Studies on Fuel Properties of Refined Soybean Oil, Soybean Ethyl Ester and Their Blends with Diesel to Assess Usefulness as CI Engine Fuel

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The characteristic fuel properties of refined soybean oil, soybean ethyl ester as well as diesel-refined soybean oil and diesel-soybean ethyl ester blends in the proportions of 85:15, 75:25, 65:35 and 55:45 (v/v), respectively were studied. The viscosity, relative density, heat of combustion, cloud and pour point, flash point, ash content, carbon residue and acid values were compared with diesel to study their usefulness as CI engine fuel. The characteristic fuel properties of diesel-soybean ethyl ester blends were found to be close to that of diesel. The fuel properties were found to deviate more from diesel when higher proportions of refined soybean oil was blended with diesel.

Keywords: Soybean oil; Ethanol; Esterification; Diesel; Blends; Renewable fuel

INTRODUCTION

The continuing hike in global prices of crude oil has reflected an adverse impact on local economy of many countries, especially the oil importing countries posing a severe burden on their foreign exchange. Apparently vegetable oils have been gaining worldwide attraction as an alternative energy source because they are environment-friendly and renewable in nature. Moreover, it operates well in a conventional diesel engine with very few or no engine modifications and can also be blended with conventional diesel while still achieving substantial reductions in emissions. Yusuf, *et al*[1] determined the fuel properties of beef tallow, soybean oil, their ester and their blends with diesel fuel and ethanol. It was indicated that viscosity of soybean oil and beef tallow reduced from 28.08 cS and 51.15 cS to 4.06 cS to 4.11 cS after esterification. Blending to soybean methyl ester and methyl ester of tallow fat with ethanol in proportion of 63.35 (v/v) further reduced the visco-sity to 2.13 to 2.03 which was similar to that of diesel (2.07 cS). Sangha, *et al*[2] reported viscosity of linseed oil, sunflower oil and jatropha oil as 37.85 cS, 44.86 cS and 49.04 cS, respectively. The observed viscosity of methyl esters was reported to be 9.75 cS, 9.42 cS and 8.16 cS for linseed ester, sunflower ester and jatropha ester, respectively. Azian, *et al*[3] reported that viscosity is an important transport property of fluid and it strongly affects the flow behavior at different temperatures. Oils owe to their relatively higher viscosities to the intermolecular attraction of the long chains of the glyceride molecules. Therefore, oils containing triacylglycerols of low molecular weight are slightly less viscous than the oils of an equivalent degree of unsaturation containing only higher molecular weight triacylglycerols. Thus besides viscosity other characteristic fuel properties, such as, relative density, gross heat of combustion, flash point, cloud and pour point, ash content, total acidity need to be assessed to select a vegetable oil or ester for supplementation as CI engine fuel. In this study, the characteristic fuel properties of selected refined soybean ethyl ester and non-esterified refined soybean oil and their blends with diesel fuel were studied to compare their usefulness as diesel engine fuel.

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MATERIAL AND METHODS

The soybean ethyl ester of 5.03 cS viscosity and refined soybean oil of 35.4 cS viscosity were blended with diesel. Soybean ethyl ester of 5.03 cS viscosity was prepared by esterifying refined soybean oil. The esterification was performed at 6:1 molar ratio of ethyl alcohol and refined soybean oil. The refined soybean oil was preheated at 55°C for 20 min then reacted with ethyl alcohol for 1 h using 1% NaOH at 55°C. The ester formed was separated from glycerol by allowing a settling time of 24 h. The ester was washed with water for 3 times to remove traces of glycerol from ester. The diesel-soybean ethyl ester or diesel- refined soybean oil blends were prepared by mixing 15%, 25%, 35% and 45% of ethyl ester/oil with diesel on volume basis. The characteristics fuel properties, such as, relative density, kinematic viscosity, heat content, cloud point and pour point, flash point and fire point, ash content, carbon residue and total acidity of diesel, refined soybean oil, soybean ethyl ester, diesel ester blends and diesel-refined soybean oil blend were measured. The relative density at 15°C was determined in accordance with IS:1448 [P:32]:1992. A Redwood Viscometer No 1 was used for the measurement of kinematic viscosity. Kinematic viscosity in centistokes was calculated from time units as proposed by Guthrie[5]. The gross heat of combustion as per IS: 1448 [P:6] :1984 was determined using Isothermal Bomb Calorimeter. The cloud and pour point of fuels were determined as per IS: 1448 [P:10]: 1970 using the cloud and pour point apparatus. A Penskey Martin flash and fire point apparatus was used for measuring the flash and fire points of the fuel samples. The ash content was studied as per standard ASTM-D 482-IP 4 issued by Institute of Petroleum, London using an electric muffle furnace. Carbon residue of different fuels was determined by the method specified by ASTM-D 189-IP 13 of

