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Fuel properties of methyl ester of cottonseed oil blended with ethanol

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Abstract
In principle, an extensive range of vegetable oils as fuel alternatives found a special importance in the renewable energy research arena. Among these, methyl ester of cottonseed oil blended with ethanol would be an ideal fuel and examining properties of this fuel is a prerequisite for utilization in CI engine. As a cause, the methyl ester of cottonseed oil (MECSO) and ethanol was blended in the proportion of 100:0, 90:10, 80:20, 70:30, 60:40 and 50:50 on volume basis at room temperature for testing its properties. The fuel properties of formulated blends like kinematic viscosity, relative density, API gravity, calorific value, cloud and pour point, flash and fire point, carbon residue, ash content and copper strip corrosion tests were tested and found comparable with diesel. All conducted tests are discussed in the framework of Bureau of Indian Standards

Keywords: Biofuel, Ethanol, Fuel blends, Fuel properties, Methyl ester of cottonseed oil, Viscosity

Introduction
At present, Indian agriculture has been developing as an economic sector where energy plays a dominant role in getting the final output. While in the growing economy, the energy is a critical input from both fossil fuels and its derivatives. The energy generated with an optimum mix of primary resources could lead to achieve friendly environment and energy security which is the mandate of country's energy strategy. The petroleum fuels have been acting as a key in energy scenario of India and expected to be exhausted within next five decades if their use continues at the present pace.

Worldwide, most of the research mandate in energy sector seems to replace the fossil fuel by renewable fuels as a future perspective. As an omen for an alternative fuel, the use of biofuel is becoming more common worldwide. To provide the solution as an alternative fuel, a cottonseed oil has potential to produce a biofuel by transesterification process. Basically, cottonseed oil is obtained from seeds of cotton which is a byproduct of cotton and seldom used as cooking oil. Cottonseed oil is attracting significant attention as diesel substitute either in the form of the biofuel. It is possible to use cottonseed oil as an alternative supplementary fuel for a diesel engine (Recep *et al*., 2001; Rao and Mohan, 2003; Goering, 1981) [1-3]. For this reason, the usage of cottonseed oil as a fuel is an important alternative resource. It will be beneficial to utilize cottonseed oil in fuel production, especially in countries where cotton is used intensively in some industries (Karaosmanoglu *et al*., 1999) [4]. Also, alcohol especially ethanol known as a quality motor fuel which has potential remedy to the diminishing reserves of petroleum fuel. Use of ethanol in an engine can reduce carbon deposition on the injectors to allow engine running in a smoother way and keeps fuel injection systems clean for better performance. This happens due to some inherent detergent properties of ethanol and its lesser viscosity. Less carbon deposition leads to lowest abrasive wear of the cylinders and results in greater combustion efficiency (Meiring *et al*. 1983) [5]. The methyl ester of cottonseed oil and ethanol are supposed to be supplementary fuels to the diesel in the country. Therefore, the blending of these two at suitable proportion will be more appropriate to replace fossil fuel completely.

Drastically, the prediction of different fuel properties of any biofuel or its blends or diesel is important for the design of various systems of CI engine. Characteristics such as power output, combustion and exhaust emission are related to fuel properties. Different researchers have studied the fuel properties of biofuel by experimentally. Īlkiliç and Yücesu (2008) [6] produced methyl ester of cottonseed oil from the crude cottonseed oil and fuel properties like density and viscosity of methyl ester of cottonseed oil fuel decreased from 0.923 kg/*l* to 0.88

kg/*l* and from 34.89 cSt to 4.3 cSt respectively. The viscosity and calorific value of methyl ester of cottonseed oil were determined by Nabi *et al*. (2009) [7] which found, kinematic viscosity as 6.0 cSt at 40 °C and calorific value as 41.68 MJ/kg. İlkılıç and Aydın (2011) [8] conducted an experiment to find out the physical properties of cottonseed oil and its biofuel which found that, the viscosity and density of the oil decreased while the calorific value slightly increased. Therefore, the use of methyl ester of cottonseed oil on a CI engine is possible as comparable results with diesel fuel in terms of engine performance and emission characteristics. Also, it does not affect engine, bearing components and lubricating oil as well as it produces a comparable amount of carbon deposit.

Low-level mixing of ethanol can reduce the emissions and able to decrease the viscosity of the formulated mix (Fazal *et al*., 2011) [9]. Also, the fuel properties of cottonseed oil observed to meet the fundamental necessities of a diesel engine (Guangyi and Daren, 1987; Yarbrough *et al*., 1982) [10, 11]. Therefore, the study was planned to investigate the fuel properties of the methyl ester of cottonseed oil and its blends with ethanol which is the prerequisite to use it as biofuel in CI engine.

