social Responsibility; SDG; Sustainability

## INTRODUCTION

This paper discuss in some detail how we expose our students to important non-technical issues in the standard social projects and humanities course requirement, how we assess their achievement, and how we improve students' levels of skills. Employability or Entrepreneur soft skills are important across all the fields and all sorts of professions. These skills are important to both employees and the entrepreneur who are trying to place in a company or build the start-up. Therefore, the education boards with the help of polytechnic institutes should modify the curriculum in a way that emphasizes and cherishes the inclusion of soft skills and social innovation projects along with technical core skills. Technical education should play a crucial role in preparing students to become responsible engineers, to act in accordance with ethical, social, environmental standards, be consciously responsible for the technical decisions they make, be able to forecast and reduce/prevent damage from the technologies they develop, i.e. prepare them to follow the principles of Sustainable Development Goals and apply the adequate criteria and values in their professional activity. STEM education develops skills that allow access to economic and social benefits [11], through learning engineering by doing engineering.

Future generations of engineers will not only be catalysts of technical innovation but will also play a leading role in addressing various social issues. The framework of the Sustainable Development Goals (SDGs) offers an opportunity to consider the competences needed of tomorrow's engineers. The 17 objectives of the UN 2030 Agenda for Sustainable Development can be considered as a formalised reference for achieving environmental, social and economic sustainability. Thus, the objective of this paper the education board is to look integrates soft skills; social projects and technical knowledge are comprehended by the students.

## SOFT SKILL

### Motivation and Overview

Graduates, who are equipped technically, lose out on opportunities due to lack lustre soft skills. To avoid such problems, the project intends to create a model that the institutions can utilize to timely evaluate the students from scratch, to find out their shortcomings. This will help institution improve the quality of graduates by floating relevant courses and skill development opportunities to make them industry ready. The first step is to identify the necessary parameters that will be essential in determining the employability factor. After thoroughly going through multiple research papers, similarities were observed among the papers regarding some core parameters. Also, the parameters were concluded upon keeping in mind the Industry 4.0 mind-set which is the current trend in the industry and has set a common standard for all the



graduates in terms of the skillset one needs to be equipped with.

### What are Soft Skill?

Technical elements measure “HARD” technical skills while the communication elements measure “soft” skills which include the attitudes and approaches applicants take to their work, such as the ability to collaborate on team projects. Skills gap is defined “as the difference between the markets need (demand) and the current skills supplied by local education institutes (supply)”.

- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues

Today’s engineer needs the broad education that extends beyond the classical non-engineering electives requirement that has long been the norm in engineering colleges. Requiring students to take a certain number of courses (mostly of their choosing) to broaden their education is no longer sufficient particularly if we are serious about successfully teaching soft skills and assessing them.

### Parameters

- (i) Cognitive Analytics: Cognitive Flexibility, Creativity, Logical Reasoning, Problem Sensitivity, Mathematical Reasoning, Visualization
- (ii) Physical Abilities: Physical strength, Manual dexterity, Manual precision
- (iii) Systems Skills: Judgment and decision-making, Systems analysis
- (iv) Content Skills: Oral expression, Reading comprehension, written expression, Active learning, ICT literacy
- (v) Process Skills: Critical thinking, Active listening, Monitoring self and others
- (vi) Complex Problem Solving Skills: Complex problem solving
- (vii) Social Skills: Coordinating with others, Negotiation, Persuasion, Emotional intelligence, Service orientation, Training and Teaching others
- (viii) Resource Management Skills: Managing financial and material resources, Time management, People management
- (ix) Technical Skills: Equipment maintenance, Repair, operation and control, Programming, Quality control, Troubleshooting, Technology and user experience design. Keeping these outcomes in mind, the most important and common parameters amongst the research papers were identified, these parameters are as follows:
  - Planning and Organizing skills
  - Leadership skills
  - Communication skills
  - Time management skills
  - Team Work
  - Decision Making skills
  - Problem Solving skills
  - Self-management skills
  - Self Confidence
  - Creativity skill
  - Analytical skill
  - Technical knowledge

