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Research Article

Experimental Investigation of Performance and Emission Characteristics of Mahua Biodiesel in Diesel Engine

S. Savariraj,[1] T. Ganapathy,[2] and C. G. Saravanan[3]

[1] *Annai Velankanni Polytechnic College, Siruvathur, Cuddalore, Tamil Nadu, Panruti 607110, India*
[2] *St. Anne's College of Engineering & Technology, Siruvathur, Cuddalore, Tamil Nadu, Panruti 607110, India*
[3] *Department of Mechanical Engineering, Faculty of Engineering, Annamalai University, Tamil Nadu, Annamalai Nagar 608002, India*

Correspondence should be addressed to T. Ganapathy, tganpati@gmail.com

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Biodiesel derived from nonedible feed stocks such as *Mahua*, *Jatropha*, *Pongamia* are reported to be feasible choices for developing countries including India. This paper presents the results of investigation of performance and emissions characteristics of diesel engine using Mahua biodiesel. In this investigation, the blends of varying proportions of Mahua biodiesel and diesel were prepared, analyzed compared with the performance of diesel fuel, and studied using a single cylinder diesel engine. The brake thermal efficiency, brake-specific fuel consumption, exhaust gas temperatures, Co, Hc, No, and smoke emissions were analyzed. The tests showed decrease in the brake thermal efficiencies of the engine as the amount of Mahua biodiesel in the blend increased. The maximum percentage of reduction in BTE (14.3%) was observed for B-100 at full load. The exhaust gas temperature with the blends decreased as the proportion of Mahua increases in the blend. The smoke, Co, and No emissions of the engine were increased with the blends at all loads. However, Hc emissions of Mahua biodiesels were less than that of diesel.

1. Introduction

The recent research shows renewed interest on biodiesel as fuel in diesel engines, although concept of using vegetable oil as engine fuel is as old as the engine itself. The lower cost of the petroleum diesel has so far attracted the world to use it as fuel in diesel engines until now. But nowadays due to global political turmoil and other reasons, the cost of petroleum diesel has been increasing exponentially. Moreover, the emission norms are more stringent as ever before. In this context, many biodiesels have been used by different countries, but only a very few and nonedible type such as Jatropha, Pongamia, and Mahua can be considered to be economically affordable to some developing nations like India in particular. Mahua biodiesel is one of the most promising biodiesel options among these. Mahua (*Madhuca indica*) is one of the forest-based tree-borne nonedible oils with large production potential of about 60 million tons per annum in India [1]. The kernel of the Mahua fruit contains about 50% oil, but the oil yield is 34–37% by small expeller. The expelled cake is relevant to recover the residual oil. As Mahua grows mainly in forest area, and also in waste and fallow land, its cultivation would not produce any impact on food production but would in long way improve the environmental condition by massive aforestation. Mahua oil is an underutilized nonedible vegetable oil, which is available in large quantities in India.

Many experimental studies of biodiesel as a diesel substitute have been reported in the literature [2–8]. Yet, experimental investigation of effects of Mahua biodiesel on diesel engine is seldom appeared. The major properties of Mahua biodiesel include calorific value, diesel index, flash point, fire point, cloud point, pour point, specific gravity, and kinematic viscosity. The various physicochemical properties of diesel and Mahua biodiesel are measured and listed in Table 1 for comparison. It can be noted that the calorific value of Mahua biodiesel is 3% less than that of diesel. This might be due to the presence of oxygen atoms in the fuel molecule of Mahua biodiesel. The specific gravity and kinematic viscosity are, respectively, 1.66% and 22.36% greater in the case of Mahua biodiesels than that for diesel. The higher specific gravity of Mahua biodiesel makes the fuel

Table 1: Comparison of properties between Mahua biodiesel and diesel.

