Determination of optimum diesel: jatropha blend for compression ignition diesel engines through fuel properties analysis

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Abstract

The non-edible oil jatropha biodiesel is a diesel blend fuel source for the compression ignition (CI) diesel engines. Hence, the determination of the exact blending ratio of biodiesel to diesel fuel for best engine operation is needed through research. Keeping this in mind, this work investigated various acceptable jatropha biodiesel-diesel blends for diesel engines through fuel properties analysis. In this study, six different volumetric percentages of the biodiesel-diesel fuel samples were prepared. The percentage of the biodiesel was varied from 5 to 30% with a step of 5% by volume. The important properties required for engine operation like cloud and pour point, flash and fire point, density, viscosity and calorific value were measured under standard conditions. The average measured properties of biodiesel-diesel blends were compared with diesel fuel. The possibility of using 100% biodiesel in diesel engines without any modifications is also checked by comparing its properties with diesel fuel. The investigation revealed that the cold flow properties of diesel fuel such as cloud and pour point were improved with jatropha biodiesel blended fuels. Also, the results confirmed the good ignition quality and stability, energy content and atomization property of jatropha biodiesel blended fuels. The diesel and 20% jatropha biodiesel blending (B20) fuels showed an identical pour point temperature of -3.5°C . Similarly, B20 fuel has produced only 2.28% lower calorific value and 1.2% higher density as compared to diesel fuel. The other B20 fuel properties such as fire point, viscosity, flash point and cloud point were found within 7.44% to 12.5% higher than the diesel fuel. Hence, the study has recommended the B20 as the optimum blend fuel for CI diesel engines.

Keywords Jatropha biodiesel · Cold flow properties · Cloud point · Pour point · Diesel fuel

List of symbols

ASTM	American society for testing and materials
CI	Compression ignition
CP	Cloud points
IP	Institute of petroleum
kJ	Kilo Joule
$^{\circ}\text{C}$	Degree centigrade
cc	Cubic centimetre
CO_2	Carbon dioxide
cSt	Centi Stroke
JOME	Jatropha oil methyl ester
PP	Pour points
%	Percentage

1 Introduction and background

The compression ignition (CI) diesel engines use petroleum diesel fuel for its combustion and it exhausts carbon dioxide (CO_2) into the atmosphere which results in global warming. One of the methods to reduce the amount of CO_2 emissions from diesel engines is to reduce diesel fuel consumption by blending renewable fuels like biodiesel. The use of biodiesel in CI diesel engines improves fuel properties, engine operation and reduces CO_2 emissions. Although biodiesel also releases CO_2 during its combustion, it is fixed and recycled by plants [1, 2]. Jatropha curcas oil is a non-edible alternative liquid fuel for CI engines explored by some researchers in their work [3, 4]. They

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have concluded that the blending of the oil with diesel produced a better performance of the CI engines. However, to increase the performance of the CI engines further, the viscosity of the vegetable oil is to be reduced by removing fatty acids through the transesterification process [5–7]. Biodiesel produced from non-edible jatropha oil known as jatropha oil methyl ester (JOME) is a suitable fuel used in CI diesel engines directly or as a diesel blend. Due to its comparable diesel fuel properties, the JOME is used in CI diesel engines with little or no modification [8–10].

The common biodiesel blends tried to date range from 2 to 100% by volume [11]. The findings showed that a 20% biodiesel blend (B20) can be used in nearly all CI diesel engines. A higher blending ratio than B20 needs engine modifications as the engine piping systems clog up [12]. Also, B20 blends reduce exhaust emissions and improve engine performance [13]. The researchers have found a drastic reduction in exhaust emissions along with an improved performance from CI engines by using butanol as additives to diesel and vegetable oils [14, 15]. Several experiments were conducted on JOME blend in CI diesel engines and improved engine performance and reduced harmful exhaust emissions were reported [16–21]. Various studies showed that the blending of biodiesel changes the properties of diesel fuel blends [22–24]. The selection of the best blend of JOME with diesel depends on the biodiesel property. Hence, for regular and long-term use of diesel–biodiesel suitable blends in CI diesel engines, it is essential to evaluate blended fuel properties like pour and cloud point, flash and fire point and, viscosity, etc. [25, 26].

In general, pour points (PP) and cloud points (CP) of liquid fuels determine the behavior of diesel fuels in cold weather conditions. The cloud point is the temperature at which the first wax crystal is formed within the oil. Whereas, the pour point is the temperature at which the liquid flow ceases [24, 27, 28]. The flash point of liquid fuel is the lowest temperature at which an ignition source converts to vapor of the liquid. The fire point is the lowest temperature of the liquid at which vapor combustion and burning commences. The flash and fire points indicate the flammability quality of liquid fuels. Vegetable oils have high flash points than diesel fuels and hence, direct engine applications are difficult due to their poor vaporization and mixing properties. However, biodiesel has a comparable flash point with diesel fuel which allows for direct compression ignited diesel engine application. Viscosity, which offers resistance in between fluid layers, is an important property to predict the atomization and spray characteristics of suitable liquid fuel blends for engine operation. The property density decides the mass of fuel to be injected through the fuel injector. The calorific value of fuels demonstrates its energy content capability [29]. The viscosity

and density properties of vegetable oils have been measured and predicted through modeling and artificial neural network numerical analysis by some researchers [30, 31].

