Antimicrobial Textiles — an Overview

Dr T Ramachandran, *Member*
K Rajendrakumar, *Non-member*
R Rajendran, *Non-member*

Microbial infestation poses danger to both living and non living matters. Obnoxious smell form the inner garments such as socks, spread of diseases, staining and degradation of textiles are some of the detrimental effects of bad microbes. Though the use of antimicrobials have been known for the decades, it is only in the recent couple of years several attempts have been made on finishing textiles with antimicrobial compounds. The consumers are now increasingly aware of the hygienic life style and there is a necessity and expectation for a wide range of textile products finished with antimicrobial properties. The new developments such as non-leaching type of finishes would help reduce the ill effects and possibly could comply with the statutory requirements imposed by regulating agencies. This paper reviews ways and means of finishing textiles and assessing their antimicrobial properties.

Keywords: Microbes; Antimicrobial; Bactericidal; Bacteriostatic; Chitosan

INTRODUCTION

The inherent properties of the textile fibres provide room for the growth of micro-organisms. Besides, the structure of the substrates and the chemical processes may induce the growth of microbes. Humid and warm environment still aggravate the problem. Infestation by microbes cause cross infection by pathogens and development odour where the fabric is worn next to skin. In addition, the staining and loss of the performance properties of textile substrates are the results of microbial attack. Basically, with a view to protect the wearer and the textile substrate itself antimicrobial finish is applied to textile materials.

HISTORICAL ACCOUNT

During World War II, when cotton fabrics were used extensively for tentage, tarpaulins and truck covers, these fabrics needed to be protected from rotting caused by microbial attack. This was particularly a problem in the South Pacific campaigns, where much of the fighting took place under jungle like conditions. During the early 1940 s, the US army Quartermaster Crops collected and compiled data on fungi, yeast and algae isolated from textiles in tropical and subtropical areas throughout the world. Cotton duck, webbing and other military fabrics were treated with mixtures of chlorinated waxes, copper and antimony salts that stiffened the fabrics and gave them a peculiar odour. At the time, potential polluting effects of the application of, these materials and toxicity-related issue were not a major consideration.

Dr T Ramachandran and K Rajendrakumar are with the Department of Textile Technology, PSG College of Technology, Coimbatore 641 004; while R Rajendran is with the Department of Applied Microbiology, PSG College of Arts and Science, Coimbatore 641 014.

This paper was received on September 09, 2003. Written comments on the paper will be received till May 31, 2004.

After World War II, and as late as the mid-to-late 1950's fungicides used on cotton fabrics were compounds such as 8-hydroxygiunoline salts, copper naphthenate, copper ammonium fluoride and chlorinated phenals. As the government and industrial firms became more aware of the environmental and workplace hazards these compounds caused. Alternative products were sought. A considerable amount of work was done by the Southern Regional Research Laboratory of the US Department of Agriculture, the Institute of Textile Technology (ITT) and some of the ITT's member mills to chemically modify cotton to improve its resistance to rotting and improve other properties by acetylation and cyanoethylation of cotton. These treatments had limited industry acceptance because of relatively high cost and loss of fabric strength in processing . In addition, the growing use of man-made fibres such as nylon, acrylics and polyester, which have inherent resistance to microbial decomposition, came into wider use to replace cotton in many industrial fabrics.

WHAT ARE MICROBES ?

Microbes are the tiniest creatures not seen by the naked eye. They include a variety of micro-organisms like Bacteria, Fungi, Algae and viruses. Bacteria are uni-cellular organisms which grow very rapidly under warmth and moisture. Further, sub divisions in the bacteria family are Gram positive (Staphylococcus aureus), Gram negative (E-Coli), spore bearing or non spore bearing type. Some specific types of bacteria are pathogenic and cause cross infection. Fungi, molds or mildew are complex organisms with slow growth rate. They stain the fabric and deteriorate the performance properties of the fabrics. Fungi are active at a pH level of 6.5.

