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Studies on the performance and emission characteristics of Mahua oil fuelled low heat rejection diesel engine

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The world energy reserves are depleting day-by-day and the demand is increasing. This leads to search for suitable renewable alternative fuels. Among the available alternative fuels, biodiesel can be used as an immediate substitute for the diesel engine. However, the biodiesel fuelled diesel engine gives lower brake thermal efficiency due to higher viscosity and lower volatility of the biodiesel. Hence, in this work, an attempt was made to increase the performance of the biodiesel fuelled engine using ceramic coating on the engine combustion chamber components. In this experimental study, engine components such as cylinder head, piston, exhaust and inlet valves were coated with Nickel Chromium (NiCr) alloy and Yttria Stabilized zirconia $(Y_2O_3–Z_rO_2)$ *of thickness 250 µm using plasma spray coating. Since mahua oil has significant potential for the biodiesel production, it was used for the biodiesel production. In this work, the engine tests were conducted on a single cylinder four stroke direct injection diesel engineand different blends were used as the fuels. The engine performance and emission characteristics were analysed by varying the load under both coated and uncoated conditions of the engine and results were compared with neat diesel. From the engine test results, it was observed that the engine performance with biodiesel blends such as B10 and B20, was increased from 3 to 7% depends upon the load on the engine with thermal barrier coating as compared to the normal engine without coating.*

Keywords: *Mahua oil, transesterification, thermal barrier coating, engine, performance.*

1.0 INTRODUCTION

The depletion of world's non-renewable resources provided the incentives to seek alternatives to conventional, petroleum-based fuel and brought an idea to use vegetable oils as fuels for diesel engine. To meet tough automotive competition and stringent government regulations, more efficient engine components, improved engine oils, and high performance coating materials have been developed within the automotive industry. Energy conservation and efficiency have always been the quest of engineers concerned with internal combustion engines. The diesel engine rejects about two third of the heat energy of the fuel. Among which one-third is carried away by the coolant and one-third goes to the exhaust, leaving only about one-third as useful power output.

Theoretically if the heat rejected by the engine could be reduced, then the thermal efficiency would be improved. Low Heat Rejection (LHR) engines aim to do this by reducing the heat lost to the coolant. The diesel engine with its combustion chamber walls insulated by ceramics is referred

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to as LHR engine and the methods are referred as Thermal Barrier Coatings (TBC) which are used to improve reliability and durability of metallic components of engine which are repeatedly subjected to hot environment and enhance engine performance and efficiency in diesel engines. Since the combustion chamber temperatures of ceramic-coated engines are higher than those of uncoated engines, it may be possible to use a fuel of lower quality with a large distillation range .

On the other hand, apart from the efficiency and durability considerations it is essential to look for energy sources which are more secure and produce less greenhouse gas emissions. Bio-diesel, an earth friendly choice of consumers and renewable sources of alternative fuel can serve this purpose and which occupies a great volume of the world's fuel sector. Due to its clean emission characteristics, availability, continued and increasing use of petroleum and its limited resources enhanced the production of bio-diesel. Considering all economic and environmental benefits, production of bio-diesel is growing quickly as an alternative fuel to the petroleum diesel around the world. Over the years several researchers have been investigated the feasibility of using different bio-diesels under numerous conditions with little or no modifications in the existing diesel engine. M M Musthafa *et al.* [1] carried out the experiments on fly ash coated single cylinder diesel engine fuelled by methyl ester of rice bran, pongamia oil and its blend (20% by volume) with diesel and reported that there is an increase in engine power and decrease in specific fuel consumption, as well as significant improvements in exhaust gas emissions except NOx. B Karthikeyan *et al.* [2] conducted an experiment on the glow plug assisted engine with and without insulation in order to find out the possible benefits of combustion chamber insulation in ethanol and diesel operation and reported that highest brake thermal efficiency of 32 % was obtained and volumetric efficiency of the engine was reduced by a maximum of 9% in LHR mode of operation [3-4]. H Hazar *et al.* [5-6] experimented with cotton methyl ester on molybdynum coated engine and corn oil methyl ester with Al_2O_3-TiO_2 coated engine and reported that efficiency was increased with increase in the emission of NOx. Similarly many investigators [7-17] have conducted the experiments on coated and normal engines with different biodiesel blends as fuels and reported varied results with respect to performance and engine emissions.