Materials and Methods

Materials

The refined cottonseed oil was procured from the local market of U.S. Nagar district of Uttrakhand, India. Thereafter, this oil was used to produce the methyl ester of cottonseed oil by transesterification process using process parameters given in Table 1 (Modi *et al*., 2017) [12]. The process followed as; the refined cottonseed oil was preheated at temperature of 65 ℃ and methanol and potassium hydroxide (KOH) were added. Then the mixture was stirred vigorously and kept for 60 min at suggested temperature (57 ℃) in shaking water bath. The mixture was allowed to settle down for 24 h. After transesterification the total mixture was separated into two layers. The upper layer was methyl ester of cottonseed oil and bottom layer was glycerol. The top layer was separated, washed with warm water and dried to get desired methyl ester of cottonseed oil. Another renewable fuel, ethanol (chemically known as ethyl alcohol) an oxygenated organic carbon compound was used as a part for the additive. If ethanol is in pure form, it is flammable, colourless liquid with a swe*et al*cohol odour. High speed diesel produced by Indian Oil Corporation was purchased, which was as per accordance of IS: 1460 [P: 10]: 1974. This was selected as the reference fuel for comparison with the prepared blends of methyl ester of cottonseed oil and anhydrous ethanol. The additives were prepared at room temperature (25 ℃) by simple blending from 0 to 50 % ethanol with methyl ester of cottonseed oil on the volume basis as shown in Fig. 1. Afterwards, the fuel blends were tested at Bio-Energy Laboratory of College of Technology, Pantnagar. Table 2 displays the property to be tested, the necessary apparatus to be used and test method applied.

Table 1: Transesterification process parameters selected to produce methyl ester of cottonseed oil (Modi *et al*., 2017) [12].

Process parameters	Optimum value
Molar ratio	6.9:1
KOH concentration	1.19 %
Reaction time	60 min
Reaction temperature	57 ℃
Settling time	24 h

Fig 1: Samples selected for fuel property test

Table 2: List of apparatus used for determination of fuel properties

Fuel Property	Apparatus	Test Method
Kinematic viscosity	Redwood viscometer	IS: 1448 [P: 25]: 1976
Relative density	Pyknometer	IS: 1448 [P: 32]: 1992
Gross heat of combustion	Bomb calorimeter	IS: 1448 [P: 6]: 1984
Cloud and pour point	Cloud and pour point apparatus	IS: 1448 [P: 10]: 1970
Flash and fire point	Pensky Martin flash point (closed) apparatus	IS: 1448 [P: 21]: 1992
Carbon residue	Carbon residue apparatus	IS: 1448 [P: 122]: 2013
Ash content	Electric muffle furnace	IS: 1448 [P: 4]: 1984
Acid value	Titration apparatus	Cox and Pearson, 1962
Copper strip corrosion test	Copper corrosion testing apparatus	IS 1448 [P: 15]: 2004

Fuel properties measurements

Kinematic viscosity

The kinematic viscosity is defined as a ratio of the dynamic viscosity to density of the liquid. It is generally expressed as cSt (centistoke) which is equivalent to 1 mm²/s. It was determined by using a Widson make Redwood Viscometer No. 1 at 38 ℃ fuel temperature. The working of the apparatus was based on the principle of measuring the time of gravity flow in seconds of a fixed volume (50 ml) of liquid through a specified hole in an agate piece as per IS: 1448 [P: 25] 1976. The empirical relation (Eq. 1) given by Nakra and Chaudhary, 1985 was used to calculate kinematic viscosity from time units as

$$\mathrm{K}\nu = At - \frac{B}{t} \qquad \text{(Eq.1)}$$

Where,
$\mathrm{K}\nu$ = Kinematic viscosity (cSt)
t = Time of efflux (s)
For Redwood viscometer A = 0.26 and B = 172.