The above parameters have been summed up fewer than 4 Key Employability skill factors. As shown in the table aptitude skill focus on problem solving, analytical and mathematical ability Technical skill will assess technical proficiency. Communication factor measures performance with various communication skills. Personality skill covers planning and



**Table 1** Employability and entrepreneur skill factor

Soft Skill Factors	Parameters
Aptitude	Problem solving, analytical
Technical	Graduation percentage, technical knowledge
Communication	Oral & Written Communication
Personality	Planning and organizing, Leadership, Communication, Time and self-management, teamwork, decision making, self-confidence, Responsibility, Pressure tolerance, Adaptation to change, Listening, Networking, Foreign languages, Argumentation, Proactivity and initiative, creativity and Innovation

organizing, Leadership, time management, self-management, team work, Decision making, self-confidence, creativity.

### An Approach to Teaching Soft Skills

(i) Ability to communicate effectively:

Some would argue that the need to communicate effectively extends beyond reading, writing, and presenting ideas in English, but encompasses effective communication in another language or in English to a non-native English speaker. This also includes electronic multimedia communication that extends beyond traditional speaking and writing skills. To address these issues, performance criteria must be established based on criteria that measure whether a graduate can indeed communicate effectively. These performance criteria can be that a graduate.

- (a) Can successfully communicate technical material (written in English) verbally and in writing to both native English speakers and non-native speakers.
- (b) Can present technical and non-technical material in a culturally sensitive manner that shows respect and appreciation of other cultures.
- (c) Can communicate electronically via email, audio, and video effectively without undermining the message.

Achieving these goals entails not only requiring courses in reading and writing, but participation in discussion oriented courses that demand good verbal communication, proper technical writing, and appreciation of cultures, traditions, languages, and contemporary issues. Seminar type courses that require students to think critically, discuss, write, and present on both technical and non-technical subjects are ideal for achieving these goals and meeting Outcome.

(ii) An understanding of professional and ethical responsibility:

This is another soft skill that is often difficult to teach and assess. The primary requirement that helps our students achieve this outcome is the Ethics and Technology. The performance criteria to achieve this goal may be:

- Students understand the meaning of “professional”
- Students understand the meaning of “ethical”
- Students can discuss an ethical dilemma they have faced
- Students have some knowledge of basic moral theory

Students are asked to use these measures in their designs, using ethical constraints, and their knowledge is assessed directly by a faculty member or indirectly via a peer survey.

(iii) The broad education necessary to understand the impact of engineering solutions in a global, economics, environmental, and social context

Parts of this criterion are easy to re-enforce and assess, and others are very difficult. Economic, environmental, and sustainability awareness can be taught by requiring economic analysis of proposed design and by requiring students to attend talks about environmental awareness and sustainability issues. So, in addition to the two required seminars that may focus on environmental and sustainability issues directly, and in addition to requiring reasonable economic analysis in junior and senior design projects, students do have the opportunity to take a broad range of courses that strengthen and enrich these skills. The challenge, however, is in understanding global and societal contexts. While we may claim that we teach these skills by requiring a broad range of courses, or because of study abroad programs, or the work of Engineers without Borders, we cannot support such a claim using a predefined set of skills that are being taught and assessed. The performance criteria for achieving these goals may be:

- Students can assess the impact of their engineering solutions in an economic context.



- Students can assess the impact of their engineering solutions in an environmental context.
- Students can assess the impact of their engineering solutions in a global context.
- Students can assess the impact of their engineering solutions in a societal context.

(iv) a recognition of the need for, and an ability to engage in life-long learning

Performance criteria for this outcome may be:

- (a) students recognize the need for life-long learning
- (b) Students are able to teach themselves

We believe that by assigning open-ended problems and open-ended design projects we encourage the students to recognize the need for life-long learning. The students' ability to engage in life-long learning is more important and more difficult to measure. We also believe that our graduates can improve (using life-long learning) their communications skills and their global awareness, and we see the evidence of success when alumni return and tell our students of their learned ability to talk about new products and software in a way that reflects curriculum requirements while studying as undergraduates.

