Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

Elixir Mech. Engg. 55 (2013) 12978-12982

ISSN: 2229-712X

Performance and Emission Characteristics of a Diesel Engine Operated on Mahua Oil Methyl Ester

M.Harinathareddy[1], P.Nageswara Reddy[2] and K.Vijayakumar Reddy[3]

[1]Sri Venkateswara Institute of Science and Technology, Kadapa.

[2]Gudlavalleru College of Engineering, Gudlavalleru, Krishna (DT).

[3]Department of Mechanical Engineering, JNTUH, Hyderabad.

ARTICLE INFO

Article history:

Received: 17 December 2012;

Received in revised form:

2 February 2013;

Accepted: 8 February 2013;

Keywords

Kirloskar engine,

Mahua biodiesel,

Diesel fuel blends,

Vegetable oil.

ABSTRACT

Biodiesel derived from nonedible feed stocks such as Mahua, Jatropha, Pongamia are detailed 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 paper, the blends of varying proportions of Mahua biodiesel and diesel were prepared, analyzed and compared with the performance of diesel fuel, studied using a single cylinder diesel engine. The brake thermal efficiency, brake-specific fuel consumption, exhaust gas temperatures, Co, Hc, No, and smoke emissions was analyzed. The tests showed decrease in the brake thermal efficiencies (BTE) of the engine as the amount of Mahua biodiesel in the blend increased. The maximum percentage of reduction in BTE is 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 current 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 is one of the forest-based tree-borne nonedible oils with large production potential of about 65 million tons per annum in India [1]. The kernel of the Mahua fruit contains about 55% oil, but the oil yield is 33–36% by small expeller. The excluded block is relevant to recover the residual oil. As Mahua grows mainly in jungle area, and also in waste and uncultivated 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 survey. Yet, experimental study of effects of Mahua biodiesel on diesel engine is rarely 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 less than 3% of that diesel [2, 3, 4, 5, 6, 7 and 8]. 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, 1.68% and 21.36% greater in the case of Mahua biodiesels than that for diesel. The higher specific gravity of Mahua biodiesel makes the fuel scatter narrow and its penetration deeper. The higher viscosity of Mahua biodiesel could potentially have an impact on the combustion characteristics because the high thickness 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 favourable. 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.

A biodiesel production, combustion, emissions and performance are reviewed. They reported that short-term engine tests using vegetable oils as fuels were very promising, but the long-term test results showed higher carbon built up, and lubricating oil contamination, resulting in engine failure. It was reported that the combustion characteristics of biodiesel are similar as diesel. The engine power output was found to be equivalent to that of diesel fuel. The potential and economic feasibility of large-scale bio energy production from Vegetable oils for national and international markets are presented. The effect of biodiesel on engine performance and emissions are reviewed and reported that with biodiesel (particularly with pure biodiesel), engine power will drop due to the loss of heating value of biodiesel. But some authors found that the power loss

Tele:

E-mail addresses: hari.phd2006@gmail.com

was lower than expected because of power recovery. The torque and power reduced by 3–6% for pure cotton seeds biodiesel compared to diesel, and they claimed that the heating value of biodiesel was less 5% than that of diesel has been found. But they contributed to the difficulties in fuel atomization instead of the loss of heating value.

Table 1: Comparison of properties between Mahua biodiesel and diesel

Fuel properly	Unit	Diesel	Mahua biodiesel
Kinematic viscosity at 40°C	*cSt*	*4.57*	*5.6*
Specific gravity at 15°C		*0.87*	*0.89*
Flash point	*°C*	*71*	*172*
Fire point	*°C*	*82*	*181*
Pour point	*°C*	*-16*	*3*
Cloud point	*°C*	*-3*	*11*
Diesel index		*50.2*	*51.3*
Calorific value	*kJ/kg*	*42858*	*42297*

Many authors 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. 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 [9, 10, 11 and 12].

2. Preparation of Vegetable Oil Biodiesel (Methodology)

The use of vegetable oils in place of diesel fuel in conventional diesel engines requires certain variation of their properties like viscosity and density. Transesterification is the general term used to describe the important class of organic reactions, where an ester is changed into another ester through interchange of alkyl groups and is also called alcoholysis. Transesterification is a balance reaction and the transformation occurs by mixing the reactants. In the transesterification of vegetable oils, a triglyceride reacts with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acid alkyl esters and glycerol. In the base-catalyzed process, the transesterification of vegetable oils proceeds faster than the acid-catalyzed reaction.

