# Performance and Emission Characteristics of a Kirloskar HA394 Diesel Engine Operated on Mahua Oil Methyl Ester

**Sharanappa Godiganur**
Department of Mechanical Engineering, Reva Institute of Technology and Management
Yalahanka Bangalore-560 064, Karnataka, India
Email: gsharanappa@yahoo.com

**Ch. Suryanarayana Murthy[a] and Rana Prathap Reddy[b]**
[a]Department of Mining Engineering, National Institute of Technology
Surathkal-575 025, Karnataka, India
[b]Department of Mechanical Engineering, Reva Institute of Technology and Management
Yalahanka Bangalore-560 064, Karnataka, India

**Abstract**

The use of biodiesel fuels derived from vegetable oils as a substitute for conventional petroleum fuel in diesel engines is receiving an increasing amount of attention. This interest is based on a number of properties of biodiesel, including the fact that it is produced from a renewable resource, its biodegradability, and its potential to reduce exhaust emissions. Biodiesel is a non-toxic, and renewable alternative fuel that can be used with little or no engine modification

An experimental investigation is conducted to evaluate the effect of using blends of mahua biodiesel with conventional diesel fuel, with 10%, 20%, 40%, 60% and 80% (by volume) mahua biodiesel, on the performance and exhaust emissions of a three cylinder naturally aspirated, air cooled, direct injection, Kirloskar HA394 engine. The tests are conducted using each of the above fuel blends, with the engine working at constant speed and five loads. Fuel consumption and exhaust regulated gas emissions such as nitrogen oxide, carbon monoxide and total unburned hydrocarbons are measured. The differences in the measured performance and exhaust emissions of the mahua biodiesel-diesel fuel blends from the baseline operation of the engine, i.e. when working with neat diesel fuel, are determined and compared.

**Key words:** Performance; Kirloskar engine; mahua biodiesel; Emissions; Diesel fuel blends;

# 1. Introduction

Vegetable oils have long been used as fuels for diesel engines. As early as the late 1800s, Rudolf Diesel used peanut oil in a diesel engine. However, using chemically unaltered vegetable oils directly in diesel engines can cause performance problems because of their high viscosity and low volatility. A feasible solution is to transesterify the oils with methanol to form esters. Vegetable oils are primarily composed of glycerol esters of fatty acids (triglycerides). In the process of transesterification, the glycerol components of the triglycerides molecules are exchanged for a lighter methanol. The product is composed of fatty acid methyl esters, consisting of straight saturated and unsaturated hydrocarbon chains. The most widely used product, mahua biodiesel (MOME), is made through a reaction of mahua oil and methanol. In recent years, an ester-based oxygenated fuel, called biodiesel, has been used in compression-ignited diesel engines without any engine modifications. B20 (a mixture of 20% biodiesel and 80% petroleum diesel) and B35 (a mixture of 35% biodiesel and 65% petroleum diesel) are the most popular biodiesel fuel blends used to date in the United States.

In the last several years, many studies [1-7] have looked at the potential of biodiesel as an alternative fuel for diesel engines. Few researchers [1 2 3] have tested blends of mahua biodiesel with diesel on single cylinder diesel engines. Schumacher [4] studied several blends of diesel and soybean methyl ester (SME) to determine and compare engine emissions from a Detroit Diesel Corporation (DDC) 6V92TA engine (a type of diesel engine widely used in transit buses and heavy trucks) operated on those fuels. Similar emissions trends were seen: an increased percentage of SME blended with diesel led to increased emissions of $NO_x$ and decreased emissions of PM, HC, and CO. Christopher. Sharp[5], employed a 1997 DDC series 50 engine to determine emissions of $NO_x$, CO, HC, and PM that result from blending biodiesel and conventional diesel. The tests showed that as the percentage of biodiesel blend in the fuel increased, the $NO_x$ increased but HC, CO, and PM decreased. Engine efficiency for biodiesel blends proved to be the same as that of diesel fuel. Kalam M. A,[6] selected a Isuzu engine (model 4FB1) to determine emissions of $NO_x$, CO, HC, and PM that result from blending Palm oil biodiesel and conventional diesel. The results showed that as the concentration of biodiesel increased, the Isuzu engine produced lower levels of HC, CO, and PM, but a higher level of $NO_x$.