Relative density and API gravity

The relative density of formulated blends at 15°C was determined according to IS: 144[P: 32]: 1992. The samples were filled in the pyknometers and weighed. In order to have weight of the test sample, weight of the empty pyknometer was subtracted from the weight of the filled one. Three replications were taken for each sample and there mean was calculated. The samples were maintained at 15℃ by placing them in a temperature control chamber and temperature of test oil was measured. The relative density was calculated by using Eq. 2

$$\text{Relative density} = \frac{\text{Density of fuel at } 15°C\,(\rho_f)}{\text{Density of distilled water at } 15°C\,(\rho_w)} \quad \text{(Eq.2)}$$

Where,
ρ_w = Density of water (0.9992 g/cc)
ρ_f = Density of fuel (g/cc)

The gravity of a fuel usually expressed in degrees API (American Petroleum Institute), a scale devised by the API indicates the lightness of the fuel and as its value increases, the fuel becomes lighter. To determine API gravity of selected fuels the following Eq. 3 was used.

$$\text{API degrees} = \frac{141.5}{\text{Relative density of fuel at } 15°C} - 131.5 \quad \text{(Eq.3)}$$

Calorific value

The calorific value of a test oil sample is important property because, the heat produced by the fuel inside the engine enables the engine to do the useful work. The calorific value of test oil samples was determined in accordance to IS: 1448[P: 6]: 1984, using a Toshniwal Microprocessor Bomb Calorimeter. The calorific value of the test oil samples was calculated using the Eq. 4

$$Hc = \frac{WC \times \Delta T}{Ms} \quad \text{(Eq.4)}$$

Where,
Hc = Calorific value of the test oil sample (cal/g)
WC= Water equivalent of the calorimeter (2283.32 cal/℃)
ΔT= Rise in temperature (℃)
Ms = Mass of test oil sample burnt (g)

Cloud and pour point

The cloud and pour point are the measure which indicates that the test oil sample is satisfactorily transferred by pump. Hence it holds significance to engines operating in cold climate. Both properties may indicate the tendency towards filter plugging and flow problems in the fuel line. The cloud and pour point of test oil samples were determined in accordance with IS: 1448 [P: 10]: 1970 by the cloud and pour point apparatus. The apparatus mainly consists of 12 cm high glass tubes of 3 cm diameter. These tubes were enclosed in an air jacket, which was filled with a freezing mixture of crushed ice and sodium chloride crystals. The glass tube containing test oil sample was taken out from the jacket at every 1℃ interval as the temperature falls and was inspected for cloud formation. The point at which a haze was first seen at the bottom of the sample was chosen as the cloud point. The pour point was taken to be the temperature 1℃ above the temperature at which no motion of test oil sample was observed for five seconds on tilting the tube to a horizontal position.

Flash and fire point

Ability of fuel sample to form a flammability mix with air at controlled laboratory condition measures the flash point. This is the property that must be taken care in assessing the complete flammability and hazard of the sample. Also, an existence of highly volatile and combustible material in comparatively non-volatile material is indicated by flash point. It is defined as the possible lowest temperature at which the test oil sample gives off sufficient vapors and ignites for a moment. The fire point is extended form of flash point which reflects the state at which vapor burns continuously for at least five seconds. The flash and fire point of the test oil samples were determined according to IS: 1448 [P: 21]: 1992 by a Pensky Martin flash point (closed) apparatus. The sample filled test cup was heated with the help of a heater by air bath. It was heated in such way that rate of temperature rise was approximately 5 ℃ per min which was stirred at a slow constant rate. At every 1 ℃ temperature rise, flame was introduced for a moment with the help of a shutter. The temperature at which a flash appeared in the form of a sound was recorded as flash point. The fire point was recorded as the temperature at which test oil sample vapors catches fire and stays for minimum of five seconds.

Carbon residue

Carbon residue gives an approximate measure of the carbon depositing possibility of a fuel remaining after evaporation and pyrolysis. It was determined with the help of IS: 1448 [P: 122]: 2013 and specified to provide indication of relative coke forming properties. Carbon residue was determined for different fuels by using a Khera make carbon residue apparatus. A moisture free 10 g weight of each fuel sample was taken in iron crucible of the apparatus. The fuel sample was then heated with a high strong flame from gas burner for 20 min. When the smoke appeared on the chimney, immediately the burner was moved or tilled so that the gas flame plays on the sides of the crucible for the purpose of igniting the vapors. The cover of skid more was then removed with a tong and it was cooled and weighed. The percentage of carbon residue on the original sample was then calculated using the Eq.5

$$Cr = \frac{Wc}{Ws} \times 100 \quad \text{(Eq.5)}$$

Where,
Cr = Carbon residue (%)
W_C = Weight of carbon residue (g)
W_S = Weight of the sample (g)

Ash content

The ash content is a measure of the mineral ash residue when a fuel is burned. Ash in a fuel can result from oil, water soluble material compounds or extraneous solids, such as dirt and rust. The ash content of selected test oil samples was measured by electric muffle furnace as per IS: 1448 [P: 4]: 1984. The sample was then placed in a muffle furnace and heated at 775±25 °C for two hours. The dish was then cooled to room temperature in desiccators and then weighed. The ash content was obtained using the Eq.6

$$A_s = \frac{Wa}{Ws} \times 100 \quad \text{(Eq.6)}$$

Where,
A_s = Ash content (%)

