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A Comparative Analysis on the Performance and Emission Characteristics of Thevetia Peruviana Seed Oil (TPSO) with other Non-edible Oil in CI Engine

T. Balusamy*[1] and R. Marappan+

Abstract – *The methyl ester of vegetable oils, known as biodiesel are becoming increasingly popular because of their low environmental impact and potential as a green alternative fuel for diesel engine. In this study, different kinds of methyl ester of vegetable oil are derived by transesterification process. Experimental investigations have been carried out to examine properties, performance, combustion and emission characteristics of five different methyl ester of biofuels namely thevetia peruviana seed oil, jatropha oil, pungamia oil, mahua oil and neem oil at blend ratio of 20/80, in a standard, fully instrumented, four stroke, direct injection, Kirloskar 'TV1' diesel engine. The series of tests are conducted using each of the above fuel blends, with the engine working at a speed of 1500 rpm. The performance, combustion and emission parameters like, brake thermal efficiency, bsfc, volumetric efficiency, air-fuel ratio, P-θ curves, instantaneous heat release, cumulative heat release, exhaust gas temperatures, CO, HC, NOx, CO_2 and smoke are measured and analyzed. It is observed that methyl ester of thevetia peruviana seed oil has comparable engine performance with less emission compared to other blends. Hence, it is suggested that 20% of methyl ester of thevetia peruviana seed oil blended with diesel can be substituted as an alternate fuel for the diesel engine without any engine modification.*

Keywords – Bio-diesel, comparative performance and emissions, methyl ester, non-edible oil, transesterification.

1. INTRODUCTION

Concerning the environmental aspect, rational and efficient end use technologies are identified as key options for achievement of the Kyoto targets of greenhouse gas emissions reduction. For the transport sector of the European Union, energy savings of 5–10% in the medium term and an aggregate of 25% in the long term (2020) are targeted, with an expected cut of CO_2 emissions by 8% by the year 2010 [1]. In recognition of the contribution of motor vehicle exhaust emissions to the rising urban and global air pollution, the European Commission has introduced strict emission regulations with the goal of improving air quality through the reduction of gaseous and particulate exhaust emissions from a wide range of vehicles. In particular, automotive fuel (conventional and alternative) quality has proved to be one of the main factors in order to meet the mandatory emission limits adopted for 2005 [2].

Their major problem associated with biodiesel is highly increased viscosity, 10–20 times greater than that of normal diesel fuel. Thus, although short-term tests using neat vegetable oils showed promising results, problems appeared after the engine had been operated for longer periods. These included: injector clogging with trumpet formation, more carbon deposits and piston oil ring sticking, as well as thickening and gelling of the engine lubricating oil [1]. To solve the problems associated with the very high viscosity of neat vegetable oils, the following usual methods are adopted: blending in small blend ratios with normal diesel fuel, micro-emulsification with methanol or ethanol, cracking and their conversion into bio-diesel fuels [2]. The advantages of bio-diesels as diesel fuel, apart from their renewability, are their minimal sulfur and aromatic content, higher flash point, higher lubricity, higher cetane number and higher biodegradability and non-toxicity. On the other hand, their disadvantages include their higher viscosity, higher pour point, lower calorific value and lower volatility. Furthermore, their oxidation stability is lower, they are hygroscopic, and as solvents, they may cause corrosion of components, attacking some plastic materials used for seals, hoses, paints and coatings [3]. They show increased dilution and polymerization of engine sump oil, thus requiring more frequent oil changes. For all the above reasons, it is generally accepted [4] that blends of standard diesel fuel with 20% (by volume) bio-diesels can be used in existing diesel engines without any modifications, but there are concerns about the use of higher percentage blends that can limit the durability of various components, leading to engine malfunctioning [5]. Thus, bio-diesels are not viable options at present, but their addition to diesel fuel at low concentrations can be considered as equivalent to other oxygenated fuel additives, of course with the added advantage of renewability and emitted CO_2 reduction [6]. Authors [7]-[8] have already found that engine performance and combustion characteristics with METPSO has been found comparable to that of diesel and CO, HC emissions are less but NO_x and smoke are slightly higher than that of diesel

The present work is to compare the properties, performance, combustion and emission characteristics of methyl ester of thevetia peruviana seed oil with other methyl esters of biofuels namely jatropha oil, pungamia oil, mahua oil and neem oil at blend ratio of 20/80.

