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Performance and Emission Characteristics of CI Engine Fueled with Diesel - Biodiesel (Mahua/Pongamia Oil) Blend with Methyl/Ethyl Esters

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Abstract**—** An experimental investigation has been conducted to evaluate the effects of using methyl/ethyl esters as an additive to biodiesel/diesel blend on the performance and emission of a direct injection diesel engine. High viscosity, poor volatility and heavy chemical structure of vegetable oil are the main constraints to replace diesel fuel. The mahua/pongamia biodiesel and diesel are blended with methyl/ethyl esters in the ratio of 0:100:0, 20:70:0, 30:70:0, 40:60:0, 10:75:5, 20:75:5 and 30:65:5 by volume and tested in CI Engine. Based on iteration method, the best composition is B20 of methyl and ethyl esters of Pongamia oil (POME20, POEE20), methyl and ethyl esters of Mahua oil (MOME20, MOEE20) and standard diesel fuel separately. The performance and emission characteristic results were compared with diesel fuel. Results indicate that from all the experiments 20% Pongamia oil methyl ester produces 13.2% less power at 3.22% more specific fuel consumption than diesel fuel at maximum load. From the emission results the observation is that slight reduction of hydrocarbon, carbon monoxide and smoke emissions with moderate increase in carbon dioxide emission.

Keywords**—** Diesel engine, Performance, Biodiesel, Emissions, Methyl ester, Ethyl ester.

I. INTRODUCTION

Increasing demand of energy with limited fossil-fuel-based resources has caused a move towards sustainable and renewable sources of energy [1]. The most suitable alternative to fossil fuel is biomass-based renewable energy sources, which accounted for almost 59% of total renewable-based energy sources in 2015 for European Union [2]. Global exposure to renewable energy sources raised their consumption level in 2012 to about 19 per cent of global energy consumption. The European Union ‘s commitment to renewable energy is expected to rise by 55–75% by 2050 [2,3]. The action plan to shift towards a sustainable low-carbon economy by 2050 established key elements for EU climate action which will help the EU to become a competitive low-carbon economy by 2050 [3]. Presently the Indian government has taken unprecedented initiatives in field of biofuels to meet the huge energy demand in transportation, power generation, and agriculture. The Indian government has undertaken several policy interventions and biodiesel blending targets. For example, the biodiesel blending program (BBP) that started on 10 August 2015 in five cities has been extended to six states in the country [4]. Further, the government of India is exploring supplying a 5% biodiesel blend to bulk consumers such as Indian Railways and the defense sector [5].

However, large-scale production of biodiesel has still not started in India. On the other hand, there has been much criticism of the sustainability of first-generation biofuels crops (food versus fuel debate), net greenhouse gases (GHG) balance, and net energy balance. These criticisms have led to growing interest in second-generation and third-generation biofuels. Microalgae could be a promising option among third-generation biofuels due to its high potential of energy production per acre compared to conventional oilseed crops. Microalgae can mature within 2–3 days as compared to Jatropha, Karanja etc. (second-generation biofuels), which take 2–3 years. Microalgae have good potential for production of different types of biofuels, such as biodiesel, bioethanol, biogas, and biohydrogen. In addition, microalgae biofuels do not have any competition with agricultural land as they are aquatic species and can be cultivated in brackish or waste water. Some microalgae can double their biomass within 6–24 h and accomplish up to 50% lipid content in dry biomass [6,7].

Microalgae species are able to produce 7–30 times more oil than high-yielding terrestrial oilseed crops [8,9]. In addition to this, terrestrial crops are seasonal while microalgae can be cultivated in photo-bioreactors or open ponds throughout the year. Furthermore, microalgae require about 49–132 times less space compared to agricultural crops, such as rapeseed and

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soybean, for the same quantity of biodiesel production [10–12].