W_a = Weight of ash (g)
W_s = Weight of sample (g)

Acid value
Acid number is used to find the level of free fatty acids or processing acids that may be present in biofuel. Biofuel with a highest acid number has been shown to increase deposits in fuel system and may increase the chances for corrosion. Free fatty acids present in a vegetable oil may act as corrosive agent to some engine parts. At elevated temperature, free fatty acids react with many metals forms fatty acid metal salts which increases wear. The acid value defined as the mg of KOH required to neutralize the free fatty acid present in one gram of sample. The total acid value of different fuel samples was measured as per described method (Cox and Pearson, 1962). The procedure described below was followed in order to determine total acidity of various fuels selected for the study

- Dissolved 1 to 10 g of oil in 50 ml of the neutral solvent, neutral solvent was the mixture of 25 ml ether, 25ml alcohol and 1 ml of 1% phenolphthalein solution and neutralize with N/10 alkali in a 250 ml conical flask.
- Few drops of phenolphthalein were added.
- Titrated the contents against 0.1N KOH.
- Shake constantly until a pink color which persists for 15 seconds was obtained.

During the course of study, each sample was replicated three times. The total acidity of fuel sample was then calculated using the Eq.7

$$Av = \frac{56.1\ N \times Tv}{Ws} \quad \text{(Eq.7)}$$

Where,
Av = Acid value (mg of KOH/g)
N = Volume of KOH utilized in titration (ml)
T_v = Normality of the potassium hydroxide solution
W_s = Weight of sample (g)

Copper strip corrosion test
The presence of acids and or sulphur- containing compounds in biodiesel can lead to, among other problems, corrosion of nonferrous material such as copper, zinc, brass and bronze in an engine. The use of alternate fuels may pose a problem to the engine material especially when the fuel sample contains water or any oxygenate. The corrosiveness to copper was determined according to IS 1448 [P:15]: 2004 by using Widson make copper corrosion testing apparatus. A 30 ml of completely clean sample was put in chemically clean dry test tube and copper strip polished with the grit paper was slide in the sample tube with the lid of sample screwed tight. The completely tight sample bomb was immersed in a boiling water bath of the apparatus maintained at 100 °C. After completion of the test the bomb was opened and strip was withdrawn and inspected for tarnishing or corrosion by comparison with the copper strip corrosion standard chart. The colour of the strip was matched with the standard chart and the result was reported as the level of tarnishing or corrosion.

Analysis of fuel properties
Fuel properties of selected fuel blends were analysed and represented variation by mathematical equation and regression coefficient (R^2) from Fig 2 to. Fig 13. The mathematical equation was developed for each property using regression analysis by using data in Table 3. In all developed equations 'x' denotes the ethanol percentage in a particular fuel blends of methyl ester of cottonseed oil - ethanol. The Table 4 represent the mathematical relation between fuel properties and ethanol percentage in methyl ester of cottonseed oil.

Results and Discussion
Kinematic viscosity
The kinematic viscosity at 38 °C of selected fuel types in terms centistokes is presented in *Table 3*. *Fig. 2* shows variation of kinematic viscosity with increase in ethanol percentage. It is seen that the kinematic viscosity decreases linearly with an increase in the ethanol volumetric percentage in the methyl ester of cottonseed oil- ethanol blends. Also, the kinematic viscosity of blends 100:00, 90:10 and 80:20 was found to be higher than that of diesel. This was mainly due to the presence of higher percentage of methyl ester of cottonseed oil and also due to longer chain length of carbon in methyl ester containing free fatty acids and hydrocarbons. The observed values of kinematic viscosity for all the methyl ester-ethanol blends was found within the range as specified by Bureau of Indian Standard.