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2. TRANSESTERIFICATION

To reduce the viscosity of the vegetable oil, transesterification method is adopted. Viscosity of all five vegetable oils is reduced by the same method. The procedure involved in this method is as follows: sodium hydroxide is added to methanol and stirred until properly dissolved. The solution thus prepared is called methoxide, which is added to vegetable oil and stirred at a constant rate at 60^0C for one hour. After the reaction is over, the solution is allowed to settle for 20-24 hours in a separating flask. The glycerin settles at the bottom and the methyl ester floats at the top (coarse biodiesel). Coarse biodiesel is separated from the glycerin and it is heated above 100^0C and maintained for 10-15 minutes for removing the untreated methanol. Certain impurities like sodium hydroxide (NaOH), etc. are still dissolved in the coarse biodiesel. These impurities are cleaned two or three times by washing with 1% (by vol.) of petroleum ether and 15-20% (by vol.) of water for 1000 ml of coarse biodiesel. This cleaned biodiesel is taken up for the study. All the properties of biofuels and its blends are measured as per the ASTM standards as shown in Table 1 [9].

Table 1. Comparison of properties of methyl ester of various origins and diesel.

Property	Diesel	METPSO	MEJO	MEPO	MEMO	MENO	ASTM Code
Calorific Value(KJ/Kg)	43200	42652	42250	42334	42062	41905	D4809
Specific Gravity	0.804	0.811	0.8157	0.8212	0.815	0.829	D445
Viscosity(at 40^0C)cst	3.9	3.96	4.84	6.4	4.8	6.8	D2217
Cetane number	46	48	48	47	47	48	D4737
Flash point ^{o}C	56	72	92	95	85	87	D92
Fire point ^{o}C	64	79	96	98	92	93	D92
Cloud point ^{o}C	-8	-7	-3	-5	-4	-6	D97
Pour point ^{o}C	-20	-12	-16	-17	-14	-16	D97

Fig. 1. Experimental setup.

Table 2. Engine specifications.

Particulars	Specification
Make and model	Kirloskar –TV1
BHP and speed	5 HP and 1500 rpm
Type of engine	Single cylinder, DI and 4 Stroke
Compression ratio	16.5:1
Bore and stroke	80 mm and 110 mm
Method of loading	Eddy current Dynamometer
Method of cooling	Water Cooling
Inlet valve opening	4.5^0 before TDC
Inlet valve closing	35.5^0 after BDC
Exhaust valve opening	35.5^0 before BDC
Exhaust valve closing	4.5^0 after TDC
Injection timing	23^0 before TDC
Injection pressure	210 bar

3. EXPERIMENTAL SET UP AND MEASUREMENT

Experiments were conducted in a fully automated single-cylinder, four-stroke, naturally aspirated, direct injection diesel engine (Figure 1) using these biofuels. The specification of the engine is given in Table 2. Two separate fuel tanks with a fuel switching system were used, one for diesel and the other for biodiesel. The fuel consumption was measured with the aid of optical sensor. A differential pressure transducer was used to measure air flow rate. The engine was coupled with an eddy current dynamometer which is used to control the engine torque through computer. Engine speed and load were controlled by varying excitation current to the eddy current dynamometer using dynamometer controller. A piezoelectric pressure transducer was installed in the engine cylinder head to measure the combustion pressure. Signals from the pressure transducer were fed to charge amplifier. A high precision crank angle encoder was used to give signals for TDC and the crank angle. The signals from the charge amplifier and crank angle encoder were supplied to data acquisition system. An AVL five gas analyzer and AVL smoke meter were used to measure the emission parameters and smoke intensity respectively. Thermocouples (chrommel alumel) were used to measure different temperatures, such as exhaust temperature, coolant temperature, and inlet air temperature. Load was changed in eight levels from no load (0 KW) to the maximum load (3.5 KW). The engine was operated at the rated speed i.e., 1500 rpm for all the tests. The performance, combustion and emission parameters like brake thermal efficiency, specific fuel consumption, volumetric efficiency, P-θ curves, instantaneous heat release, cumulative heat release, exhaust gas temperatures, CO, HC, NOx, CO_2, and exhaust gas temperature were measured for diesel and all five methyl esters mentioned in this study. Then all the results were compared and analyzed.

