

A Study of Fuel Properties of Ternary Blend Fuels

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ABSTRACT: A number of studies currently focus on the renewable fuels to reduce the reliance on petroleum fuels. Bio fuels such as ethanol and biodiesel have been studied and tested in many countries including India. One of the methods to reduce the use of fossil fuel is blending ethanol and biodiesel with fossil diesel. The rice bran biodiesel (RBD) and Mahuva biodiesel (MBD) offers an alternative application as an emulsifier for diesel and ethanol blends. The present work is aimed to investigate experimentally the physic-chemical properties of the ternary fuel blend (diesel-ethanol-biodiesel) and compared with that of diesel fuel. We studied the fuel properties such as density, viscosity, heat of combustion, cetane number, flash point, pour point, cloud point, water and sediment, sulphur, ash, oxygen content of ternary blend. It was found that the fuel properties of ternary fuel blend were close to the standard values of diesel fuel. However, the flash point of the blends (20°C) was quite different from that of conventional diesel fuel (74°C) it is due to low flash point of the ethanol (13°C). The cetane index of the ternary blend (43) was same as that of diesel fuel (45). The heating value of the ternary blends (about 37000kJ/kg) were lower than the diesel fuel (42000kJ/kg), this is due to lower heating value of ethanol (26000kJ/kg). The fatty acid composition of ternary blend was analysed by Gas chromatography (GC), the functional group and characteristic absorption of the blended fuel was analysed by FTIR method. The blend level of the ternary blend was analysed by UV test.

KEYWORDS: Ternary blend, Bio fuel, Biodiesel, FTIR, UV, GC.

I. INTRODUCTION

For the past few decades, a lot of effort has been made to reduce the dependency on petroleum fuels for power generation and transportation all over the world. Among the proposed alternative fuels, biodiesel and alcohols have received much attention in recent years for diesel engines and could be one remedy in many countries to reduce their oil imports [S.A.Sahir 2014]. Biodiesel and alcohol have many advantages over regular diesel as renewable and domestically produced energy resources. Moreover, they are recognised as environmentally friendly alternative fuels [Istvan Barbas 2010]. Biodiesel can be used as a supplementary fuel in diesel engines and it will be implemented in automotive fleets and power genset diesel engines in near future in our country; however it is the major problem for use of biodiesel blends in unmodified or in-use engines, which can be overcome by modifying the fuel quality. Biodiesel is an alkyl ester of fatty acids made from a wide range of vegetable oils, animal fat and used cooking oil by the transesterification process. The researchers [K.A.Subramanian, et al 2014] have worked on the production of biodiesel from non edible feed stock, *Spirulina platensis* algae biomass.

The biodiesel can be considered as an alternative for compression ignition engines, but some of its properties (density, viscosity) are incompetent with diesel fuel. These properties can be improved by adding ethanol, which on one side improves the bio fuel content in mixture, and on the other side maintaining the properties as par with the diesel fuel. [Ludivine Pidl 2012]. Ethanol is used as an alternative fuel, a fuel extender, an oxygenate and an octane enhancer. Moreover, the use of ethanol can also increase farmer's income, because it can be produced domestically from many kinds of agricultural products such as sugar cane, molasses or cassava root. Generally, ethanol can be blended with diesel and can be used as a fuel with no engine modifications [Alan C.Hansen 2005]. However, a major drawback in diesel-ethanol blends is that ethanol is immiscible in diesel over a wide range of temperatures and water content. These can result in fuel instability due to phase separation. Prevention of this separation can be accomplished in two ways; by

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adding an emulsifier, which acts to suspend small droplets of ethanol within the diesel fuel, or by adding a co-solvent, which acts as a bridging agent through molecular compatibility and bonding to produce a homogeneous blend [S.Fernando 2004].