The biodiesel is obtained from Vegetable oil in the following steps:

- ➢ The Vegetable oil is heated to 100^{o}C temperature and maintained for 15 minutes. It is allowed to stay for one day for removal of water
- ➢ Sodium hydroxide (NaOH) is added to ester and stirred thoroughly to produce sodium methoxide
- ➢ The prepared sodium methoxide is poured into the mixture and the mixture is heated to 55^{o}C and the whole reaction is maintained
- ➢ After heating for one hours the oil should be poured into decanter
- ➢ Glycerin is removed and water wash should be done with Phosphoric acid
- ➢ After washing the neat bio diesel is heated to 100^{0}C to remove the traces of water

2. Experimental Setup

An experimental setup used in the present work is shown in Figure 1. The engine was loaded with current dynamometer. The mass flow rate of intake air was measured with an orifice meter connected to a manometer. A flow 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 442 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.

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 verify 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 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 35 minutes 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-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 BTE, brake-specific fuel consumption (BSFC), exhaust gas temperature (EGT), carbon monoxide (Co), unburned hydro-carbons (Hc), nitrogen oxide (No), and smoke.

2.1 Test Engine Specifications

Make: Kirloskar oil engines Ltd. India
Type: Single cylinder, DI engine
Stroke: 110mm
Bore: 87.5mm
Injection pressure: 180bar
Rated output: 5.2 KW
Compression ratio: 16.5

Speed: 1500 r/min, constant
Working cycle: Four stroke
Type of sensor: Piezo electric
Loading device: Eddy current dynamometer

2.2 Experimental Procedure

The series of exhaustive engine tests were carried out on Kirloskar HA394 diesel engine using diesel and mahua biodiesel blends separately as fuels at 1500 rpm. The experimental data generated were calculated, and presented through appropriate graphs. Performance and emission tests were conducted on various biodiesel blends in order to optimize the blends concentrations for long-term usage in CI engines. To achieve this, several blends of varying concentrations were prepared ranging from 0 % (Neat diesel oil) to 80 %, through 10 %, 20 %, 40 %, 60 %, and 80 % by volume. These blends were then subjected to performance and emission tests on the engine. The performance data was then analyzed from the graphs recording power output, fuel consumption, specific fuel consumption, thermal efficiency for all blends of biodiesel. The optimum blend was found from the graphs, based on maximum thermal efficiency. The major pollutants appearing in the exhaust of a diesel engine are carbon monoxide, hydrocarbons and oxides of nitrogen. For measuring exhaust emissions, a QRO-402 analyzer was used. The brake specific fuel consumption is not a very reliable parameter to compare the two fuels as the calorific value and the density of the blend follow a slightly different trend. Hence, brake specific energy consumption is a more reliable parameter for comparison. For an optimum biodiesel, the blend concentration has been determined based on maximum thermal efficiency at all loads and minimum brake specific energy consumption.

3. Results and Discussions

3.1 Brake Thermal Efficiency (BTE)

It is obvious 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.

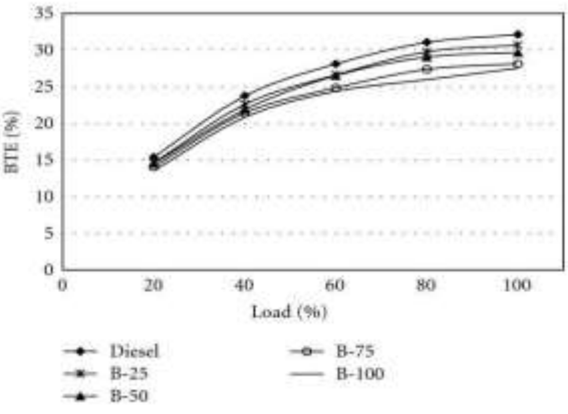

Figure 2: Comparison of BTE between diesel, Mahua biodiesel, and blends

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.

3.2 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.

