ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Experimental Study of D I Diesel Engine to Estimating the Performance, Emission and Combustion Characteristics using poon oil-based fuels

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ABSTRACT:

Experiments were carried out to conduct the performance, emission and combustion characteristics of a DI diesel engine the using of poon oil-based totally fuels. In the present work, poon oil and poon oil methyl ester are tested as diesel fuels in Neat and mixed forms. Methyl esters of poon oil (MEPO) have been blend with standard diesel separately at different ratios of 25/75%, 35/65%, 45/55%, 55/45% and 100/0% (by means of volume) and standard diesel. This types of blend is to enhance the volatility and to reduce the viscosity of methyl esters. The blends with higher attention of methyl esters also have the properties closer to the standard diesel.

The reductions in smoke, hydrocarbon and CO emissions were observed for poon oil methyl ester and its diesel mixture at the side of elevated NOx emission in comparison to the ones of standard diesel. However, a reduce in NOx emission and an increase in smoke, hydrocarbon and CO emissions had been observed for Neat poon oil and its diesel blend compared to the ones of standard diesel. The experimental result showed that there was now not plenty variant of poon oil after they had been used in blended form. However, the trend became barely modified when methyl esters were used. MEPO45 blend performed higher than other blends and preferred diesel in terms of brake thermal performance and smoke emission.

Key Point:

Biodiesel, Methyl ester poon oil (MEPO), Performance and Emission.

1. Introduction:

Vegetable oils have better ignition characteristics for diesel engines than light alcohols, in view that their cetane range being over 40 [1]. There are various vegetable oils, which may be used as fuels in diesel engines like peanut oil, linseed oil, rapeseed oil and solarflower oil [2]. The chemical composition of vegetable oil allows in lowering the emission of undesirable components while they're burned [3]. Vegetable oil fuels generated an appropriate engine performance and exhaust fuel emission levels for short-term operation only, due to the fact they brought about carbon deposit buildups and sticking of piston rings after extended operation. The practical solution to overcome those problems encompass increasing fuel temperature to 200°C, blending vegetable oil with diesel, blend it with ethanol or converting vegetable oil into methyl ester [3–6]. Blending of vegetable oils with diesel fuel might solve the issues of diesel engine operation with Neat vegetable oils. Vegetable oil dissolves quite well in diesel fuel. It was reported that a diesel engine would run efficiently on a blend of vegetable oil and diesel fuel without damage to engine components for brief-term operation. Vegetable oil fuels led to decrease thermal efficiency lower NOx and higher CO and HC emissions [5–7]. Significant efforts were made to develop vegetable oil derivatives that approximate the properties and overall performance of hydrocarbon-primarily based diesel fuels. The problem with substituting triglycerides for diesel fuels are commonly related to their high viscosities and low volatilities. These may be changed through transesterification [7,8]. The methyl ester produced with the aid of transesterification of vegetable oil has a excessive cetane number, low viscosity and higher heating value as compared to those of Neat vegetable oil which ends up in shorter ignition put off and longer combustion length and hence low particulate emissions. Its use result within the minimization of carbon deposits on injector nozzles [9]. Bio-diesel has been utilized in blends with hydrocarbon based diesel fuels. Several studies have shown that diesel–biodiesel blends lessen smoke emission, particulates, unburned hydrocarbons, carbon dioxide and carbon monoxide emissions with a singlr increase in oxides of nitrogen emissions [10–15].

1.1. Purpose of study:

In an agricultural country like India, the usage of vegetable oils in diesel engines must be widely investigated due to the large manufacturing potential and possibility of producing it near the consumption point. Since vegetable oils have cetane numbers close to the ones of diesel fuel, they can be used in existing compression ignition engines with little or no modifications. The problem posed via the higher viscosity of vegetable oil can be minimized by using blending it with diesel. Another way to make vegetable oil appropriate for diesel engines is converting it into bio-diesel by means of transesterification process. The vegetable oil–diesel blend is a simple way to reduce the viscosity of Neat vegetable oil. This method does now not require any chemical process. The vegetable oil transesterification represents some other method to conquer the problems related to the high viscosity of Neat vegetable oil. The transesterification system reduces the molecular size resulting in greater volatile, much less viscous liquids. In both the strategies, the properties of vegetable oil have improved. In the present work each the strategies have been adopted and the result are presented.