Biodiesels and ethanol alone cannot be used as an effective alternative fuel for compression ignition (CI) engines. Even diesel-biodiesel blends or diesel-ethanol blends will not fulfil the requirements of CI engines [PrommesK wanchareon 2007]. Hence an idea was generated for ternary blend fuel which is the mixture of diesel, biodiesel and ethanol with agreeable proportion

In the present investigation ethanol (99.1% pure), Rice bran oil biodiesel (RBD) and Mahuva biodiesel (MBD) were considered for investigation purpose. Rice is the main cultivation in subtropical southern Asia, and it is a staple food for the large part of the world's human population. Rice bran oil (RBO) is extracted from the germ and inner husk of the rice. Rice bran is mostly inner layer of rice grain which is heated to produce RBO [Subbaiah GV 2007]. RBO is not a common source of edible oil compared to other traditional cereal or seed sources such as corn, cotton, sunflower or soybean. One of the best ways for the potential utilization of RBO is the production of biodiesel.

Another biodiesel used is mahuva biodiesel; scientifically it is called as madhuca indica. It is abundantly available in the northern part of India. The seeds of madhuca indica are used to produce biodiesel by the transesterification process. The fractional replacement of the fossil diesel fuel with the combination of biodiesel and ethanol in compression ignition engines found to be successful as this blend has similar fuel properties like the commercial diesel fuel. Many scientists and investigators have studied this blend with different biodiesels and proportions of diesel, biodiesel and ethanol to study its suitability as a fuel in the existing CI engines.[Avinash Kumar 2007]. There is a little research on the ternary blend with Rice bran biodiesel (RBBBD) and Mahuva biodiesel (MBD). In present investigation the physico-chemical properties of two ternary blend fuels were determined. One is 70% diesel, 20% RBBBD, 10% ethanol (D70RBBBD20E10) and another is 70% diesel, 20% MBD, 10% ethanol (D70MBD20E10). The obtained properties were compared with that of diesel fuel for their suitability as an alternative fuel in compression ignition engines.

II. RELATED WORK

The properties of the diesel fuel-ethanol-biodiesel ternary mixtures were investigated using commercial diesel fuel, biodiesel produced from rice bran oil, mahuva oil and ethanol with purity 99.9%. The blends were obtained by mixing diesel, ethanol and biodiesel by (v/v %) in the proportions of 70%, 10%, and 20% respectively. This proportion was chosen by taking in to consideration of the recommendations from the literature [Istavan barbas, Cheenkachorn K 2010]. Many researchers have recommended that for the effective ternary diesel-ethanol-biodiesel blend the ratio of biodiesel to ethanol should be greater than 1:1, and the ethanol proportion was 5-10% [Pidol L, et al.2012]. Thus in this work the ratio of biodiesel to ethanol was 2:1, and ethanol proportion was 10%. Two different ternary blend samples were used for investigation: Diesel-Ethanol-Rice bran oil biodiesel (D-E-RBBBD) and Diesel-Ethanol-Mahuva biodiesel (D-E-MBD).

The blends were prepared in two steps: First biodiesel was blended with the ethanol and then diesel was added to the blend. All the three components were mixed in to a homogeneous mixture by a magnetic stirrer, and then the final blend was kept in a glass bottle with screw cap for observing the physical appearance. Laboratory tests were then carried out using ASTM test standards to determine the following properties: density, viscosity, gross heating value, flash point, pour point, cloud point, water and sediment, carbon residue, ash and sulphur content. The cetane number was calculated by the analytical method. The functional groups in the ternary blend were determined by the FTIR analysis. Fatty acid components were determined by gas chromatography method (GC). The absorption range of the ternary blends was determined by ultra violet test (UV). The basic fuel properties were determined in the laboratories of Bangalore test house Ltd. The ultra violet and gas chromatographic test were carried out in the laboratories of Indian Institute of science Bangalore. Bar charts were drawn to compare the fuel properties of pure diesel fuel, ethanol, rice bran oil biodiesel, mahuva biodiesel and D-RBBBD-E and D-MBD-E.

