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Performance and emission characteristics of diesel engine operating on mahua methyl ester and blends

Shivakumar Biradar[1] Adarsh Adeppa[2]

1. Assistant professor, Dept of Mechanical Engineering BKIT, Bhalki Karnataka, India
2. Assistant professor, Dept of Mechanical Engineering BKIT, Bhalki Karnataka, India

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ABSTRACT

The use of biodiesel fuels derived from vegetable oils as a substitute for conventional petroleum fuel in diesel engine 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. A single cylinder, four stroke D.I. diesel engine was used to evaluate the performance and emissions characteristics of mahua biodiesel oil. The volumetric blending ratios of biodiesel with conventional diesel fuel were set at 0, 20,40,60,80,100. Engine performance (brake specific fuel consumption, brake specific energy consumption, thermal efficiency and exhaust gas temperature) and emissions (CO, HC and NOx) were measured to evaluate and compute the behavior of the diesel engine running on biodiesel. The results indicate that with the increase of biodiesel in the blends CO, HC reduces significantly, fuel consumption and NOx emission of biodiesel increases slightly compared with diesel. Brake specific energy consumption and thermal efficiency of engine slightly degreases when operating on 20% biodiesel than that operating on diesel.

Keywords: Engine emissions; Diesel blends; Engine performance; Mahua biodiesel

Nomenclature

CMO - Crude mahua oil
MEMO - Methyl Esters of mahua oil
BSFC - Brake specific fuel consumption
BSEC - Brake specific energy consumption
NOx - Nitrogen Oxide
CO - Carbon monoxide
HC - Hydrocarbon

EGT - Exhaust gas temperature
B20 - Blend with 20 % biodiesel
DI - Direct injection
CI - Compression Ignition

1. INTRODUCTION

Diesel engine is a popular prime mover for surface transportation, agricultural machinery and industries. More than 6.5 million diesel engines being used in the Indian Agricultural sectors for various activities. The enormous growth of world population, increased technical development and standard of living in the industrial nations has led to this intricate situation in the field of energy supply and demand. Import of petroleum products is a major drain on our foreign exchange sources and with growing demand in future years the situation is likely become even worse. Diesel engines are the main sources of carbon dioxide, and carbon monoxide levels in the atmosphere leads to global warming and green house effect. Inherent properties of vegetable oils make them suitable for use in diesel engines solely with an acceptable loss in efficiency. Among various options investigated for diesel fuel, biodiesel obtained from vegetable oils has been recognized world over as one of the strong contenders for reductions in exhaust emissions. India has already begun substituting the conventional diesel by a certain amount of biodiesel. Worldwide biodiesel production is mainly from edible oils such as soybean, sunflower and canola oils. Since, India is not self sufficient in edible oil production, hence, some non-edible oil seeds available in the country are required to be tapped for biodiesel production. With abundance of forest and plant based non-edible oils being available in our country such as Pongamia pinnata (karanja), Jatropha curcas (jatropha), Madhuca indica (mahua), Shorea robusta (Sal), Azadirachta indica A Juss (neem) and Hevea braziliensis (rubber). No much attempt has been made to use esters of these non-edible oils as substitute for diesel except jatropha and honge. Many investigators have already obtained biodiesel from some of these oils However, as compared to other non-edible oils, not much work has been reported on biodiesel produced from mahua oil, which has an estimated annual production potential of 181 thousand tons in India.