4. RESULTS AND DISCUSSION

Brake Thermal Efficiency

It is a good measure in assessing the fuels ability to convert the energy they inherit into outputs. Undoubtedly, brake thermal efficiency increases with increasing brake power for all fuels as shown in Figure 2. This is due to reduction in heat loss and increase in power developed with increase in load. Moreover, as the load increases the fuel consumption is also increased intern releases higher heat. Hence, brake thermal efficiency increases as load increases. It is observed that with the brake thermal efficiency curves of five blends of biodiesel closely follow that of diesel and the maximum deviation is found to be 9.39% for neem oil at the maximum load. However, it is only 2% for METPSO. This is due to higher energy content and lower density of the METPSO blend compared to other bio-diesel blends.

In addition to that, as the load is increased, volumetric efficiency slightly decreases in turn air fuel ratio decrease i.e., engine operates rich side to lean side as the load increases.

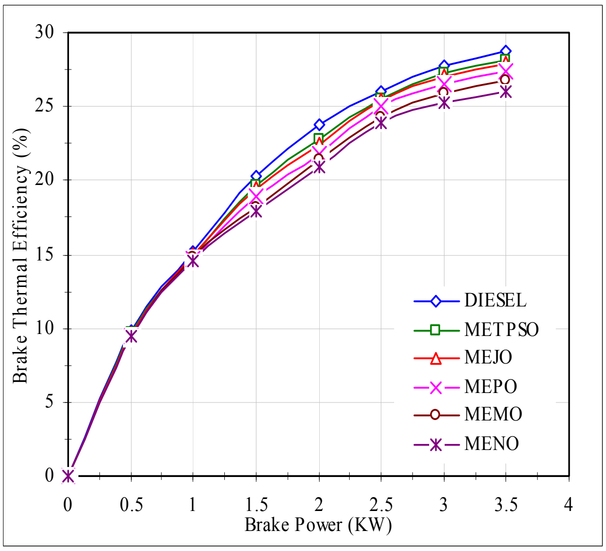

Fig. 2. Variation of brake thermal efficiency with brake power.

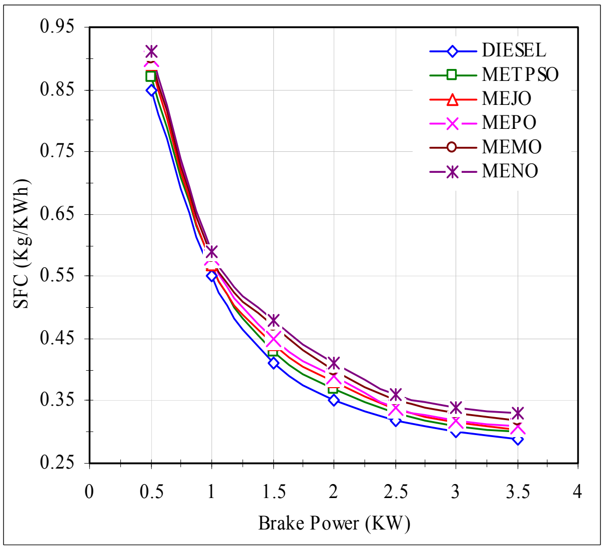

Fig. 3. Variation of bsfc with brake power.

Brake Specific Fuel Consumption

The variation of brake specific fuel consumption with load for different fuels is presented in Figure 3. For all fuels tested, brake specific fuel consumption is found to decrease with increase in load. This is due higher percentage increase in brake power with load as compared to increase in fuel consumption. Brake specific fuel consumption of MENO and METPSO has 13.7% and 3.4% higher than that of diesel respectively at the maximum load. In the similar way, other biofuel blends followed comparable trend. This is due a fact that variation in higher density and lower calorific value. As the variation in calorific value and density of biodiesel, equal amount of heat input is required to maintain the same load. Hence, more fuels consumed in order to maintain the same brake power.