Therefore, the main aim of this work is to determine the optimum diesel-JOME blend range for CI engine operation without modifications. The study was done by evaluating and analyzing the properties like cloud and pour point, fire and flash point, density, kinematic viscosity and calorific value of diesel-JOME blends up to volumetric 30% of JOME biodiesel. These properties of diesel fuel and biodiesel blended fuels were compared and, the optimum diesel-JOME blend for CI diesel engine was established.

2 Materials and apparatus

The fuels used in this work, diesel and JOME biodiesel were procured from the local market. Six samples of the diesel-JOME blend were prepared with 5–30% JOME by volume. The fuel blend was prepared at room temperature with continuous mixing by a stirrer. The properties taken into consideration of characterization of these blends were cloud and pour point, flash and fire point, density, kinematic viscosity and calorific value. All the measurements were carried out three times and the average value was used for analysis. The blend properties were compared with the diesel fuel and JOME corresponding properties. The complete experimental design of fuels tested is presented in Table 1.

The fuel samples were tested as per the ASTM standards at the School of Mechanical Engineering laboratories of Vellore Institute of Technology Vellore, Tamil Nadu, India. Cloud and Pour Point temperatures were measured with apparatus available at Fuel Testing Laboratory according to the ASTM D-6751 and ASTM D-2500, D97 standards respectively. The fuel flash point and fire point measurements were conducted using a Pensky Martens Apparatus as per the ASTM D93–18 standards. Fuel samples of 50 cc were poured into a flash point cup for flash and fire

Table 1 Experimental design of fuels

Type of fuel	Fuel description	Designation of measurement
Diesel fuel	100% diesel fuel	B0
Diesel-JOME blend	95% diesel, 5% JOME	B5
Diesel-JOME blend	90% diesel, 10% JOME	B10
Diesel-JOME blend	85% diesel, 15% JOME	B15
Diesel-JOME blend	80% diesel, 20% JOME	B20
Diesel-JOME blend	75% diesel, 25% JOME	B25
Diesel-JOME blend	70% diesel, 30% JOME	B30
JOME biodiesel	100% JOME	B100

Table 2 Results of various fuel blend properties

Fuels	Testing method	B0	B5	B10	B15	B20	B25	B30	B100
Cloud point (°C)	ASTM D-6751	5.6	5.7	5.9	6.2	6.3	6.8	7	7.7
Pour point (°C)	ASTM D-2500, D97	−3.5	−3	−2.8	−3.1	−3.5	2.5	3.3	4.2
Flash point (°C)	ASTM D93–18	62	66	65	65	69	69	69	150
Fire point (°C)	ASTM D93–18	67	70	70	68	72	71	72	155
Density (kg/m ³)	ASTM D-1298	842	845	848	851	852	855	860	876
Kinematic viscosity (cSt) @40 °C	IP 70	8.53	8.59	8.68	9	9.25	9.51	10.65	11.4
Calorific value (kJ/kg)	ASTM D-240	41,600	41,350	41,100	40,850	40,650	40,300	40,100	36,800

Fig. 1 Effect of diesel-JOME blend on CP temperature **Fig. 2** Effect of diesel-JOME blend on PP temperature

point temperature measurements. The fuel viscosity was analysed as a function of temperature using a Redwood viscometer as per the standard Institute of Petroleum (IP) 70. The density of tested fuels was measured by using a density meter as per the standard ASTM D-1298. Similarly, the calorific value of fuels was recorded through a bomb calorimeter as per ASTM D-240 standard.

The measurement errors contributed by various instruments were calculated by using the sequential perturbation techniques [32, 33]. The estimated fuel properties were accepted to occur precisely within as following: cloud point ($\pm 3\%$), pour point ($\pm 3\%$), flash and fire point ($\pm 2\%$), calorific value ($\pm 1.5\%$), density ($\pm 0.5\%$) and kinematic viscosity ($\pm 1.5\%$).

3 Results and discussion

The designated fuel blends were tested in respective measuring instruments with ASTM standards and the average results of these fuel properties were recorded as given in Table 2.

3.1 Cloud and pour point

The effects of all six JOME-diesel blend fuels on cloud and pour point temperatures are illustrated in Figs. 1 and 2

Table 3 Summary of diesel-JOME blend performance

Type of fuel	Increase in CP (°C)	Increase in PP (°C)
B0	0	0
B5	0.1	−0.5
B10	0.2	−0.7
B15	0.6	−0.4
B20	0.7	0
B25	1.2	6
B30	1.4	6.8
B100	2.1	7.7

respectively. The CP and PP for diesel fuel were recorded as 5.6 and -3.5 °C respectively. For B100, the CP and PP were measured as 7.2 and 4.2 °C respectively. The CP and PP of diesel-JOME blends were found higher than that of only diesel case due to the higher CP and PP properties of JOME biodiesel. The CP temperature becomes higher with more volume% of the JOME blend. The effect of diesel-blend on CP and PP temperature are listed in Table 3.