(v) A knowledge of contemporary issues

This is, perhaps, the most difficult of all soft outcomes to teach and assess. Performance criteria for this outcome are:

- (a) Students can determine what a contemporary issue is
- (b) Students are knowledgeable of contemporary issues

While energy sustainability is the most important contemporary issue for some, others may consider climate change as the most important.

## **SOCIAL INNOVATION**

### **Skill Gaps Input to Curriculum Enhancement**

The development of an individual's knowledge, skills, and attitudes is not just the sole responsibility of the academic community; nevertheless, it is a joint responsibility of the students, school and industry. Identifying areas where students may not measure up to the expectations of industry companies and in improving the curriculum at their universities to better prepare them for their future careers. Although there is a correlation between the specific skills that industry requires and those which students possess, however, there is a knowledge gap of certain technical and technological skills that are still lacking from the formal Information System (IS) curriculum. In all of these studies, both the academic community and industry partners play important roles in providing needed information about skill gaps in the key industrial work areas. To achieve this, it needs to establish mechanisms for active, structured and meaningful consultation with industry partners on a regular basis through In-plant training or Internship. The researchers believe that this research will surely provide academic community and the industry with more knowledge to obtain more effective collaboration so that it will be helpful to both academic and industries.

### **Social Innovations in Sustainable Development**

Today cities and rural communities are facing diverse types of challenges, including the big issues of the twenty-first century (e.g. climate change, aging, migration, unemployment, democratic governance), which threaten to dissolve their social and economic fabric. In addition, the public sectors cut down on public spending due to ongoing austerity, and the private sector fails to satisfy citizen's needs. Consequently, over the last decade, social innovation has gained momentum. Among policymakers and academics as a potential instrument to help communities to tackle complex societal challenges and unmet social needs, especially those that the welfare state or the market is not able to address adequately. Most of the social innovations arise because existing systems have been hit by a crisis (e.g. earthquake) or sustained problem (e.g. declining capacity to cope with demographic decline), which create a trigger event – a spark that causes the SI to emerge – and can improve the existing situation. Many welfare systems have been confronted with new demographic, social, and cultural challenges and austerity policies, which has prompted more active involvement on nonpublic actors in the delivery of social services, promoting social innovation initiatives.

Social innovations create employment, provide community services, and manage shared resources while empowering citizens and, in particular, vulnerable groups. All these contribute to enhancing the capacity of communities to adapt to and/or address new challenges. At the same time, social innovation helps to meet social needs involving and empowering the citizens and making them participants of the sustainable development of their communities. Social



innovation can contribute significantly to making cities and communities more sustainable, inclusive, resilient and safer and plays a strategic role in achieving the Sustainable Development Goals (SDGs). Particularly in developing economies, it can contribute to building resilient infrastructure, deploy new technologies, and expand the capacity to achieve their sustainable development ambitions. Overall, social innovation initiatives are needed in order to move from current unsustainable models of living to new, sustainable ones and accompanying the social and economic transitions.

### Future Directions

In the context of the SDGs and the broad understanding that there are pressing contemporary societal challenges shared across frontiers, it is widely accepted that solutions are and have to be local within common goals. In this context, social innovation is critical to advance toward more sustainable communities. Social innovation delivers enhancement of societal well-being in a wide range of topics while contributing to community and citizens empowerment. In any case, unlocking the potential of social innovations in each community requires action and engagement not only of civil society but of local, national, and international governments as well. From a material perspective, it is necessary to ensure that enablers are in place to allow each community to take ownership of their sustainable development and so their future. Providing an enabling context means investment in key infrastructures including ICTs and provision of appropriated funding and financing opportunities to support community initiatives. In addition, it is necessary for social innovation to flourish and consolidate the existence of stable democratic political frameworks that supports and seeks inclusive social participation and the development of just communities with an equality agenda. Although in some cases SI initiatives may have developed precisely as a bottom-up community response to socio political contexts not paying enough attention or even jeopardizing an inclusive agenda, democratic governance mechanisms will incentivize and facilitate the flourishing of initiatives led by civil society. And last, it is necessary to create and disseminate narratives of empowerment and inclusion that encourage and reward an active and engaged citizenship. Those narratives are important at local level but also within national and international frameworks that recognize and support the actions and goals of the sustainable communities. The future of sustainable communities passes for the individuals to take an active role and responsible ownership of their communities in a framework that respects, supports, and encourages it.