The aim of this work was to produce biodiesel from mahua oil and to study the effect of mahua biodiesel in combination with diesel on the engine which is provided with thermal barrier coating. Figure 1 shows the seeds of mahua tree.

FIG. 1 MAHUA SEEDS

2.0 MATERIALS AND METHODS

In the present work, Mahua oil was used as raw material for the production of the biodiesel. A single stage transesterification reaction was used for the production of biodiesel. Biodiesel was produced using a 25 litre biodiesel production setup. Few engine components such as cylinder head, piston, exhaust and inlet valves were coated with nickel chromium alloy and yttria stabilized zirconia in the ratio 30:70 of thickness 250 µm, by the method of plasma spray coating. [18-20]

2.1 Thermal Barrier Coating

Insulating the combustion chamber of an internal combustion engine theoretically results in improved thermal efficiency according to the second law of thermodynamics. However, this may not be the case practically due to the complex nature of the internal combustion and the mechanical and thermal limitations of the insulation material and lubricants. Several investigators have reported, based on their own test results that the overall thermal efficiency of a low heat rejection diesel engine could be lower or higher than the uninsulated one depending upon the engine configuration, test conditions, and methods used.

2.2 Plasma Spray Coating Method

Material in the form of powder is injected into very high temperature plasma flame, where it is rapidly heated and accelerated to a high velocity. The hot material impacts on the substrate surface and rapidly cools thereby forming a coating. Plasma gun comprises of a copper anode and tungsten cathode, both of which are water cooled. Plasma gas (argon, helium, nitrogen, hydrogen) flows around the cathode and through the anode which is shaped as a constricting nozzle. Atmospheric plasma spray coating method was used to coat the combustion chamber components. As for plasma gas, a mixture of Argon (Ar) and Nitrogen (N_2) was used.

The conventional combustion chamber of a diesel engine was insulated with nickel chromium alloy bond coat and yttria stabilized zirconia top coat of 250 μm thickness as shown in Table 1. Thermal insulation of the combustion chamber was provided to have a hotter environment for the complete combustion. Figure 2 and 3 shows the schematic diagram of plasma spray coating and photographic view of insulated engine components. piston, cylinder head, exhaust and inlet valves of the diesel engine used in the tests were coated with Nickel Chromium (NiCr) alloy bond coat and Yttria Stabilized Zirconia (Y_2O_3–ZrO_2) top coat. The thickness of coating was selected as 250 μm, within the optimum range of thickness 0.1–1.5 mm. Cylinder liner was not coated because of very negligible area. Combustion chamber geometry was maintained by machining the components.

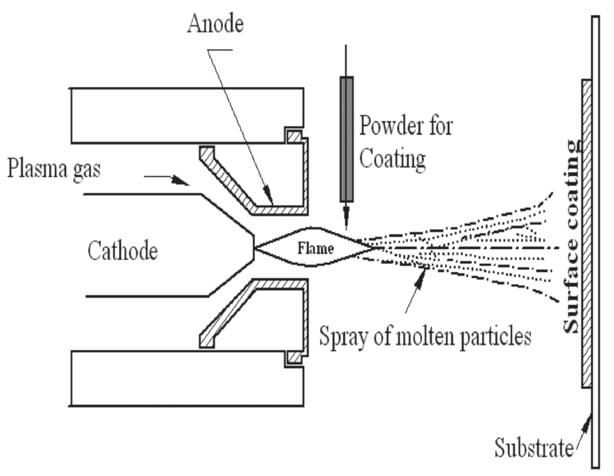

FIG. 2 SCHEMATIC DIAGRAM OF PLASMA SPRAY COATING

FIG. 3 PHOTOGRAPHIC VIEW OF INSULATED ENGINE COMPONENTS

TABLE 1

COATING MATERIALS

Particulars	Coating material	Thickness
Bond coating	Nickel chromium (NiCr) alloy	50 μm
Top coating	30% Nickel chromium (NiCr) alloy and 70% yttria stabilized zirconia (Y_2O_3–ZrO_2)	200 μm

2.3 Production of Biodiesel

Biodiesel is a methyl ester formed by a process called transesterification. Transesterification also called alcoholysis, is the displacement of alcohol from an ester by another alcohol. Suitable alcohols include methanol, ethanol, propanol, butanol, and amyl alcohol. This process is widely used to reduce the viscosity of triglycerides, thereby enhancing the physical properties of fuel and improve engine performance.

