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Emission and Performance Characteristics of Diesel Engine Using Mamey Sapote Biodiesel as Alternate Fuel

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Abstract: In the present study an experimental investigation was carried out with Mamey Sapote oil as an alternative fuel in a compression ignition engine. The problems associated with fruit seed oil are high viscosity, low volatility and high reactivity, but at the same time their higher cetane number, lower sulphur content and higher oxygen concentration are the desirable properties to use as a fuel in compression ignition engines. The process of transesterification of fruit seed oil with methyl alcohol provides a significant reduction in viscosity, thereby enhancing the physical properties of fruit oil. The current paper reports a study carried out to investigate the combustion, performance and emission characteristics of Mamey Sapote oil methyl ester with diesel fuel on a single-cylinder, four-stroke, direct injection and water cooled diesel engine. This study gives the comparative measures of brake specific fuel consumption, brake power, brake thermal efficiency, mechanical efficiency, volumetric efficiency, CO, CO_2, HC, NOx and smoke opacity. Mamey Sapote Biodiesel was blended at 5%, 10% , 15% and 20% ratio with diesel fuel in the present study. The results indicate that the CO and HC emissions were lower than diesel at 15% of MSO, and NOx emissions decreased up to 20.5% for 15% MSO when compared with diesel. From the investigation it can be concluded that biodiesel can be used as an alternative to diesel in a compression ignition engine without any engine modifications.
Keywords: Diesel engine, Mamey Sapote biodiesel, Engine performance, Exhaust emissions, transesterification.

I. INTRODUCTION

Environmental concerns and limited amount of petroleum resources have caused interests in the development of alternative fuels for I.C. Engines. Petroleum resources are finite and therefore search for their alternative is continuing all over the world. The major energy demand is fulfilled by the use of conventional energy resources like coal, petroleum and natural gas. These sources are in the verge of getting extinct. The scarcity of conventional fossil fuels, growing emissions of combustion generated pollutants and their increasing costs will make biomass sources more attractive. The use of biodiesel is rapidly expanding around the world, making it imperative to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. Bio fuels like ethanol and bio-diesel being environment friendly, will help us to conform to the stricter emission norms. Bio fuels are generally considered as offering many priorities, including sustainability, reduction of greenhouse gas emissions, regional development, social structure and agriculture and security of supply. In the developed countries, there is a growing trend towards employing modern technologies and efficient bio energy conversion using a range of bio fuels, which are becoming cost-wise competitive with fossil fuels.

Environmental benefits in comparison to petroleum based fuels include:

A. "At the tailpipe, biodiesel emits more CO_2 than petroleum diesel". However, if "biomass carbon (is) accounted for separately from fossil-derived carbon", one can conclude that biodiesel reduces emissions of carbon monoxide (CO) by approximately 50% and carbon dioxide by 78% on a net lifecycle basis because the carbon in biodiesel emissions is recycled from carbon that was in the atmosphere, rather than the carbon introduced from petroleum that was sequestered in the earth's crust.

B. Biodiesel can reduce by as much as 35 % the direct (tailpipe) emission of particulates, small particles of solid combustion products on vehicles with particulate filters, compared with low-sulfur (< 50 ppm) diesel.

C. Particulate emissions as a result of production are reduced by around 50%, compared with fossil-sourced diesel.

D. Biodiesel has a higher cetane rating than petro diesel, which can improve performance and clean up emissions compared to crude petro-diesel (with cetane number lower than 40).

For developing countries fuels of bio-origin can provide a feasible solution to this crisis. Certain edible oils such as cottonseed, palm, sunflower, rapeseed, safflower can be used in diesel engines. For longer life of the engines these oils cannot be used straightway. These oils are not cost effective to be used as an alternate fuel in diesel engines at present. Some of the non-edible oils such as mahua, castor, neem (Azadiracta indica), rice bran, linseed, Karanja (Pongamia pinnata), jatropha (Jatropha curcas) etc. can be used in diesel engines after some chemical treatment. The viscosity and volatility of these vegetable oils is higher, and these can be brought down by a process known as "transesterification". Biodiesel has a higher cetane number than petroleum diesel, no aromatics and contains upto 10% oxygen by weight. The characteristics of biodiesel reduce the emissions of carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) in the exhaust gas as compared with petroleum diesel [1, 2].

Sanjib Kumar Karmee et al., [3] have prepared biodiesel of Pongamia Pinnata with a yield of 95% using methanol and potassium hydroxide as a catalyst. The viscosity of the oil decreased from 74.14 Cst (at 30°) to 4.8 Cst (at 40°C) on transesterification and the flash point was 150°C. Both these properties meet the ASTM and German biodiesel standards. Suresh Kumar et al., [4] have investigated the performance and emission characteristics on a single cylinder diesel engine and reported decrease in NOx and HC emissions. A 40% blend (B40) of biodiesel in diesel has been recommended by the authors.

Biodiesel is an esterified version of vegetable oil. viscosity of triglycerides. The reaction is conducted This could be edible or non-edible oils. Oils having high at temperature close to the boiling point of methanol, free fatty acids (FFA) need a different treatment from that 60-70°C, at atmospheric pressure. The mahua oil of low FFA oils. High viscosity and FFA and Gum cause chemically reacted with alcohol in the presence of a clogging and injector nozzle plugging. High FFA results catalyst to produce methyl esters. After completing the in corroding engine parts, increases viscosity and tends process, they were separated in the separating flask under

to increase deposit [5].. Banapurmath et al., [6] have reported tests on a single cylinder C.I. engine with 3 different biodiesels viz methyl esters of honge, jatropha and sesame. All the fuels gave a slightly lower efficiency. HC and CO emissions were slightly higher and NOx emission decreased by about 10%. They have reported that these oils can be used without any major engine modifications.