### CONCLUSION

The industrial engineering program seeks develop those 20 soft skills in their students, for this reason important to recognize their importance and proficiency in the Social Practice course. In this case, the survey shows that the teamwork skill is recognized as one of the most important to resolve the current problems and challenges. Additionally, the student says that the argumentation is the second most important skill and is necessary to develop critical thinking and to make engineering reports. The third most important skill is the Meeting deadlines, because the industrial engineer needs to be on time. Finally, the Social Practice course seeks to develop projects with social impact oriented by the SDGs. However, the survey showed that the students projects don't have the SDG 4 and the SDG 9, for this reason is necessary to promote those SDGs to resolve problems about this topics.

### REFERENCES

1. National Science Board, Science & Engineering Indicators, National Science Foundation, 2016.
2. S. Celine, M. Maria Dominiv, M Savitha Devi. Logistic Regression for Employabilty Preditio'. International Journal of innovative Technology and Exploring Engineering (IJITEE) ISSN:2278-3075, Volume-9 Issue- 3, January 2020
3. Juan Sebastián Sánchez-Gómez Soft skills for the development of social and sustainable projects in industrial engineering students 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC) | 978-1-6654-2488-2/21/\$31.00 ©2021 IEEE | DOI: 10.1109/WEEF/GEDC53299.2021.9657323
4. Frederick F. Patacsil Exploring The Importance Of Soft And Hard Skills As Perceived By It Internship Students And Industry: A Gap Analysis Journal of Technology and Science Education JOTSE, 2017 7(3): 347-368 –Online ISSN: 2013-6374 – Print ISSN: 2014 53549
5. Radermacher, A., Walia, G. Knudson, D. (2014, May). Investigating the skill gap between graduating students and industry expectations. In Companion Proceedings of the 36th international conference on software engineering (pp. 291-300). ACM. <https://doi.org/10.1145/2591062.2591159>
6. Scott, E., Alger, R., Pequeno, S., Sessions, N. (2002). The skills gap as observed between IS graduates and the systems development industry—a South African Experience. Informing Science, June.
7. Shariff, N.M., Kayat, K., Abidin, A.Z. (2014). Tourism and hospitality graduates competencies: Industry perceptions



- and expectations in the Malaysian perspectives. *World Applied Sciences Journal*, 31(11), 1992-2000
8. Song, T.K., Tang, J. (2016). Managing skills challenges in Asean-5 final report, 93 Yorke, M., & Harvey, L. (2002). Graduate Attributes and Their Development. *New Directions for Institutional Research*, 128, 41-58.
  9. Mohd Fairus Awang, Lily Khairiah Kadaruddin, Siti Khadijah Najid, Mohd Zaidi Omar, Analysis of Employability for Bachelor Graduates of Faculty Engineering and Built Environment for Year 2011, UKM Teaching and Learning Congress 2011, *Procedia - Social and Behavioral Sciences* 2012.
  10. Taiwo Oladipupo, Ayodele, Types of Machine Learning Algorithms, University of Portsmouth, United Kingdom, February 2010
  11. Darwin Nelson & Gary Low. ESAP Emotional Skills Assessment Process, Interpretation and Intervention Guide. Professors of Education Texas A&M University-Kingsville, Fall 2003