Notations	
Standard diesel	
MEPO100%	100% methyl ester poon oil
MEPO25%	25% methyl ester poon oil 75% standard diesel
MEPO35%	35% methyl ester poon oil 65% standard diesel
MEPO45%	45% methyl ester poon oil and 55% standard diesel
MEPO55%	55% methyl ester poon oil and 45% standard diesel

2. Potential and characterization of poon oil

The scientific poon tree is Sterculia foetida. S. foetida is a large evergreen tree determined typically in the western and southern components of India, Burma, and Ceylon and occasionally in east tropical Africa, Borneo, Java, Sumatra, Indo-China, Malaya, and North Australia. The tree is regularly grown for ornament and on the roadsides mainly in South India. However the foetid odour of the vegetation is a disadvantage. It may easily be raised from seed and ripe cuttings; seedlings may be transplanted for the duration of the primary rains, without a lot issue. The single large seed is surrounded by using a shell and a thin 1– 2 mm layer of pulp. The fruit, to start with white in coloration, and later turns black. Whilst ripe, it acquires a shining blue-black colour. The kernel, of path, is white. A hundred seeds weigh 200–250g. The kernel of the seeds yields 50–60% of bland, mild-yellow fatty oil. The seed oil is appropriate for culinary functions however is often used as an illuminant; different in all likely uses are within the surface-coating industries and soap-making industry.

2.1 Preparation of oil from oil seeds:

Poon oil seeds amassed from our location are dried in sunlight for per week and the dried seeds are peeled to attain the kernel for extraction of poon oil via the use of a mechanical expeller. Small traces of organic count number, water and other impurities have been present in the poon oil. These can be removed by including 5% by means of volume of hexane to the raw oil and stirring it for 15 to 20 min at 80° to 90 °C and allowing it to settle for 30 min. Since that hexane is having low boiling factor (68.7 °C), it gets evaporated on heating beyond the boiling point of hexane. The impurities and gum particles settle down at the bottom can remove. The remaining oil is the purified oil. The purified oil may be used for transesterification process.

2.2 Transesterification process [16–18]

Poon oil was converted into its methyl ester by way of transesterification process. This involves making the triglycerides of the poon oil to react with methanol within the presence of a potassium hydroxide (KOH) catalyst to produce glycerol and fatty acid ester. The known amount of (a 1000 ml) poon oil, 400 ml of methanol and 10 g potassium hydroxide had been taken in a round backside flask. The contents were stirred till ester formation commenced. The combination became heated to 70 °C and held at that temperature without stirring for an hour, after which it became allowed to chill for 24 h without stirring. Two layers were shaped. The lowest layer consisted of glycerol and the top layer changed into the ester. The bottom layer was removed and ester turned into collected for further analysis.

2.3 Fatty acid composition

Poon oil was tested for its fatty acid contents in a fuel chromatography (GC) analysis for the purpose of finding out the major fatty acid additives. From the GC test, it was located that poon oil contains 29.7% saturated acids (palmitic and stearic) and 62.3% unsaturated acids (linoleic and oleic). The important constituent of poon oil is linoleic acid that differentiates poon oil from different vegetable oils as shown in table 1.

Table 1: Fatty acid distribution of poon oil, Karanja oil, Jatropha oil, soyabean oil and rapeseed oil [2,5,11]

Fatty acid	Poon oil (% by wt)	Karanja (% by wt)	Jatropha (% by wt)	Soyabean (% by wt)	Rapeseed (% by wt)
Palmitic $C_{16}H_{32}O_2$	22.4	3.7-7.9	14.1-15.3	12	3
Stearic $C_{18}H_{36}O_2$	7.3	2.4-8.9	3.7-9.8	3	1
Oleic $C_{18}H_{34}O_2$	16.4	44.5-71.3	34.3-45.8	23	64
Linoleic $C_{18}H_{32}O_2$	45.9	10.8-18.3	29-44.2	55	22
Arachidic $C_{20}H_{40}O_2$	6.46	_	0.3	0	0