Fuel properly	Unit	Diesel	Mahua biodiesel
Kinematic viscosity at 40°C	cSt.	4.56	5.58
Specific gravity at 15°C		0.8668	0.8812
Flash point	°C	72	174
Fire point	°C	80	185
Pour point	°C	−18	4
Cloud point	°C	−3	12
Diesel index		50.6	51.4
Calorific value	kJ/kg	42850	42293

spray narrow and its penetration deeper. The higher viscosity of Mahua biodiesel could potentially have an impact on the combustion characteristics because the high viscosity affects its atomization quality slightly. The higher diesel index value of Mahua biodiesel is conducive to low engine operating noise and good starting characteristics. The pour and cloud points of Mahua biodiesel are not favorable. However, the flash and fire points of Mahua biodiesel are much higher than that of diesel, which make Mahua biodiesel safer than diesel from ignition due to accidental fuel spills during handling. It can be seen that the properties of Mahua biodiesel are found to be within the limits of biodiesel specifications of many countries.

Many researchers investigated the effects of diesel-biodiesel blends on performance and emission characteristics in diesel engine and concluded that partial or full replacement of diesel with biodiesel is feasible [9–18]. However, the experimental study of performance and emission characteristics of Mahua biodiesel on diesel engine is hardly reported. Therefore, such an attempt is made in the present work, to experimentally investigate the performance (brake thermal efficiency, brake-specific fuel consumption, and exhaust gas temperature) and emission (carbon monoxide, unburned hydrocarbon, nitrogen oxides, and smoke) parameters of Mahua biodiesel and diesel-Mahua biodiesel blends as fuel in diesel engine.

2. Experimental Method

2.1. Test Engine. The present research work was carried out on a 5.2 kW, single cylinder, vertical, naturally aspirated, four stroke, water cooled, direct injection, constant speed, Kirloskar TV-1 diesel engine having the main technical features presented in Table 2. This engine has been widely used in agricultural lands irrigation applications. The main objective has been to study the performance and emission characteristics of Mahua biodiesel as fuel in diesel engine. For conducting the desired set of experiments and to gather required data from the engine, it is essential to get the various instruments mounted at the appropriate location on the experimental setup.

2.2. Experimental Setup. An experimental setup used in the present work is shown in Figure 1. The engine was loaded with an eddy current dynamometer. The mass flow rate of intake air was measured with an orifice meter connected to a manometer. A surge tank was used to damp out the pulsations produced by the engine, for ensuring a steady flow of air through the intake manifold. The fuel consumption rate was determined using the glass burette and stop watch. The engine speed was measured using a digital tachometer. An AVL 444 Di gas analyzer was used for measuring the exhaust gas components such as Co, Hc, and No. The smoke density was measured using AVL 413 smoke meter. The exhaust gas temperature was measured with k-type thermocouple.

Table 2: Test engine specifications.

Parameter	Specification
Engine model	Kirloskar TV-1
Engine type	DI, naturally aspirated, water cooled
Number of cylinders	1
Bore (mm)	87.5
Stroke (mm)	110
Displacement (cm^3)	661
Compression ratio	17.5
Maximu power (kW) at rated rpm	5.2
Rated rpm	1500
Injection pressure (bar)	220
Injection timing (°btdc)	23

Figure 1: Experimental setup.

Before starting the measurements, some important points should be considered in order to get meaningful data from the experiments. The engine was warmed up prior to data acquisition. The lubricating oil temperature was monitored to confirm that the engine was in a sufficiently warmed-up situation. Ambient conditions should be maintained for different engine runs because the ambient pressure and temperature have the effect on intake air drawn into the engine cylinder, there by changing the fuel-air mixing as well as combustion process. All the engine test runs were carried out in the fair constant ambient conditions. During the tests with Mahua biodiesel, the engine was started with diesel until

Table 3: List of measurements uncertainty.

Measurements	Accuracy	% uncertainty
Load	±10 N	±0.2
Speed	±10 rpm	±0.1
Burette fuel measurement	±0.1cc	±1
Time	±0.1s	±0.2
Temperature	±1°C	±0.1
Manometer	±1 mm	±1
Co	±0.06%vol	±0.2
No	±12 ppm	±0.2
He	±12 ppm	±0.2
smoke	±1%	±0.1

it warmed up. Then fuel was switched to Mahua biodiesel. After finishing the tests with Mahua biodiesel, the fuel was always switched back to diesel and the engine was run until the Mahua biodiesel had been purged from the fuel line, injection pump, and injector in order to prevent the starting difficulties at later time.