Volumetric Efficiency

The Figure 4 indicates the variation of volumetric efficiency with brake power. It is observed that decrease in volumetric efficiency (5%) occurred with increase in a brake power for all kinds of biofuels and diesel. This is due a fact that increasing temperature of residual gases by increasing the brake power causes decrease in volumetric efficiency. In internal combustion engine design, volumetric efficiency refers to the efficiency with which the engine can move the charge into and out of the cylinders. It is observed that volumetric efficiency for biofuels decrease range from 0.8% (METPSO) to 2.1% (MEMO) less observed compared to that of diesel. This is due to higher temperature of retained gases, which heats the incoming fresh air. Volumetric efficiency is closely related to exhaust gas temperature (Figure 8) and decreases with increase in exhaust temperature.

Air-Fuel Ratio

Figure 5 shows the variation of air-fuel ratio with brake power for diesel and different 20% biodiesel blends. It was observed that air-fuel ratio decreases with brake power for diesel and biodiesel blends. This is due consumption of more amount of fuel and less amount of air when the load is increased. It is also observed that air-fuel ratio is higher for diesel than that of biodiesel blends. This is because of higher bsfc and lower volumetric efficiency of biodiesel blends compared to that of diesel.

Pressures-Crank Angle Analysis

Figure 6 shows the P-θ diagram for 20% biodiesel blends and diesel at injection pressure of 210bar and injection timing of 23^0 before TDC at maximum load. For all biofuel blends, combustion proceeds faster during the premixed combustion zone in comparison to that of diesel. In addition, it is observed that peak pressure is reached at 15^0 after TDC for all fuels. Much of variation in combustion process is not observed among these fuels. The maximum deviation of peak pressure for MENO and METPSO are 9.4% and 2.4% lesser than pure diesel respectively. This is due to O_2 content present in the biodiesel blend and higher cetane number.

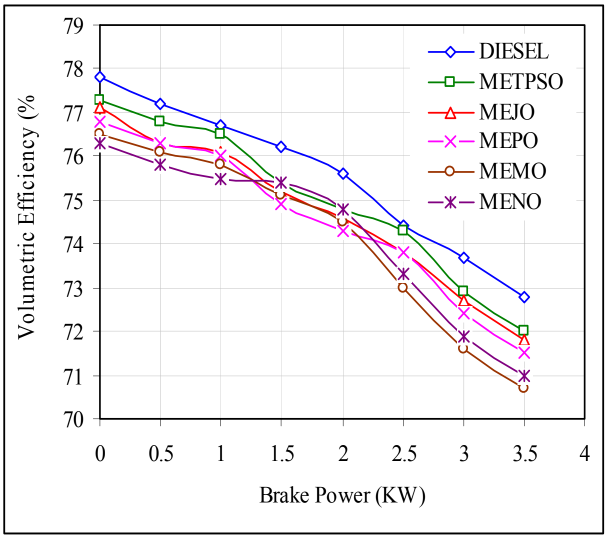

Fig.4. Variation of volumetric efficiency with brake power.

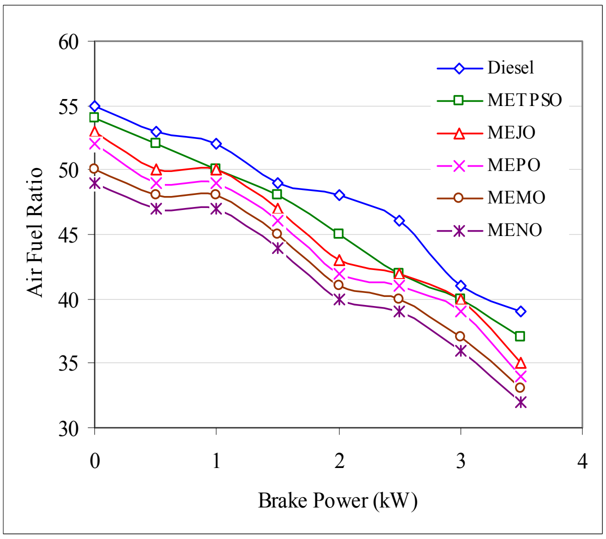

Fig. 5. Variation of air-fuel ratio with brake power.