III. EXPERIMENTAL RESULTS

3.1 Density

Density is very important property of any fuel which affects the engine performance characteristics directly. Other properties like cetane number and heating value are also associated with density. Fuel atomization efficiency and combustion characteristics are influenced by its density. The variation of fuel density will affect the output power of the engine due to altered mass of the injected fuel. Generally higher density causes greater fuel flow resistance which results in higher viscosity which may lead to inferior fuel injection. [Alan C.Hansen. et al 2012]. Fig 3.1 shows the densities. The density of diesel fuel, ethanol, RBBD, MBD, D-E-RBBD, and D-E-MBD, are 0.848, 0.780, 0.945, 0.894, 0.850 and 0.840 g/ml, respectively. The density of the ethanol is inferior to the diesel fuel; whereas the density of the RBBD and MBD are greater than diesel fuel which compensates the density of the ternary blend. The density of the both ternary blends has same density as that of the diesel fuel; hence these blends can be used as an alternative fuel in diesel engines.

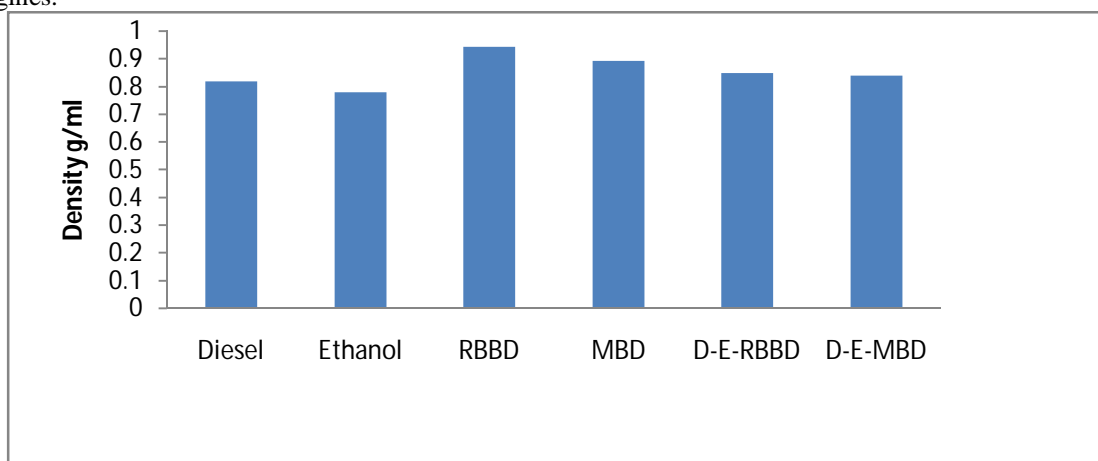


Fig.3.1. Density of the samples

3.2 Kinematic viscosity:

Viscosity is very important fuel property. It affects the fuel drop size, the jet penetration, quality of atomization, spray characteristics and the combustion quality. The operations of the injection systems in CI engines are also affected by viscosity [Barbas I, et al]. For every engine there is highest and lowest limit for the viscosity of a fuel for that engine. If very low viscous fuel is used, it could cause the fuel system leakage. It typically results in smaller mean droplet diameters, thereby increasing the surface area of the fuel droplets and significantly influences the evaporation characteristics time [Heywood JB] .on the other hand high viscosity of the fuel can cause, poor fuel atomization and incomplete combustion, increasing the engine deposits, requiring more energy to pump the fuel and causing the more problems in cold weather.

The viscosities of diesel fuel, ethanol, RBBD, MBD, D-E-RBBD and D-E-MBD are 2.5, 1.06, 29, 6, 3.6 and 2.6 CST respectively. The lower viscosity of ethanol in the blend was compensated with the higher viscosity of biodiesel. Hence the viscosity of the ternary blend was compensated and is same as diesel fuel. Thus ternary blends are suitable for diesel engines. From the fig.3.2 we can observe that the viscosity of the rice bran and mahua biodiesels are too high as compared with that of diesel fuel, hence it's not suitable to use these biodiesels in its pure form, hence the blend of diesel, ethanol and biodiesel of rice bran and mahua will give the viscosities same as that of diesel fuel. Hence these ternary blend fuels are more suitable for CI engines as an alternative fuels.