Initially the test engine was operated with base fuel-diesel for about 30 min to attain a normal working temperature condition after that base line data were generated and the corresponding results were obtained. The engine was then operated with blends of diesel and Mahua biodiesel (B-25, B-50, B-75, and B-100). At every operation the engine speed was checked and maintained constant. All the measurements were repeated thrice, and the arithmetic mean of these three readings was employed for calculation and analysis. The different performance and emission parameters analyzed in the present investigation were brake thermal efficiency (BTE), brake-specific fuel consumption (BSFC), exhaust gas temperature (EGT), carbon monoxide (Co), unburned hydrocarbons (Hc), nitrogen oxide (No), and smoke.

3. Error Analysis

Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading, and test planning. Uncertainty analysis is needed to prove the accuracy of the experiments. Percentage uncertainties of various parameters like total fuel consumption, brake power, brake-specific fuel consumption, and brake thermal efficiency were calculated using the percentage uncertainties of various instruments used in the experiment. For the typical values of errors of various parameters given in Table 3, using the principle of propagation of errors, the total percentage uncertainty of an experimental trial can be computed as

= Square root of ((uncertainty of tfc)^2 + (uncertainty of brake power)^2 + (uncertainty of specific fuel consumption)^2 + (uncertainty of brake thermal efficiency)^2 + (uncertainty of Co)^2 + (uncertainty of Hc)^2 + (uncertainty of No)^2 + (uncertainty of smoke)^2 + (uncertainty of EGT indicator)^2) = ± 2.1%.

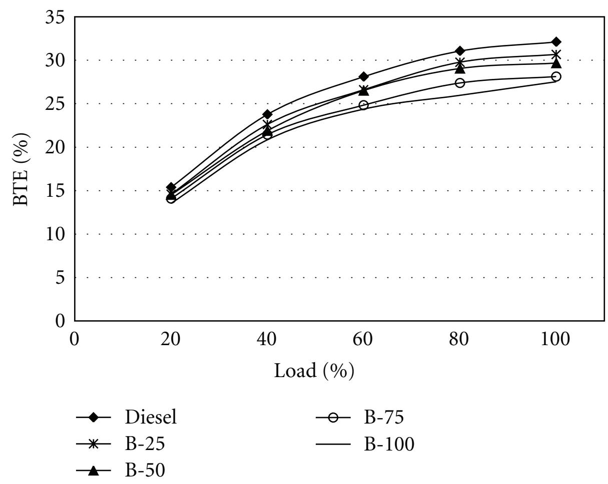

Figure 2: Comparison of BTE between diesel, Mahua biodiesel, and blends.

4. Results and Discussion

4.1. Performance Parameters

4.1.1. Brake Thermal Efficiency (BTE). It is evident from Figure 2 that the overall trends of BTE characteristics of Mahua biodiesel, diesel, and their blends are almost similar in nature. It is observed that at any given load condition, the brake thermal efficiency of neat Mahua biodiesel (B-100) and other blends (B-25, B-50, B-75) is lower than that of diesel operation. It can be seen that as the percentage of Mahua biodiesel in the blend increases, there is more decrease in brake thermal efficiency as compared to diesel fuel mode, that is, diesel operation. This lower BTE of Mahua biodiesel operation is due to the combined effect of higher viscosity, higher density and lower calorific value of Mahua biodiesel. The percentage decrease in brake thermal efficiency for B-25, B-50, B-75, and neat Mahua biodiesel operation at full load were 4.48, 7.6, 12.43, and 14.3, respectively. The maximum brake thermal efficiency observed were 32.1%, 30.7%, 29.7%, 28.1%, and 27.5% at this load for diesel, B-25, B-50,B-75, and neat Mahua biodiesel, respectively.