The performance of engines commonly depends on fuel quality. Borecki et al. proposed a capillary sensor with disposable optrode of diesel fuel quality, which shows an ability to classify known and unknown fuel samples [13]. The physicochemical properties of the biodiesel fuels generally depend upon their fatty acid methyl esters (FAMEs) compositions [14–16]. It has been reported that microalgae biodiesel fuels have similar favorable physiochemical properties as that of second-generation biodiesel fuels for diesel engine applications [17–19].

In this direction, Tüccar et al. examined the effect of algae biodiesel blends on the diesel engine performance [20] and observed a significant deterioration in brake thermal efficiency when the engine run with algae biodiesel blends. In another experimental investigation, they run a compression engine (CI) engine fueled with 10% and 20% diesel–butanol–microalgae biodiesel blends at different loads [21]. As a result, they found a slight increase in engine efficiency along with the benefit of emission reduction. Makareviciene et al. performed experiments on a multicylinder diesel engine generator using microalgae biodiesel (MB) fuel blends (70% diesel+30% MB) and also observed a slight decrease in the engine efficiency [22].

Fast depletion of petroleum fuel resources, increasing demand and stringent regulations of environment pollution made researchers to search for new suitable future alternative fuels for diesel engines. Biodiesels made from renewable oils can be used in diesel engines to replace diesel fuel. These fuels have properties similar to diesel oils and reduced emissions from a cleaner burn due to their higher Oxygen content. [23, 24]. Alternative fuels are easily available, renewable and environment friendly. One of the promising alternative fuels considered for diesel engine is biodiesel. Particularly non-edible oils can be used to make biodiesel to replace feature fuel requirement for diesel engines [25]. Biodiesel also offer the advantage of being able to readily use in existing diesel engines without any modifications of the engine [26]. Even though biodiesel has many advantages, its usage is restricted to the maximum of 20%, this is due to gum deposits on the cylinder surface for long run [27, 28]. Use of biodiesel as fuel in the existing engines the observation is decrease in power, drop in thermal efficiency, increase in specific fuel consumption and higher emissions [29, 30]. In order to overcome these problems the modifications in engine operating parameters suggested that are varying the compression ratio and injection pressure, use of multiple injections and oil preheating.[31-35]. Various blends of a non-edible vegetable oil, commonly known as honge (Pongamia pinnata L.) in India, were prepared and tested over a wide range of engine load. Results obtained from the study showed that 15–20 per cent pongamia methylester-diesel blend (B15 and B20) could be a better fuel in terms of fuel efficiency and power developed. [36].

The objective of the present work is to investigate the effect of Methyl/Ethyl ester as an additive on the performance of CI diesel engine. In the present work different blends of biodiesel, diesel without/with Methyl/Ethyl ester additive was prepared and their comparative performances were evaluated with neat diesel.

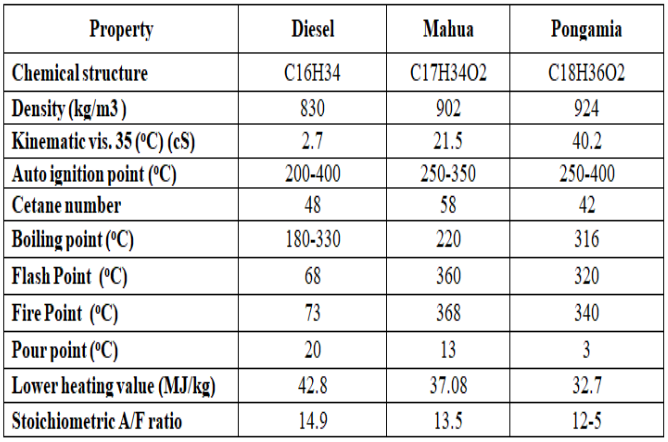
II. MATERIALS AND METHODS

Mahua oil is obtained from the seeds of madhuca indica, a deciduous tree which can grow in semi-arid, tropical and sub-tropical areas. It grows even on rocky, sandy, dry shallow soils and tolerates water logging conditions. Mahua oil was procured from an oil mill. The oil was filtered to remove the impurities. Flash point and fire point was determined by using of pensky martens fire point apparatus. The viscosity was determined at different temperatures using redwood viscometer to find the effect of temperature on the viscosity of mahua biodiesel. The viscosity of mahua oil was found to be approximately 8 times higher than that of diesel fuel. The flash point of mahua oil was higher than diesel and hence it is safer to store. It is seen that the boiling range of mahua oil was different from that of diesel.