Institute of Petroleum, London. The acid values of different fuels were measured in terms of total acidity as per ASTM-D 974-IP 1/64 of Institute of Petroleum, London.

RESULTS AND DISCUSSIONS

Viscosity

The viscosity of liquid is an important characteristic as it determines the ease of flow through pipelines, injector nozzles and orifices and formation of fuel in the cylinder. The viscosity of refined soybean oil, soybean ethyl ester and diesel fuel was observed to be 35.4 cS, 5.03 cS and 2.94 cS, respectively and is shown in Table 1. The viscosity of diesel-soybean ethyl ester and diesel-refined soybean oil blends mixed in 85:15, 75:25, 65:35 and 55:45 proportions were observed to be 3.5 cS, 3.86 cS, 4.24 cS and 4.91 cS and 4.91 cS and 4.22 cS, 5.66 cS, 6.71 cS, and 8.64 cS, respectively. The viscosity of soybean oil was found to be extremely high compared to soybean oil ester and the diesel fuel. The higher viscosity of refined soybean oil could be attributed to its molecular composition and structure, increased carbon chain length and reduced number of double donds compare to diesel fuel as suggested by Goering, *et al* [6]. Peterson and Auld[7] reported that plant oil ester were only 1.5 times to 2.5 times more viscous than diesel fuel. The esterified refined soybean oil used in the experiment had viscosity lower than that of refined soybean oil but higher than the diesel-soybean oil ester blends. It is also evident from the table that the viscosity within the blends increased as the percentage of ester increased in the blend. The result indicated that the viscosity of soybean oil was 12 times that of diesel fuel. The viscosity of soybean ethyl ester was 1.7 times that of diesel. The diesel-soybean ethyl ester blends and diesel-refined soybean oil blends were found to have their viscosity 1.43 times to 2.94 times higher than the diesel. The Indian Standard recommends the range of the viscosity of diesel from 2 cS to 7.5 cS for use in high speed diesel engines. The comparison of viscosity of oil, its ester and their blends suggest that soybean ethyl ester can be blended with diesel in any proportion to meet the viscosity requirement as proposed by Bureau of Indian Standards where as blending of refined soybean oil with diesel could be to a certain limit, *ie*, up to 35% so as to maintain viscosity within the prescribed limit.

Relative Density

The density of fuel is correlated with particulate emissions. Mullions[8] reported that increase in density of fuel increases particulate matter emissions. Table 1 shows the observed values of different fuel samples. It is evident from the table that the relative density of refined soybean oil, soybean ethyl ester and diesel fuel were 0.9269, 0.8330 and 0.8162, respectively. The relative density of diesel-soybean ethyl ester and diesel-soybean oil blends were 0.8165, 0.8201, 0.8326 and 0.8330 and 0.8203, 0.8311, 0.8345 and 0.8445, respectively for the blends prepared in 85:15, 75:25, 65:35 and 55:45 proportions. The observed values indicate that the relative density of diesel-soybean ethyl ester blends were less or closer to that of diesel fuel while the relative density of diesel-soybean oil blends were higher than that of diesel fuel. For the diesel-ethyl ester blends and diesel-refined soybean oil blends the relative density increased with the increase in volume of either ester or oil within the blend. On the basis of above it can be suggested that all diesel-soybean ethyl ester blends and diesel-refined soybean oil blends mixed in 85:15 to 75:25 proportion could be selected as alternate to diesel.