4.1.2. Brake-Specific Fuel Consumption (BSFC). Figure 3 shows the comparison of effect of load on brake-specific fuel consumption between diesel and Mahua biodiesel for different blend conditions. It is seen that brake-specific fuel consumption decreases when the load is increased for all operations of diesel and Mahua biodiesel and their blends. However, the rate of decrease in brake specific fuel consumption is more during lower loads up to 50% than that of higher loads (50 to 100%). It can also be observed that brake-specific fuel consumption increases when Mahua biodiesel proportion in the blend is increased for any given load, but the increase in brake-specific fuel consumption for B-100 operation (neat Mahua biodiesel) is much more than that of other blends and diesel operations at higher load conditions.

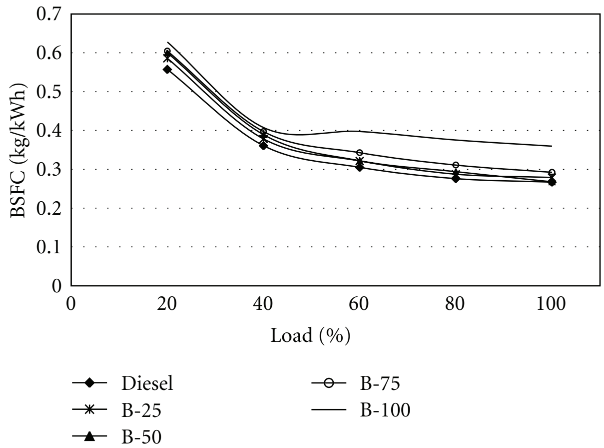

Figure 3: Comparison of BSFC between diesel, Mahua biodiesel, and blends.

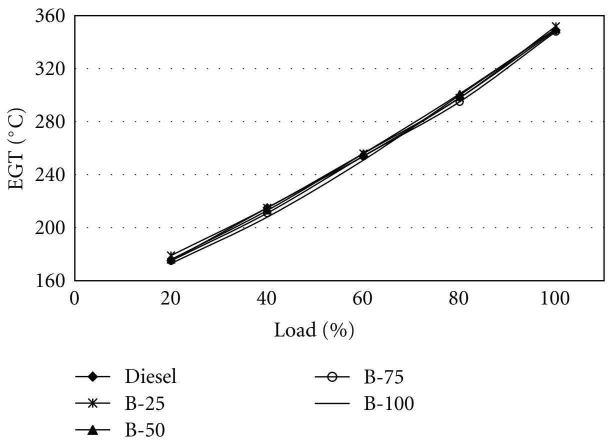

Figure 4: Comparison of EGT between diesel, Mahua biodiesel, and blends.

4.1.3. Exhaust Gas Temperature. The relationship between exhaust gas temperature (EGT) and load for different fuel blends and diesel has been shown in Figure 4. The results showed that with the increase in the load, EGT increased in all the blends of Mahua biodiesel and diesel operation. But EGT showed decreasing trend from B-25 to B-100 at a particular load. The minimum EGT at 20% load was found to be 179°C in B-25 and followed by 176°C for B50, 175°C for B-75, 173°C for B-100, and the lowest EGT is (173°C) for B-100. Similarly the EGT in case of B-25 and B-100 were found to be respectively 2% more and 1% less than the reference diesel fuel at 20% load condition. The increase in EGT with increase in load may be attributed to the increased cylinder pressure due to improved combustion of fuel as a result of improved atomization at warmed-up condition. The increase in EGT with increase in the proportion of Mahua biodiesel may be due to the delayed combustion. This may also be due to the slower combustion characteristics of Mahua biodiesel.

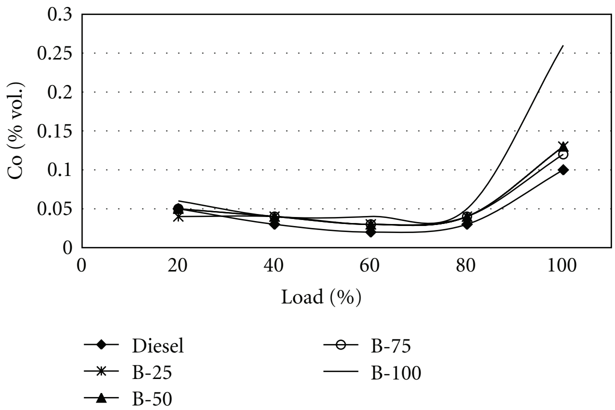

Figure 5: Comparison of Co emissions between diesel, Mahua biodiesel, and blends.