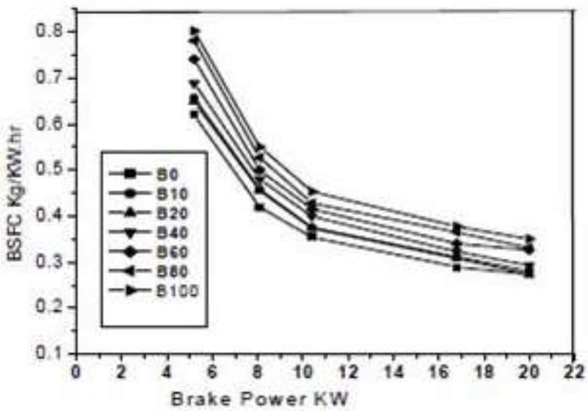

Figure 3: Comparison of BSFC between diesel, Mahua biodiesel, and blends

3.3 Brake thermal efficiency

The variation of brake thermal efficiency with load for different fuels is presented in Figure.2. In all cases, it increased with increase in load. This was due to reduction in heat loss and increase in power with increase in load. The maximum thermal efficiency for B20 (31.38%) was higher than that of diesel. The brake thermal efficiency obtained for B-40, B-60, B-80 and B-100 were less than that of diesel. This lower brake thermal efficiency obtained could be due to reduction in calorific value and increase in fuel consumption as compared to B-20. This blend of 20% also gave minimum brake specific energy consumption. Hence, this blend was selected as the optimum blend for further investigations and long-term operation. In the literature, researchers have concluded that, the thermal efficiency of diesel engines is not appreciably affected when diesel is substituted by biodiesel fuel that is either pure or blended.

3.4. Engine Emissions

The engine emissions with mahua biodiesel were evaluated in terms of C_O, H_C and N_{Ox} at different loading conditions of the engine is shown in the Figure 4. The emissions follow trends established by previous research.

3.4.1 Carbon Monoxide

Variation of C_O emissions with engine loading for different fuel is compared in Figure 4. The minimum and maximum C_O produced was 0.02% - 0.0.075 %, resulting in a reduction of 66% and 44 %, respectively, as compared to diesel. It is observed that the C_O emissions for biodiesel and its blends are lower than for diesel fuel. These lower C_O emissions of biodiesel blends may be due to their more complete oxidation as compared to diesel. Some of the C_O produced during combustion of biodiesel might have converted into C_{O2} by taking up the extra oxygen molecules present in the biodiesel chain and thus reduced C_O formation. It can be observed from Figure 4 that the C_O initially decreased with load and later increased sharply up to full load. This trend was observed in all the fuel blend tests.

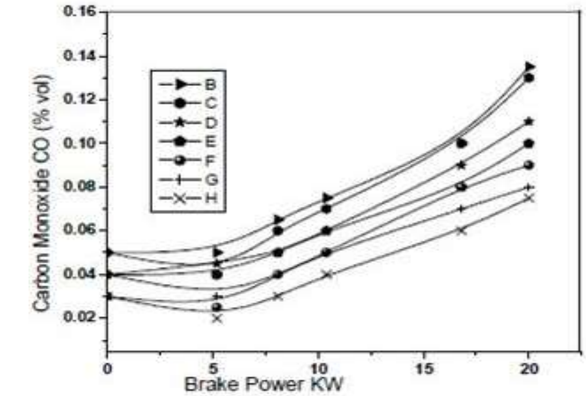

Figure 4: Comparison of carbon monoxide with brake power for diesel, methyl ester of mahua oil and its blends

3.4.2 Hydrocarbons

The hydrocarbons (HC) emission trends for blends of methyl ester of mahua oil and diesel are shown in Figure 5.

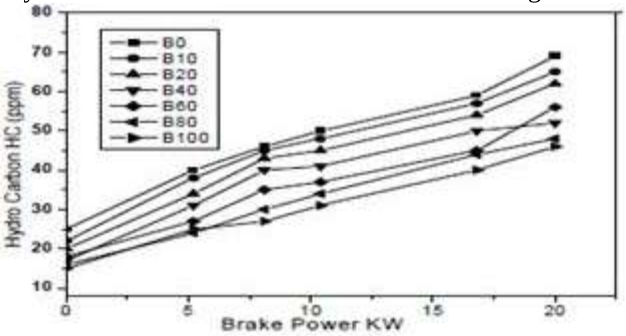

Figure 5: Comparison of hydrocarbons with brake power for diesel, methyl ester of mahua oil and its blends

The reduction in HC was linear with the addition of biodiesel for the blends tested. These reductions indicate a more complete combustion of the fuel. The presence of oxygen in the fuel was thought to promote complete combustion. There is a reduction from 75 ppm to 45 ppm, resulting in a reduction of 40 %, as compared to diesel at the maximum power output.

3.4.3 Nitrogen Oxides

The variation of NOx with engine load for different fuels tested is presented in Figure 6.