2.4. Property analysis:

The physical and chemical properties of standard diesel, poon oil, methyl esters of poon oil, soybean oil and rapeseed oil are presented in Table 2. The important properties of poon oil based fuels are comparable with those of std. diesel. The saponification number (SN), iodine value (IV) and cetane number (CN) of methyl ester of poon oil (MEPO) were calculated empirically and used to establish its suitability for use as bio-diesel which can meet the specification of U.S. bio-diesel standard (ASTM D 6751). SN and IV of poon oil methyl ester were calculated from fatty acid methyl ester compositions with the help of Eqs. (1) and (2), respectively [19]:

$$SN = SUM\ (560*A_j)/MW_i \tag{1}$$

$$IV = SUM\ (254*D*A)/MW_i \tag{2}$$

Where Ai is the percentage of each component, D is the number of double bonds and MWi molecular mass of each component. Cetane number of MEPO was calculated from Eq. (3) [19]

$$CN = 46.3+5458/SN-0.225*IV \qquad (3)$$

Table 2: Physico-chemical properties of poon oil, std. diesel methyl esters of poon oil, soybean oil and rapeseed oil [2,17]

Properties	Poon oil	Poon methyl ester	Soyabean methyl ester	Rapeseed methyl ester	Biodiesel standards ASTM D 6751	Std.diesel
Density at 15 °C, g/cm^3	0.9264	0.875	0.885	0.882	–	0.84
Kinematic viscosity at 40 °C in cSt	49.7	6.0	4.08	4.7	1.9-6.0	3-4
Flash point	158°C	162°C	178	170	>130	50
Pour point	-5°C	1°C	-7	-12	–	-23
Acid number as mg KOH/kg	0.36	0.14	–	0.03	<0.8	–
Ash content,%	0.032%	NILL	NILL	0.007	<0.02	–
Water content, %	NILL	NILL	NILL	–	<0.03	–
Lower heating value kj/kg	39650	40211	36700	37000	–	42700
Distillation at 90% recovery	–	368°C	358	356	–	–
Saponification number	191.1	184	–	–	–	–
Iodine value	100	98	–	112	–	–
Cetane number	–	54	45	51	47(minimum)	47
Carbon % by mass	–	75.55	78.4	77.8	–	–
Hydrogen % by mass	–	12.6	12.0	12.4	–	–
Oxygen % by mass	–	11.85	11.1	11.3	–	–
Sulphur, %	–	0.011	<0.005	NILL	–	–

2.5. Experimental and test procedure

Fig. 1 shows the schematic diagram of the experimental set-up. The test engine used was the Kirloskar TAF1 model. The specification of the engine is given in table 3. A single cylinder four-stroke air-cooled diesel engine developing 4.4 kW at a pace of 1500 rpm speed into used for this work. This engine was coupled to a BENZ eddy- current dynamometer with a control machine. The cylinder pressure was measured through piezoelectric pressure transducer (Kistler) fitted on the engine cylinder head and a crank attitude encoder fitted on the flywheel. The fuel injection system and nozzle information are given underneath:

Nozzle Configuration

Type of fuel injection:

Pump-line-nozzle injection system
Nozzle type: Multi hole
No. of holes: 3
Nozzle opening pressure: 207–215 bar
Needlelift (mm): 0.25
Spray-hole diameter (mm): 0.25
Cone angle: 110°

Exhaust emission from the engine was measured with the help of the QRO TECH, QEO-402 gas analyzer and smoke emission was measured with the help of the Bosch smoke meter. To obtain base line parameters, the engine was first operated on standard diesel. After taking the engine performance at all load conditions on standard diesel, four test fuels were prepared, namely, Neat poon oil methyl ester, 25%, 35%, ,45%, 55%, 100% poon oil methyl ester blend on a volume basis, and similar experiments were conducted over the same range of loads.