Many researchers have used Methyl esters of Pongamia pinnata [7,8], mahua oil [9], rapeseed oil [10], linseed oil [11], soybean [12,13], jatropha [14], cottonseed [15,16,17], and palm oil [18] reported the performance and emission characteristics in diesel engines. Barnwal et al., [19] have discussed about prospects of biodiesel production from vegetable oils in India. They have also given the yield and production cost of various methyl esters, in general non-edible oils. The methyl esters of non-edible oil are much cheaper than petroleum diesel. The objective of this paper is to investigate the performance and emission characteristics of a single cylinder, 4 stroke, constant speed, water cooled diesel engine with diesel and blends of bio-diesel and diesel (B20, B40) at a fuel injection pressure of 200 bar.

II. EXPERIMENTAL SET-UP

The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Research engine connected to eddy current dynamometer. It is provided with necessary instruments for combustion pressure, crank-angle, airflow, fuel flow, temperatures and load measurements. These signals are interfaced to computer through high speed data acquisition device. The set up has stand-alone panel box consisting of air box, twin fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and piezo powering unit. Rotameters are provided for cooling water and calorimeter water flow measurement. In petrol mode engine works with programmable Open ECU, Throttle position sensor (TPS), fuel pump, ignition coil, fuel spray nozzle, trigger sensor etc. The setup enables study of VCR engine performance for both Diesel and Petrol mode and study of ECU programming. Engine performance study includes brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, Air fuel ratio, heat balance and combustion analysis.

A. Engine Software

Engine Soft is Lab view based software package developed by Apex Innovations Pvt. Ltd. for engine performance monitoring system. Engine Soft can serve most of the engine testing application needs including monitoring, reporting, data entry, data logging.

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The software evaluates power, efficiencies, fuel consumption and heat release. Various graphs are obtained at different operating condition. While on line testing of the engine in RUN mode necessary signals are scanned, stored and presented in graph. Stored data file is accessed to view the data graphical and tabular formats. The data in excel format can be used for further analysis.

B. Instrumentation

Product is supplied with best quality instruments. The eddy current dynamometer is SAJ, Pune make. The components like Open ECU (PE USA), Combustion pressure sensor (PCB Piezotronics, USA), Crankangle sensor(Kubler, Germany), Fuel flow transmitter(Yokogawa, Japan), Pressure transmitter (Wika, Germany), High speed data acquisition device (National instruments, USA) are of MNC grades.

Table 2.1 Engine Specifications

Feature	Description
Make and Model	Research Engine Test setup code 240 PE Apex innovations pvt.Ltd.
Type of Engine	Multi fuel
Number of Cylinders	Single cylinder, Four Stroke
Cooling Media	water cooled,
Rated Capacity	3.5 KW @ 1500 rpm,
Cylinder diameter	87.5 mm
Stroke length	110 mm,
Compression ratio range	12-18
Injection variation	0- 25 ^{o} BTDC
Dynamometer	Eddy current Dynamometer
Overall dimensions	W 2000 x D 2500 x H 1500 mm

Table-2.2. AVL Five Exhaust gas analyzer

Exhaust gas	Measurement range	Resolution	Accuracy
CO	0-10% vol.	0.01% vol.	<0.6% vol.: ± 0.03%, ≥0.6%vol.:± 5% of ind. val
HC	0-20000 ppm	≤2000:1 ppm vol. >2000: 10 ppm vol.	<2000 ppm vol.:± 10 ppm ≥2000 ppm vol:± 5% of ind. val.
CO_2	0-20%vol.	0.1 % vol. .	<10%vol.:± 0.5 %vol. ≥10% vol.:± 0.5% of ind. val.
O_2	0-22%vol.	0.01% vol.	<2%vol.: ± 0.1%vol. ≥2% vol.:± 5%of ind. val
NO_X	0-5000 ppm	1 ppm vol.	<500 ppm vol.:± 50 ppm. ≥500 ppm vol:± 10% of ind. val

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III. RESULTS AND DISCUSSION

A. *Brake Power*

Brake power of the engine increases with the increase in load on the engine. Brake power is the function of calorific value and the torque applied. Diesel has more calorific value than the biodiesel, so diesel has the highest brake power among the different blends of biodiesel. From Fig 3.1 Due to the more calorific value of 5 % & 10 % MSO blends it produces slightly higher brake power when compared to 15% & 20% MSO. All most all blends are closely showing the same brake power of pure diesel. It can also be seen that as we increase the load, torque increases and thus there is an increase in brake power with the load.