Biodiesel is gaining more and more importance as an attractive fuel to the depleting fossil fuel resources. Chemically biodiesel is mono alkyl esters of long chain fatty acids derived from renewable feed stock like vegetable oils and animal fats. It is a clean burning; renewable, non toxic, biodegradable and environmentally friendly transportation fuel that can be used in neat form or in blends with petroleum derived diesel in diesel engine. It is the only EPA approved alternative fuel for diesel engines. Biodiesel has physical properties very similar to conventional petroleum diesel. Emission properties however, are better for biodiesel than for conventional diesel except oxides of nitrogen which slightly higher than diesel. Biodiesel runs in any conventional unmodified diesel engine and yields approximately equal performance as petroleum diesel so basically, the engine just runs like normal. Esters have lower viscosities than the parent oils. Accordingly, they improve the injection processes and ensure better atomization of the fuel in the combustion chamber. Biodiesel can be blended in any ratio for reduced emissions and the increased lubricity makes for a better running vehicle. Sukumar Puhan. et al. (2005) transesterified mahua oil using methanol in presence of alkali and the biodiesel obtained was studied for fuel properties. Their conclusions on engine performance, shows that MOME as a fuel does not differ greatly from that of diesel, slight power loss due to lower heating value of ester. A.K.Babu et al. (2003) surveyed recent studies and research on vegetable oil based fuels. In their work fuel related properties are reviewed and compared with conventional diesel fuel. The use of neat vegetable oil (edible or non edible), biodiesel and its blends in diesel engine have been discussed. Performance and emissions are highlighted. A.S Ramadhas et al. (2004) gave comprehensive review of the methods used for producing biodiesel, experimental investigation on different oils, characterization, merits, demerits and challenges faced by bio-diesel are described. Agarwal et al. (2009) observed significant improvement in engine performance and emission characteristics for the biodiesel fuelled engine compared to diesel fuelled engine. Thermal efficiency of the engine improved, brake specific energy consumption reduced and a considerable reduction in the exhaust smoke opacity was observed. Masjuli et al. (1996) investigated preheated palm oil methyl ester in a diesel engine. They observed that by preheating the POME above room temperature the engine performance, especially the brake power output and exhaust emission characteristics improved significantly. Mohmad I AL et al. (2000) evaluated waste vegetable oil as a feedstock for biodiesel production. This research was focused on the engine performance and emission characteristics of esterified vegetable oil, when used in a diesel engine. When blends of biodiesel and diesel are used in diesel engines, a significant reduction in hydrocarbon (HC) and particulate matter (PM) are observed but NOx emissions are found to have increased. In general, engine performance and power remains unchanged The objective of this investigation was to produce a sample of MOME, determine its physical properties and perform tests on a

Table 1
Composition of mahua oil

Properties	Diesel	mahua	*MME*
Density Kg/m^3	850	924	916
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
Fuel properties of diesel, mahua and MME

Properties	Values (wt %)
Oleic	41.0 – 51.0
Palmitic	16.0 – 28.2
Stearic	20.0 - 25.1
Linoleic	8.9 - 13.7
Arachidic	0.0 - 3.3

Table 3

Make	Kirloskar
Type	Four stroke, single cylinder, water cooled, naturally aspirated, direct injection and vertical
Rated power	3.75 KW at 1500 rpm
Bore and stroke	80 mm & 100 mm
Injection timing	27 deg bTDC
Std injection pr.	190 bar

single cylinder 4 stroke direct injection diesel engine to determine exhaust emissions and engine performance in comparison with using standard diesel fuel.

2. Experimental

2.1. Composition of mahua oil

The basic composition of any vegetable oil is triglyceride, which is the ester of three fatty acids and glycerol. The fatty acid composition of mahua oil is given in Table 1.

2.2. Biodiesel production

In the transesterification of vegetable oils, triglycerides react with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acid alkyl esters and glycerol. Biodiesel is an alternative fuel, which has a correlation with sustainable development, energy conservation, management, efficiency and environmental preservation. In transesterification, mahua oil was chemically reacted with an alcohol in the presence of a catalyst to produce vegetable oil esters. Glycerol was produced as a by-product of the reaction. The mixture was stirred continuously and then allowed to settle under gravity in a separating funnel. Two distinct layers form after gravity settling for 24hr. The upper layer was ester and lower layer was of glycerol. The lower layer was separated out. The separated ester was

Plate 1

Experimental setup

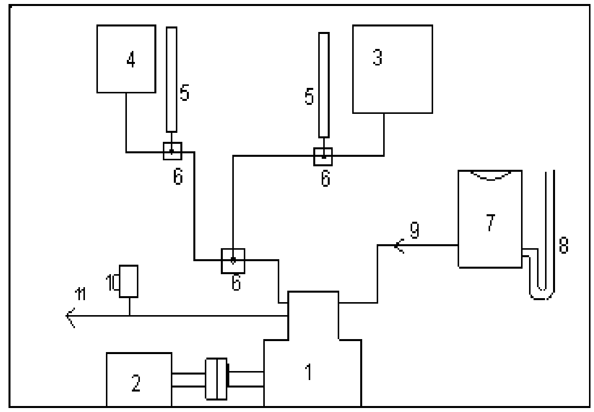

Figure 1

Layout of experimental setup with instrumentation

mixed with some warm water (around 10% volume of ester) to remove the catalyst present in the ester and allowed to settle under gravity for another 24hr.The ester was then blended with mineral diesel to be used in CI engine.