Pongamia oil is derived from the seeds of the Millettia pinnata tree. Pongamia oil is extracted from the seeds by expeller pressing, cold pressing, or solvent extraction. The oil is yellowish-orange to brown in color. It has a high content of triglycerides, and its disagreeable taste and odor are bitter flavonoid constituents

including karanjin, pongamol, tannin and karanjachromene.

Table 1: Properties of diesel, mahua, pongamia biodiesel



Property	Diesel	Mahua	Pongamia
Chemical structure	C16H34	C17H34O2	C18H36O2
Density (kg/m3)	830	902	924
Kinematic vis. 35 (°C) (cS)	2.7	21.5	40.2
Auto ignition point (°C)	200-400	250-350	250-400
Cetane number	48	58	42
Boiling point (°C)	180-330	220	316
Flash Point (°C)	68	360	320
Fire Point (°C)	73	368	340
Pour point (°C)	20	13	3
Lower heating value (MJ/kg)	42.8	37.08	32.7
Stoichiometric A/F ratio	14.9	13.5	12-5

Trans-esterification process is used to make biodiesel from ***pongamia/Mahua*** oil. Filtered oil is heated at 105^0C temperature to remove all the water content as shown in figure 1. Methanol of 99% pure, 120 ml per liter of oil is added and stirred for ten minutes. Two milliliter of 98% pure sulfuric acid (H_2SO_4) is added for each liter of oil, heated and stirred for one hour at 60^0C in a closed conical beaker in acid treatment. The mixture is allowed to settle for four hours and glycerin is removed from methyl/ethyl ester.

Methanol of 200ml (20% by volume) with 6.5 grams of 97% pure sodium hydroxide (NaOH) is thoroughly mixed until it forms a clear solution called "***Sodium Methoxide***". This *solution* is added to oil at 60^0C temperature by stirring at 500 to 600 rpm in a closed container. The solution turns into brown silky in colour after completion of reaction. After settlement of the mixture, glycerin is separated from biodiesel in the base treatment as shown in figure 2.

Fig. 1:- Initial heating of oil

Fig. 2:- Glycerin separation after acid and base treatment

The formed methyl ester is bubble washed with distilled water for about half an hour to remove soaps and un-reacted alcohol as shown in figure 3. Washing is repeated till the methyl ester separated with clear water as shown in figure 4.

Fig. 3:- Soap water during water washing

Fig. 4:- Clean water during water washing

Collected methyl ester is heated to remove water and formed biodiesel as shown in figure 5 which is used to make blend fuel (POME20) with diesel. By using similar procedure of making biodiesel as shown in figure 2, other blend fuels (MOME20, POEE20 and MOEE20) were also prepared for experimental work.

Fig. 5:- Biodiesel

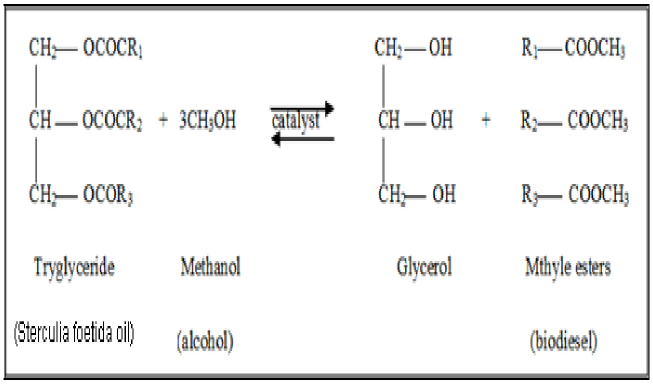


Fig 6: Reaction of Biodiesel formation

III. EXPERIMENTATION

Test has been conducted on four-stroke, single cylinder water cooled direct injection and naturally aspirated diesel engine coupled with eddy current dynamometer is used for the experimental work. The specifications of the dynamometer are demonstrated in Table 2.