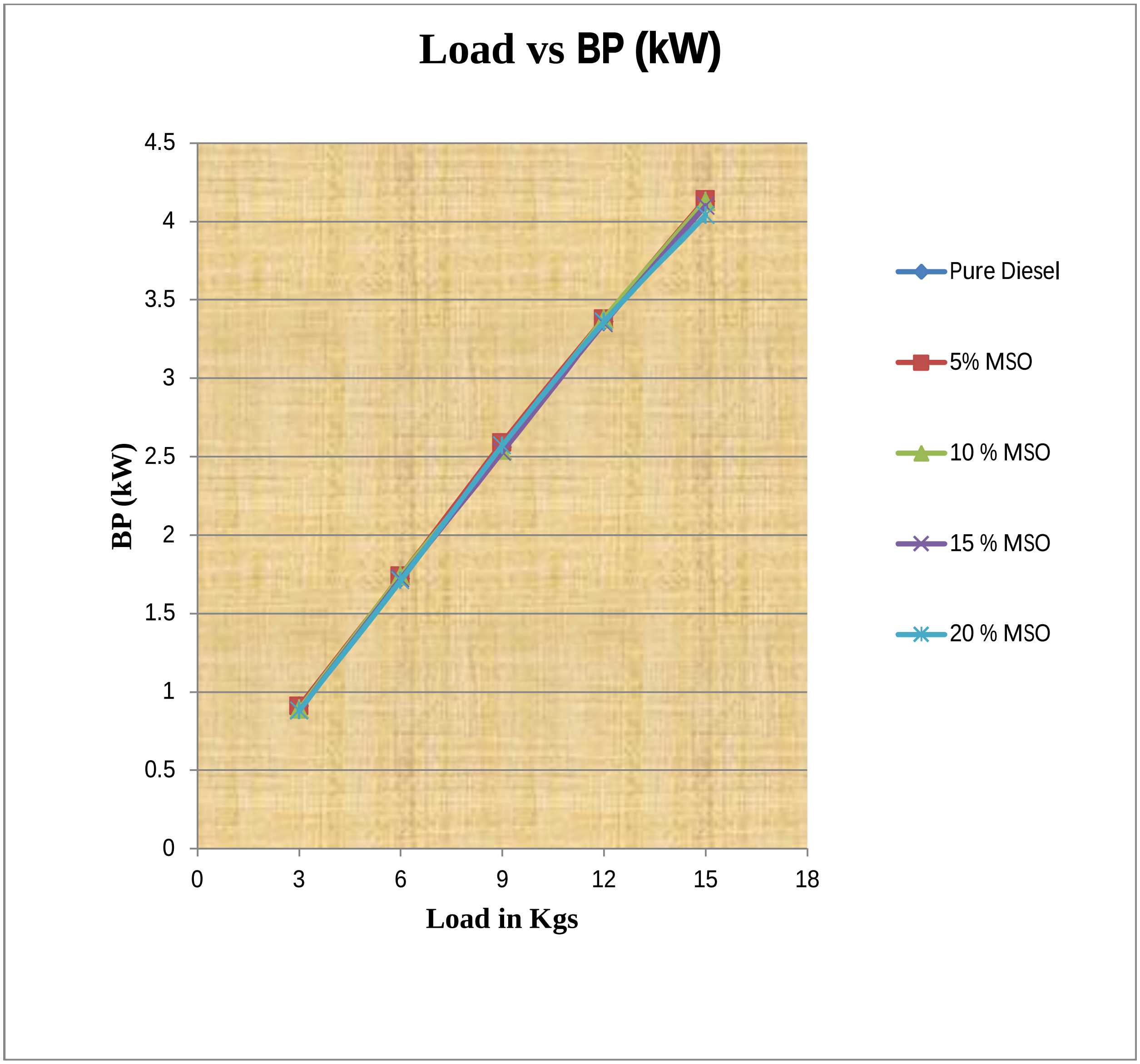

Fig 3.1 Load vs Brake Power

B. *Brake Specific Fuel Consumption (BSFC)*

Fig. 3.2 illustrates the variation in brake specific fuel consumption with the change in load. For all blends and diesel tested, BSFC decreased with increase in load. One possible explanation for this reduction is the higher percentage of increase in brake power with load as compared to fuel consumption.