# Restructuring of Engineering Courses to Enhance the Quality of Education and Aptitude of Engineering Graduates

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**Abstract:** Education is as important as the eye of a person. Education has the power to change the behaviour, character, and life style of a person and totally the whole society. So, the general education in a country is a social issue of that country. But engineering education in a country is not only a social issue it is also an economic issue and national security issue. Hence, equip engineers with sound technical knowledge with analytical power and desired ability is the prime factor and impart quality engineering education in institutions is very much essential. The demand for engineers in the industry and infrastructure sector and the opening of numerous engineering colleges followed by requirements to produce engineers changed society and had a big impact on employment. This paper reviews the need for technology in every moment, the necessity of updating the technology development and research innovations for sustainability, the Demand for engineers in the industries, the availability of plenty of engineers graduated from private, self-finance engineering colleges with unsound technical knowledge, the impact of poor-quality education in society and insist the restructuring of engineering courses in technical institutions.

**Keywords:** Engineering Education; Sustainability; Industry; Production; Self-reliant

## INTRODUCTION

The self-sufficiency of a country depends on the three major factors. First one is production of more than sufficient food and other agricultural products. Second one is production of cotton for clothing and establishment of textile mills for cloth processing. Finally shelters to all in the country and sufficient infrastructural facilities. Nowadays the production of agricultural products involved mechanisms in all activities from ploughing the field to packing and stocking to the distribution of consumers. In this mechanization Technology and engineers plays a vital role in invention, innovation and modification for comfortable operation and easy production. Shelter provision and infrastructure facilities are under development. Contemporary the Self-reliant of a country depends on the development of industrial products and the growth of industries and a strong challenging defence system. These are depending up on the availability of raw material resources, infrastructure, and technology. Here the role of engineers is to contribute in engineering operations in their relevant field.

## NEED FOR TECHNOLOGY IN EVERY MOMENT AND UPDATION

Perhaps many possibilities in doing a job either in production or in service, utilizing the optimum resources, automation in operation and applications as much as possible in wide range is the technology. Application of technology, results in time consumption, economy and supply to demand or requirement. This is most effective from our day to day life activities. Last year India imported mineral fuels worth US \$ 170.40 billion. This was 29.90 % of total imports in 2021. In the import material series precious metals, machineries and equipment worth US \$ 192.40 billion took place according to World's Exports.com. We have resources to conserve the solar energy as electrical energy, which can be utilized as best alternative for major part of mineral fuels to fulfil our major part of the requirement. Hydroelectric power production in our country is very little among the availability of natural hydraulics system and hydraulic structures. We have coastline length of more than 7000 kilometres having waves to generate power. To achieve this goal and likewise the technology developments, updating and advancements are much essential to be independent. Further every Indian has to keep in mind that India is the second largest defence importer of weapons and military equipment in the world. Due to this import we have not only the economic issue and also the safety issue. The suppliers know about the function of the weapons supplied by them and our defence system. At the same time suppliers supply only out dated weapons and equipment in their country which enable others to analyse and estimate our defence system and capacity. There is a question mark in our protection and growth, however we were in the situation that anything is better than nothing. So becoming zero worth defence importer and having secured defence system, technology development and research inventions and innovations for Make in India is severely not ignorable. Made in India is proud for every one in Indiansub-continent.



## DEMAND FOR ENGINEERS IN THE INDUSTRIES

In India we have 48 million small and medium enterprises with 4.50 % growth rate. The above enterprises and infrastructure development required plenty of engineers. It is evident that most of the industries expressed their demand of technicians and engineering executives all over India through frequent advertisements and employment agencies. At the same time around 45 % of management graduates and 48 % of engineering graduates seeking their suitable jobs and stand as unemployed. [Published in Indian express 21.01.22 as that NITI Aayog Chairman Rajiv Kumar stressed in a virtual event organised by Indian school of business]. If we speak about the scope of civil engineering graduates, most of the buildings and projects are constructed with insufficient supervision of engineers and managerial persons. There is a big shortage in providing consultancy services and advisory personalities for execution. We can see that the projects and buildings are constructed with over reinforcement and rich mortar for being safer side, but this is a huge lose to the proprietors going out without even knowing the real loss to them. All the above problems associated with non-availability of engineers with sound technical knowledge and proper experience results in construction of non-engineered buildings and structures.