Oil can be extracted from the seeds of mahua tree with a simple oil extraction unit. The mahua oil was reacted with methanol in the presence of a catalyst to yield methyl esters and glycerol. In this work, potassium hydroxide was used as the catalyst. The sodium hydroxide pellets were dissolved in methanol to make a homogenous mixture. The filtered oil was transferred to the biodiesel reactor and the homogenous mixture of methanol and catalyst was transferred to the reactor vessel. Then the heater of the reactor vessel was switched on and the reaction temperature of 60 degree was maintained.

The reactants were mixed vigorously using a motor. After the reaction of 2 hour, the products of the transesterifiction was transferred to the separating tank for the sepration of biodiesel and the glycerol. The top layer, biodiesel, was separated and was subjected to water wash using the warm water. After water wash, biodiesel was seprated and heated above 100°C for 10 minutes, to remove the moisture.

2.4 Fuel Properties

After esterification, the biodiesel was tested for fuel properties. Table 2 Shows the notations used for the different fuels tested and Table 3 Shows the comparison of fuel properties between mahua oil blends and diesel.

TABLE 2

NOTATIONS FOR BIODIESEL BLENDS

Amount of diesel (%)	Amount of mahua (%)	Notation
100	0	B0
90	10	B10
80	20	B20
70	30	B30
60	40	B40
0	100	B100

TABLE 3

PROPERTIES OF DIESEL AND BIODIESEL BLENDS

Fuel	Specific gravity	Kinematic viscosity at 40°C (cst)	Flash point(°C)	Fire point(°C)	Calorific value (kJ/kg)
B100	0.91	5.8	208	217	40100
Diesel	0.82	2.6	55	64	42935
B10	0.825	2.96	67	74	42601
B20	0.83	3.31	70	77	42268
B30	0.835	3.66	73	81	41934
B40	0.84	3.90	75	84	41601

2.5 Engine Tests

Figure 4 shows the engine experimental setup. A single cylinder water cooled four stroke direct injection compression ignition engine with the specifications as shown in Table 4 was used for the test. An AVL Digas 444 exhaust gas analyzer has been used to measure the emission of carbon monoxide, unburnt hydrocarbon and oxides of nitrogen in the engine exhaust. Experiments were conducted initially by using neat diesel at various loads and then with mahua oil methyl ester blends under uncoated and coated engine conditions. Experiments were repeated by changing the load(Brake power).

FIG. 4 ENGINE EXPERIMENTAL SETUP

TABLE 4

ENGINE SPECIFICATIONS

Make	Kirloskar
Compression ratio	16.5:1
Bore	80 mm
Stroke	110 mm
Cylinder capacity	553 cc
Cooling	Water cooled
Loading	Eddy current dynamometer
Rated power	5 hp
Rated speed	1500 rpm

3.0 RESULTS AND DISCUSSIONS

The engine was running without any problem with the diesel-mahua oil biodiesel blends. The engine parameters such as Load, speed, air flow rate, fuel flow rate, exhaust gas temperature, exhaust emissions of hydrocarbon, carbon monoxide, carbon dioxide and oxides of nitrogen were recorded and the results were compared.

3.1 Experimental observations for engine performance and emissions

The effect of mahua bio-diesel on the engine performance and emissions for both uncoated and coated conditions of the engine are discussed in the following paragraphs.