These findings suggest trends in engine exhaust emissions with biodiesel-fueled engines. Data reviewed usually pertain to use of biodiesel blends with diesel, on small and heavy-duty diesel engine. Data pertaining to fueling heavy-duty diesel engine with mahua biodiesel/ diesel fuel blends was deficient in the literature. Gathering this data becomes the central focus of this work.

# 2 Experimental

## 2.1 Fuel properties

The test fuel sample of mahua biodiesel was prepared in Mahatma Gandhi Regional Institute for Rural Development, Bangalore. The physical characteristics of mahua methyl ester are close to diesel oil. The fuel properties were tested in Bangalore Test House Bangalore (India), and listed in Table 1.

**Table 1** Fuel properties of diesel oil, crude mahua oil and methyl ester of mahua oil

| **Properties** | **Diesel** | **Raw mahua** | **MME** |
|---|---|---|---|
| Density $Kg/m^3$ | 850 | 924 | 916 |

**Table 1** Fuel properties of diesel oil, crude mahua oil and methyl ester of mahua oil (cont.)

| Properties | Diesel | Raw mahua | MME |
|---|---|---|---|
| Specific gravity | 0.85 | 0.924 | 0.916 |
| Kinematic viscosity at $40^0$C.(Cst) | 3.05 | 39.45 | 5.8 |
| Calorific Value (KJ/kg) | 42800 | 37614 | 39400 |
| Flash Point $^0$C. | 56 | 230 | 129 |
| Fire Point $^0$C. | 63 | 246 | 141 |

**Table 2** Engine specifications

| Make | Kirloskar Engine |
|---|---|
| Model | HA394 |
| No. cylinders | 3 Inline |
| Aspiration | Natural |
| Bore & Stroke | 100mm x 120mm |
| BHP/BP | 32.5/20KW |
| Rated power | 25 KVA |
| Displacement | 2826 cc |
| Type of cooling | Air-cooled |
| Fuel consumption @90% load | 5 liters/hr. |
| Firing order | 1-3-2 |
| Speed | 1500 rpm |
| Compression ratio | 17: 1 |

**Table 3** Generator specification

| Model | Genset model |
|---|---|
| Genset rating | 25 kVA |
| Current(Amps) | 34.8 |
| Voltage | 380/415 |
| RPM/Frequency | 1500/50Hz |
| No. Phases | 3 phase |
| Power Factor | 0.8 |

### 2.2 Experimental setup

Tests have been conducted on a Kirloskar Engine HA394, four strokes, three cylinders, air-cooled direct injection, and naturally aspirated diesel engine with displacement of 2826 cc, bore 100 mm, stroke 120mm, compression ratio of 17:1 and run at a constant speed of 1500 rpm. The engine was coupled to a Generator set and loaded by electrical resistance to apply different engine loads. The specification of the engine and generator is demonstrated in Table 2 and Table 3. The voltage, current and power developed by the engine were directly displayed on the control panel. The layout of experimental test rig and its instrumentation is shown in Fig.1.

### 2.3 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 percent (Neat diesel oil) to 80 percent, through 10 percent, 20 percent, 40 percent, 60 percent, and 80 percent 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 system, the blend concentration has been determined based on maximum thermal efficiency at all loads and minimum brake specific energy consumption.