Heat of Combustion

The heat of combustion or calorific value of a fuel is an important measure since it is the heat produced by the fuel within the engine that enables the engines to do the work. Table 1 shows that the observed gross heat of combustion of refined soybean oil, soybean ethyl ester and diesel was 37.20 MJ/kg, 40.02 MJ/kg and 45.70 MJ/kg, respectively. The gross heat of combustion of diesel- soybean ethyl ester and diesel-soybean oil blends were 44.2 MJ/kg, 43.1 MJ/kg, 42.0 MJ/kg and 42.0 MJ/kg and 41.9 MJ/kg, 40.9 MJ/kg, 39.4 MJ/kg and 38.7 MJ/kg, respectively for the blends of 85 : 15, 75 : 25, 65 : 35 and 55 : 45 proportions. It is evident from the table that gross heat of combustion of refined soybean oil was less than that diesel. The decrease in gross heat of combustion could be attributed to the presence of few hydrogen atoms in the molecule as suggested by Georing, *et al* [6]. Esterification of soybean oil into ethyl ester increased the gross heat of combustion of soybean oil but was still less than that of diesel. The gross heat combustion of diesel-soybean ethyl esters were found to be close to that diesel fuel.

Table 1 Characteristic fuel properties of fuel samples

Fuel Properties	Diesel	Refined Soybean Oil	Soybean Ethyl Ester	Diesel-Soybean Ethyl Ester Blend				Diesel-Soybean Oil Blend			
				85 : 15	75 : 25	65 : 35	55 : 45	85 : 15	75 : 25	65 : 35	55 : 45
Kinematic Viscosity at 38°C, cS	2.94	35.36	5.03	3.50	3.86	4.24	4.91	4.22	5.66	6.71	8.64
Relative Density at 15°C	0.8162	0.9269	0.8330	0.8165	0.8201	0.8326	0.8330	0.8203	0.8311	0.8345	0.8445
Heat of Combustion, MJ/kg	45.7	37.2	40.02	44.2	43.1	42.0	42.0	41.9	40.9	39.41	38.74
Cloud Point, °C	7	– 9	15	10	10	10	11	5	5	6	6
Pour Point, °C	– 8	– 12	5	– 8	– 8	– 8	– 7	– 7	– 7	– 5	– 5
Flash Point, °C	53	284	55	54	54	55	55	67	67	71	77
Fire Point, °C	59	290	60	59	59	60	60	74	74	77	84
Acid Value, mg of KOH/g	0.22	0.53	0.27	0.24	0.25	0.27	0.27	0.40	0.40	—	—
Ash Content, %	0.0005	0.17	0.0049	0.0035	0.0046	0.0075	0.0012	0.0051	0.0059	0.012	0.013
Carbon Residue, %	0.17	7.25	0.48	0.25	0.30	0.37	0.48	0.50	0.81	1.165	1.75

Cloud Point and Pour Point

The cloud point and pour point are important in predicting the temperature at which the fuel is sufficiently fluid to be transferred. Therefore, they are of great importance to engine operating in cold climate. Both properties may also indicate the tendency towards filter plugging and flow problems in the fuel line. Table 1 shows that the observed values of cloud point of refined soybean oil, soybean ethyl ester and diesel was – 9°C, 15°C and 7°C, respectively. The cloud point of diesel-soybean ethyl ester and diesel-soybean oil blends were 10°C, 10°C, 10°C and 11°C and 5°C, 5°C, 6°C and 6°C, respectively for 85:15, 75:25, 65:35 and 55:45 proportions of blending. It is evident from the table that the cloud point of ester was significantly higher than diesel and refined soybean oil but was within the limits of cloud points suggested for vegetable oils (20°C maximum) by Hawkins and Fuls[10]. The blend of refined soybean oil and diesel have cloud points lesser or closer to that of diesel where as the blends of soybean ethyl ester and diesel have higher cloud points which could be a problem for cold start.

The trend of pour point was similar to that of cloud point. The pour point of refined soybean oil, soybean ethyl and diesel were found to be – 12°C, 5°C and – 8°C, respectively. The pour point of diesel-soybean ethyl ester and diesel soybean oil blends were – 8°C, – 8°C, – 8°C and – 7°C and – 7°C, – 7°C, – 5°C and – 5°C, respectively for the 85:15, 75:25, 65:35 and 55:45 proportion of blending. The pour point of soybean ethyl ester was found higher than both of diesel and soybean oil. The cloud point of blends of diesel-soybean ethyl ester and diesel soybean oil blends were less or closer to that of diesel.