3.1.1 Brake specific fuel consumption

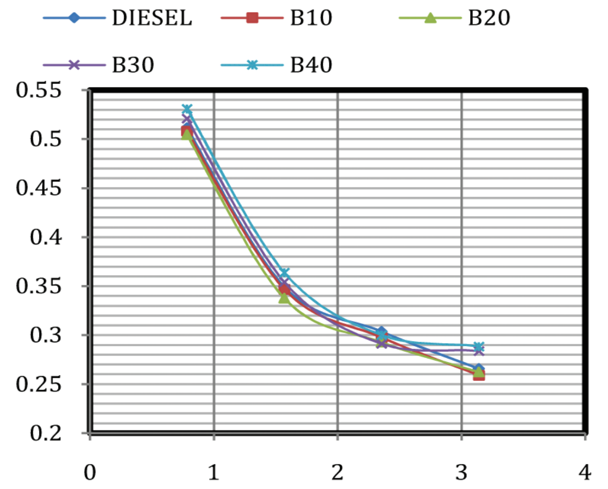

FIG. 5 BRAKE SPECIFIC FUEL CONSUMPTION (kg/kWh) V/S BRAKE POWER(kW)-UNCOATED ENGINE

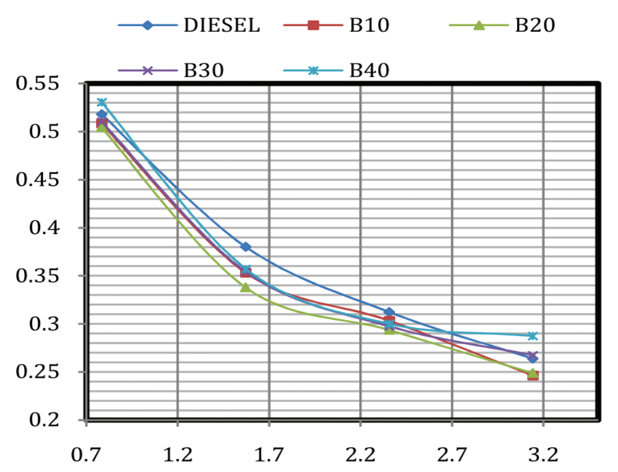

FIG. 6 BRAKE SPECIFIC FUEL CONSUMPTION (Kg/kWh) V/S BRAKE POWER(kW)-COATED ENGINE

The variation of brake specific fuel consumption with respect to brake power for uncoated and coated engine is shown in Figure 5 and 6. From the figure it is observed that as the brake power increases the brake specific fuel consumption decreases for all the fuels. For uncoated engine , lowest brake specific fuel consumption was observed for B10 and B20 blends which was less than diesel by about 2.5%. where as under coated condition brake specific fuel consumption for the B10 and B20 blend is reduced by about 5 % compared to diesel at maximum brake power tested. Higher proportion of mahua oil in blends such as B30 and B40 increases the viscosity which in turn increased the brake specific fuel consumption due to poor atomization of the fuel.