For fuel injection, a high-pressure fuel pump with a three hole nozzle injector was used. The injector nozzle was located at the center of the combustion chamber and has an operating pressure of 220 bar. Experiments were conducted by varying loads of 0, 20, 40, 60, 80 and 100% for diesel, biodiesel blends with diesel for different compositions at 1500 rpm constant rated speed of the engine as shown in figure 8. Fuel consumption and exhaust gas temperatures were measured by usual procedure.

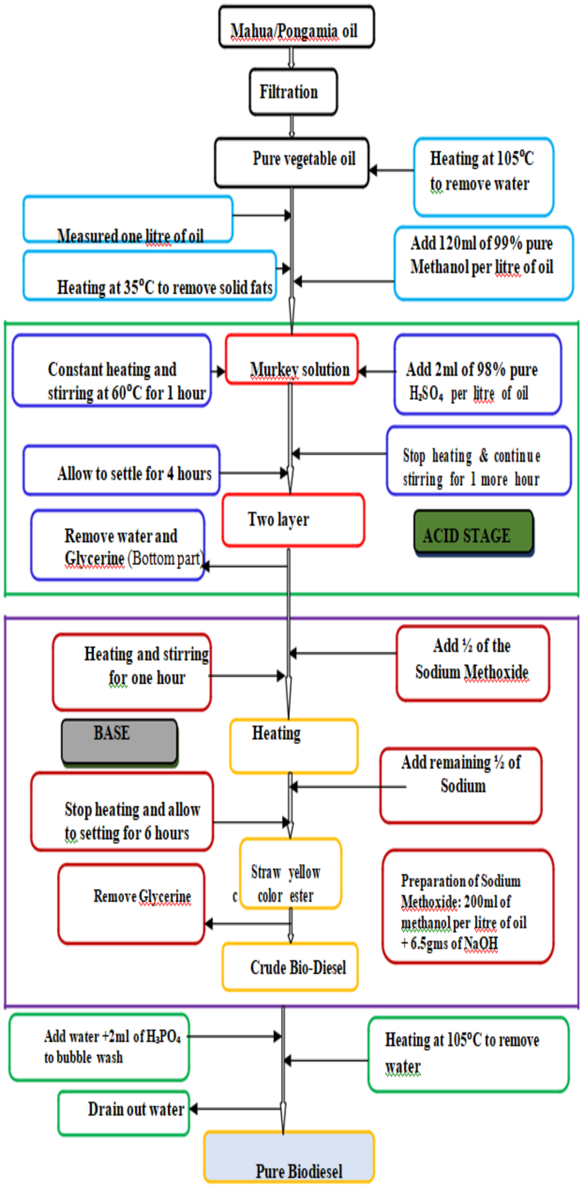


Fig 7: Biodiesel process Chart

Table 2: Specification details of dynamometer

Dynamometer type	Eddy current
KVA	3.5 KVA
Current /voltage	14.6 A / 240V
Phase	Single
Speed	1500 rpm
Power factor	0.8
Frequency	50 Hz
Model	DI

The parameters like brake thermal efficiency and brake specific fuel consumption are evaluated at all load conditions. The emissions characteristics were measured at steady state condition of the engine with the help of AVL437C model. Exhaust gas analyzer used for this experiment is AVL DI 444 model. In this cable one end is connected to the inlet of the analyzer and the other end is connected at the end of the exhaust gas outlet. Continuous charging of the analyzer is essential to work in an effective way. The measuring method is based on the principle of light absorption in the infrared region, known as "non-dispersive infrared absorption".