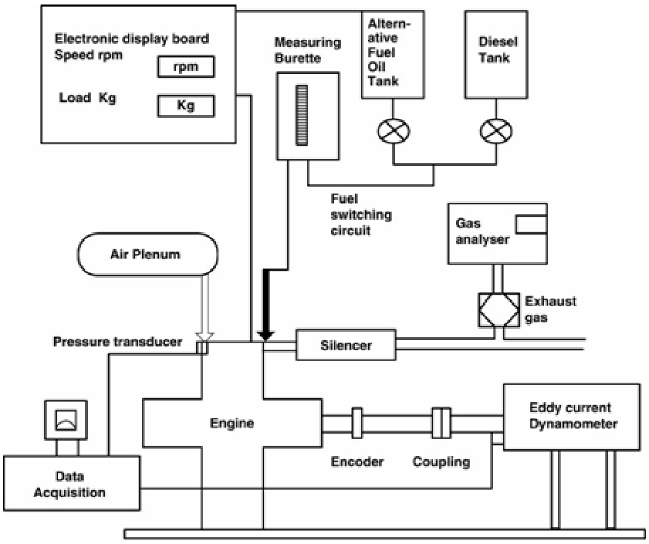

Fig. 1 Schematic diagram of experimental set-up

Table 3: Engine specifications

Model	Kirloskar TAF1
Type	Single cylinder, four-stroke, direct injection.
Piston type	Bowl-in-piston
Capacity	661 cm3
Bore and stroke	87.5 mm X 110 mm
Compression ratio	17.5:1
Speed(constant)	1500rpm
Rated powder	4.4kw
Dynamometer	Eddy current
Cooling system	Air cooling
Injection timing	23°bTDC
Injection pressure	200bar

2.6. Error analysis

Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. Uncertainties analysis is needed to prove the accuracy of the experiments. An uncertainty analysis was performed using the method described by Holman [20]. The list of instruments used for measuring various parameters and measurement techniques are presented in Table 4. The list of instruments and the range, accuracy and uncertainties are given in Table 5. The total percentage of uncertainty of this experiment is calculated as given below:

Total percentage uncertainty of this experiment is

= square root of {(uncertainty of TFC)^2 + (uncertainty of BP)^2 + (uncertainty of BSFC)^2 + (uncertainty of brake thermal efficiency)^2 + (uncertainty of CO)^2 + (uncertainty of CO2)^2 + (uncertainty of UBHC)^2 + (uncertainty of NOx)^2 + (uncertainty of Bosch smoke number)^2 + (uncertainty of EGT)^2 + (uncertainty of pressure pick up)^2}

$$= \text{square root of } \{(1.5)^2 + (0.2)^2 + (1.5)^2 + (1)^2 + (0.2)^2 + (0.15)^2 + (0.2)^2 + (0.2)^2 + (1.0)^2 + (0.15)^2 + (1.0)^2\}$$

$$= \pm 2.8\%.$$

Table 4:List of instruments used for measuring various parameters and measurement techniques

Instruments	purpose	Make and model	Measurement techniques
Exhaust Gas Analyser	Measurement of HC, CO, CO2 and NOx emissions	QRO 401, QROTECH Co. Ltd, Republic of Korea	NDIR principle (non-depressive infra red sensor) NOx -electro chemical sensor
Smoke meter	Measurement of smoke emission	TI diesel tune, 114 smoke density meter, TI tran Service	-
EGT indicator	Measurement of exhaust gas temperature	-	k-type (Cr Al) thermocouple
Speed measuring unit	Measurement of engine speed	-	Magnetic pick up type
Pressure transducer and charge amplifier	Measurement of cylinder pressure	Type 5015A, Kistler Instruments, Winterthur, Switzerland	-
Crank angle encoder	-	-	Magnetic pick up type
Load indicator	Loading device	BENZ	Strain gauge type load cell

Table 5: List of instruments and the range, accuracy and percentage uncertainties

S.NO	Instruments	Range	Accuracy	%uncertainties
1	Gas analyzer	NOx 0-5000ppm HC CO CO2	±20 ppm ±15 ppm ±0.02 % ±0.03 %	±0.2 ±0.2 ±0.2 ±0.15
2	Smoke level measuring instrument	BSN 0-10	±0.2	±1.0
3	EGT indicator	0-900°C	±1 °C	±0.15
4	Speed measuring unit	0-10000ppm	±10 rpm	±1.0
5	Load indicator	0-100kg	±0.1 kg	±0.5
6	Burette for fuel measurement	-	±0.2cc	±1.5
7	Digital stop watch	-	±0.2s	±0.2
8	Manometer	-	±1mm	±1.0
9	Pressure pick up	0-110bar	±1 bar	±0.1
10	Crank angle encoder	-	±1°	±0.2

3. Performance analysis

It is seen from the preceding sections that, the overall performance and emission characteristics of poon oil and their higher blends are poorer than the standard diesel. That is in particular because of their higher viscosities and lower volatility. It is found from the literature that the performance of vegetable oils can be improved by adopting modifications to the fuel system. As a result, in the present work the methyl ester of poon oil (MEPO) is evaluated and the outcomes are discussed inside the following sections.