3.1.2 Brake thermal efficiency

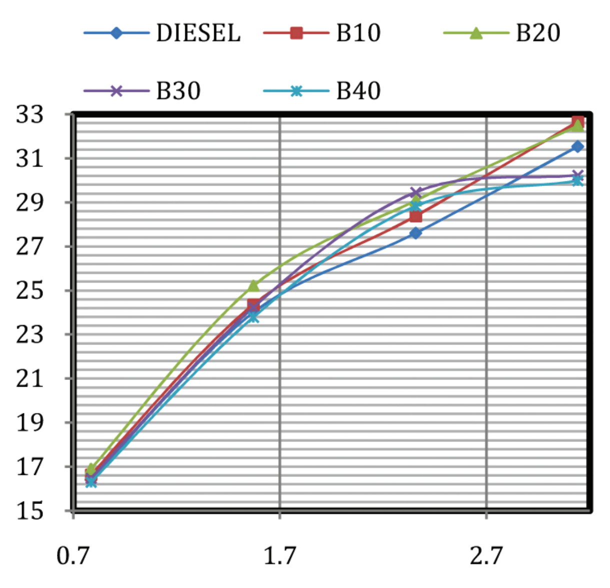

FIG. 7 BRAKE THERMAL EFFICIENCY(%) V/S BRAKE POWER(kW)-UNCOATED ENGINE

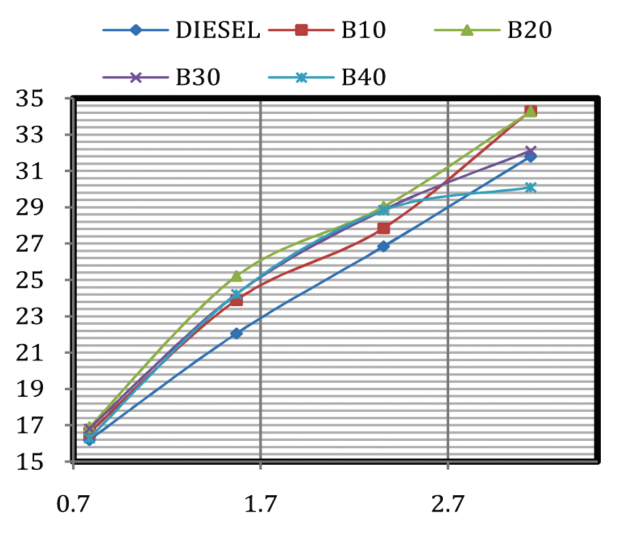

FIG. 8 BRAKE THERMAL EFFICIENCY(%) V/S BRAKE POWER(kW)-COATED ENGINE

Figure 7 and 8 reveals that the brake thermal efficiency increases with the increase in brake power for all the fuel modes. For uncoated engine the highest brake thermal efficiency was observed for B10 and B20 fuel which was 32.66 % and 32.48% than the diesel which was 31.54% at maximum power. The blending of biodiesel have brake thermal efficiency higher than conventional diesel. For the coated engine improvement in thermal efficiency of about 7 % was observed for the blends B10 and B20 compared to the diesel under uncoated condition of the engine. This is due to the reduction of in-cylinder heat transfer. The decrease in brake thermal efficiency with increase in mahua oil concentration was observed for B30 and B40 and was due to the poor atomization of blends due to their high viscosity.