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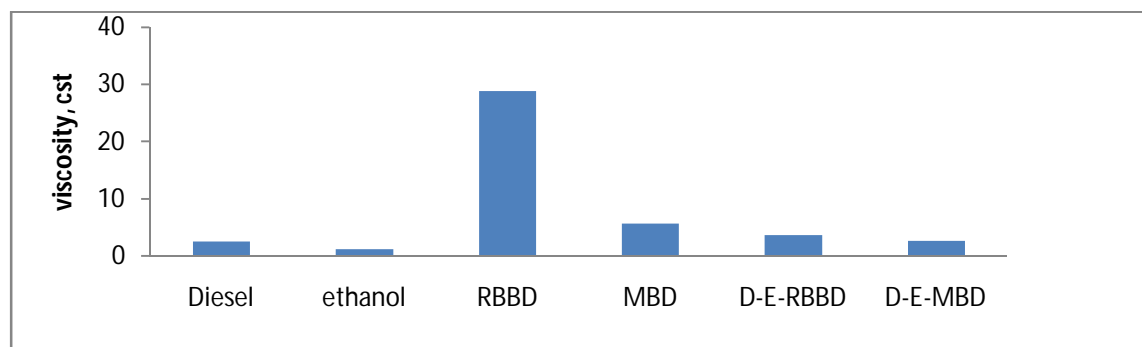


Fig.32. kinematic viscosity of samples.

3.3 Gross calorific values:

Gross heat of combustion or calorific value of the ternary blend sample was determined by the adiabatic bomb calorimeter with SI.no: 318062700 make MAC, using IS: 1448 PART-6 test standards. This instrument consists of: the bomb, the container of the water in which the bomb is placed and a surrounding compartment of temperature controlled water. A known mass of the ternary blend sample was taken in clean crucible. The crucible was then supported over the ring. A fine magnesium wire, touching the fuel sample, was stretched across the electrode. A cotton thread was made to attach with the magnesium wire and touches the fuel sample. The bomb lid was tightly screwed and bomb was filled with oxygen to about 20-25 atmospheric pressure. The bomb was then lowered in to copper calorimeter, containing a known mass of water. Electrical circuit is completed by connecting the electrodes to a 6-volt battery and stirring of the water was also started. Due to burning of the sample, heat is liberated. Uniform stirring of the water was continued and maximum temperature attained recorded. The heating values of diesel, ethanol, RBBB, MBD, D-E-RBBB and D-E-MBD are 42600, 26800, 38430, 39120, 37804 and 39891 kJ/kg, respectively. The calorific value of biodiesel and ethanol is less than the diesel fuel. Thus their addition to the diesel fuel lowers the calorific value of the final blend. Lower heating value leads to less power output of the engine, however, the ternary blends have heating value nearer to diesel fuel. Hence ternary blends can be effectively used as an alternative fuels for compression ignition engines to get the same power output.

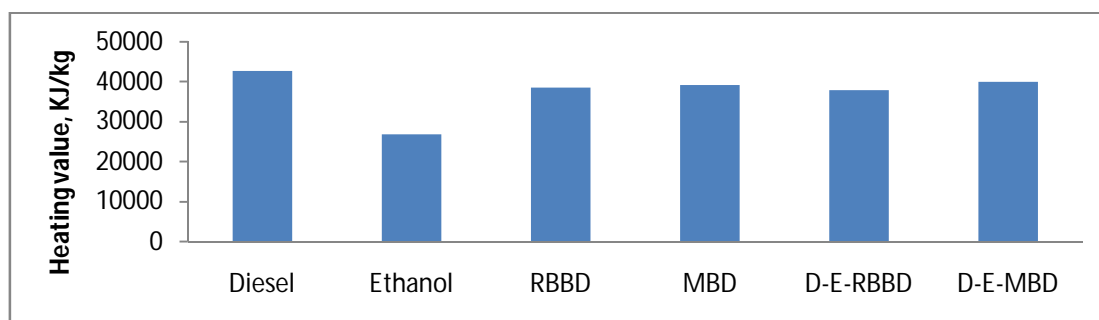


Fig.3.3. Gross calorific value of samples fuels.