The broadband infrared radiation produced by the light source passes through a chamber filled with gas, generally methane or carbon dioxide. The exhaust gas analyzer was used to measure the carbon dioxide (CO2), carbon monoxide (CO) and hydrocarbon emission (HC). Smoke intensity was measured with smoke meter and the results were compared with the diesel fuel.

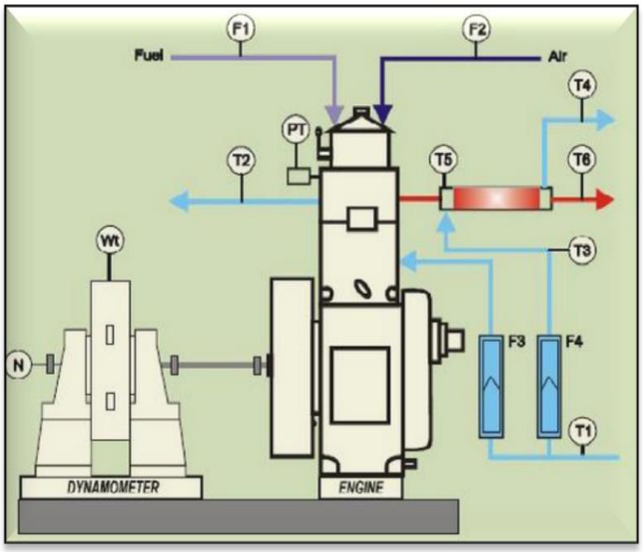


Fig 8: Experimental setup

IV. RESULTS AND DISCUSSION

The performance analysis of diesel engine is analyzed with 20% of Methyl/Ethyl Esters of Mahua/Pongamia Oil with diesel blend and compared the results with diesel fuel.

A. Performance Analysis

i. Brake thermal efficiency (BTE) variation with load is shown in figure 9. The fuel mass flow rate is calculated from the respective measured volume flow rate value and the fuel density. BTE of all blends of esters are inferior to diesel, this is due to the lower calorific value of mahua/pongamia oil. Biodiesel of methyl esters performance is better than ethyl esters. However BTE of POME20 is higher than other blends of esters and 4.5% less than diesel fuel. This is due to low calorific value and high viscosity of biodiesel which promotes the combustion process.