3.1.3 Exhaust gas temperature

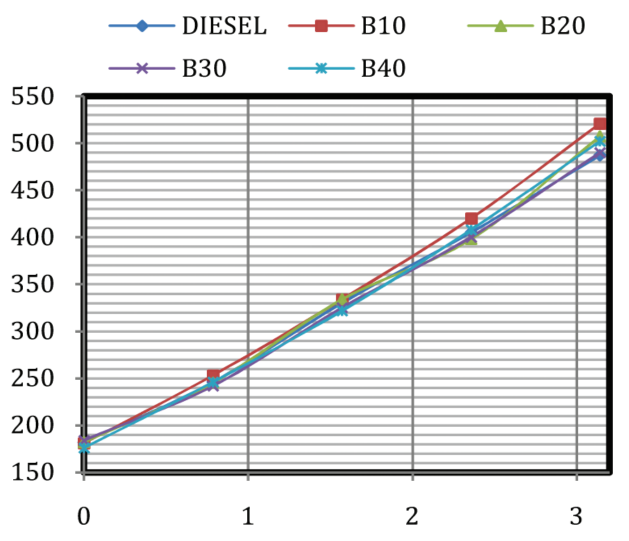

FIG. 9 EXHAUST GAS TEMPERATURE(0°C) V/S BRAKE POWER(kW)-UNCOATED ENGINE

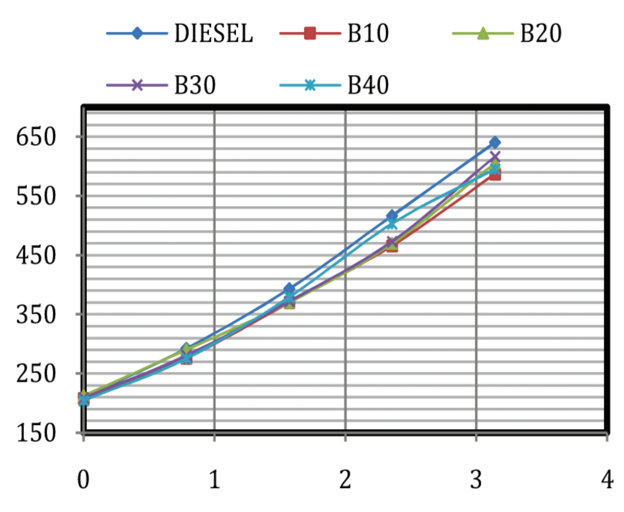

FIG. 10 EXHAUST GAS TEMPERATURE(0^0C) V/S BRAKE POWER(kW)-COATED ENGINE

Figure 9 and 10 shows that the exhaust gas temperature increases with increase in brake power for all blends.At all the values of brake power, diesel was found to have the lowest temperature and the temperature for various blends show an upward trend with increasing concentration of mahua oil in the blends. The biodiesel contains oxygen which enables the combustion process and the exhaust gas temperatures were higher. The increase in exhaust gas temperature for all test fuels used in coated engine compared with uncoated might be explained by the decrease in heat losses into the cooling system and transfer of this heat to the exhaust gas as a result of thermal barrier coating. The biodiesel contains oxygen which enables the combustion process and the exhaust gas temperatures were higher.

3.1.4 Carbon Monoxide (CO) emission

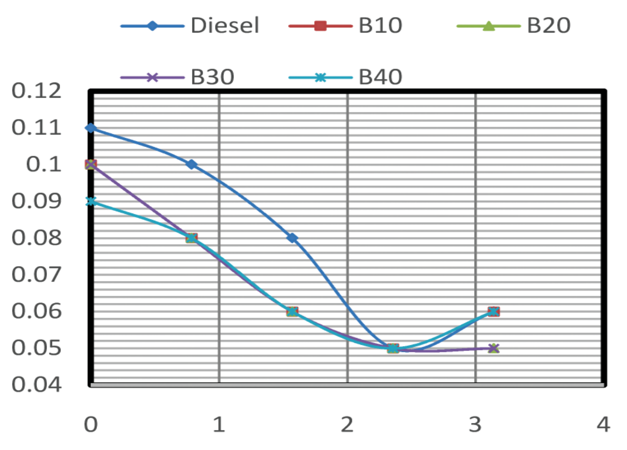

FIG. 11 CARBON MONOXIDE EMISSION (%) V/S BRAKE POWER(kW)-UNCOATED ENGINE

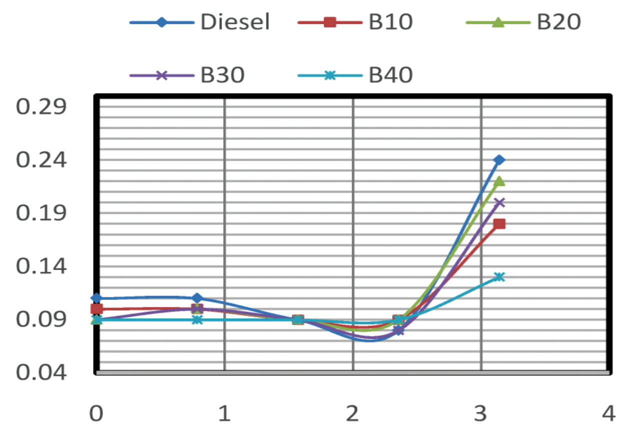

FIG. 12 CARBON MONOXIDE EMISSION (%) V/S BRAKE POWER(kW)-COATED ENGINE

The emission of carbon monoxide with increase in brake power is shown in Figure 11 and 12 for uncoated and coated engine. The CO emission for diesel is more than the blends for coated and uncoated engines. The percentage of CO decreases at 2.35 kW brake power for blends in uncoated engines where as in coated engines it increases at maximum power and at all other loads it is less.