Algae are typical micro organisms which are either fungal or bacterial. Algae require continuous sources of water and sun light to grow and develop darker stains on the fabrics. Algae

Table 1 Some harmful species of microorganisms

Bacteria	Fungi
Gram positive bacteria	**Cloth damaging fungi**
Staphylococcus aurues or pyogens	Aspergillus niger
Staphylococcus epidermidis	Aspergillus fumigatus
Corynebacterium diphtheroids	Trichoderma viride
	Curvularia lunota
	Penicillium species
Gram negative bacteria	**Crop damaging fungi**
Escherichia coli	Fusarium species
Klebsiella pneumoniae	Rhizoctonia solani
Proteus vulgaris	Sclerotium rolfsii
Pseudomonas pyocynans	
Salmonella typhi	
Vibrio cholerae	

are active in the PH range of 7.0-8.0. Dust mites are eight legged creatures and occupy the household textiles such as blankets bed linen, pillows, mattresses and carpets. The dust mites feed on human skin cells and liberated waste products can cause allergic reactions and respiratory disorders.

Some harmful species of the bacteria and fungi are listed in Table 1.

NECESSITY OF ANTIMICROBIAL FINISHES

Antimicrobial treatment for textile materials is necessary to fulfill the following objectives:

- To avoid cross infection by pathogenic micro organisms;
- To control the infestation by microbes;
- To arrest metabolism in microbes in order to reduce the formation odour; and
- To safeguard the textile products from staining, discolouration and quality deterioration.

REQUIREMENTS FOR ANTIMICROBIAL FINISH

Textile materials in particular, the garments are more susceptible to wear and tear. It is important to take into account the impact of stress strain, thermal and mechanical effects on the finished substrates. The following requirements need to be satisfied to obtain maximum benefits out of the finish:

- Durability to washing, dry cleaning and hot pressing;
- Selective activity to undesirable microorganisms;
- Should not produce harmful effects to the manufacturer, user and the environment;
- Should comply with the statutory requirements of regulating agencies;
- Compatibility with the chemical processes;
- Easy method of application;
- No deterioration of fabric quality;
- Resistant to body fluids; and
- Resistant to disinfections/sterilization.

ANTIMICROBIAL FINISHING METHODOLOGIES

The antimicrobial agents can be applied to the textile substrates by exhaust, pad-dry-cure, coating, spray and foam techniques. The substances can also be applied by directly adding into the fibre spinning dope. It is claimed that the commercial agents can be applied online during the dyeing and finishing operations. Various methods for improving the durability of the finish include:

- Insolubilisation of the active substances in/on the fibre;
- Treating the fibre with resin, condensates or cross linking agents;
- Micro encapsulation of the antimicrobial agents with the fibre matrix;
- Coating the fibre surface;
- Chemical modification of the fibre by covalent bond formation; and
- Use of graft polymers, homo polymers and/or co-polymerization on to the fibre.

MECHANISM OF ANTIMICROBIAL ACTIVITY

Negative effect on the vitality of the microorganisms is generally referred to as antimicrobial. The degree of activity is differentiated by the term 'cidal' which indicates significant destruction of microbes and the term 'static' represents inhibition of microbial growth without much destruction. The differentiation of antimicrobial activity is given in the diagram (Figure 1).