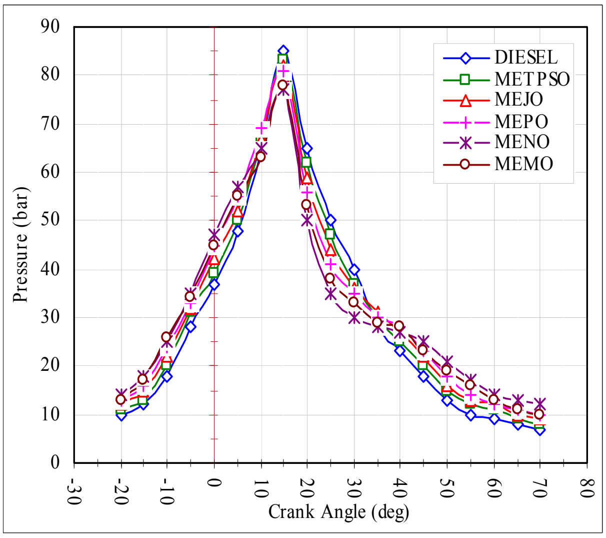

Fig. 6. Variation of mean effective pressure with crank angle.

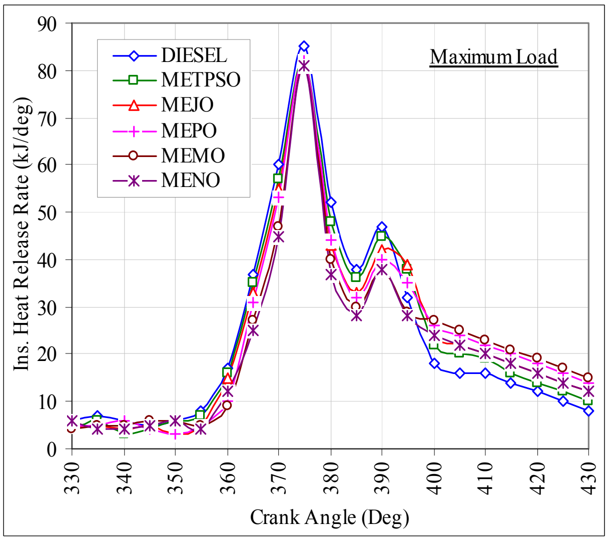

Fig. 7. Variation of instantaneous heat release rate with crank angle.

Heat Release Rate

Figure 7 shows the variation of heat release rate with crank angle for 20% biodiesel blends and diesel at injection pressure of 210bar (23^0 before tdc) at maximum load. All biofuel blends experienced rapid premixed burning followed by diffusion combustion. After the ignition delay period, the premixed fuel air mixture burns rapidly releasing heat at a very rapid rate, after which diffusion combustion takes place, where the burning rate is controlled by the availability of combustible fuel-air mixture [10]. It is observed that when engine is fueled with biofuels, the combustion starts earlier under all operating conditions and biofuels have shown shorter ignition delay compared to diesel. The maximum deviation of heat release rate for MENO and METPSO are 4.7% and 3.5% lesser than pure diesel, respectively.

Cumulative Heat Release

Figure 8 shows the variation of cumulative heat release rate with crank angle for 20% biodiesel blends and diesel at injection pressure of 210bar (23^0 before tdc) at maximum load. Cumulative heat release is indicative of the energy spent for a given output. It is again reconfirming the heat release for biodiesel blend. Cumulative heat release is slightly higher at premixed combustion zone and significantly lower at the latter part of combustion for biodiesel blend compared to mineral diesel possibly because of lower calorific value of biodiesel blend and higher density. It is observed that among the biodiesel blends, the METPSO has the higher cumulative heat release.