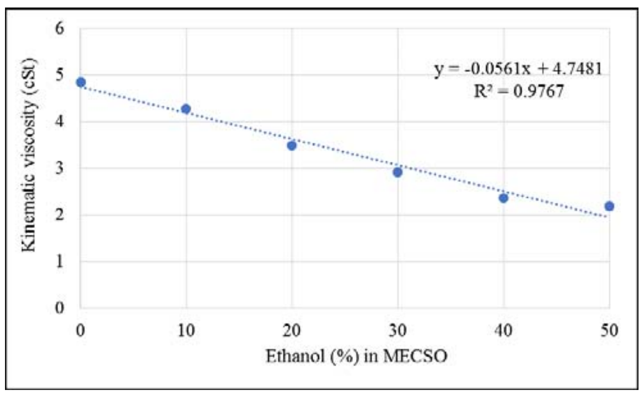

Fig 2: Variation in kinematic viscosity of methyl ester of cottonseed oil-ethanol blends

Table 3: Fuel properties of diesel, methyl ester of cottonseed oil-ethanol blends and ethanol

Fuel Properties	Measuring Unit	Diesel	Methyl ester of cottonseed oil: ethanol						Ethanol
			(100:0)	(90:10)	(80:20)	(70:30)	(60:40)	(50:50)	
Kinematic viscosity at 38 ˚C	cSt	3.18	4.85	4.27	3.49	2.92	2.37	2.18	1.11
Relative density at 15˚C	g/cc	0.821	0.874	0.865	0.853	0.848	0.840	0.824	0.786
API gravity	API degrees	40.90	30.43	32.09	34.38	35.31	36.86	40.31	48.54
Calorific value	MJ/kg	46.93	41.84	40.98	39.92	37.93	35.92	35.64	23.75
Cloud Point	˚C	-1	8.0	6.7	5.0	4.0	2.3	1.7	not visible
Pour Point	˚C	-6	4.0	3.0	0.7	-0.3	-1.0	-1.7	not visible
Flash Point	˚C	61	162.0	51.0	37.0	32.0	29.0	26.7	17.0
Fire Point	˚C	65	173.3	53.3	41.0	36.3	32.7	29.3	20.0
Carbon residue	%	0.185	0.559	0.510	0.430	0.349	0.297	0.204	-

Ash content	%	0.0033	0.0133	0.0071	0.0061	0.0058	0.0040	0.0026	-
Acid value	mg KOH/g of oil	0.23	0.60	0.52	0.47	0.43	0.34	0.33	Colour change was not visible
Copper strip corrosion test	Copper strip number	1a	1a	1a	1a	1a	1a	1a	1a

Relative density and API gravity

The relative density and API gravity of selected fuel types is shown in *Table 3*. From Fig. 3 it is seen that the relative density decreases linearly with an increase in the ethanol percentage (volume basis) in the methyl ester of cottonseed oil- ethanol blends. The relative density and API gravity of diesel used in the experiment was found to be 0.821 g/cc and 40.90 API degrees respectively. Methyl ester of cottonseed oil had relative density and API gravity of 0.874 g/cc (6.44% higher than that of diesel) and 30.43 API degrees respectively. Also, there was increasing trend in API gravity as ethanol percentage increased (Fig.4). While comparing the API gravity of all the selected fuel blends it was found to be 25.61 to 1.44 percent less than that of diesel. Therefore, the observations on relative density of selected fuel blends were found almost near to the diesel.

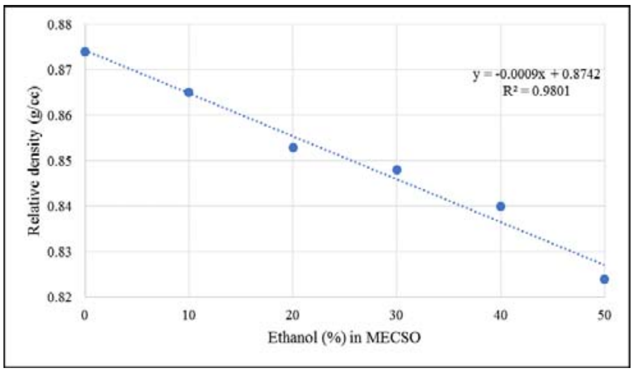

Fig 3: Variation in relative density of methyl ester of cottonseed oil-ethanol blends

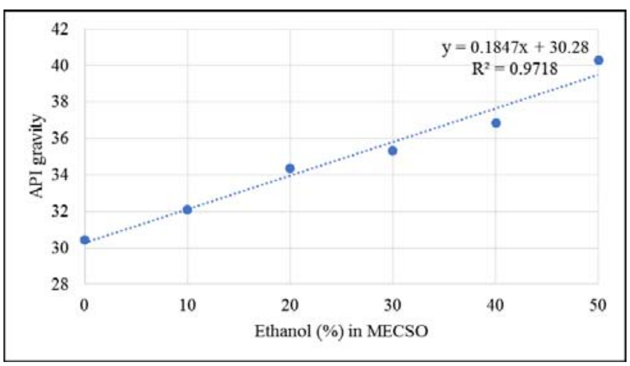

Fig 4: Variation in API gravity of methyl ester of cottonseed oil-ethanol blends

Calorific value

The calorific value of selected fuel types is shown in *Table 3*. A greater heat release from a hydrocarbon means a smaller fuel mass could be used to attain the same engine power output, thus more favorable. The calorific value obtained from the methyl ester of cottonseed oil was 41.84 MJ/kg, which was 10.84 percent lower than that of diesel (46.93 MJ/kg). From Fig. 5, it was observed that, there was linear and gradual decrease in calorific value with increase in ethanol content in methyl ester of cottonseed oil blends because of ethanol which had lowest calorific value (23.75 MJ/kg).