2.3. Fuel Properties

The fuel properties were determined and listed as given in Table 2, for crude mahua oil (CMO), methyl ester of mahua oil (MEMO) and diesel.

2.4. Experimental set up

A single cylinder, four strokes, water cooled, compression ignition engine with a bore 80 mm and stroke of 110 mm and a compression ratio of 16.5:1 was used for the experimental work. The engine was rated for 5 HP at 1500 rpm with centrifugal governor to control the speed. The performance and exhaust emission tests were carried out in a constant speed, direct injection diesel engine. The engine specifications are represented in Table 3. The engine was loaded with electrical resistive load. Fuel consumption was volumetrically measured using metering burette; the consumption was determined by measuring the time for the consumption of a fixed fuel volume. The air flow was measured using an orifice flow meter and the exhaust gas temperatures were recorded with chromel-alumel thermocouples. The engine was started on neat diesel fuel and warmed up. The warm up period ends when the cooling water temperature was stabilized. The Kirlosker, engine is one of the widely used engines in agriculture tractor, pump sets, farm machinery and medium scale commercial purposes. Experimental set up is also shown in plate I.

2.5. Experimental procedure

The engine was started by battery with diesel fuel and it was allowed to reach its steady state (for about 10 minutes), (Figure 1). The test fuels used during this program were neat (100%) biodiesel, a neat (100%) diesel fuel, and blends of 20, 40, 60and 80 percent biodiesel by volume in the diesel fuel. Selected properties for fuels are listed in Table 2. The engine was sufficiently warmed up and stabilized before taking all readings. The performance of the engine and emissions were studied at variable loads corresponding to the load at maximum power at an average speed of 1500 rpm. After the engine reached the stabilized working condition, load applied, fuel consumption, brake power and exhaust temperature were measured from which brake specific fuel consumption, brake specific energy consumption and thermal efficiency were computed. The emissions such as CO, HC, and NO_x were measured using an automotive emission analyzer QRO – 402 exhaust gas analyzer. These performance and emission characteristics for different fuels are compared with the result of baseline diesel. Each reading was obtained thrice to obtain a reasonable value.

1) Engine 2) Dynamometer 3) Fuel Tank (Biodiesel) 4) Diesel Tank 5) Burettes 6) Three way valve 7) Air box 8) Manometer9) Air flow direction 10) Exhaust Analyzer 11) Exhaust flow

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 an average 85% of 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 become a strong candidate to replace the mineral diesel if need arises. The CMO however, was found to have much higher values of fuel properties, especially viscosity, thus restricting its direct use as a fuel for diesel engine.

3.2. Engine performance

Biodiesel has low heating value (10% lower than diesel) on weight basis, because of presence of substantial amount of oxygen in the fuel but at the same time biodiesel has a higher specific gravity (0.916) as compared to diesel (0.85) so overall impact is approximately 5% lower energy content per unit volume. The engine performance with mahua biodiesel was evaluated in terms of brake specific fuel consumption, brake specific energy consumption, brake thermal efficiency and exhaust gas temperature at different loading conditions of the engine.

3.2.1. Brake specific fuel consumption

The BSFC of the engine obtained for different fuels is shown in Figure 2 as a function of load for C.R. of 16:1. The BSFC in general, was found to increase with increasing proportion of B100 in the fuel blends with diesel, where as it decreases sharply with increase in load for all fuels. The main reason for this could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads. As the BSFC was calculated on weight basis obviously higher densities resulted in higher values for BSFC. As density of biodiesel was higher than that of diesel, which means, the same fuel consumption on volume basis resulted in higher BSFC in case of 100% biodiesel. The higher densities of biodiesel blends caused higher mass injection for the same volume at the same injection pressure. The calorific value of biodiesel is less than diesel. Due to these reasons, the BSFC for other blends were higher than of diesel. Similar trends of BSFC with increasing load in different biodiesel blends were also reported by other researchers while testing biodiesel obtained from karanja, mahua and honge oils. Different trend observed by researcher.