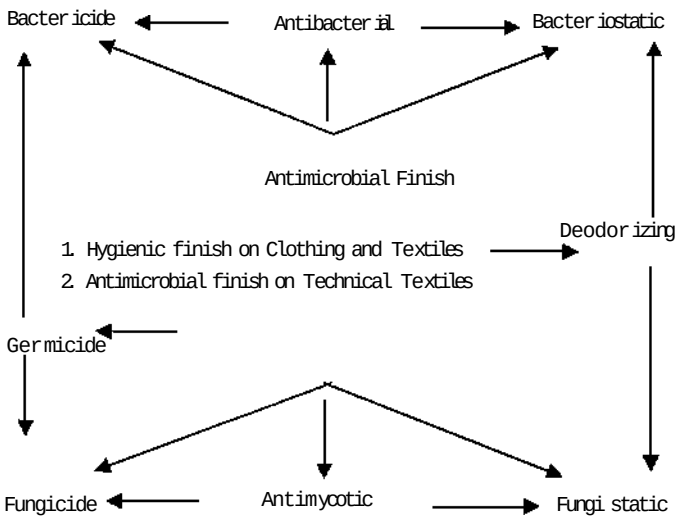


Figure 1 Differentiation of antimicrobial activity

The activity which affects the bacteria is known as antibacterial and that of fungi is antimycotic. The antimicrobial substances function in different ways. In the conventional leaching type of finish, the species diffuse and poison the microbes to kill. This type of finish shows poor durability and may cause health problems. The non-leaching type or bio-static finish shows good durability and may not provoke any health problems. A large number of textiles with antimicrobial finish function by diffusion type. The rate of diffusion has a direct effect on the effectiveness of the finish. For example, in the ion exchange process, the release of the active substances is at a slower rate compared to direct diffusion ad hence, has a weaker effect. Similarly, in the case of antimicrobial modifications where the active substances are not released from the fibre surface and so less effective. They are active only when they come in contact with microorganisms. These so called new technologies have been developed by considering the medical, toxicological and ecological principles.

The antimicrobial textiles can be classified into two categories, namely, passive and active based on their activity against microorganisms. Passive materials do not contain any active substances but their surface structure (Lotus effect) produces negative effect on the living conditions of microorganisms (Anti-adhesive effect). Materials containing active antimicrobial substances act upon either in or on the cell.

ANTIMICROBIAL SUBSTANCES AND THEIR EFFECT

Many antimicrobial agents used in the textile industry are known from the food stuff and cosmetics sector. These substances are incorporated with textile substrates comparatively at lower concentrations. It must be ensured that these substances are not only permanently effective but also that they are compatible with skin and the environment. A wide palette of antimicrobial compounds is now in use but differ in their mode of action. The following list demonstrates the polyvalent effect of the various antimicrobial substances:

- Materials with active finishes contain specific active antimicrobial substances, which act upon microorganisms either on the cell, during the metabolism or within the core substance (genome). However, due to the very specific nature of their effect, it is important to make a clear distinction between antibiotics and other active substances which have abroad range of uses.

- Oxidizing agents such as aldehydes, halogens and proxy compounds attack the cell membrane, get into the cytoplasm and affect the enzymes of the microorganisms.

- Coagulants, primarily alcohols irreversibly denature the protein structures. Redical formers like halogens, isothiazones and peroxo compounds are highly reactive due to the presence of free electrons. These compounds virtually react with all organic structures in particular oxidizing thiols in amino acids. Even at the lowest level of concentrations, these substances pose particular risk to nucleic acids by triggering mutations and dimerization.

- One of the most durable type of antimicrobial products is based on a diphenyl ether (bis-phenyl) derivative known as either 2, 4, 4'-trichloro-2' hydroxy dipenyl ether or 5-chloro-2-(2, 4-dichloro phenoxyl) phenol. Triclosan products have been used for more than 25 years in hospitals and personal care products such as antimicrobial soap, toothpaste and deodorants. Triclosan inhibits growth of microorganisms by using a electro chemical mode of action to penetrate and disrupt their cell walls. When the cell walls are penetrated, leackage of metabolites occurs and other cell functions are disabled, thereby preventing the organism from functioning or reproducing. The Triclosan when incorporated within a polymer migrates to the surface, where it is bound. Because, it is not water-soluble, it does not leach out, and it continuously inhibits the growth of bacteria in contact with the surface using barrier or blocking action.