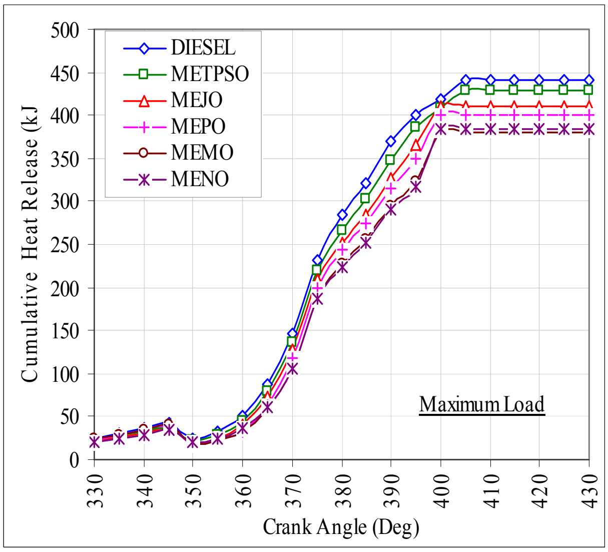

Fig. 8. Variation of cumulative heat release rate with crank angle.

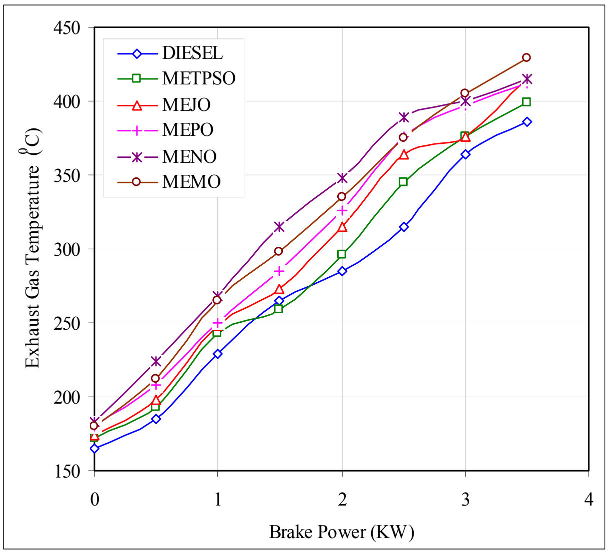

Fig. 9. Variation of exhaust gas temperature with brake power.

Exhaust Gas Temperature

The exhaust gas temperature increases with load for all kinds of fuel as shown in Figure 9. The amount of injected fuel increases with load in order to maintain a constant engine speed; consequently, the heat release will be more by burning these fuels leading to increased exhaust gas temperatures. At the maximum load, the exhaust gas temperature of MENO and METPSO deviation is observed to be 11.13 % and 3.37 % higher than that of diesel. This is due to heat release in the after burning stage is more in biodiesel blends leads compared to that of diesel leads to higher exhaust gas temperature.

Carbon Monoxide

The variation of carbon monoxide with load is shown in Figure 10. It was observed that CO emission decrease with increase of load. This is primarily due to the lower gas temperature in the engine cylinder at lower engine load, which prevents the CO component to be effectively converted to CO_2. However, the air-fuel ratio decreased with the increase in engine load, resulting in an increased gas temperature in the engine cylinder. This led to an increase in conversion rate of CO to CO_2 and hence lower CO emission at higher load. All kinds of biodiesel blends are found to emit significantly lower CO emission compared with that of diesel. At peak load, the carbon-monoxide content of METPSO has 23.07 % lower than diesel, which is due higher oxygen content of biodiesel lending in better combustion.

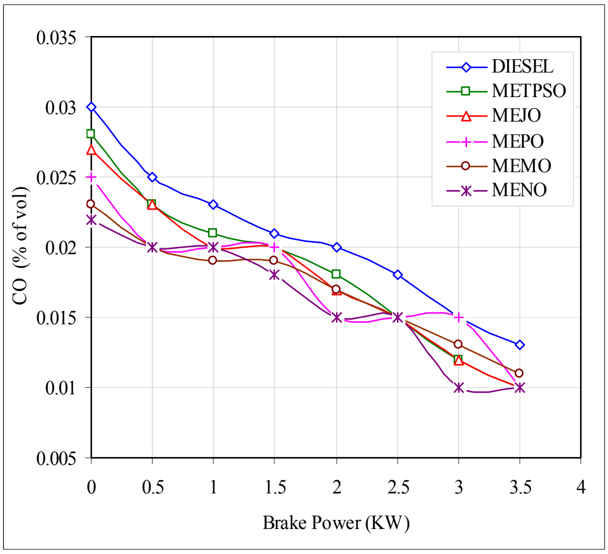

Fig. 10. Variation of carbon monoxide with brake power.