Flash Point

Flash point measure the tendency of the sample to form a flammability mixture with air. This is the property which shall be considered in assessing the over all flammability and hazard of fuel. Flash point can indicate the possible presence of highly volatile and flammable material in relatively non volatile material. The fire point is an extension of flash point in a way that it reflects the condition at which vapour burns continuously for five second. Table 1 shows that the flash point of refined soybean oils, soybean ethyl ester and diesel fuel was 284°C, 55°C and 53°C, respectively. The flash point of diesel- soybean ethyl ester blends and diesel-soybean oil blends were 54°C, 54°C, 55°C and 55°C and 67°C, 67°C, 71°C and 77°C, respectively for the 85 : 15, 75 : 25, 65 : 35 and 55 : 45 proportion of blending. The flash point of soybean oil was observed to be much higher than that of diesel. Esterification of refined soybean oil was found to significantly reduce the flash point of soybean oil to almost that of diesel. The flash point of the blends of soybean ethyl ester and diesel were lower than those of soybean oil blends with diesel.

Ash Content

Table 1 shows that the percent ash content of refined soybean oil, soybean ethyl ester and diesel was 0.17, 0.0049 and 0.0005, respectively. The ash content of diesel-soybean ethyl ester blends and diesel-refined soybean oil blends were 0.0035, 0.0046, 0.0075, 0.012, 0.0051, 0.0059, 0.012 and 0.013, respectively for the proportions mentioned earlier. The ash content of soybean oil was observed to be higher than that of diesel. The increase in ash content could be attributed to long chain of hydrocarbon of fatty acids. The ash content of diesel-soybean ethyl ester blends was lower than those of diesel-soybean oil blends. The ash content of both the blends was in the range of ash content specified by the Indian Standard[4] (0.01 max).

Carbon Residue

The carbon residue of diesel fuel correlates with the amount of carbonaceous deposits the fuel will form in the combustion chamber of the engine. The higher the carbon residue value, the greater the expected carbon deposits in the combustion chamber. Therefore, carbon residue is intended to provide some indication of relative coke-forming properties. The percent carbon residue to refined soybean oil, soybean ethyl ester and diesel fuel were 7.25, 0.48 and 0.17, respectively as shown in Table 1. The carbon residue of diesel-soybean ethyl ester and diesel-soybean oil blends was observed to be 0.25, 0.30, 0.37, 0.48, 0.50, 0.81, 1.165 and 1.75, respectively. It was observed that the carbon residue of soybean oil was 43 times that of diesel fuel. Esterification of soybean oil into soybean ethyl ester reduced the carbon residue but was still higher than diesel fuel. The carbon residue of diesel-soybean ester blends was lower than that of diesel-soybean oil blends. The ash content of both the blends was still higher than that of diesel.

Acid Values

Petroleum products may contain acidic constituents present as additives or as degradation products, such as, oxidation products during service. The acid value can be used as a guide in quality control of fuels. Table 1 shows that the observed acid value of refined soybean oil, soybean ethyl ester and diesel fuel was 0.53 mg, 0.27 mg and 0.22 mg of KOH/g, respectively. The acid values of diesel-soybean ethyl ester blends was 0.24 mg, 0.25 mg, 0.27 mg and 0.27 mg of KOH/g, respectively for the proportions of blending mentioned earlier. It was found that the acid value of different fuel samples of diesel-soybean ethyl blends was in the range recommended for diesel fuel by India Standard[4] (0.50 mg of KOH/g).

CONCLUSIONS

On the basis of observed fuel properties, the following conclusions may be drawn :

The use of refined soybean oil as diesel fuel depends on its characteristics fuel properties. The fuel property, such as, viscosity, ash content, carbon residue, flash point of refined soybean oil was found to be far greater that of diesel and therefore, make it unsuitable for use as fuel in diesel engines.

Esterification of refined soybean oil to ethyl ester brought the fuel properties closer to that of diesel. The viscosity of soybean ethyl ester was within the recommended limit. Blending the soybean ethyl ester with diesel further brought the properties to be close to diesel.

Soybean ethyl ester may be blended with diesel because the blends seems to have some of the major fuel characteristics, such as, viscosity, heat of combustion, density, ash content, carbon residue close to diesel.

The use of blends of diesel with soybean oil may be restricted to the lower proportions as the higher proportions tend to deviate more than diesel.

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