3.1.5 Hydro Carbon (HC) emission

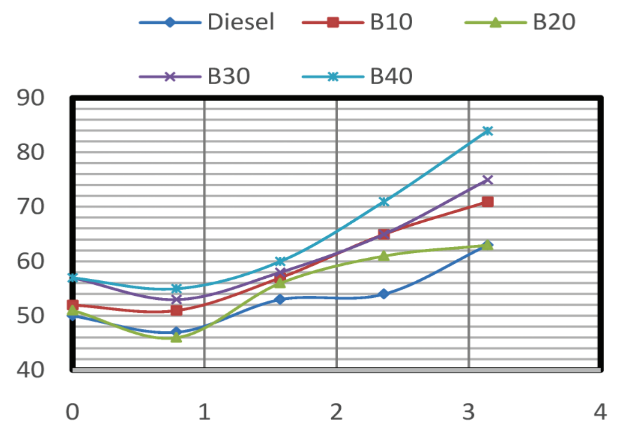

FIG. 13 HYDROCARBON EMISSION (ppm) V/S BRAKE POWER(kW)-UNCOATED ENGINE

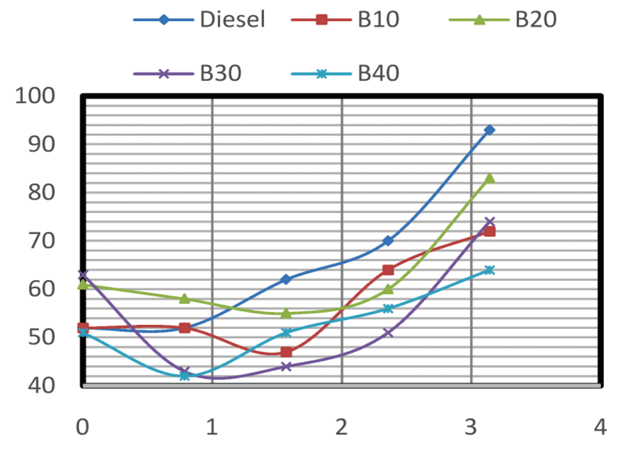

FIG. 14 HYDROCARBON EMISSION (ppm) V/S BRAKE POWER(kW)-COATED ENGINE

Figure 13 and 14 shows that the hydrocarbon emission increases with the increase in brake power. The emission of hydrocarbon for diesel is less than the blends for uncoated engine where as in coated engine HC emissions for blends were less than that of diesel. The presence of oxygen in the mahua oil leads to better combustion, hence the HC emission was reduced. At higher load the effects of viscosity have increased the HC emission for the blends. At the higher load the HC emission for the blends was less in coated engine compared to uncoated engine.

3.1.6 *Carbon Dioxide (CO_2) emission*

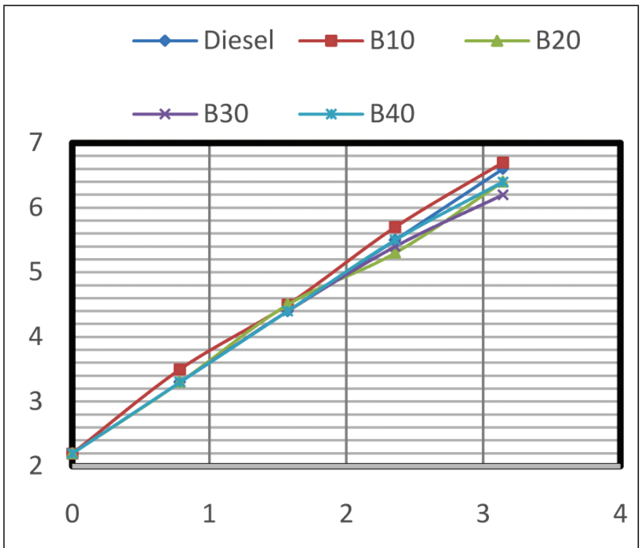

FIG. 15 CARBON DIOXIDE EMISSION(%) V/S BRAKE POWER(kW)-UNCOATED ENGINE

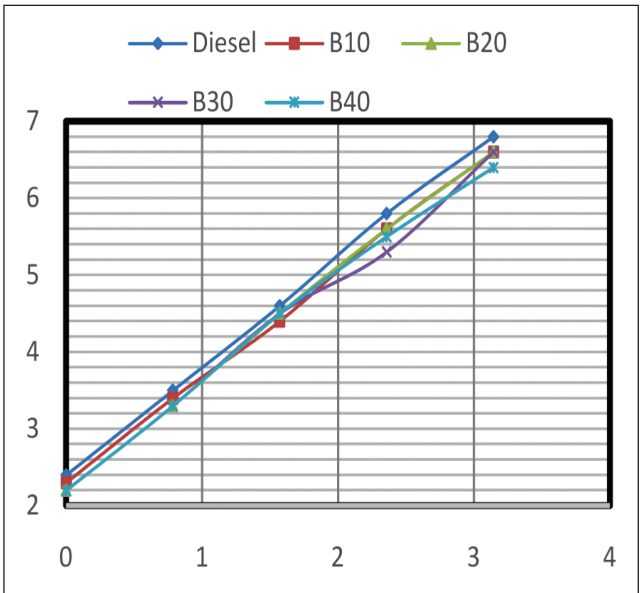

FIG. 16 CARBON DIOXIDE EMISSION(%) V/S BRAKE POWER (kW)-COATED ENGINE

The rising trends of CO_2 emission with load is due to the higher fuel entry as the load increases which is observed in Figures 15 and 16. Till 1.57 kW brake power, the CO_2 emission for diesel is higher than the blends in coated and uncoated engines. At the higher loads the effects of viscosity have increased the CO_2 emission for blends.