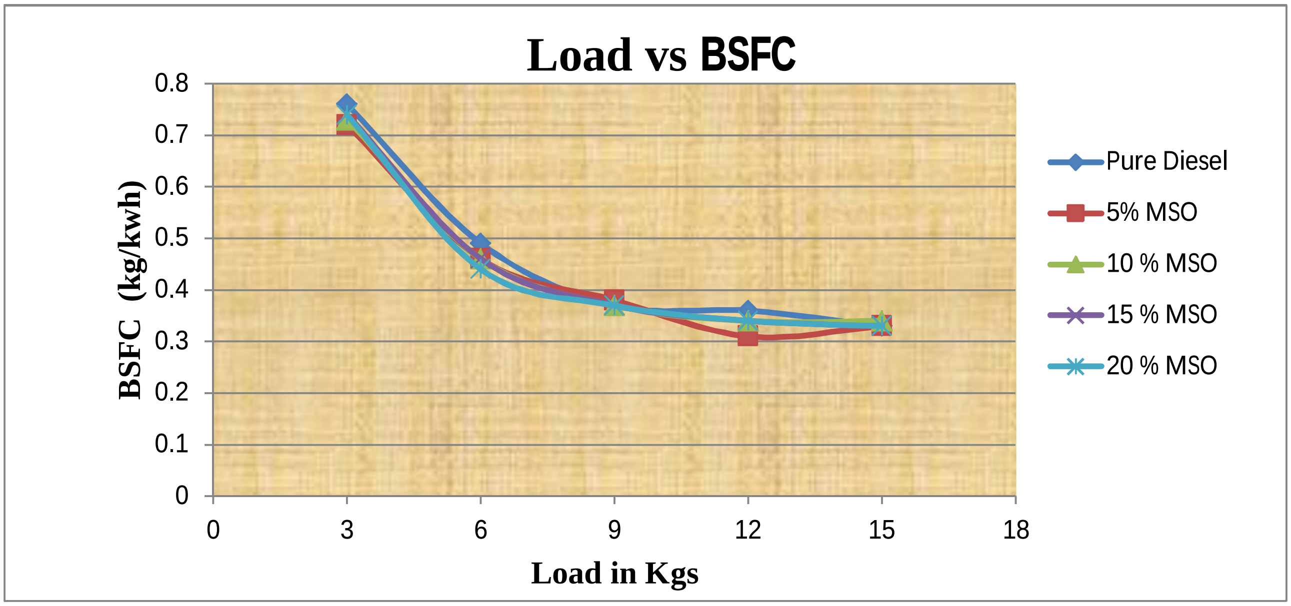

Fig 3. 2: Variation in brake specific fuel consumption with change in load

In case of biodiesel mixtures, the BSFC values were determined to be lower than that of neat diesel fuel at all loads. It is well known that brake specific fuel consumption is inversely proportional to the brake thermal efficiency. Among the four different blends of biodiesel, 5% MSO has the lowest value of brake specific fuel consumption and the value is 0.31 Kg/Kw-hr at 12 kgs load.

C. Brake Thermal Efficiency (BTE)

Fig. 3.3 illustrates the variation in brake thermal efficiency (BTE) with the change in load. In all cases, brake thermal efficiency increases with an increase in load. This can be attributed to reduction in heat loss and increase in power with increase in load.

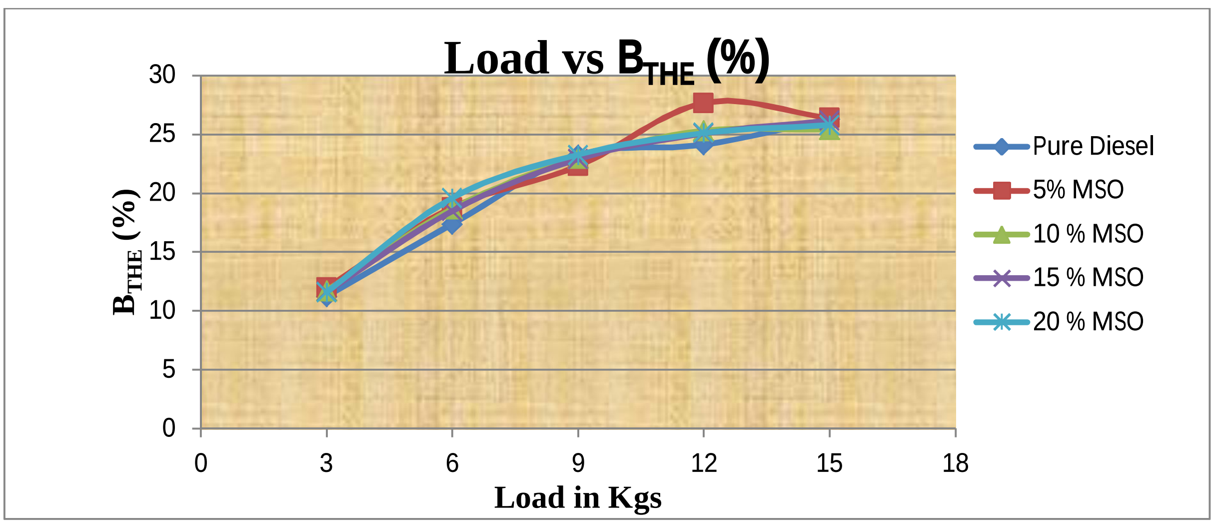

Fig. 3.3: Variation in brake thermal efficiency with change in load

It is also observed that biodiesel blends exhibits slightly higher thermal efficiency at most of the loads than diesel. Among the four different blends of biodiesel and pure diesel, 5% MSO has higher brake thermal efficiency at 12 kgs load which is 14.72 % higher than the diesel. The brake thermal efficiency depends upon the combustion quality of the fuel. The Mamey Sapote methyl ester

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blends give better combustion quality than that of diesel.

D. Hydrocarbons

The biodiesel blends have more oxygen content than that of standard diesel. So it involves in complete combustion process. The hydrocarbon emissions of the biodiesel blends are lower than the standard diesel due to complete combustion process. When percentage of blends of biodiesel increases, hydrocarbon decreases. Fig 3.4 shows that among the four different blends of biodiesel 15 % MSO has lower hydrocarbons than the other. But at peak loads 5% MSO have more hydrocarbon emissions compared to pure diesel and other blends.