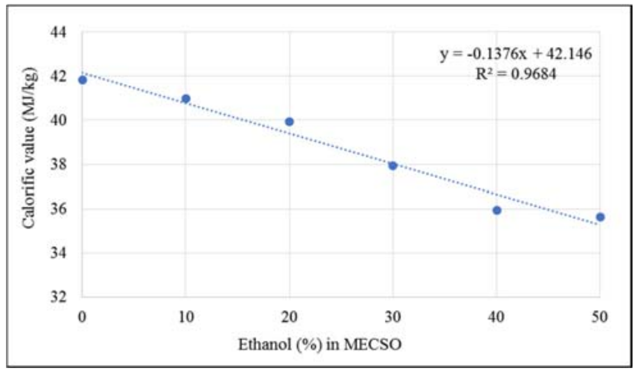

Fig 5: Variation in calorific value of methyl ester of cottonseed oil-ethanol blends

Cloud and pour point

Table 3 presents cloud and pour point and Fig. 6 illustrates the measurement of cloud and pour point of selected fuel types. The cloud and pour point of diesel was found as -1 and -6 ˚C respectively whereas for the methyl ester of cottonseed oil it was 8.0 and 4.0 ˚C respectively. From Fig 7 and Fig. 8 results shown that, as the percentage of ethanol in methyl ester of cottonseed oil increases, the cloud point and pour point decreases because of ethanol having lower value of cloud and pour point.