3.1.7 *Oxides-of-Nitrogen (No_x) emission*

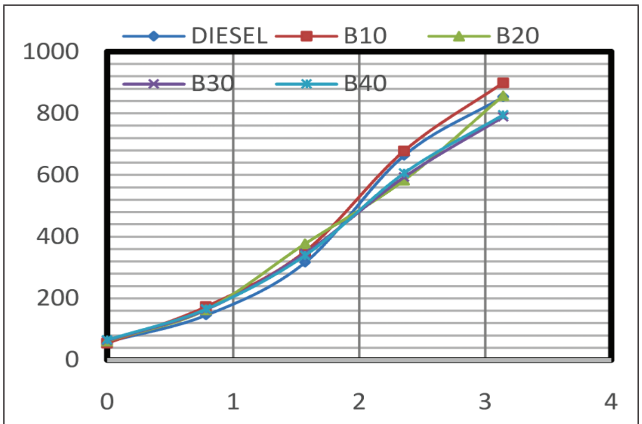

FIG. 17 OXIDES OF NITROGEN EMISSION (PPM) V/S BRAKE POWER (kW) -UNCOATED ENGINE

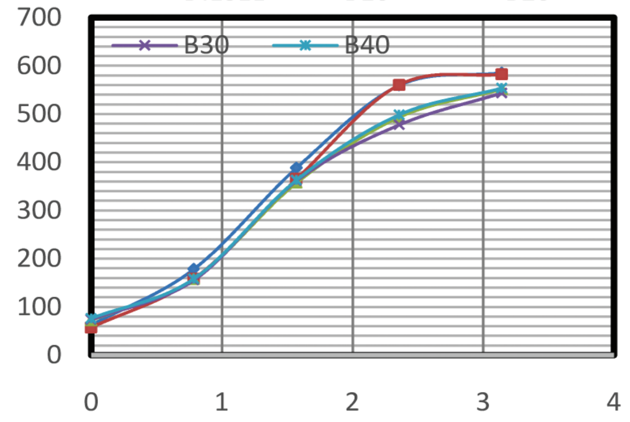

FIG. 18 OXIDES OF NITROGEN EMISSION (ppm) V/S BRAKE POWER (kW)-COATED ENGINE

Figure 17 and 18 shows that the NO_X emission for diesel and all the biodiesel blends followed increasing trend with respect to the brake power. For the biodiesel blends an increase in emission is found approximately at all loads when compared to the diesel. Blends B10 and B20 showed the higher NO_X emission in uncoated engines where as in coated engines NO_X emission was reduced comparatively due to higher exhaust temperature.

4.0 CONCLUSIONS

The biodiesel was produced from mahua oil and engine tests were conducted successfully with blends of biodiesel and diesel. From this experimental work, the following conclusions are drawn.

- The properties of the mahua oil biodiesel were found to be close to the fossil diesel and better than the raw oil.
- The engine performance and emission characteristics of coated or low heat rejection engine is better than the normal engine. This is due to higher temperature inside the combustion chamber due to thermal barrier coating which increases the atomisation and vapourisation of the biodiesel.
- Among the biodiesel blends tested, for B10 and B20, the engine efficiency improves from 3 to 7 % depends upon the load.
- The engine emissions such as HC and CO decreases significantly for the coated engine due to better combustion. However, the engine emits higher NOx with coating as compared to the normal engine. This is due to increased combustion temperature which leads to higher NOx emissions.
- From this work, it can be concluded that mahua oil biodiesel can be used as a partial replacement to fossil diesel with thermal barrier coating in the diesel engine.

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