- Quaternary ammonium compounds, biguanides, amines and glucoprotamine show poly cationic, porous and absorbent properties. Fibres finished with these substances bind micro organisms to their cell membrane and disrupt the lipo poly saccharide structure resulting in the breakdown of the cell.

- Complexing metallic compounds based on metals like cadmium, silver, copper and mercury cause inhibition of the active enzyme centres (inhibition of metabolism). Amongst these, the silver compounds are very popular and already been used in the preparation of antimicrobial drinking water.

- Chitosan is an effective natural antimicrobial agent derived from Chitin, a major component in crustacean shells. Coatings of Chitosan on conventional fibres appear to be the more realistic prospect since, they do not provoke an immunological response. Fibres made from Chitosan is also available in the market place.

- Natural herbal products can be used for antimicrobial finishes since, there is a tremendous source of medicinal plants with antimicrobial composition to be the effective candidates in bringing out herbal textiles.

COMMERCIAL ANTIMICROBIAL AGENTS AND FIBRES

Thomsan Research Associates markets a range of antimicrobials under the trade name 'Ultrafresh' for the textile and polymer industry. Ultrafresh products were

developed to be used in normal textile processes. Most Ultrafresh treatments are non-ionic and are compatible with a wide range of binders and finishes. To incorporate antibacterial into high temperature fibres like polyester and nylon, it is necessary to use an inorganic antimicrobial like Ultrafresh CA-16 or PA-42. These must be added as a special master batch to the polymer mixture before the extrusion process. For fibres such as polypropylene which are extruded at lower temperatures, it is possible to use organic antimicrobials such as Ultrafresh Nm-100, Dm-50 or XQ-32.

In the case of Rossari's Fabshield with AEGIS microbe shield programme, the cell membrane of the bacteria get ruptured when the microbes come in contact with the treated surface. Thus, preventing consumption of antimicrobial over a period of time and remain functional throughout the life of the product. The active substance 3-Trimethoxy silyl propyl dimethyl octadecyl ammonium chloride gets attached to the substrate either through bond formation on the surface or by micropolymersing and forming a layer on the treated surface; the antimicrobial agent disrupts the cell membrane of the microbes through physical and ionic phenomena.

Ciba Speciality Chemicals markets Tinosan AM 110 as a durable antimicrobial agent for textiles made of polyester and polyamide fibres and their blends with cotton, wool or other fibres. Tinosan contains an active antimicrobial (2, 4, 4'-Trichloro-2' - hydroxyl-dipenylether) which behaves like a colourless disperse dye and can be exhausted at a very high exhaustion rate on to polyester and polyamide fibres when added to the dye bath.

Clariant markets the Sanitized range of Sanitized AG, Switzerland for the hygienic finish of both natural and synthetic fibres. The branded Sanitized range function as a highly effective bacteriostatic and fungistatic finishes and can be applied to textile materials such as ladies hosiery and tights. Actigard finishes from Clariant are used in carpets to combat action of bacteria, house dust mites and mould fungi.

Avecia's Purista-branded products treated with Reputex 20 which is based on poly (hexamethylene) biguanide hydrochloride (PHMB) claimed to posses a low mammalian toxicity and broad spectrum of antimicrobial activity. PHMB is particularly suitable for cotton and cellulosic textiles and can be applied to blends of cotton with polyester and nylon.

In addition to the aforesaid antimicrobial agents, the fibres derived from synthetic with built-in antimicrobial properties are listed in Table 2.