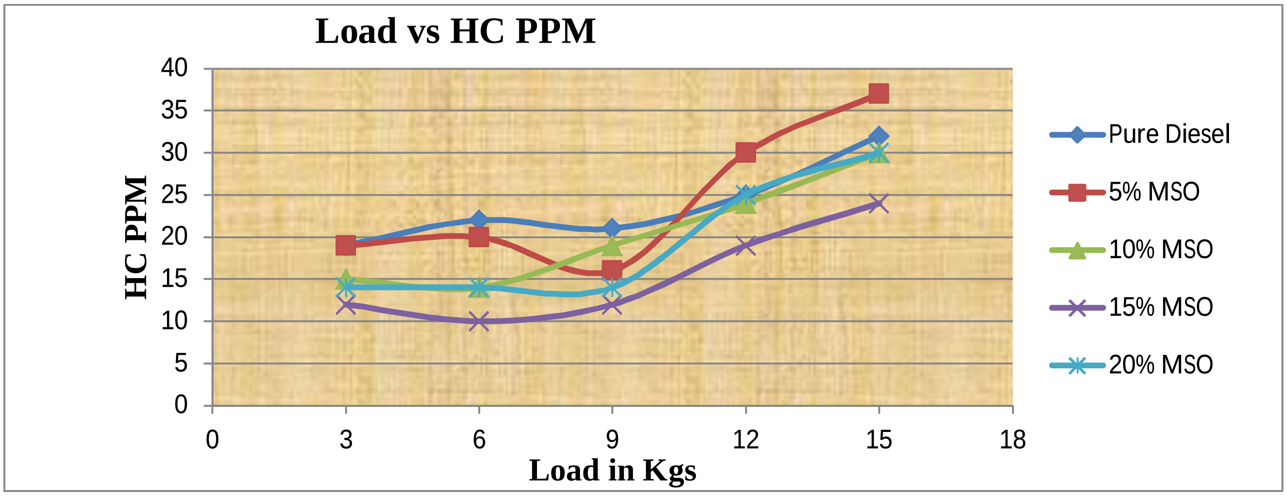

Fig 3.4: Variation in Hydrocarbon with change in load

E. Carbon monoxide

The carbon monoxide emission depends upon the oxygen content and cetane number of the fuel. The biodiesel has more oxygen content than the diesel fuel. So the biodiesel blends are involved in complete combustion process. The major reason to the CO formation is insufficient time and oxygen for oxidation of CO to CO_2. Fig. 3.5 illustrates the variation in Carbon monoxide with the change in load. It can be observed that CO emissions increase with increasing engine load, due to increase in the peak combustion temperature and the associated increase in the rate of dissociation reaction. From the graph it is observed that 20% MSO has lower Carbon monoxide than the other blends and neat diesel. But at peak loads 10% & 5% MSO blends has higher emissions than other blends and neat diesel.

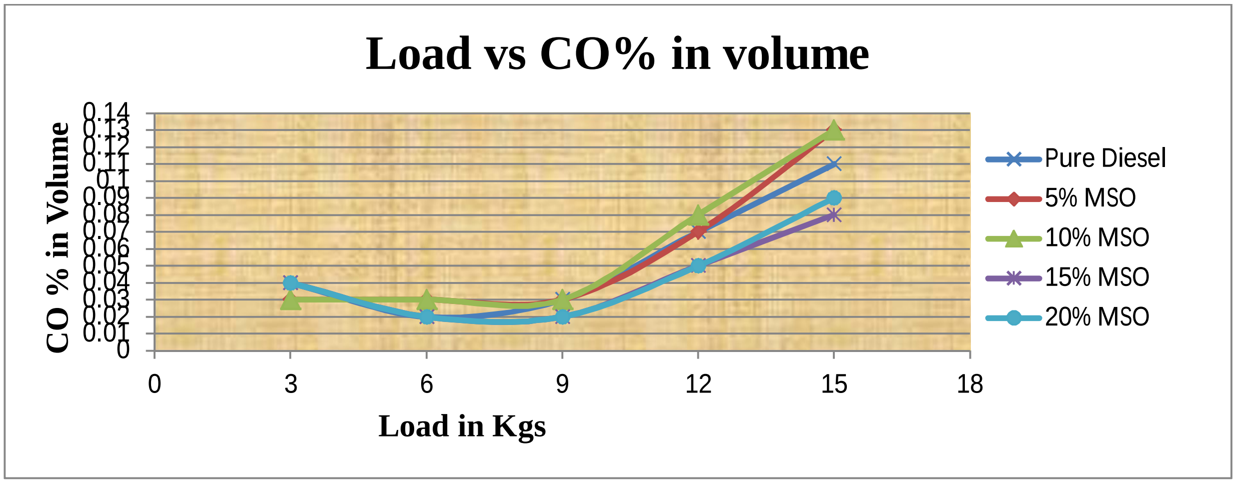

Fig 3.5: Variation in carbon monoxide with change in load

F. CO_2 Emissions

The carbon dioxide emission depends upon the oxygen content and cetane number of the fuel. The biodiesel has more oxygen content than the diesel fuel. So the biodiesel blends are involved in complete combustion process. The maximum carbon monoxide emission was observed at full brake power of the engine. Fig. 3.6 illustrates the variation in Carbon dioxide with the change in load. It can be observed that the 20% MSO gives low carbon monoxide emission than other biodiesel blends at all load conditions.