## QUALITY OF EDUCATION IN ENGINEERING COLLEGES AND TECHNICAL INSTITUTIONS

The National Institutional frame work (NIRF) released by union ministry of Education rankings of 2022 in July states that in an analysis of the top 200 technical Institutions the first best institution scored 90.04%, but 50th best institution scored 50.11% only and the 200th institution scored as low as 33.70%. Imagine the situation of the remaining 1049 institutions that applied but got no rank. We need not explain the terrible must be the situation in more than 4500 institutions which did not even apply for the ranking.

The 'National Employability Report for Engineers 2019' put out by a job assessment platform Aspiring Minds, has shown that over 80% of engineers in India are unfit to take up any job in the knowledge economy and only 2.5% of them possess tech skills in Artificial Intelligence(AI) that industry requires. . According to the report, Indian engineers still lag the relevant digital skills that companies nowadays are looking to hire for. This includes advanced tech skills such as artificial intelligence, machine learning, data science and wireless technologies among others. Merely 2.5% of engineers in India possess skills in artificial intelligence while only a handful of engineers (5.5%) are qualified with basic programming, the report assessed. This means, overall, only 1.5% of engineers in India have the required skills for new-age jobs. The findings match other reports about the shortage of digital skills in India. The emerging sector has nearly 4,000 vacant jobs in India due to lack of qualified talent. This may be because of the education system imparting theory-based knowledge. The data collected has revealed that only 40% of the total graduate engineers opt for internships for hands on experience with 36% taking up projects other than their course work. While 47% of students attend industry talks to boost their knowledge. "We find that a low proportion of engineers take up projects beyond curriculum and do internships. Also, there is a lack of faculty talking about industry application of concepts in class or students getting exposure through industry talks," Varun Aggarwal, Chief Technology Officer and co-founder Aspiring Minds told PTI. The report analysed engineers across India, China and the US. As per the conclusions drawn, US job applicants were found to be the head of Indian Engineers in terms of good coding skills, while China Engineers compete almost at the same levels.

All India Council for Technical Education (AICTE) approved 5926 institutions so far to offer programmes in engineering and technology to admit 23.67 lakhs students. Sudden increase in institutions during last two decades had to meet out so many deficiencies and become troublesome in providing good quality education to the students. Since most of the institutions started at same period they had to face the non-availability of trained teachers, right persons to establish laboratories, Libraries and Infrastructural facilities in the institutions. At last the institutions had appointed post graduate students as lecturer to the graduate courses. In continuation huge number of mediocre teacher were appointed and let to teach the students at a lower pay. Some institutions having less number of students the teachers are assigned to teach 3 to five courses. Such teachers have big constraint to develop their knowledge and improve their skills because of the over burden.

In business parlance the institutions came to fulfil the needs just enough to the minimum requirement for approval and namesake. AICTE Inspection committee doing numerical check on laboratory apparatuses and equipment in the labs not the quality and precision of equipment does not verified during their inspection. This is very much favourable situation to the owners of the institutions for purchase of poor quality equipment at very lowest rate. These types of equipment are useful only to keep in the lab for namesake, otherwise these apparatuses fail to perform well in very few operations. Hence, the students are let to look at a glance over the equipment and not given to do experiments. The students never understood the experiment procedure and the results in their carrier. Since same teacher is conducting and evaluating the semester examination they awarded the marks to reach a high score. Here the transformation of knowledge and real education key is buried.