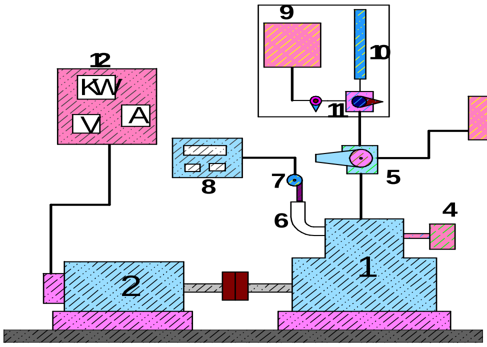


**Fig. 1** Layout of experimental setup with instrumentation

*1 Kirloskar HA394 2 Alternator 3 Diesel tank 4 Air filter 5 Three way valve 6 Exhaust pipe 7 Probe 8 Exhaust gas Analyzer 9 Biodiesel tank 10 Burette 11 Three way valve 12 Control panel*

## 3. Results and discussions

### 3.1 Fuel properties

After pretreatment and transesterification, the colour of crude mahua oil (CMO) changed from yellow to reddish yellow, and on average, 80% recovery of biodiesel was possible. The various fuel properties of CMO and mahua biodiesel were determined. The characteristics of biodiesel are close to mineral diesel, and therefore biodiesel is a strong candidate to replace mineral diesel if need arises. Table 1 summarizes the results of fuel tests of diesel fuel, and mahua methyl ester.

### 3.2 Engine performance

The engine performance with mahua biodiesel was evaluated in terms of brake specific fuel consumption, brake specific energy consumption, thermal efficiency and exhaust gas temperature at different loading conditions of the engine.

#### 3.2.1 Brake specific fuel consumption (BSFC)

The variation in BSFC with load for different fuels is presented in Figure 2. Brake-specific fuel consumption (BSFC) is the ratio between mass fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to thermal efficiency. The specific fuel consumption when using a biodiesel fuel is expected to increase by around 35% in relation to the consumption with diesel fuel. BSFC decreased sharply with increase in load for all fuels. The main reason for this could be that the percent increase in fuel required to operate the engine is less than the percent increase in brake power, because relatively less portion of the heat is lost at higher loads. The mean BSFC for blends was higher than that of pure diesel by 6.9%, 16.98%, 25%, 27.7% and 35%, respectively, for every 20% additional blending of biodiesel in diesel. As the BSFC was calculated on a weight basis, higher densities resulted in higher values for BSFC. The heat content of pure B100 was lower than diesel by about 8%. Due to these reasons, the BSFC for other blends, namely B40, B60, B80 and B100 were higher than that of diesel. Similar trends of BSFC with increasing load in different biodiesel blends were also reported by other researchers [1, 11, and12] while testing biodiesel obtained from mahua, karanja, and rapeseed oils.

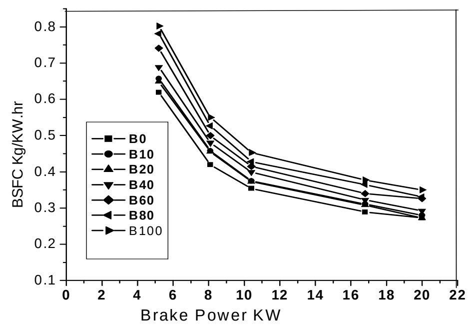


**Fig. 2** Comparison of brake specific fuel consumption with brake power for diesel, methyl ester of mahua oil and its blends.

### 3.2.2. Brake specific energy consumption

Brake specific energy consumption (BSEC) is an ideal variable because it is independent of the fuel. Hence, it is easy to compare energy consumption rather than fuel consumption. The variation in BSEC with load for all fuels is presented in Fig.3. In all cases, it decreased sharply with increase in percentage of load for all fuels. The main reason for this could be that the percent increase in fuel required to operate the engine is less than the percent increase in brake power, because relatively less portion of the heat is lost at higher loads.

The BSEC for all blends was higher than that of diesel. This trend was observed due to lower calorific value, with increase in biodiesel percentage in blends. This trend of BSEC with increasing load in different biodiesel blends were also reported by some researchers [1, 11] while testing biodiesel obtained from mahua and karanja oils.