3.1 Ignition delay:

Figure 2 shows the variation of ignition delay with load for different methyl esters of poon oil blends and standard diesel. The ignition delay of the methyl ester of poon oil and its diesel blends is shorter than that of standard diesel. due to the high in-cylinder temperature existing duration in the course of fuel injection, biodiesel may additionally undergo thermal cracking; because of this, lighter compounds are produced, which might have ignited earlier, ensuing in shorter ignition delay. This is because of the fact that the methyl linoleate gift inside the MEPO break up into smaller compounds whilst it enters the combustion chamber ensuing in better spray angles thus inflicting earlier ignition as suggested in Yu et al (2002). The shorter ignition delay will also be due to the higher cetane range of the methyl ester of poon oil than standard diesel.

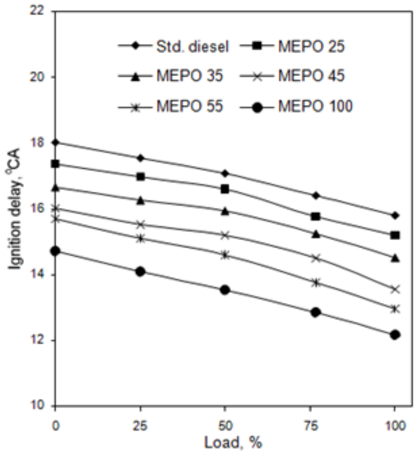

Figure 2 Variation of ignition delay with load for standard diesel, methyl ester of poon oil and its diesel blends

3.2 Cylinder peak pressure:

Figure 3 shows the variation of the cylinder peak pressure with load for different methyl ester of poon oil blends and standard diesel. It can be observed from the figure that cylinder peak pressures for methyl ester of poon oil and its diesel blends are lower than that of standard diesel. The cylinder peak pressure depends mainly on the combustion rate in the initial stages, which, in turn, is influenced by the fuel taking part in the premixed combustion phase. The combined effect of the shorter ignition delay and reduced lower heating value, resulted in a lower premixed combustion phase which led to lower cylinder peak pressure.

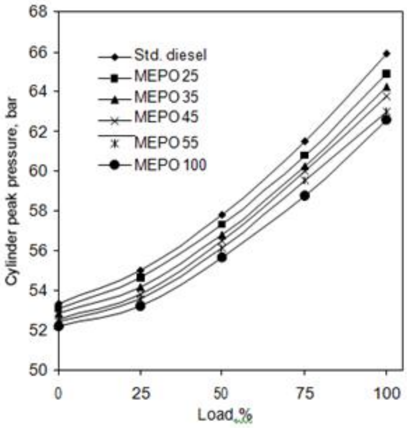

Figure 3 Variation of cylinder peak pressure with load for standard diesel, methyl ester of poon oil and its diesel blends

3.3 Maximum rate of pressure rise

The variation of the maximum rate pressure raise with load for specific methyl ester of poon oil blends and standard diesel is shown in figure 4. It can be observed from the figure that the maximum rate of pressure raise is lower for methyl ester and its diesel blends. This can be because of the shorter ignition delay; the fuel burned inside the premixed combustion is much less as stated through Agarwal (2007). The rate of pressure raise decrease as the fraction of methyl ester will increase within the blend. This is probably due to the presence of heavier hydrocarbon molecules in methyl ester of poon oil, which have a higher boiling factor and lower volatility.