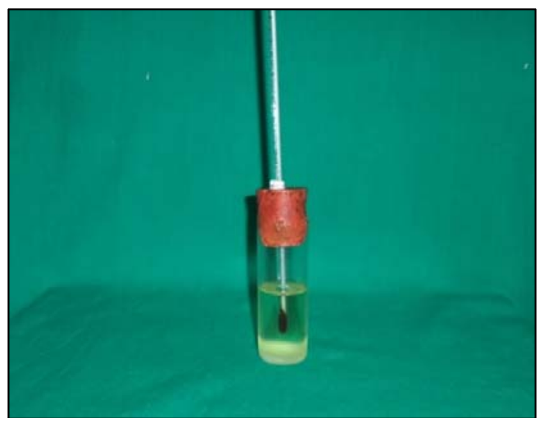

Fig 6: Measurement of cloud and pour point of selected fuel types

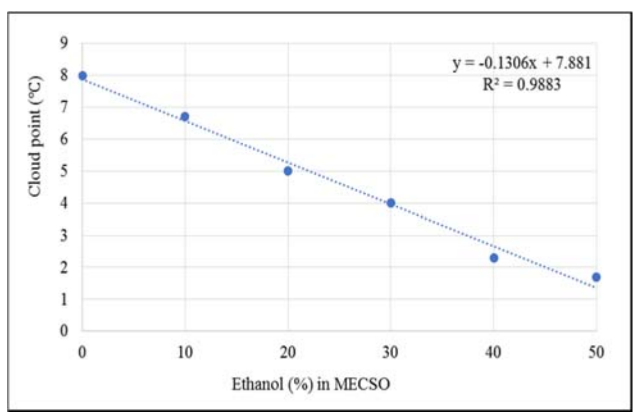

Fig 7: Variation in cloud point of methyl ester of cottonseed oil-ethanol blends

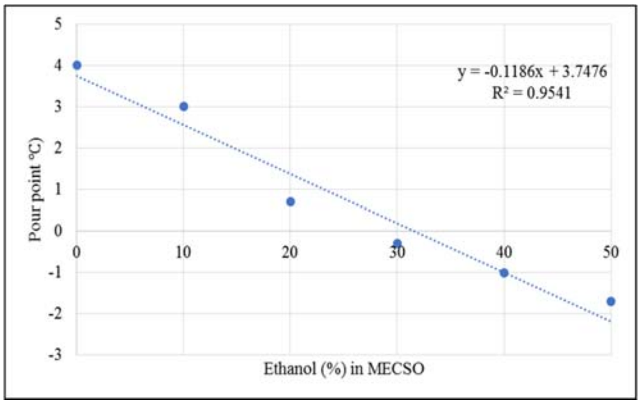

Fig 8: Variation in pour point of methyl ester of cottonseed oil-ethanol blends

Flash and fire point

The values of flash and fire point for methyl ester of cottonseed oil was observed as 162 and 173.3 °C respectively. From Table 3 the flash and fire point of diesel used in the experiment was found to be 61 and 65 °C respectively. Furthermore, by adding 10 per cent ethanol to the methyl ester of cottonseed oil the flash and fire point were abruptly reduced to 51 and 53.3°C respectively. Thereafter, the flash and fire point were steadily decreased as the ethanol percentage was increased, as depicted in *Fig 9* and *Fig. 10.* The maximum increase in flash and fire points of methyl ester of cottonseed oil was 165.5 and 166.6 per cent higher than that of diesel respectively. Fuels with a flash point above 62 °C can be considered to be safer fuels. Thus, methyl ester of cottonseed oil can be considered as a safe fuel for handling and storage.

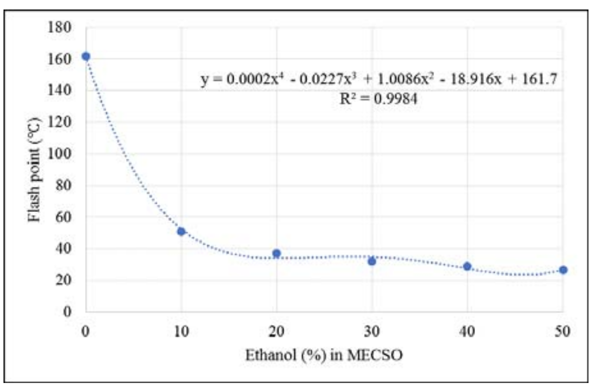

Fig 9: Variation in flash point of methyl ester of cottonseed oil-ethanol blends

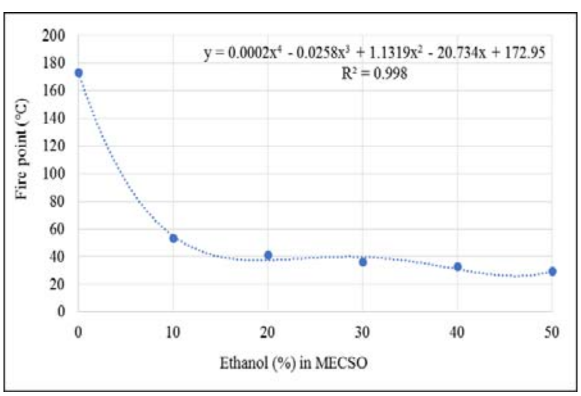

Fig 10: Variation in fire point of methyl ester of cottonseed oil-ethanol blends

Carbon residue and ash content

In this experiment the carbon residue of methyl ester of cottonseed oil used was found to be 0.559 per cent which was within the BIS limit. While the carbon residue content of diesel used was found to be 0.185 per cent. From *Fig.* 11 consequence of ethanol addition was that, as its percentage increases in methyl ester of cottonseed oil, the carbon residue content decreases. However, the ash content of methyl ester of cottonseed oil was found to be 0.0133 per cent which was 75.2 per cent higher than diesel. Ethanol addition in methyl ester of cottonseed oil resulted in gradual reduction in ash content. Ash content indicates quantity of residue metals in the fuel, it was revealed that ash content was affected by transesterification process which might came from the catalyst used.

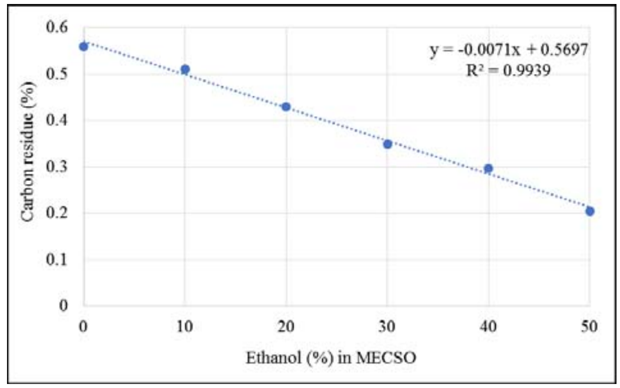

Fig 11: Variation in carbon residue of methyl ester of cottonseed oil-ethanol blends