4.2. Emissions

4.2.1. Carbon Monoxide. The effect of load on carbon monoxide (Co) emissions for diesel, neat Mahua biodiesel, and their blends is shown in Figure 5. It can be seen from the figure that the higher Co emissions were obtained with blends of Mahua biodiesel and diesel and neat Mahua biodiesel mode of operation. The Co is 0.1, 0.13, 0.13, 0.12, 0.26% for diesel, B-25, B-50, B-75, and B-100, respectively, at 100% load. Higher Co emissions in the exhaust gas of the engine may be attributed to the polymerization that takes place at the core of the spray; this also caused concentration of the spray core and decreased the penetration rate [19]. Low volatility polymers affected the atomization process and mixing of air and fuel causing locally rich mixture, which leads to difficulty in atomization and vaporization of neat Mahua biodiesel due to improper spray pattern produced. This feature increases the incomplete combustion and hence higher Co emission.

4.2.2. Unburned Hydrocarbon. The effect of load on unburned hydro-carbon (Hc) emissions for diesel, neat Mahua biodiesel and their blends is shown in Figure 6. It can be seen from the figure that the lower Hc emissions were obtained with blends of Mahua biodiesel-diesel and neat Mahua biodiesel mode of operation for loads above 40%. The Hc emission is 42, 37, 39, 31, 32 ppm for diesel, B-25, B-50, B-75, and B-100, respectively, at 100% load. Lower Hc emissions in the exhaust gas of the engine may be attributed to the efficient combustion of Mahua biodiesel and blends due to the presence of fuel bound oxygen and warmed-up conditions at higher loads. Whereas at lower loads (up to 40%) higher Hc emissions were observed with blends of Mahua biodiesel-diesel and neat Mahua biodiesel operations. This is due to the reason that at lower loads the lower cylinder pressure and temperatures were experienced that was caused by lower rate of burning. This feature results in higher Hc emissions.

4.2.3. Nitrogen Oxide. Nitrogen oxide (No) is generally formed at a temperature higher than 1500°C. High temperature, especially in the regions containing O_2, and time spent

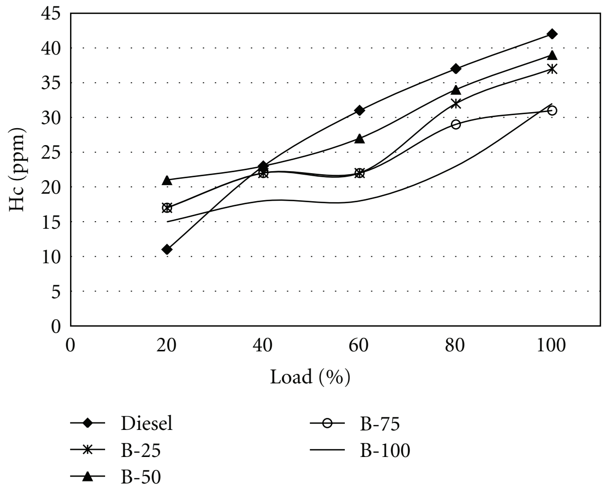

Figure 6: Comparison of Hc emissions between diesel, Mahua biodiesel, and blends.