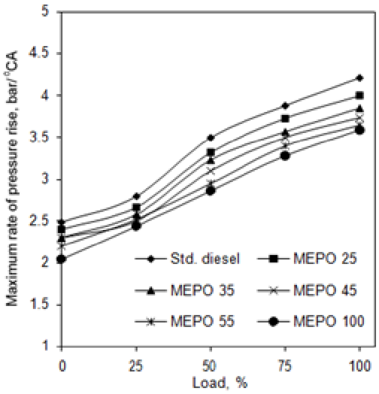

Figure 4 Variation of maximum rate of pressure rise with load for standard diesel, methyl ester of poon oil and its diesel blends

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
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3.4 Heat release rate

The variation of the heat release rate with load for different methyl ester of poon oil blends and standard diesel is shown in figure 5. Due to the vaporization of the fuel accrued for the duration of the ignition delay period, at the beginning a negative heat release is observed and, after combustion is initiated, this will become positive. After the ignition delay period, the premixed fuel air combination burns unexpectedly liberating heat at a rapid rate, and then diffusion combustion takes place. The premixed heat release is decrease for the MEPO and its diesel blends while compared to that of standard diesel, possibly because of the lower heating value of the methyl ester and its diesel blends as reported by Agarwal (2007). As the percentage of MEPO within the blend increases, the maximum heat release rate decreases.

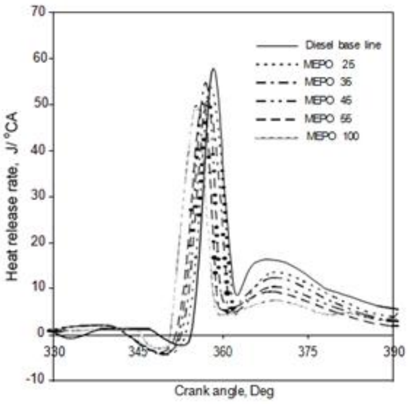

Figure 5 Variation of heat release rate with crank angle for standard diesel, methyl ester of poon oil and its diesel blends

3.5 Brake thermal efficiency

The variation of the brake thermal efficiency with load for different methyl ester of poon oil blends and standard diesel is shown in Figure 6. Brake thermal efficiency increases upto 45% blend (MEPO45) and after that it starts decreasing. The increase in the brake thermal efficiency may be due to the combined effect of the lower heating value, density, and better lubricity provided by the methyl esters and their fatty ester compositions.

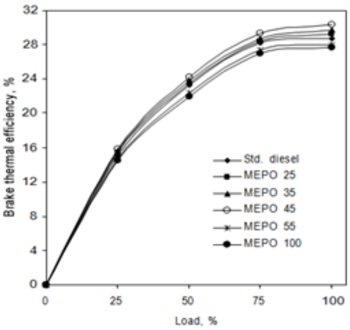

Figure 6 Variation of brake thermal efficiency with load for standard diesel, methyl ester of poon oil and its diesel blends

3.6 Exhaust gas temperature

The variation of the exhaust fuel temperature with load for different methyl ester of poon oil blends and standard diesel is shown in figure 7. The result show that the exhaust gas temperature increase with load in all the cases. It is quite apparent that with bio-diesel because of advanced combustion, the temperature inside the combustion chamber may be expected to be better due to the presence of oxygen molecules in the methyl ester. The exhaust fuel temperature is observed to increase with an increase the proportion of biodiesel in the blends.

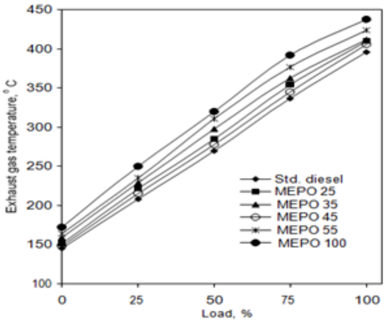

Figure 7 Variation of exhaust gas temperature with load for standard diesel, methyl ester of poon oil and its diesel blends

3.7 Oxides of nitrogen emission:

The variation of oxides of nitrogen emissions with load for different methyl ester of poon oil blends and standard diesel is shown in figure 8. The increase in NOx emission is observed for the methyl ester of poon oil and its diesel blends.

It can be because of the motive that with biodiesel, the temperature in the combustion chamber may be predicted to be higher, leading to the formation of a higher quantity of NOx in biodiesel engines. The higher NOx emission can also be due to the presence of methyl linoleate which has two double bonds as suggested with the aid of Ban-Weiss (1997). Another reason for the increase in NOx emissions may be because of combustion which starts earlier in advance for biodiesel, partially owing to a shorter ignition delay and in partially owing to advanced injection timing (because of the higher bulk modulus and higher density of biodiesel).