3.2.2. Brake specific energy consumption

Brake specific energy consumption (BSEC) is a more reliable criteria compared to BSFC for comparing fuels having different calorific values and densities. The variation in BSEC with load for all fuels is presented in Figure 3. In all cases it decreased sharply with increase in percentage load for all fuels. The main reason for this could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads. The BSEC for B20 was observed approximately equal to that of diesel fuel. In case of B40, B60, B80 and B100, the BSEC was higher than that of diesel. This trend was observed due to lower calorific value with increase in biodiesel percentage in the blends. Different trends of BSEC with increasing load in different biodiesel blends were also reported by some researchers while testing biodiesel obtained from linseed, mahua, and rice bran oils.

3.2.3. Brake thermal efficiency

The variation of brake thermal efficiency with load for different fuels is presented in Figure 4. In all cases it increased with increase in percent load. This was due to reduction in heat loss and increase in power with increase in percent load. The maximum thermal efficiency was obtained for B20 (32.01%) which was approximately equal to that of diesel. The brake thermal efficiency obtained for B40, B60, B80 and B100 were 31.02%, 30.33%, 29.37% and 28.6% respectively less than efficiency for diesel. This lower brake thermal efficiency obtained could be due to reduction calorific value and increase in fuel consumption as compared to B20. Hence this blend was selected as optimum blend for further investigations and long term operation. Based on these results it can be concluded that the performance of the engine with biodiesel blends is comparable to that with diesel, in terms of brake thermal efficiency. The maximum value of BTE for B20 is comparable with the maximum values of 32 % for B10 and 34% for B20 by other researcher when test conducted on MEMO and LOME respectively.

3.2.4. Exhaust gas temperature

The variations of EGT with respect to engine loading are presented in Figure 5. In general the EGT increased with increase in engine loading for all the fuel tested. The mean temperature increased linearly from 178^{0}C at no load to 385^{0}C at full load condition. This increase in exhaust gas temperature with load is obvious from the simple fact that more amount of fuel was required in 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. The mean EGTs of B20, B40, B60, B80 and B100 were higher than the mean EGT of diesel respectively. This could be due to the increased heat losses of the higher blends, which are also evident from, their lower brake thermal efficiencies as compared to diesel. Similar findings were obtained by other researchers while testing different biodiesel.