Table 2 Antimicrobial fibre on the basis of synthetic polymers

Polymer	Company	Brand
Polyester	Trevira	Trevira Bioactive
	Montefibre	Terital SANIWEAR
	Brilen	Bacterbril
Polyacryl	Accordis	Amicor
	Sterling	Biofresh
Polyamide	Kaneba	Livefresh
	R-STAT	R-STAT
	Nylstar	Meryl Skinlife
Polypropylene	Asota	Asota AM Sanitary
Polyvinyl chloride	Rhovyl	Rhovyl's asAantibacterial
Regenerated cellulose	Zimmer AG	Sea Cell Activated

BENEFITS OF ANTIMICROBIAL TEXTILES

A wide range textile product is now available for the benefit of the consumer. Initially, the primary objective of the finish was to protect textiles from being affected by microbes particularly fungi. Uniforms, tents, defence textiles and technical textiles, such as, geotextiles have therefore all been finished using antimicrobial agents. Later, the home textiles, such as, curtains coverings, and bath mats came with antimicrobial finish. The application of the finish is now extended to textiles used for outdoor, healthcare sector, sports and leisure. Novel technologies in antimicrobial finishing are successfully employed in non-woven sector especially in medical textiles. Textile fibres with built-in antimicrobial properties will also serve the purpose alone or in blends with other fibres. Bioactive fibre is a modified form of the finish which includes chemotherapeutics in their structure, *ie,* synthetic drugs of bactericidal and fungicidal qualities. These fibres are not only used in medicine and health prophylaxis applications but also for manufacturing textile products of daily use and technical textiles. The field of application of the bioactive fibres includes sanitary materials, dressing materials, surgical threads, materials for filtration of gases and liquids, air conditioning and ventilation, constructional materials, special materials for food industry, pharmaceutical industry, footwear industry, clothing industry, automotive industry etc.

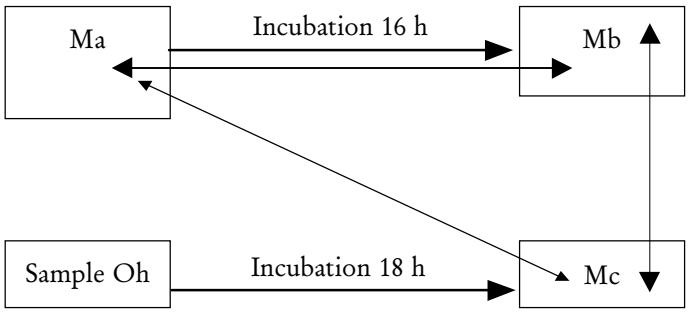
EVALUATION OF ANTIMICROBIAL ACTIVITY

Various test procedures have been used to demonstrate the effectiveness of the antibacterial activity. Some of the tests used are:

- Agar diffusion test.
- Challenge test (Quantitative).
- Soil burial test.
- Humidity chamber test.
- Fouling tests.

Agar diffusion test is a preliminary test to detect the diffusive antimicrobial finish. It is not suitable for non diffusive finishes and textile materials other than fabrics.

Objective evaluation of the antimicrobial activity is arrived at by making use of the challenge test where in which the difference between the actual bacterial count of the treated and



F = Ma-Mb (growth control)

L = Ma-Mc (general activity)

S = Mc-Ma (specific activity)

Ma = Reference Oh (non-finished textiles)
Reference count after additives introduced
(log KBE/ Reference)

Mb = Reference after 18h (log KBE/ Reference)

Mc = Sample after 18h (textile with an antimicrobial finish)
(log KBE/Sample)

Figure 2 Hohenstein modified evaluation method

untreated material is accounted for. A series of test methods are available from AATCC (USA), DIN(International), JIS (Japan) and SN(Switzerland).

The degree of antimicrobial activity of the active substance is expressed by the terms specific antimicrobial activity and general antimicrobial activity. A clear distinction between the two terms as per the modified Hohenstein Test Method which is based on the Japanese standard (JIS L 1902) is shown in the Figure 2.

The general activity or the bactericidal effect in the Japanese standard is based on the difference between the initial bacteria count on the non modified material (Ma value) and the bacteria count of the modified material after 18 h of incubation (Mc value). The specific antimicrobial activity or bacteriostatic effects is based on the difference between the bacteria count of the reference value (Mb value) and the sample after 18 h of incubation (Mc value).