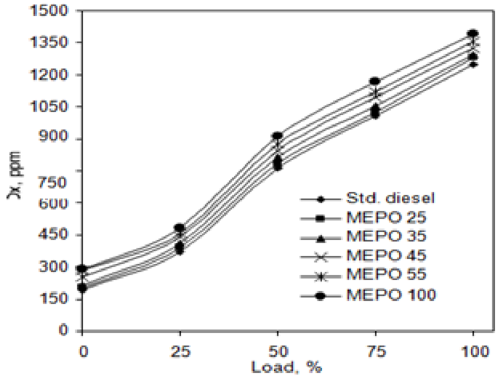

Figure 8 Variation of NO_X emission with load for standard diesel, methyl ester of poon oil and its diesel blends

3.8 Smoke emission:

The variation of smoke emission at different loads for the methyl ester of poon oil and its diesel blends is shown in figure 9. The smoke emission is much lower for the methyl ester of poon oil and its diesel blends as compared to that of standard diesel. This will be due to the presence of the oxygen molecules in the methyl esters which led to finish combustion. And, additionally it may be observed from the heat release rate diagram that diffusive combustion is more for methyl esters and their diesel blends. For the reason that smoke is specially produced in the diffusive combustion segment, the addition of oxygenated fuel leads to an improvement in diffusive combustion.

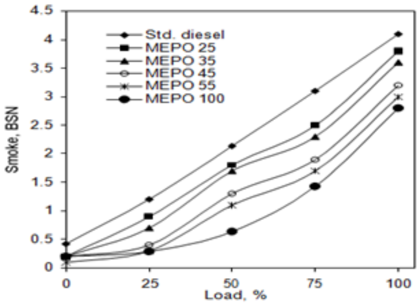

Figure 9 Variation of smoke emission with load for standard diesel, methyl ester of poon oil and its diesel blends

3.9 Hydrocarbon emission

The variation of hydrocarbon emission at different loads for the methyl ester of poon oil and its diesel blends is shown in figure 10. It is observed that MEPO and its diesel blends provide incredibly lower HC emission than standard diesel. This is because of the complete combustion of the methyl ester of poon oil and its diesel blends inside the combustion chamber because of the presence of the oxygen molecules inside the methyl ester.

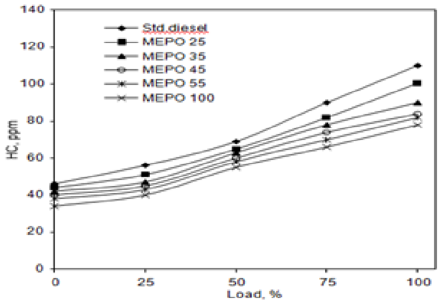

Figure 10 Variation of hydrocarbon emission with load for standard diesel, methyl ester of poon oil and its diesel blends

3.10 Carbon monoxide emission

The variation of carbon monoxide emission at different loads for the methyl ester of poon oil and its diesel blends is shown in Figure 11. It can be seen from the figure that CO emission decreases for the blended fuels at higher loads. This may be due to the enrichment of oxygen owing to the methyl ester addition, as increasing the proportion of oxygen will promote the further oxidation of CO during the engine exhaust process.

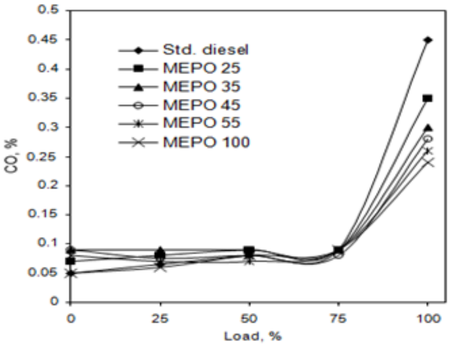

Figure 11 Variation of carbon monoxide emission with load for standard diesel, methyl ester of poon oil and its diesel blends

4. Conclusion:

From the preceding section it is found that the performance of the MEPO45 blend is better than that of standard diesel. MEPO55 and MEPO100 blends have resulted in lower brake thermal efficiency and higher NO_X emissions than other blends.

References:

[1] A.K. Agarwal, Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines, Progress in Energy and Combustion Science 33 (2007) 233–271.

[2] A. Srivastava, R. Prasad, Triglycerides-based diesel fuels, Renewable and Sustain- able Energy Reviews 4 (2000) 111–133.