The carbon dioxide emission depends upon the complete combustion of the fuel. The biodiesel blends have the 11.5% oxygen content, resulting in complete combustion. Due to the complete combustion of the biodiesel blends, carbon dioxide emission also increases. The carbon dioxide emission using diesel fuel is lower because of the incomplete combustion. The combustion of biodiesel also produced more carbon dioxide but crops are focused to readily absorb carbon dioxide and hence these levels are kept in balance

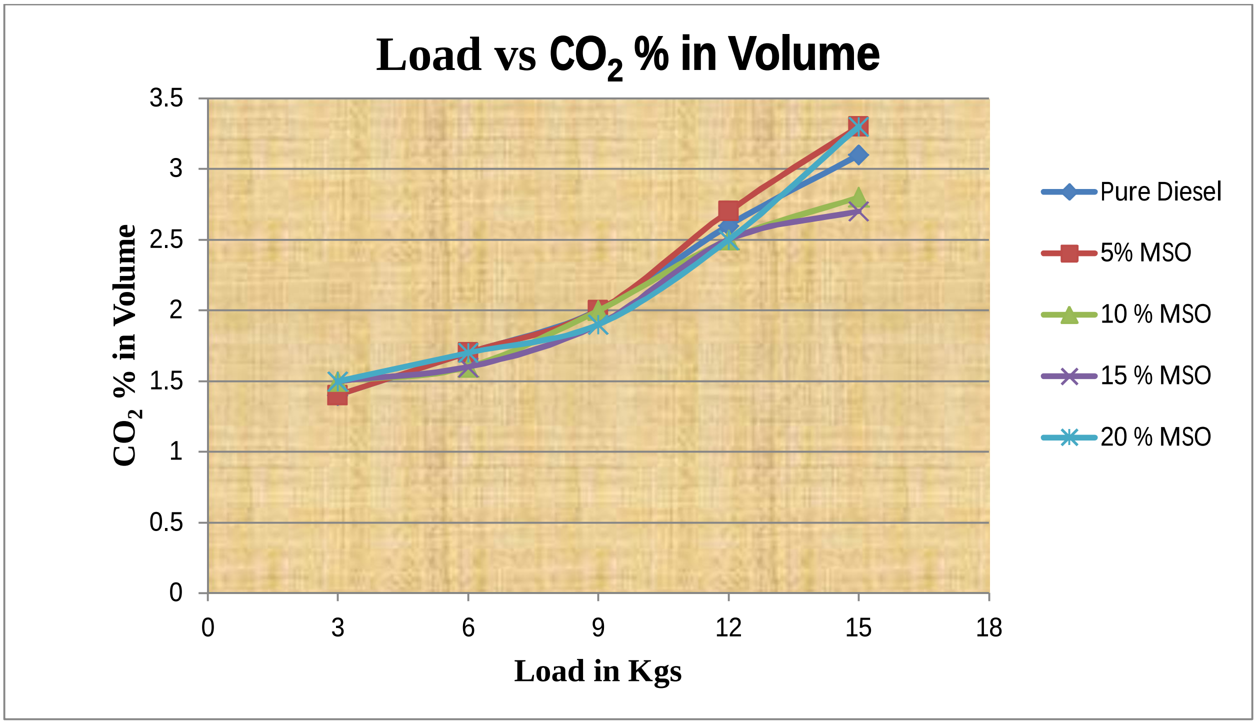

Fig 3.6 : Variation in carbon monoxide with change in load

G. NOx Emissions

The variation in the NOx emissions at different engine load is shown in Fig. 3.7. Oxides in the engine exhaust are the combination of nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen and oxygen react relatively at high temperature. Therefore high temperature and availability of oxygen are the two main reasons for formation of NOx. When the more amount of oxygen is available, the higher the peak combustion temperature the more is NOx formed. The NOx emission for all the blends is lower than that of diesel for all the loads except 5% MSO. At lean and rich air-fuel mixture the NOx concentration is comparatively low. As the engine is approaching the rated load the NOx emission is higher. At peak load 10% MSO produces 32.5 % lower than pure diesel.