The blends show less effect on the increase in values of CP as compared to that of diesel fuel when the

Fig. 3 Effect of diesel-JOME blend on flash point temperature

Fig. 4 Effect of diesel-JOME blend on fire point temperature

amount of JOME blend increased. The B20 blend has less than 1 °C increase in CP and its CP can be comparable with diesel fuel. The PP temperatures of diesel-JOME blends showed different behavior. Adding JOME to diesel fuel up to 15% by volume, the PP temperature reduced. However, when the JOME is blended more than 20% by volume, the PP temperatures increased sharply. The blend with B20 has the same PP temperature as diesel fuel. Hence, considering both CP and PP temperatures, B20 is the most effective blend for the CI diesel engines without any engine modifications.

3.2 Flash and fire point

The diesel-JOME blends have higher flash and fire point temperatures than diesel fuel as shown in Fig. 3 and 4 respectively. The increase in flash and fire points of diesel-JOME blends is considered as safe for fuel handling purpose. The B100 has resulted in the highest flash and fire points of 150 °C and 155 °C respectively as compared to diesel fuel of 62 °C and 67 °C. As observed from the Figure, the flash and fire points increase linearly with an increase in biodiesel composition up to B30.

Fig. 5 Effect of diesel-JOME blend on kinematic viscosity

Fig. 6 Effect of diesel-JOME blend on density

3.3 Kinematic viscosity

The increase in high viscous JOME volume% with diesel fuel increased the kinematic viscosity of all tested blends as shown in Fig. 5. However, the increase in viscosity compared to diesel fuel was marginal up to B20 blend and then after it was stiff increase with more volume of JOME with diesel fuel. It was observed that when the temperature increased the viscosity decreased for all the tested fuels. At all the temperature conditions, the trend of increase in viscosity was found similar for the B20 blend. The B20 blend has matched viscosity with diesel fuel and hence, it is the most suitable blend with diesel fuel which will produce good atomization of fuels with no delay in combustion.

3.4 Density

The density value indicates the energy content and ignition quality of the fuel. The density of biodiesel blend fuels was found higher as compared to diesel fuel (Fig. 6). As the JOME composition is increased, the density was also increased almost linearly with it. The increase in density of B20 is about 1.2% higher than that of diesel fuel which

Fig. 7 Effect of diesel-JOME blend on calorific value

is in the acceptable range to be a fuel for CI engines. This suggests that the mass of fuel injection of JOME blends and hence, engine power output is not going to affect significantly due to density property.

3.5 Calorific value

It presents the amount of energy content of the given fuel which decides the efficiency of the fuel. The calorific value of the diesel and JOME were measured as 41,600 kJ/kg and 36,800 kJ/kg respectively. For the JOME blend fuels, the calorific value was found to be decreased as compared to the diesel fuel but less linearly as shown in Fig. 7. For B20 fuel, the calorific value was found to be 40,650 kJ/kg which is only 2.3% less energy content than diesel fuel. This indicates that B20 can be used for CI engines without compromising much for fuel efficiency.

4 Conclusion

In this work, six diesel-JOME blended properties were evaluated as per the standards and compared with the diesel fuel. The current work underlines the following conclusion.

- A higher volume of JOME blending with diesel fuel produced a higher cloud point temperature. However, overall, the diesel-JOME blends didn't mark a significant difference to the cloud points of blended fuels.
- An increase in JOME volume% in blended fuels has resulted in a marginal increase in pour point up to B15. When JOME is added beyond 20 volume%, it caused a huge increase in the blended fuels. The PP temperature behavior of blended fuels is found dissimilar to CP's temperature.
- The pour point of B20 was found to be equal with diesel fuel confirms the best JOME volume% to be added with

diesel fuel for engine operation without affecting the fuel properties.

- All the tested blended fuels are safe to store due to their higher flash and fire points than that of diesel fuel.
- Kinematic viscosity of B20 was found almost equal quality with that of diesel fuel.
- B20 was found a promising fuel blend in terms of fuel energy content for CI engine operation.
- The study revealed that up to B20 the CI diesel engines can run with no modifications. Whereas, the use of B100 directly in CI diesel engines need some alterations in the fuel system.

5 Scope of future work

In this study, various important properties of fuel blends were measured to determine its feasibility to use in CI diesel engines. Phase stability of blended fuels at low temperature with cold filter plugging point (CFPP) and low temperature flow (LTFT) tests could be helpful to add the values in finalizing the optimum fuel blend at any temperature conditions of the engine. Simulation and experimental work on the CI engine with an optimum fuel blend have to be done to check actual performance. Hence, research is required in similar fields.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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