[3] T. Murayama, T. Oh, N. Miyamoto, T. Chikahisa, Low carbon flower buildup, low smoke, and efficient diesel operation with vegetable oils by conversion to mono- esters and blending with diesel oil or alcohols, Society of Automotive Engineers (1984) 5.292–5.302 (paper no. 841161).

[4] Y. Ali, M.A. Hanna, Alternative diesel fuels from vegetable oils, Bioresource Technology 50 (1994) 153–163.

[5] N.J. Barsic, A.L. Humke, Performance and emissions characteristics of a naturally aspirated diesel engine with vegetable oil fuels, Society of Automotive Engineers (1981) 1173–1187 (paper no 810262).

[6] K. Babu, G. Devarajane, Vegetable oils and their derivatives as fuels for CI engines: an overview, Society of Automotive Engineers (2003) 406–418 (paper no. 2003- 01-0767).

[7] R. Altin, S. Cetinkaya, H.S. Yucesu, The potential of using vegetable oil fuels as fuel for diesel engines, Energy Conversion and Management 42 (2001) 529–538.

[8] S. Bhattacharyya, C.S. Reddy, Vegetable oils as fuels for internal combustion engines: a review, Silsoc Research Institute 57 (1994) 157–166.

[9] P.K. Sahoo, L.M. Das, M.K.G. Babu, S.N. Naik, Bio-diesel development from high acid value polanga seed oil and performance evaluation in a CI engine, Fuel 86 (2007) 448–454.

[10] S. Sinha, A.K. Agarwal, Experimental investigation of the combustion character- istics of a biodiesel (rice–bran oil methyl ester)-fuelled direct-injection transpor- tation diesel engine. Proc Instn of Mech Engrs Part D, Journal of Automobile Engineering 221 (2006) 1575–1583.

[11] M. Senthil Kumar, A. Ranesh, B. Naglingam, An experimental comparison of methods to use methanol and Jatropha oil in a compression ignition engine, Biomass and Bioenergy 25 (2003) 309–318.

[12] M. Lapuerta, O. Armas, J. Fernández Rodríguez, Effect of biodiesel fuels on diesel engine emissions, Progress in Energy and Combustion Science 34 (2008) 198–223.

[13] A.S. Cheng, A. Upatnieks, C.J. Mueller, Investigation of the impact of biodiesel fuelling on NOx emissions using an optical direct injection diesel

engine, International Journal of Engine Research 7 (2006) 297–318.

[14] H. Raheman, S.V. Ghadge, Performance of compression ignition engine with mahua (Madhuca indica) biodiesel, Fuel 86 (2007) 2568–2573.

[15] C.D. Rakopoulos, K.A. Antonopoulos, D.C. Rakopoulos, D.T. Hountalas, E.G. Giakoumis, Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesels of various origins, Energy Conversion and Management 47 (2006) 3272–3287.

[16] D.Y.C. Leung, Y. Guo, Transesterification of neat and used frying oil: optimization for biodiesel production, Fuel Processing Technology 87 (2006) 883–890.

[17] S.V. Ghadge, H. Raheman, Biodiesel production from mahua (Madhuca indica) oil having high free fatty acids, Biomass and Bioenergy 28 (2005) 601–605.

[18] L.C. Meher, D. Vidya Sagar, S.N. Naik, Technical aspects of bio-diesel production by transesterification — a review, Renewable and Sustainable Energy Reviews 10 (2006) 248–268.

[19] M. Mohibbe Azam, Amtul Waris, N.M. Nahar, Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India, Biomass and Bio energy 29 (2005) 293–802.

[20] J.P. Holman, Experimental Techniques, Tata McGraw Hill Publications, 2003.

[21] A.S. Ramadhas, C. Muraleedharan, S. Jayaraj, Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil, Renewable energy 30 (2005) 1789–1800.

[22] C.W. Yu, S. Bari, A. Ameen, A comparison of combustion characteristics of waste cooking oil with diesel as fuel in a direct injection diesel engine, ImechE 216 (2002) 237–243.

[23] T.W. Ryan III, M.O. Bagby, Identification of chemical changes occurring during the transient injection of selected vegetable oils, Society of Automotive Engineers (1993) 1440–1449 (paper no. 930933).