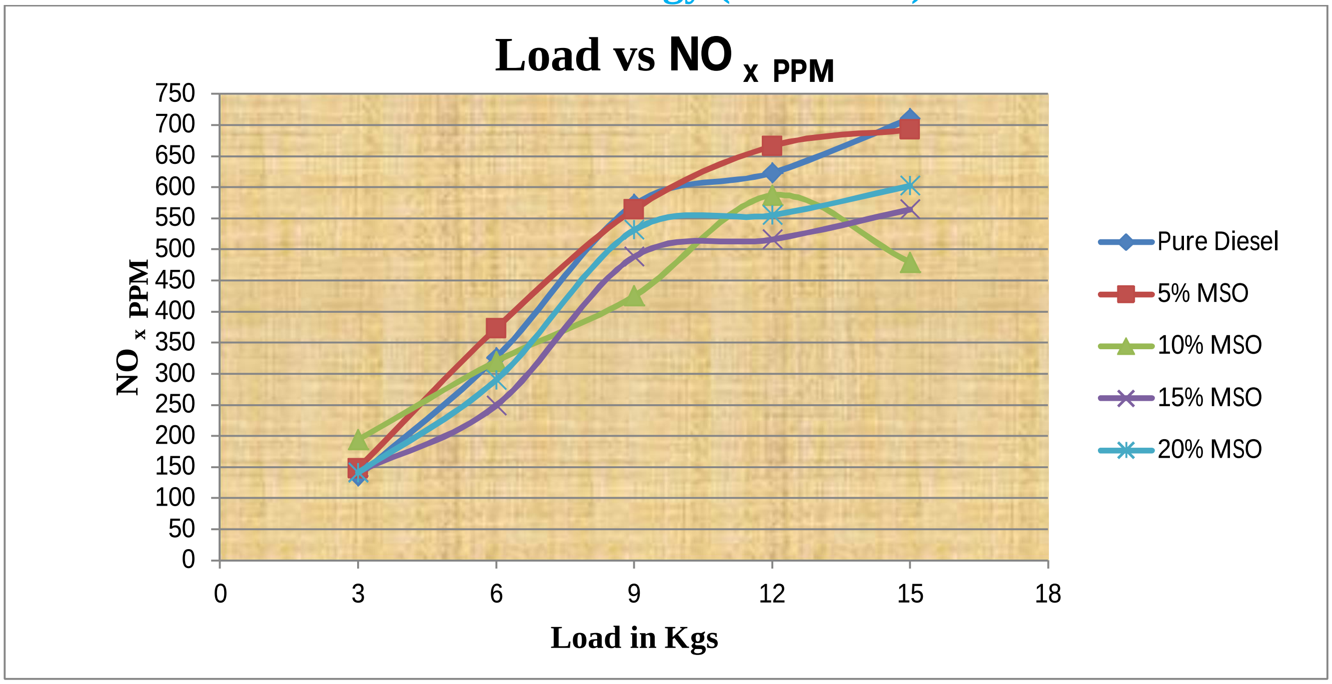

Fig 3.7: Variation in carbon monoxide with change in load

H. Smoke Opacity

Fig 3.6 represents the smoke emission measured in the engine exhaust. Any volume in which fuel is burned at relative fuel-air ratio greater than 1.5 and at pressure developed in diesel engine produces soot. The amount of soot formed depends upon the fuel ratio and type of fuel. If this soot, once formed finds sufficient oxygen it will burn completely. If soot is not burned in combustion cycle, it will pass through the exhaust, and it will become visible. The size of the soot particles affects the appearance of smoke. Black smoke largely depends upon the air fuel ratio and increases rapidly as the load is increased and available air is depleted. It can be observed from the figure that smoke opacity for the blends of biodiesel comparable with that of diesel for all loads. In comparison with diesel, the smoke is less for biodiesel blends at all loads because of complete combustion. For over load the smoke opacity is maximum, which is due to incomplete combustion. This may be due to the higher viscosity, lower volatility and poor atomization of the fuel. At full load15 % MSO produces 13.48% lower smoke opacity
Than diesel.

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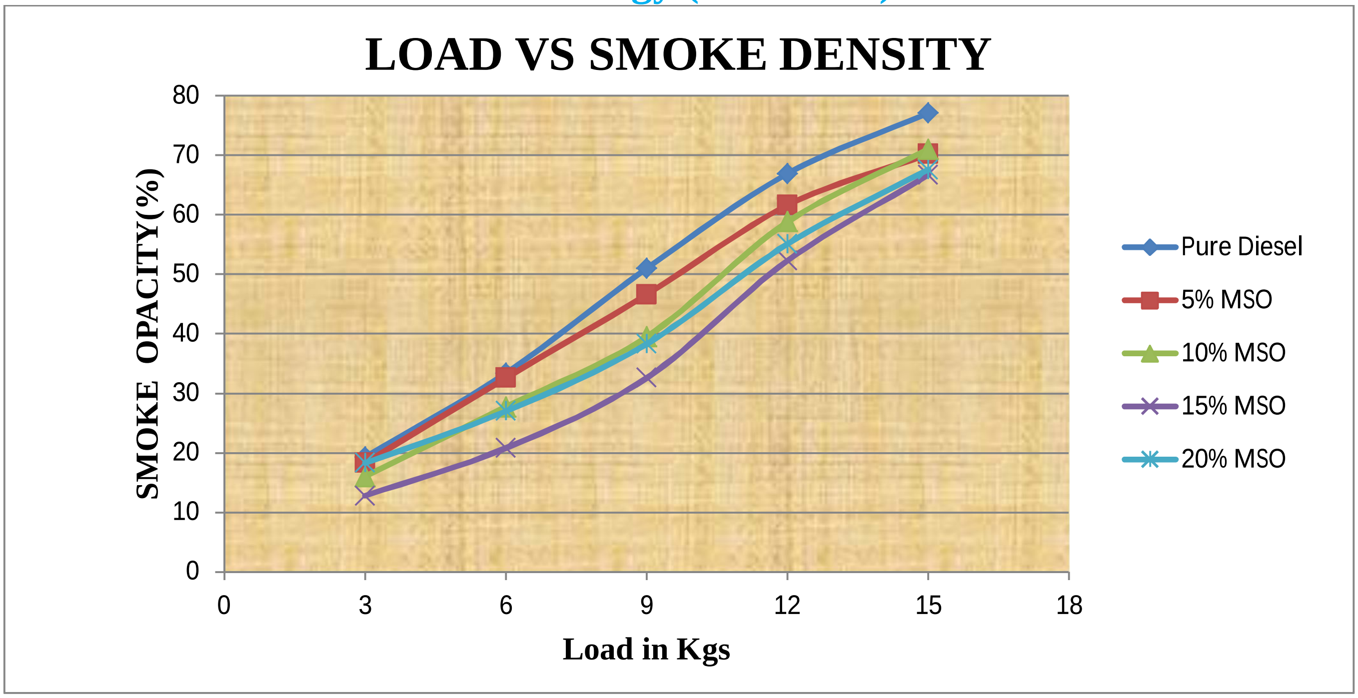

Fig 3.8: Variation in Smoke density with change in load

IV. CONCLUSIONS

Tests for emission and performance characteristics were conducted on a single cylinder, 4-stroke, constant speed diesel engine at a Compression ratio of 18. The combustion and emission characteristics of single cylinder compression ignition engine fuelled with Mamey Sapote biodiesel and its blends have been analyzed and compared to the standard diesel fuel. Based on the experimental results, the following conclusions are obtained

A. The brake thermal efficiency of Mamey Sapote biodiesel blends is higher than that of diesel at all load conditions. Among the four different blends of biodiesel and pure diesel, 5% MSO has higher brake thermal efficiency at 12 Kgs load which is 14.72 % higher than the diesel, and has the lowest value of brake specific fuel consumption.