Carbon dioxide

The variation of Carbon dioxide with load is shown in Figure 11. The CO_2 emissions from a diesel engine indicate that how efficiently the fuel is burnt inside the combustion chamber. It is observed that CO_2 emission increase when load is increased. This is due air-fuel ratio decrease with load. It is also observed that all kinds of biofuel blends, CO_2 content is higher than that of diesel. At the maximum load, MENO and METPSO have the carbon dioxide content of 20.83% and 8.3% lower than that of diesel respectively.

Hydrocarbon

It is found that the unburnt hydrocarbon (UBHC) emissions for biofuel blends are towrd to decrease when the brake power is increased as shown Figure 12. At the maximum load, MENO and METPSO have the unburnt hydrocarbon content of 25 % and 12.5 % lower than that of diesel respectively.

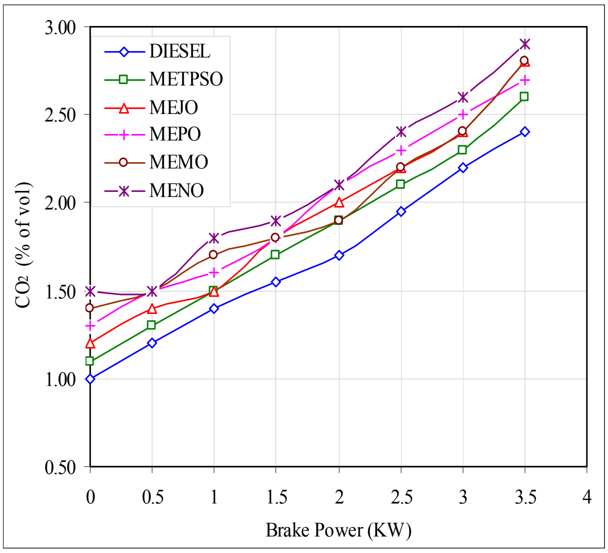

Fig. 11. Variation of carbon dioxide with brake power.

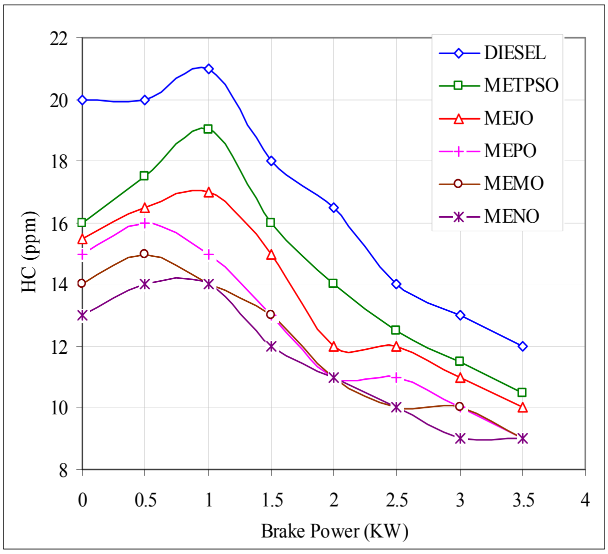

Fig. 12. Variation of unburnt hydrocarbon with brake power.