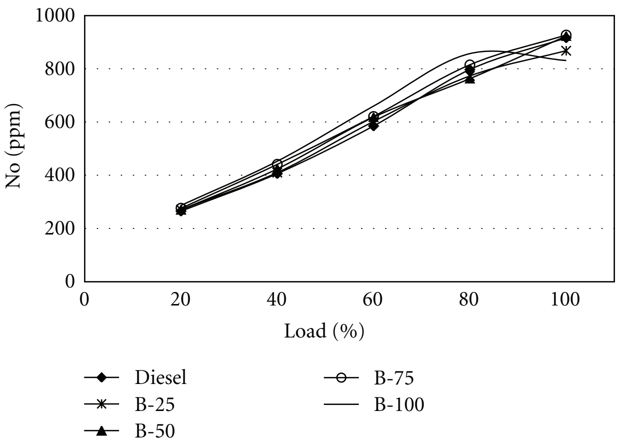

Figure 7: Comparison of no emissions between diesel, Mahua biodiesel, and blends.

at these temperatures are very conducive to no formation. The amounts of N_2 and O_2 existing in the region are also factors in no formation. Figure 7 shows no variations depending on the load of the engine. It was observed that no emissions were higher for neat Mahua biodiesel and blends compared to diesel at almost all loads. The increase in no emissions with increase in the proportion of Mahua biodiesel may be due to the delayed combustion. Also the higher oxygen content of biodiesels leads to more complete combustion resulting in greater combustion temperature peaks which caused higher no emissions. However, the higher viscosity and density of biodiesel caused delayed combustion phase which results in the slower combustion characteristics of Mahua biodiesel.

4.2.4. Smoke Density. Figure 8 shows variation of smoke opacity for diesel, Mahua biodiesel, and blends, respectively, at various loads. From the figure it follows that smoke opacity increases with increase in load. It is observed that smoke

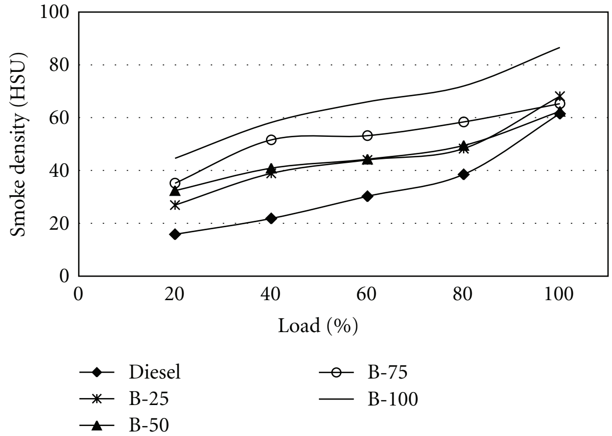

Figure 8: Comparison of smoke between diesel, Mahua biodiesel, and blends.

emissions are higher for neat Mahua biodiesel and blends compared to diesel oil. This may be due to heavier molecular structure, double bonds in vegetable oil chemical structure, and higher viscosity of Mahua biodiesel and their blends. These factors are responsible for higher smoke emissions resulting in incomplete and sluggish combustion. The number of double bonds present in the fatty acid is strongly related to emissions. The smoke opacity is 61.5, 68.1, 62.4, 65.3, and 86.6 HSU for diesel, B-25, B-50, B-75, and B-100, respectively, at 100% load.

5. Conclusion

The performance characteristics, brake thermal efficiency, brake specific fuel consumption, and exhaust gas temperature and emission characteristics, carbon monoxide, unburned hydro-carbon, nitrogen oxides, and smoke of a single cylinder vertical direct injection Kirloskar TV-1 engine using Mahua biodiesel and diesel-Mahua biodiesel blends as fuels were experimentally investigated. The following conclusions are made based on the experimental results.

(i) As the proportion of Mahua biodiesel increases in the blend, the brake thermal efficiency decreases. For B-100, the brake thermal efficiency was 14.3% less than that of diesel at full load.

(ii) More the proportion of Mahua biodiesel in the blend, more is the increase in brake specific fuel consumption for any given load.

(iii) The carbon monoxide emissions are doubled with neat Mahua biodiesel operation when compared to diesel mode at full load condition.

(iv) At 20% load, Hc emissions for Mahua biodiesel and blends are quite high. At higher loads, as the quantity of Mahua biodiesel in the blend increases Hc emissions decreases.

(v) The No and smoke emissions are higher for neat Mahua biodiesel and blends when compared to diesel at almost all loads.

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