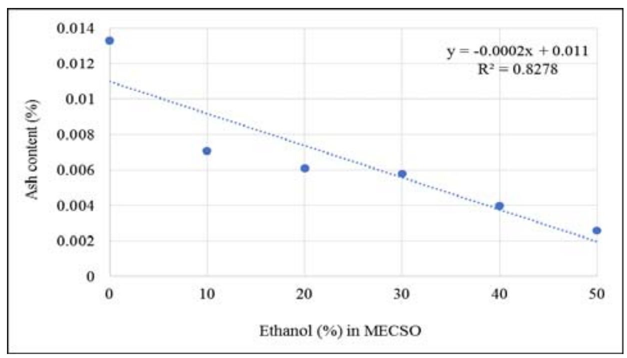

Fig 12: Variation in ash content of methyl ester of cottonseed oil-ethanol blends

Acid value

Acid value as seen from Table 3 the amount of acid value of neat methyl ester of cottonseed oil was 0.60mgKOH/g, which was higher than the 0.23 mgKOH/g of diesel. From Fig. 13 it is observed that, as the percentage of ethanol in methyl ester of cottonseed oil increases then the acid value decreases because lower acid value of ethanol.

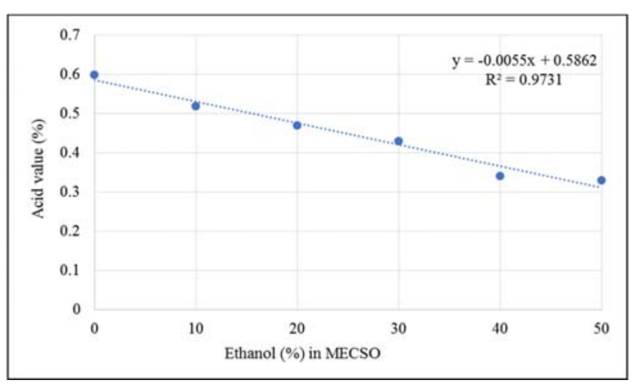

Fig 13: Variation in acid value of methyl ester of cottonseed oil-ethanol blends

Copper strip corrosion test

This test serves as a measure of possible difficulties with copper, brass, or bronze parts of the fuel system. It can be seen from Table 3 all the fuel types had similar copper strip corrosion to diesel as 1a (*Fig. 14*). The corrosion level of all the fuels was within the limit which has set the maximum limit of 3a.

Fig 14: Matching of copper strip colour with the standard chart

Table 4: Mathematical relation between fuel properties and ethanol percentage in methyl ester of cottonseed oil (x).

Sl. No.	Fuel Property	Measuring Unit	Mathematical relation	Regression coefficient (R^2)
1	Kinematic viscosity	cSt	$y = -0.0561x + 4.7481$	0.9767
2	Relative density	g/cc	$y = -0.0009x + 0.8742$	0.9801
3	API gravity	API degrees	$y = 0.1847x + 30.28$	0.9718
4	Calorific value	MJ/kg	$y = -0.1376x + 42.146$	0.9684
5	Cloud point	°C	$y = -0.1306x + 7.881$	0.9883
6	Pour point	°C	$y = -0.1186x + 3.7476$	0.9541
7	Flash point	°C	$y = 0.0002x^4 - 0.0227x^3 + 1.0086x^2 - 18.916x + 161.7$	0.9984
8	Fire point	°C	$y = 0.0002x^4 - 0.0258x^3 + 1.1319x^2 - 20.734x + 172.95$	0.998
9	Carbon residue	%	$y = -0.0071x + 0.5697$	0.9939
10	Ash content	%	$y = -0.0002x + 0.011$	0.8278
11	Acid value	mg KOH/g of oil	$y = -0.0055x + 0.5862$	0.9731

Conclusion

The fuel properties of methyl ester of cottonseed oil-ethanol fuel blends satisfy the limits of Bureau of Indian Standards. The viability found for the selected methyl ester of cottonseed oil-ethanol blends, ethanol up to 20% had kinematic viscosity at par with diesel fuel. Whereas, the relative density was slightly higher than that of diesel. Also, acid value and carbon residue of all selected blends was found more than that of diesel. It has been observed that, the calorific value of blends had nearest value while its flash point is higher than diesel fuel. Nevertheless, methyl ester of cottonseed oil can be considered as a safe fuel for handling and storage but at higher concentration of ethanol, storage problem may arise. The mathematical relations show higher coefficient of regression (R^2) between fuel properties and ethanol percentage in methyl ester of cottonseed oil. It was concluded that, the fuel properties of the blends were found to be suitable for use in compression ignition engine.

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