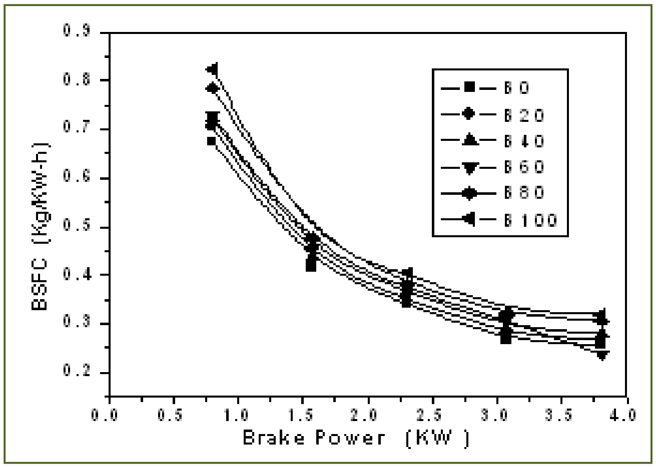

Figure 2

Comparison of BSFC with BP

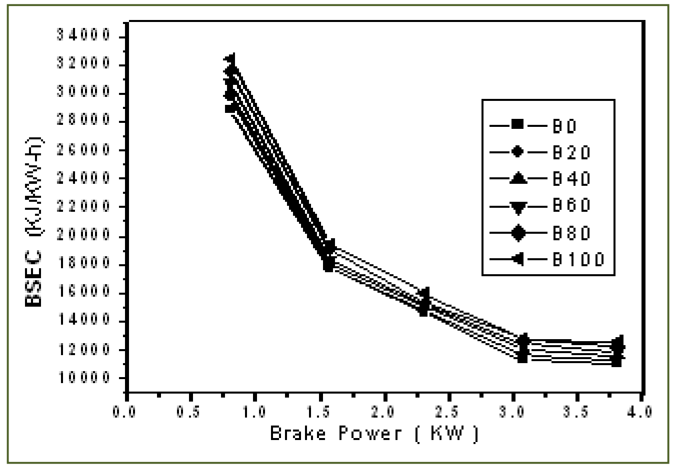

Figure 3

Comparison of BSEC with BP

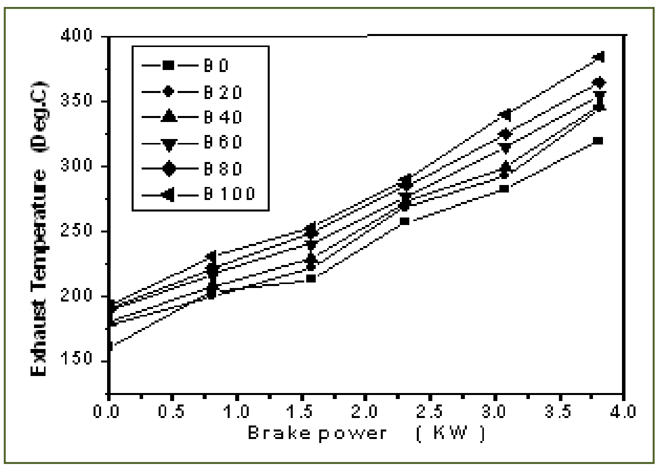

Figure 4

Comparison of BTE with BP

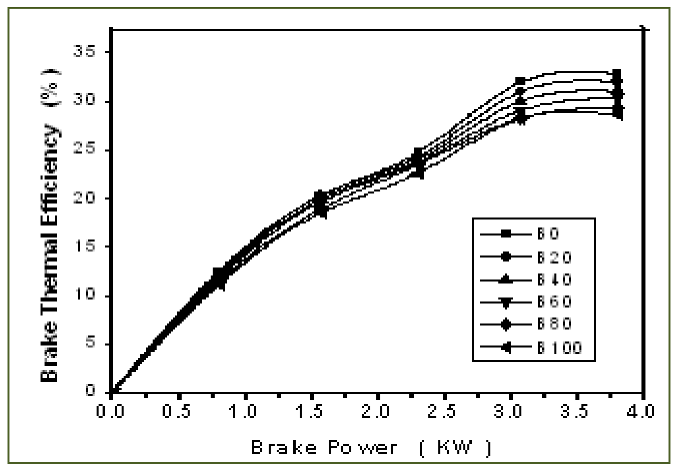

Figure 5

Comparison of EGT with BP

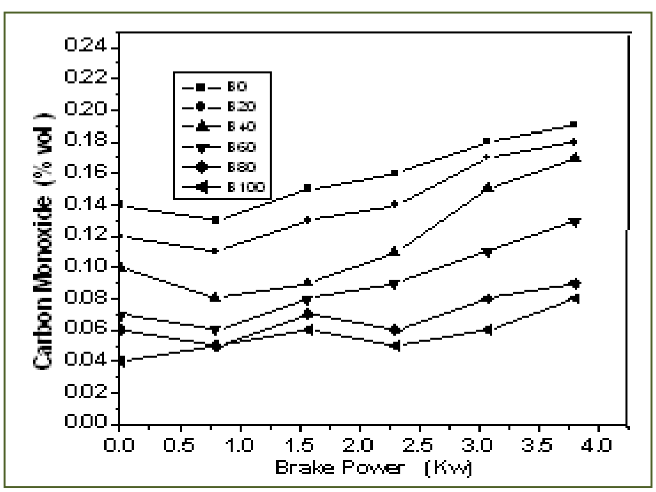

Figure 6

Comparison of CO with BP

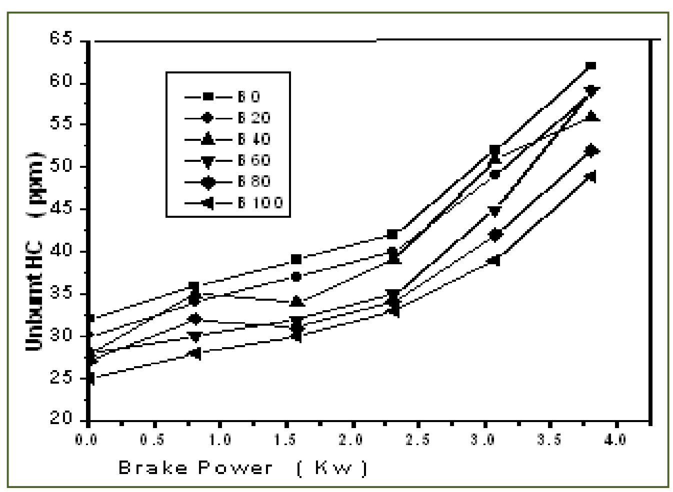

Figure 7

Comparison of HC with BP

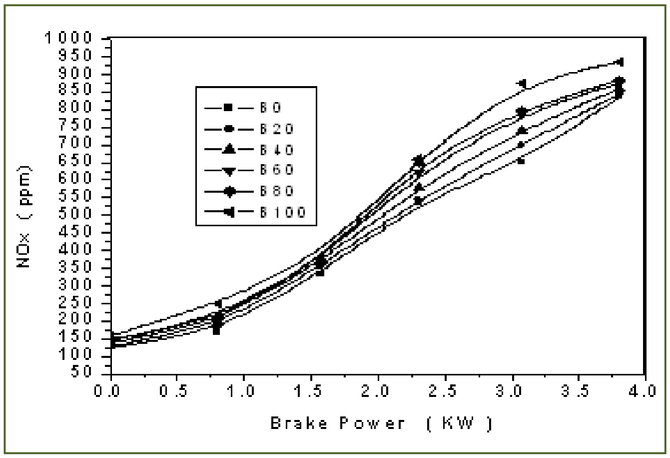

Figure 8
Comparison of NOx with BP

3.2.5. Carbon monoxide

Variation of CO emissions with engine loading for different fuel is compared in Figure 6. The minimum and maximum CO produced was 0.04-0.19 %. 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 converted into CO_2 by taking up the extra oxygen molecule 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 latter increased sharply up to full load. This trend was observed for all the fuel blends tested. Initially, at no load condition, cylinder temperature might be too low, which increase with loading due to more fuel injected inside the cylinder. At elevated temperature, performance of the engine improved with relatively better burning of the fuel resulting in decreased CO.

3.2.6. Hydrocarbon

It is seen in Figure 7 that there is a significant decrease in the HC emission level with blends of methyl ester of mahua oil as compared to pure diesel operation. There is a reduction from 62 ppm to 49 ppm at the maximum power output of 3.75 KW. These reductions indicate more complete combustion of the fuels and the HC level decreases significantly.

3.2.7. Nitrogen oxides