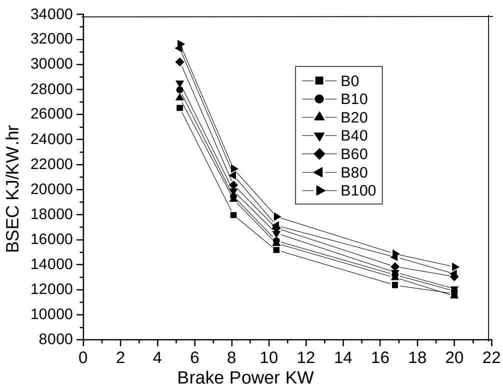


**Fig. 3** Comparison of brake specific energy consumption with brake power for diesel, methyl ester of mahua oil and its blends

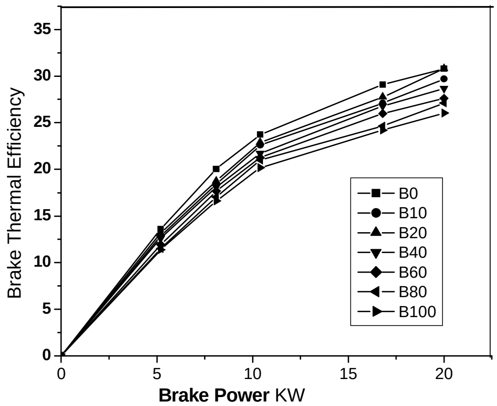


**Fig.4** Comparison of thermal efficiency with brake power for diesel, methyl ester of mahua oil and its blends

### 3.2.3. Brake thermal efficiency

The variation of brake thermal efficiency with load for different fuels is presented in Fig.4. 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 B40, B60, B80 and B100 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 B20. 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 [12].

### 3.2.4. Exhaust gas temperature

The variations of EGT with respect to engine loading are presented in Fig.5. In general, the EGT increased with increase in engine loading for all the fuels tested. The mean temperature increased linearly from 165$^0$C at no load, to 398$^0$C at full load conditions. This increase in exhaust gas temperature with load is obvious from the simple fact that more fuel was required for the engine to generate that extra power needed to take up the additional loading. The exhaust gas temperature was found to increase with the increasing concentration of biodiesel in the blends.

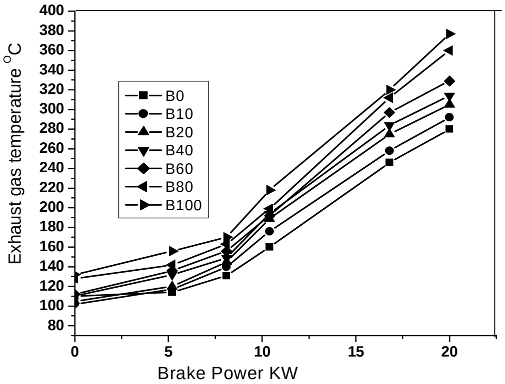


**Fig. 5** Comparison of exhaust gas temperature with brake power for diesel, methyl ester of mahua oil and its blends

### 3.3 Engine emissions

The engine emissions with mahua biodiesel were evaluated in terms of CO, HC and NOx at different loading conditions of the engine. The emissions follow trends established by previous research.

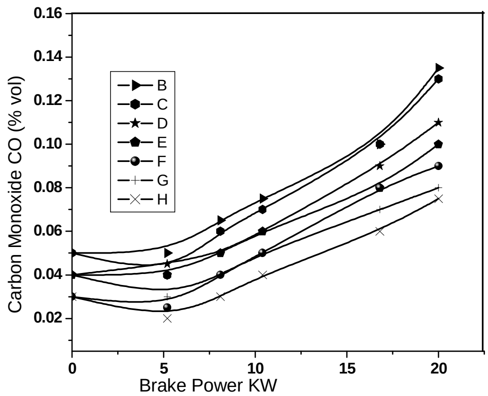


**Fig.6** Comparison of carbon monoxide with brake power for diesel, methyl ester of mahua oil and its blends

#### 3.3.1 Carbon monoxide

Variation of CO emissions with engine loading for different fuel is compared in Fig. 6. The minimum and maximum CO 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 CO emissions for biodiesel and its blends are lower than for diesel fuel. These lower CO emissions of biodiesel blends may be due to their more complete oxidation as compared to diesel. Some of the CO produced during combustion of biodiesel might have con-verted into $CO_2$ by taking up the extra oxygen molecules present in the biodiesel chain and thus reduced CO formation. It can be observed from Fig.6 that the CO initially decreased with load and later increased sharply up to full load. This trend was observed in all the fuel blend tests.