3.4 Flash point:

Flash point gives an estimation of the temperature at which the vapour pressure reaches the lower flammable limit. It does not affect the combustion directly. High flash point of fuel makes it safer regarding its handling, transportation and storage. The flash point of diesel fuel, ethanol, RBBB, MBD, D-E-RBBB and MBD are 78, 13, 165, 157, 18 and

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20°C respectively. Due to the low flash point of ethanol, the flash point of the ternary blend also becomes very low. Hence ternary blends require special containers for its storage and transportation.

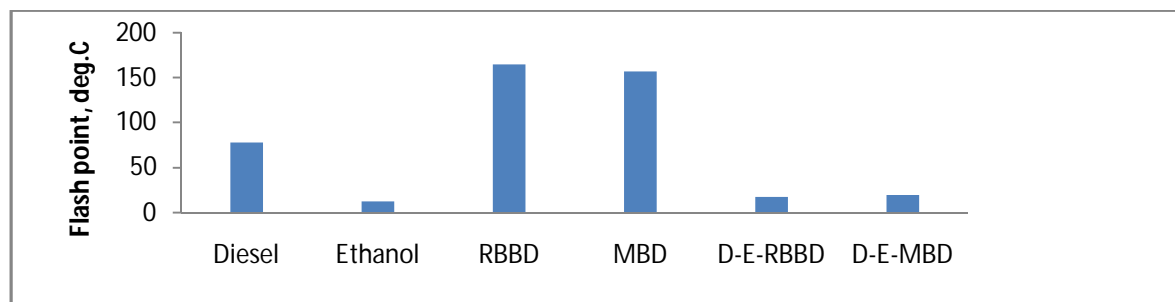


Fig.3.4. Flash point of sample fuels.

3.5 Cetane number:

As specified by the ASTM the minimum cetane number of the diesel fuel should be 40-45. The ethanol has low cetane number of 8. The RBBD and MBD have higher cetane number of 58 and 55 respectively.. Addition of ethanol to the diesel fuel lowers the cetane number of the blend it is due to lower cetane number of ethanol; the lower cetane number affects the combustion quality of a fuel in compression ignition engines. Addition of biodiesel compensates the cetane number of the ternary blend. The cetane number of ternary blends D-E-RBBD and D-E-MBD have 43 and 44 respectively. Since the cetane number of the ternary blends is in the same range of diesel fuel, hence these blends can be used as an alternative fuel in compression ignition engines.

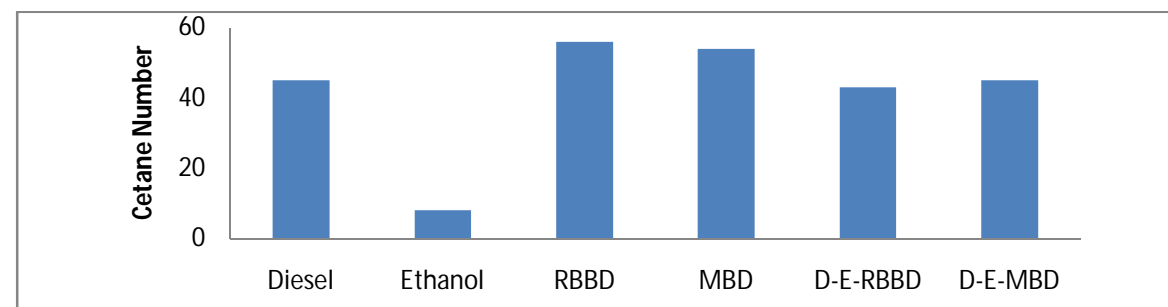


Fig.3.5. Cetane number of sample fuels.