B. CO_2emissions were more than the diesel. It can be observed that the 20% MSO gives low carbon monoxide emission than other biodiesel blends at all load conditions.

C. The hydrocarbon emissions of the biodiesel blends are lower than the standard diesel due to complete combustion process. Among the four different blends of biodiesel 15 % MSO has lower hydrocarbons than the other. But at peak loads 5% MSO have more hydrocarbon emissions compared to pure diesel and other blends.

D. It is observed that 20% MSO has lower Carbon monoxide than the other blends and neat diesel. But at peak loads 10% & 5% MSO blends has higher emissions than other blends and neat diesel.

E. The NOx emission for all the blends is lower than that of diesel for all the loads except 5% MSO. At peak load 10% MSO produces 32.5 % lower than pure diesel.

F. The smoke opacity for all the blends is lower than that of diesel for all the loads. At full load15 % MSO produces 13.48% lower smoke opacity than diesel.

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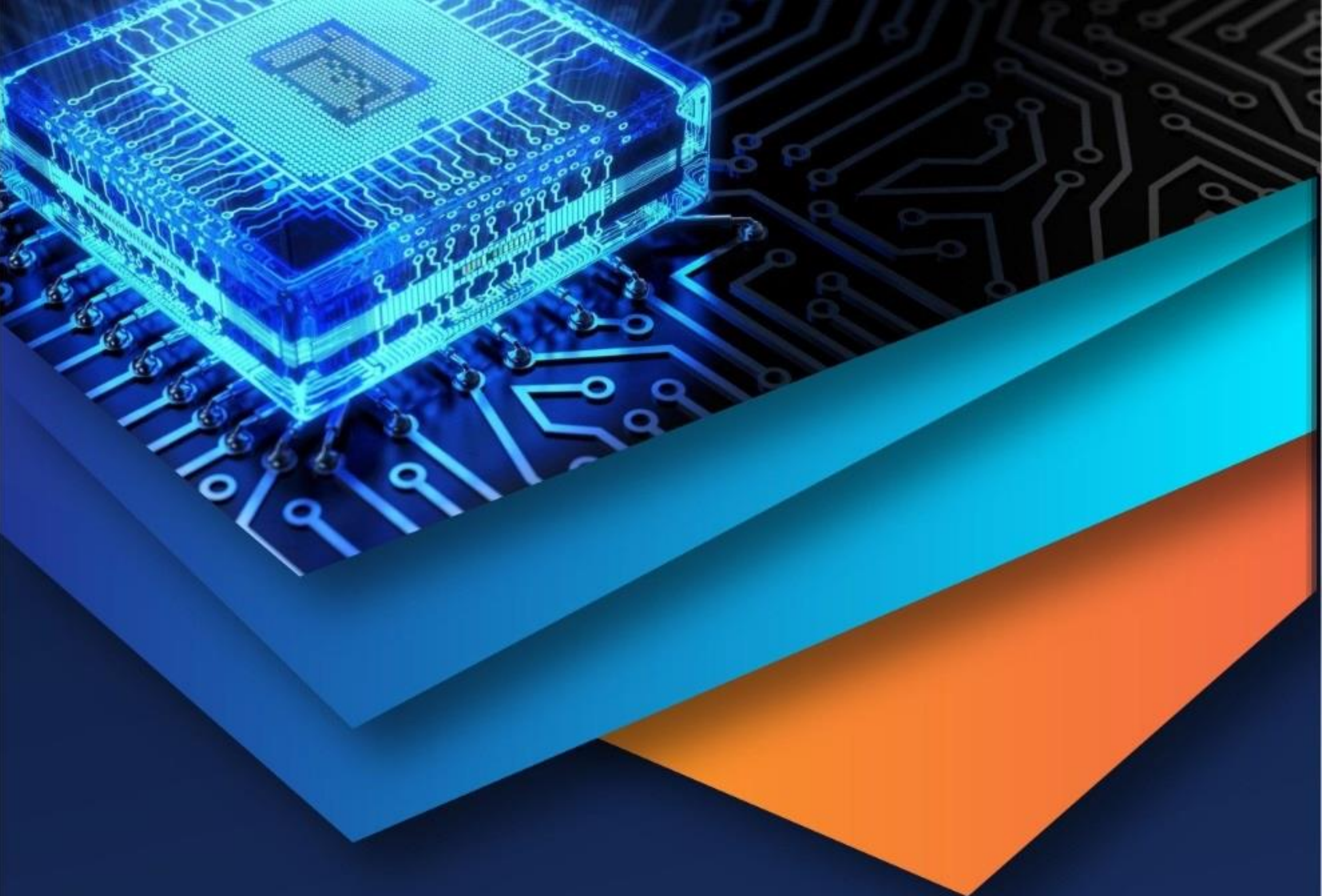

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