The NOx values as parts per million (ppm) for different fuel blends of diesel and B100 in exhaust emissions of single cylinder diesel engine are plotted as a function of load in Figure 8. The amount of NOx produced for B20 to B100 varied from 131 – 935 ppm as compared to 125-836 ppm for diesel. From this Figure 8 it can be seen that the increasing proportion of biodiesel in the blends was found to increase NOx emissions slightly (11.8 %) when compared with that of pure diesel. This could be attributed to the increased exhaust gas temperatures and the fact that biodiesel had some oxygen content in it which facilitated NOx formation. 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. CONCLUSION

The conclusion that could be drawn from the above experimental investigations is as follows:
A biomass- based renewable fuel was obtained by transesterification of mahua oil with alcohol and tested in a single cylinder DI diesel engine.

- The fuel properties of mahua biodiesel were within limits except calorific value; all other fuel properties of mahua biodiesel were found to be higher as compared to diesel.
- The brake specific fuel consumption increased and brake thermal efficiency decreased with increase in the proportion of biodiesel in the blends. A reverse trend was observed with increase in engine load.
- The amount of CO and HC in exhaust emission reduced, whereas NOx increased with increase in percentage of mahua biodiesel in the blends. However, the level of emissions increased with increase in engine load for all fuels tested.

From these findings, it is concluded that mahua biodiesel could be safely blended with diesel up to 20% with out significantly affecting the engine performance (BSFC, BSEC, EGT) and emissions (CO,HC and NOx) and thus could be suitable alternative fuel for diesel engines.

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