The nitrogen oxides emissions formed in an engine are highly dependent on combustion temperature, along with the concentration of oxygen present in combustion products. The amount of NOx produced for B-10 to B-100 varied between 124 – 497 ppm, as compared to 120 – 439 ppm for diesel. An increasing proportion of biodiesel in the blends was found to increase N_{Ox} emissions slightly (16%), when compared with that of pure diesel. In general, the N_{Ox} concentration varies linearly with the load of the engine. As the load increases, the overall fuel-air ratio increases, resulting in an increase in the average gas temperature in the combustion chamber, and hence N_{Ox} formation, which is sensitive to temperature increase.

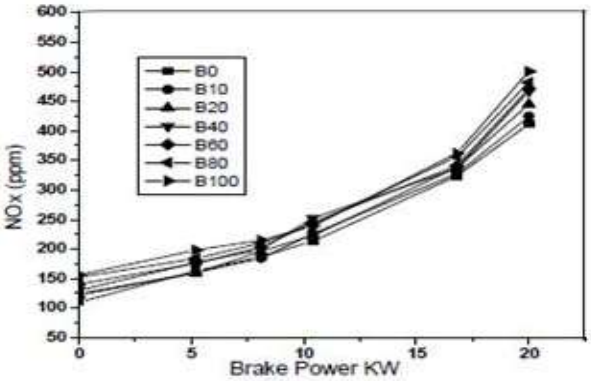

Figure 6: Comparison of NOX with brake power for diesel, methyl ester of mahua oil and its blends

4. Conclusions

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.

References

[1] Sukumar P., Vedaraman N., Boppana V. B., Ram, G. Shankaranarayanan, and K. Jaychandran, Mahua Oil (Madhuca Indica Seed Oil) Methyl Ester as Bio Diesel- preparation and Emission Characteristics, Elsevier, Biomass & Bio Energy, Vol. 28, pp. 87-93, 2005.

[2] Shashikanth V. G., and Raheman H.,Biodiesel Production from Mahua (Madhuca Indica Oil) Having High Free Fatty Acids, Elsevier, Biomass & Bio energy, Vol. 28, pp. 601-605, 2005.

[3] Sukumar Puhan, N. Vedaraman et.al.Performance and Emission Study of Mahua Oil (Madhuca Indica Oil) Ethyl Ester in a 4- Stroke Natural Aspirated Direct Injection Diesel Thammasat Int. J. Sc. Tech., Vol. 15, No. 3, July-September 2010

[4] Schumacher L. G., Borgelt S. C.,et.al., 6V-92TA DDC Engine Exhaust Emission Test Using Methyl Ester Soybean Oil/Diesel Fuel Blends, Elsevier, Bio Resource Technology, Vol. 57, pp. 31-36, 1996.

[5] Christopher A. Sharp, Exhaust Emissions and Performance of Diesel Engines with Biodiesel Fuels, South West Research Institute, 1990.

[6] Kalam M. A. et.al. Biodiesel from Palm Oil-an Analysis of its Properties and Potential, Pergamon, Biomass and Bio Energy, Vol. 23, pp. 471- 479, 2002.
[7] Wang W. G., Lyons D. W., Clark. N. N. and Gautam M., Emission from Nine Heavy- Trucks Fuelled by Diesel and Biodiesel Blend without Engine Modification, Environ. Sci. Technol., Vol. 34, pp. 933-939, 2000.
[8] Bhatt Y. C., Murthy N. S., and Datta R. K., Use of Mahua Oil (Madhuca Indica) as Diesel Fuel Extender, IE(I), Journal–AG. pp. 10-14, 2004.
[9] H. Raheman, et.al, Performance of Compression Ignition Engine with Mahua (Madhuca Indica) Biodiesel, Elsevier, Fuel 86, pp. 2568-2573, 2007.
[10] Shankarnarayan G., Jeyachandran K., Ester of Illuppai (Mahua Oil) as an Alternative Fuel for DI Diesel Engine, Institute of Engineers (India), Vol. 87, pp. 25-27, April 2006.
[11] Raheman H., et.al. Diesel Engine Emissions and Performance from Blends of Karanja Methyl Ester and Diesel, Elsevier, Biomass and Bioenergy, Vol. 27, pp. 393-39, 2004.
[12] Nwafor O. M. I., Emission Characteristics of Diesel Engine Operating on Rapeseed Methyl ester, Renewable Energy, Vol. 29, pp. 119-129, 2011.