#### 3.3.2. Hydrocarbons

The hydrocarbons (HC) emission trends for blends of methyl ester of mahua oil and diesel are shown in Fig.7. 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.

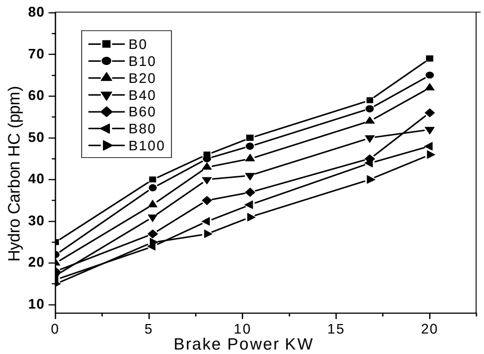


**Fig. 7** Comparison of hydrocarbons with

brake power for diesel, methyl ester of mahua oil and its blends

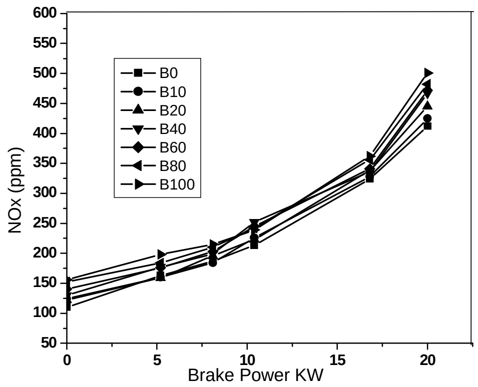


**Fig. 8** Comparison of $NO_X$ with brake power for diesel, methyl ester of mahua oil and its blends

### 3.3.2. Nitrogen oxides

The variation of NOx with engine load for different fuels tested is presented in Fig.8. 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 B10 to B100 varied between 124 – 497 ppm, as compared to 120 – 439 ppm for diesel. From Fig, 8 it can be seen that an increasing proportion of biodiesel in the blends was found to increase NOx emissions slightly (16%), when compared with that of pure diesel. In general, the NOx 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 NOx formation, which is sensitive to temperature increase.

## 4. Conclusions

Based on the results of this study, the following specific conclusions were draw:

1. In terms of fuel properties and exhaust emission characteristics, mahua oil methyl ester can be regarded as an alternative to diesel fuel.
2. Brake specific fuel consumption for B100 is higher than for diesel fuel and it decreases in blended fuels. In B20 fuel the BSFC is lower than the diesel fuel and all other fuels.
3. The maximum thermal efficiency for B20 (31.38%) was higher than that of diesel. The brake thermal efficiencies obtained for B40, B60, B80 and B100 were less than that of diesel.
4. The exhaust temperature increased as a function of the concentration of biodiesel blend, for higher percentage of MOME.
5. Increase in the exhaust temperature of a biodiesel-fuelled engine led to approximately 16% increase in NOx emissions for B100. This is due to the higher temperatures in biodiesel-fuelled engines.
6. Emissions of CO, HC were found to be lower for the ester.

## 5. 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

Engine, Elsevier, Renewable Energy, Vol. 30, pp. 1269-1278, 2005.

[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 Fueled 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, 2004.

[13] Magin Lapuerta, et.al., Effect of Biodiesel Fuels on Diesel Engine Emissions, Elsevier, Progress in Energy and Combustion Science, Vol. 34, pp. 198-223, 2008.