Due to the limitations of the existing system, a new test system ISO/TC/38/WG23 (test methods for antimicrobial finished textile products) has been evolved by considering the technological, dermatological and ecological aspects of the finish.

EVALUATION OF THE INFLUENCE OF MODULE AND FUNGI

The influence of mould fungi is evaluated by three practical test methods:

(i) At the growth test with a mixture of five different mould fungi it is evaluated how far the textile is supporting the fungus growth. The evaluation is not done only visually, but also material specific force elongation ratio is measured.

(ii) In an inhibition zone test, the question is answered, if the tested finishing agent is protecting the textile from mould stains and mould over growth. The evaluation is done by rating the fungus growth in contact to test material and the viewing of the inhibition zone around the test sample in consequence of the diffusion of the antifungal agent.

(iii) The third test the so called wet chamber test answers the question how a mould fungus contaminated textile performs in the wet chamber the evaluation is done visually by viewing the degree of growth or through tensile strength test.

CONCLUSION

With advent of new technologies, the growing needs of the consumer in the wake of health and hygiene can be fulfilled without compromising the issues related to safety, human health and environment. Taping new potential antimicrobial substances, such as, Chitosan from nature can considerably minimize the undesirable activities of the antimicrobial products. Scientists all over the globe are working in the area and few of them reported to have used antimicrobial finishes and fluoro chemicals to make the fabric having antimicrobial as well as blood repellant properties. Chitosan and fluoro polymers reported to be most suitable finishing agents for medical wears with barriers against microorganisms and blood. To carve a niche for textile materials, this kind of value adding finishes are the need of the hour.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks to the management, PSG Institutions; Dr S Vijayarangan, Principal, PSG College of Technology, Coimbatore, and Dr B Sampathkumar, Principal, PSG College of Arts and Science for providing facilities to publish this paper. The authors are also grateful to Dr A Venkatachalam, Professor and Head of the Department of Textile Technology, PSG College of Technology, for his valuable support in bringing out this paper.

REFERENCES

1. H Mucha, D Hoter and M Swerev. 'Antimicrobial Finishes and Modifications.' *Melliand International,* May 2002, vol 8, pp 148-151.

2. I Home. 'Antimicrobials Impart Durable Finishes.' *International Dyer,* December 2002, pp 9-11.

3. S Rajendran and S C Anand. 'Development of Versatile Antimicrobial Finish for Textile Materials for Health Care and Hygiene Applications.' *Bolton Institute,* UK.

4. D Gupta. 'Antimicrobial Finishing of Textiles.' www.resil.com.

5. E Menezes. 'Antimicrobial Finishing of Textiles.' *The Textile Industry and Trade Journal,* January-February 2002, pp 35-38.

6. S Zikeli. 'Bioactive Cellulosic.' *Textile Asia,* January 2003, pp 35-39.

7. Ha-Soo Seong, J P Kim and S W Ko. 'Preparing Chito-Oligosaccharides as Antimicrobial Agents for Cotton.' *Textile Research Journal,* vol 69, no 7, pp 483-488.

8. W Huang and K K Leonas. 'Evaluating a One-bath Process for Imparting Antimicrobial Activity and Repellency to Non-woven Surgical Gown Fabrics.' *Textile Research Journal,* vol 70, no 9, pp 774-782.

9. B Clemo. 'Applying Ultra Fresh.' *The Resilient,* pp 13-16.

10. Y Yang, *et al*. 'Durability of Some Antibacterial Treatments to Repeated Home Launderings.' *Textile Chemist and Colorist and American Dyestuff Reporter,* April 2000, vol 32, no 4, pp 44-49.

11. K Schatz. 'All-round Answer to Problem Microbes.' *International Dyer,* June 2001, pp 17-19.

12. T Wierzbowska, *et al.* 'Non-woven Fabrics of Bactericidal and Fungicidal Qualities from Biocide-modified Fibres.' *Asian Textile Journal,* December 2000, pp 95-98.