3.6. Pour point:

The pour points of diesel, ethanol, RBBD, MBD, D-E-RBBD and D-E-MBD are 5, -8, 12, 10, -7 and -10°C, respectively. Biodiesel generally has a pour point higher than conventional diesel while the ethanol has a very low pour point. Due to the extremely low pour point of ethanol, its addition to the diesel fuel decreases the pour point of the final blend significantly. This is the major advantage of using ethanol in the ternary blends. Although biodiesel has high pour point (Max 12 °C) than the diesel and ethanol, it does not affect the pour point of final blend. As the temperature of the fuel approaches to its pour point it becomes cloudy due to the formation of crystals and finally the crystals solidify. This causes the major operability problems like cold start.

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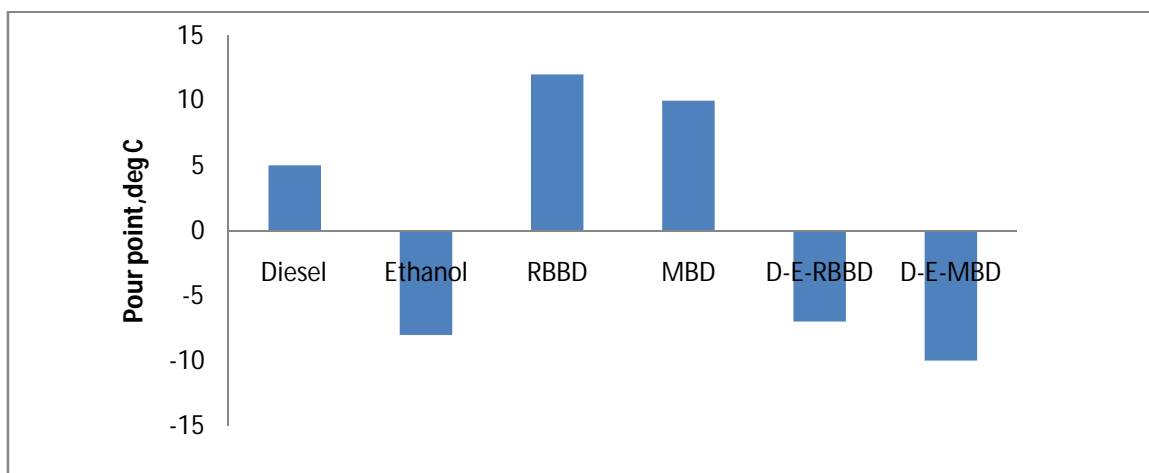


Fig.3.6. Pour point of sample fuels.

4. Gas chromatography:

The specifications regarding glycerol esters are analysed by GC using an FID in both ASTM D6751 methyl heptadecanoate is a common standard for fatty acid components. GC method utilizing a 30-m CARBOWAX column for fatty acid profile. The temperature programmes are starting out at 50°C and ending at 380°C. Generally, GC has been the most widely used method for the analysis of biodiesel owing to its generally higher accuracy in quantifying minor components. However, accuracy of GC analyses can be influenced by factors such as baseline drift, overlapping signals, and aging of standards and samples. Table 1 and Table 2 show various fatty acid compositions of ternary blends.