The students studied from the above mediocre teacher, and experiment done at usage restricted laboratories failed to perform well in the theoretical examinations also and the result highlights the above deficiencies of institutions. To tackle this problem the teachers are requested to do liberal value and some teachers don't have knowledge to justify the correct answer for the asked questions. Without knowing the correct answer giving full mark to the available answer in the papers has also happening in the central valuation system. The result obtained in this system makes the students happy and confident in attaining graduate award and promotion to the higher studies. The management of institutions were also proud without knowing the consequences. On later date the graduate comes to know that he is not suitable or fit to any type of engineering job relevant to his graduation. The institutions realised the unemployment of alumni and try to take various actions to create opportunities to their outgoing students. Placement cell, Entrepreneurship cell, Industry-Institution partnership-co-ordination committee, MoUs with Industries, Faculty development programmes are some of the establishments formed to do expected employment oriented activities in college level. The placement cell is begging the pioneer industries to consider their students for placement, but not ready or unable to prepare the students to the requirement of such industries or to the current industry standards. The entrepreneurship cells are doing the collection of data of success entrepreneurs and issued to the enrolled students instead of guide the students to various opportunities and demand of the engineering product with training. MoUs with industries are made only to show in records and advertisements to display in the portals and forgot to give training to the students. Faculty development programmes are not sufficient to develop the teaching skill of all the sub grade teachers at present. Even after taking all the effort taken by the managements of Institutions no considerable effectiveness found by the institutions on employment and entrepreneurship of outgoing students. As the result of this most of the people in the society under estimated the aptitude of engineering graduates and engineering society consequently the seats and admissions in the engineering colleges came to street market. Where the students promoted from Higher Secondary education with just passed score and minimum cut-off, fall under reserve category those who are not aspirants for engineering education were caught and admitted by canvassing the availability of 100 % scholarship from the government and Education loans. Some of the above said pupils doesn't know even to write their name without any mistake at this stage and imagine transform the engineering knowledge and technology to those pupils with weak education system.

#### **IMPACT OF POOR QUALITY EDUCATION IN SOCIETY**

First impact in the society is employability. Employability in our country during 2021 was only 45.90%. Main reason for this worst result is availability of graduates having insufficient knowledge in the relevant sector due to dearth quality education. At last most of the unemployed engineering graduates came forward to take up the jobs like sim card sales, automobile sales, finance interest collection, food door delivery services and service boys in hotels and even in bars irrespective of their qualification. Creation of non-engineered buildings and structures are another worst impact. Here the non-engineered building is defined as the building informally constructed in traditional manner without any intervention by the qualified engineer or architect in their design or the same construction done with engineering graduate having unsound technical knowledge. The buildings having leakage in the restrooms are common examples, we can see probably in all places. Recently a fly over was constructed in Coimbatore city on Trichy road to a length of 3.15 km with four lanes at a cost of Rs 232 crores and inaugurated on 11.07.2022. Immediately after inauguration more than three fatal accidents caused because of the shortened radius of curvature in the lanes. Then as remedial steps the outer lane is blocked and inner lane alone opened for traffic flow with frequent speed breakers. An additional protective structure have also provided in the guide wall. Thus a four lane flyover now becomes two lane flyovers with many speed breakers. In this case anticipated result is not found, because the structure constructed with improper application of technology and wrong justification during planning and design. We can enumerate so many examples in this series. Hence at education stage inculcating the importance of role of engineer's for sustainable development is mandate.

#### **NECESSITY OF RESTRUCTURING THE ENGINEERING COURSES AND ENHANCING THE QUALITY OF EDUCATION**

Graduate engineering courses contains eight semesters every semester have 6 theory courses and 3 laboratory practical courses. Most of the theory courses have 5 units scheduled to complete in 45 lecture periods each. This is suitable only for brilliant category students but we have average students and also slow learners. They need more lecture periods and they feel overburden. So the number of courses per semester may be reduced to 80 % of the current workload which will be helpful to thorough study about subject in a relax manner. The remaining 20 % may be pushed to further two semesters. In the author's point of view nothing wrong in restructuring the carrier to 5 years for thorough study without any choice or omission in required subjects. Industrial training must be included in the curriculum and scheduled along with theoretical studies and laboratory experiment observations, then only the students become understood the reasons for any deviation in field practice and the theory, practical difficulties, advancements in the industries. This leads the students aware about the industrial standards and need of the industries and very helpful to preparing themselves to fit in