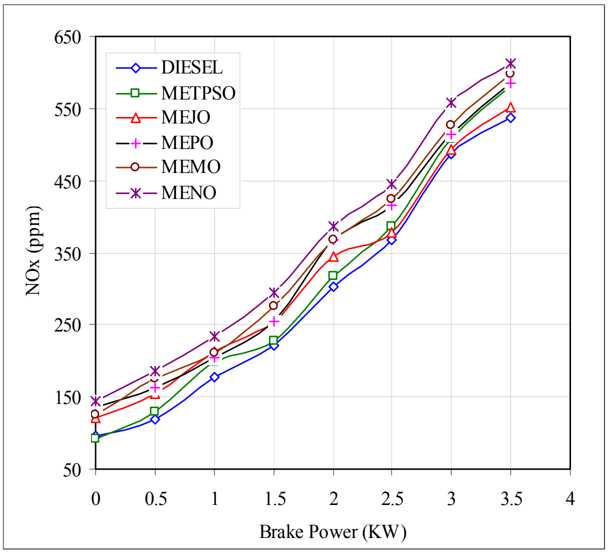

Fig. 13. Variation of oxide of nitrogen with brake power.

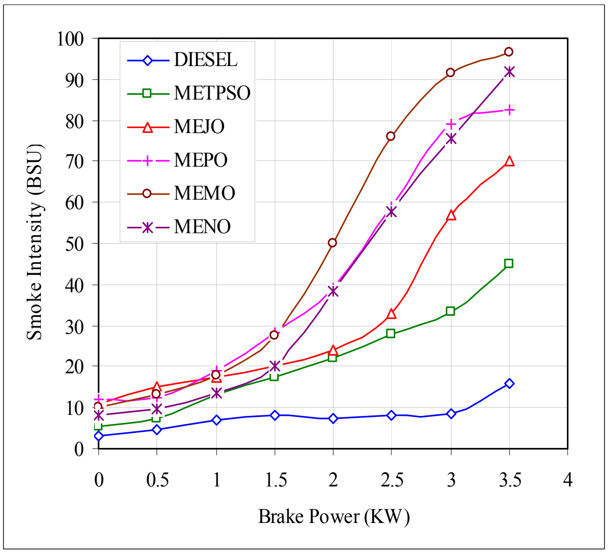

Fig. 14. Variation of smoke intensity with brake power.

Oxides of Nitrogen

In a naturally aspirated four stroke diesel engine NO_x emissions are sensitive to O_2 content, adiabatic flame temperature and spray characteristics. Higher combustion chamber temperatures increased incase of biofuels has resulted in NOx formation, which is evident from higher exhaust temperature. It is observed that all kinds of biofuel blends have higher NO_X content as shown in a Figure 13. At the maximum load, MENO and METPSO have the NO_X content of 13.97 % and 8.93 % higher than that of diesel, respectively.

Smoke Number

The variation of smoke intensity with brake power is plotted in Figure 14. It is found that the smoke intensity increased with increase in load for all kinds of fuel. Incase of bio-fuels, the smoke intensity is higher than diesel at all loads. At the maximum load, MENO and METPSO have the smoke intensity of 5 and 2 times higher than that of diesel, respectively. The increasing smoke number with load may be indicative of getting into the fuel-rich zone and heavier molecular structure and high viscosity of biodiesel blends.

5. CONCLUSIONS

The results of the experiments conducted with five different methyl esters of non-edible oils in the diesel engine lead to the following conclusions at the maximum load.

- Properties of METPSO blend are comparable with that of diesel and other biodiesel blends.
- Brake thermal efficiency and bsfc of METPSO blend is better than other biodiesel blends.
- Volumetric efficiency is higher for METPSO compared to other methyl ester of non-edible oils.
- Combustion characteristics of METPSO blend are comparable with that of diesel and other biodiesel blends.
- Emission characteristics of METPSO blend such as CO, CO_2, HC, NO_x and smoke intensity are also comparable with that of other biodiesel blend.

Hence, it is concluded that blend of 20% methyl ester of Thevetia Peruviana seed oil and 80% diesel could be used as a fuel for diesel engine for better performance with less emission when compared to other methyl ester of jatropha, pongamia, mahua and neem oil.

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NOMENCLATURE

METPSO	Methyl ester of Thevetia Peruviana seed oil
MEJO	Methyl ester of Jatropha oil
MEPO	Methyl ester of Pongamia oil
MEMO	Methyl ester of Mahua oil
MENO	Methyl ester of Neem oil
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Unburnt hydrocarbon
NO_x	Oxides of Nitrogen
ppm	parts per million
cSt	centiStoke

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