Table. 1. Fatty acid composition of Diesel-Ethanol-RBBB

Parameters	Chemical formula	Results %
Caproic Acid	-----	NIL
Caprillic Acid	-----	3.2
Capric Acid	-----	3.48
Lauric Acid	-----	3.18
Myristic Acid	C ₁₄ H ₂₈ O ₂	0.85
Palmitic Acid	C ₁₆ H ₃₂ O ₂	14.85
Stearic Acid	C ₁₈ H ₃₆ O ₂	1.84
Oleic Acid	C ₁₈ H ₃₄ O ₂	29.41
Linoleic Acid	C ₁₈ H ₃₂ O ₂	20.74
Linolenic Acid	C ₁₈ H ₃₀ O ₂	NIL
Archidonic Acid	C ₂₀ H ₄₀ O ₂	NIL
Behenic Acid	-----	NIL
Erucic Acid	C ₂₂ H ₄₂ O ₂	NIL
Lignoceric Acid	C ₂₄ H ₄₈ O ₂	NIL

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Table 2: Fatty acid composition of Diesel-Ethanol-MBD.

Parameters	Chemical formula	Results %
Caproic Acid	-----	NIL
Caprillic Acid	-----	4
Capric Acid	-----	4.18
Lauric Acid	-----	4.82
Myristic Acid	C ₁₄ H ₂₈ O ₂	2.70
Palmitic Acid	C ₁₆ H ₃₂ O ₂	5.21
Stearic Acid	C ₁₈ H ₃₆ O ₂	2.98
Oleic Acid	C ₁₈ H ₃₄ O ₂	15.98
Linoleic Acid	C ₁₈ H ₃₂ O ₂	33.71
Linolenic Acid	C ₁₈ H ₃₀ O ₂	NIL
Archidonic Acid	C ₂₀ H ₄₀ O ₂	NIL
Behenic Acid	-----	NIL
Erucic Acid	C ₂₂ H ₄₂ O ₂	NIL
Lignoceric Acid	C ₂₄ H ₄₈ O ₂	NIL

5. FT-IR:

FT-IR stands for Fourier Transform Infra Red, the preferred method of infra red spectroscopy. FTIR is a fast, cheap, reliable, accurate and non destructive method for bio fuel analysis it gives strong evidence that the bio fuel can be used as fuel. In infrared spectroscopy IR radiation is passed through a sample. Some of IR radiation is absorbed by the sample and some of it is transmitted. The resulting spectrum represents the molecular absorption and transmission, creating a molecular fingerprint of the sample. Like a finger print no two unique molecular structures produce the same infrared spectrum. This makes infrared spectroscopy useful for several types of analysis. FT-IR can provide the information about, it can identify unknown materials, it can determine the quality of a sample and it can determine the amount of components in a mixture. The FTIR analysis is done for D-E-RBBD and D-E-MBD ternary blends. Table 3 and Table 4 give the functional groups of D-RBBD-E and D-MBD-E respectively.

Table: 3 FTIR functional group frequencies of Diesel-Ethanol-Rice bran oil biodiesel.

Wave number (cm ⁻¹)	Type of Vibration	Functional group
2956.88	Stretch	O-H
2925.62	Stretch	O-H
2855.23	Stretch	O-H
1748.14	Stretch	C=O
1606.89	Bending	C=C
1461.10	Stretch	C=C
1377.57	Bending	C-H
1241.54	Stretch	C-O
1160.26	Stretch	C-H
1066.10	Stretch	C-O
722.27	Bending	=C-H

It is observed that the most abundant chemical group is O-H with stretch mode of vibration that show a peak at different band wave number of 2956.88 cm⁻¹, 2925.62 cm⁻¹, and 2855.23 cm⁻¹. And another abundant chemical group

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is C=C with both stretch and bending mode at wave number 1606 cm⁻¹ and 1461 cm⁻¹. The presence of C-H bending indicates prevalence of properties such as pour and cloud points that affect the performance during weather. The C=C cause the fuel to remain in liquid state but may be liable to possible oxidation during storage. C-O stretch reveals that the molecule contains ester functional groups.

Table: 4 FTIR functional group frequencies of Diesel-Ethanol-Mahuva biodiesel.