Figure 1 Fly over with blocked lane and speed breaker



Figure 2 Fly over with small radius of curvature

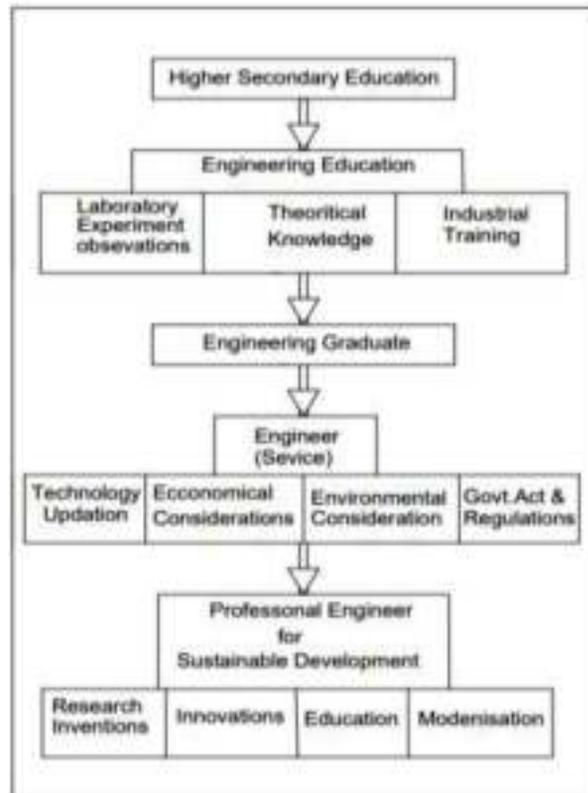


Figure 3 Flowchart for Professional Engineer

the similar industries after their graduation. If this could be achieved nobody can worried about the employment. Real estate sector plays a major role in economy and it provides employment opportunities to the engineers in all level and has a marketing potential in the society. It needs persons with knowledge about the real estate (Regulation and development) acts, building by laws and other relevant acts and the various local body approval processes. Hence necessary subjects containing real estate related contents must be included along with environment considerations in the graduate and diploma level education so far not available in the syllabus. As per the AICTE guidelines the maximum students' strength is 70 per class which is too large to control all the students and is tedious to look over the full capacity students. This may be reduced to maximum of 40 students for comfortable knowledge transformation and to have a look at individual student's attitude and aptitude. First of all, educating the educators to enhance their grade and skill is most essential. Sufficient Faculty Development schools may be established by appointing expert and experienced teachers from pioneer institutions at international level for all engineering subjects to give upgraded education and special training to the teachers those who have lack of knowledge in their subjects.

### CONCLUSION

Restructuring the engineering courses, preparing the engineering students with thorough knowledge through experiments and proper training in the industries, are the prime factors for making bright engineers. Admitting only the aspirants for engineering education will help to produce the good engineers, the reservations and scholarships does not help to make the performed engineering society. Teachers do not having minimum industrial experience should not let to teach the students. The Industrial based curriculam and accord of accreditation from industries ensure the employability. Proper evaluation and promotional award enlightes the graduates life which also leads them to serve to the society well manner. The sustainable development is based on the service of engineers.

### REFERENCES

1. Ayalur K Bakthavatsalam. and Furqan Qamar. Opinion, THE HINDU Kozhicode wednesday, September 28, 2022. .
2. National Institutional frame work (NIRF) released by union ministry of Education rankings of 2022 in July.
3. 'National Employability Report for Engineers 2019' put out by a job assessment platform Aspiring Minds.



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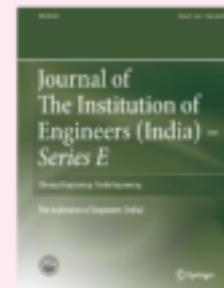
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