Wave number (cm ⁻¹)	Type of Vibration	Functional group
2925.16	Stretch	O-H
2854.16	Stretch	O-H
2729.79	Stretch	O-H
1746.50	Stretch	C=O
1606.98	Bending	C=C
1463.98	Stretch	C=C
1377.37	Bending	C-H
1169.16	Stretch	C-O
878.41	Stretch	C-H
810.35	Stretch	C-O
722.53	Bending	=C-H

It is observed that the most abundant chemical group is O-H with stretch mode of vibration that show a peak at different band wave number of 2925.16 cm⁻¹, 2854.16cm⁻¹, and 2729.79cm⁻¹. And another abundant chemical group is C=C with both stretch and bending mode at wave number 1606.98 cm⁻¹ and 1463.58 cm⁻¹. The presence of C-H bending indicates prevalence of properties such as pour and cloud points that affect the performance during weather. The C=C cause the fuel to remain in liquid state but may be liable to possible oxidation during storage. C-O stretch reveals that the molecule contains ester functional groups.

6. Ultra violet test:

The UV absorption spectra of the diesel-ethanol-biodiesel ternary blend samples were measured using a single-beam, general-purpose spectrophotometer. The absorption spectra in the range of 250to 350 nm at 1 nm intervals of different bio- diesel batches were scanned using standard 1 cm quartz cu- vette. The blend level (percentage of biodiesel in the ternary mixture) determines many important characteristics of the blended fuel. A higher-than-specified level of biodiesel may exceed the engine manufacturer's recommended limitation, compromising the engine performance. A lower blend level of biodiesel may reduce the expected benefits, such as lubricity and tail pipe emission. In addition, cloud point and pour point of biodiesel are usually higher than that of diesel fuel, and a higher blend level makes the fuel unsuitable or difficult to use in cold weather conditions. Engine injection timing can be adjusted based on the blend level in order to improve the engine emission and performance. It has been reported that the error in absorbance measurement is lowest if the absorbance value is below 2 (Bauman, 1962). In order to reduce the error, the dilution was completed in three steps; n-heptanes were used as a solvent. In each step 0.7 mL of sample was accurately mixed with 9.3 ml of n-heptanes. This dilution reduced the absorbance in the 250 to greater than 950 nm wavelength range to within 2.5 for both ternary blend samples.

IV. CONCLUSION

Following conclusions can be drawn out:

1. The density of the ethanol was lower than the diesel fuel, whereas the density of the biodiesels RBBDD and MBD are much higher than that of the diesel fuel, so these bio fuels cannot be used alone in the compression ignition engines (CI). The ternary fuel blends have density nearer to the diesel fuel which can be used as an alternative fuel in CI engines

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2. Kinematic viscosity of the ternary blend is nearer to the diesel fuel and can be used as an alternative fuel.
3. The gross calorific values (CV) of ternary blends were around 39000 to 40000 kJ/kg, which was nearer to CV of diesel fuel, 42000 kJ/kg. Hence it is suitable alternative fuel.
4. The flash point of the ternary blend fuel (13°C) was mainly influenced by the low flash point of ethanol (10°C). The lower the flash point higher the risk of storage and transportation, so ternary blend fuels requires special containers for storage and transportation.
5. The cetane number of the ternary blend fuels (43) was in the acceptable range (40-45) of diesel fuel.
6. The pour point and cloud points of the ternary blend were better values than the bio fuels (ethanol and biodiesels).
7. Water content, carbon residue, and sulphur, in ternary blend fuel was measured and they are 0.2% w/w, 0.07% w/w, and 0.002% w/w respectively.
8. There is no sediments and ash found in the ternary blend.
9. The physical appearance of the ternary blend fuels in the proportion of diesel 70%, ethanol 10% and biodiesel 20% was found to be very stable after 30 days, and was no phase separation.
10. The detailed FTIR, GC, UV analysis of the ternary blend fuels reveals the suitability and chemical stability of the fuel, which can be used effectively as an alternative fuels in CI engines.
11. The physical and chemical properties of the ternary blend fuels were more or less same as that of the diesel fossil fuel, hence this fuel can be effectively used as an alternative fuels if compression ignition engines.

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