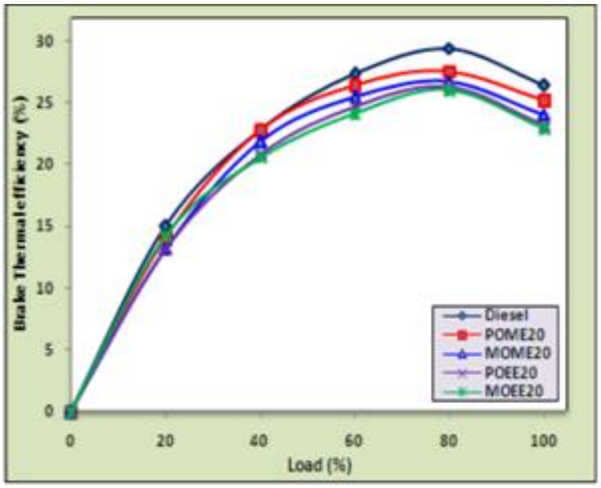


Fig 9: Thermal efficiency variation with Load

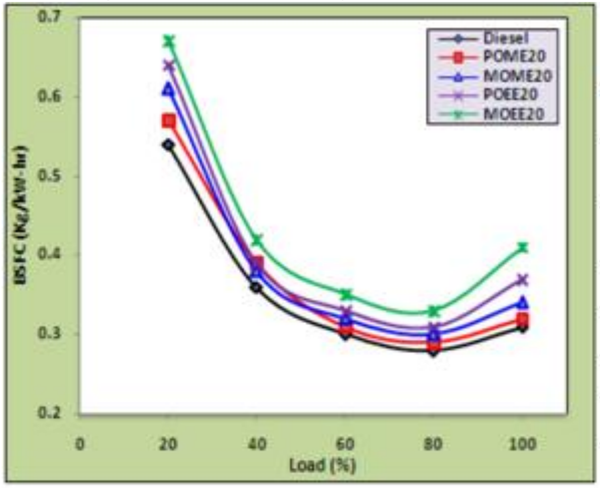


Fig 10: BSFC variation with Load

Brake specific fuel consumption (BSFC) variation with load is shown in figure 10. With increase in load the BSFC decreases sharply for all blends of fuel and it is higher than diesel. Biodiesels of methyl ester have lower BSFC as compared to ethyl esters. As the density of POME20 is lower than other esters and close to diesel, the trend is very close and nearly 3.22% less than diesel fuel.

B. Emission Analysis

i. The observation from figure 11 is that HC emission is reduced with esters compared to diesel. This is due to the presence of oxygen in the fuel. Oxygen promotes combustion processes, in turn reduces the UBHC emissions as compared to diesel. HC emission with POME is the least as compared other esters and diesel fuel.

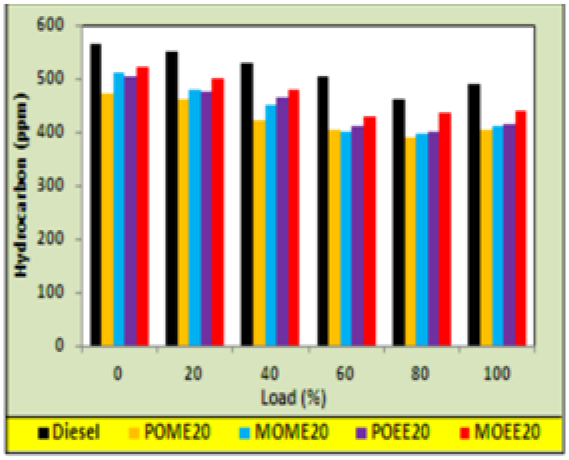


Fig 11: Hydrocarbon variation with Load

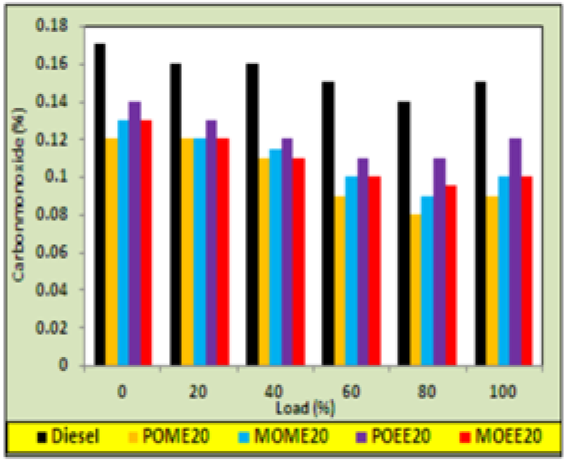


Fig 12: Carbon monoxide variation with Load

ii. Figure 12 shows the variation carbon monoxide (CO) with load. Lower CO emissions of esters may be due to more availability of oxygen leads to complete oxidation as compared to diesel. CO produced during combustion of esters might have converted into CO_2 by taking up the extra oxygen molecule present, thus reduced CO formation. Further observed that CO is increased at full load condition; this is due to excess fuel injected inside the cylinder leads to smoke and prevents oxidation of CO to form CO_2.

iii. Carbon dioxide emission variation with Load is shown in figure 13. The CO_2 emission indicates that how efficiently fuel is burnt in the combustion chamber of a diesel engine. Since the ester-based fuel burns more efficiently than diesel, POME shows 51.3% higher CO_2 emission than diesel fuel.

iv. Figure 14 shows the variation of smoke with load. The smoke emissions are reduced, for non-edible oil methyl or ethyl esters of B20; this is due to complete combustion with excess availability of oxygen content in the biodiesel. Emission of smoke is less in ethyl esters when compared to methyl esters.

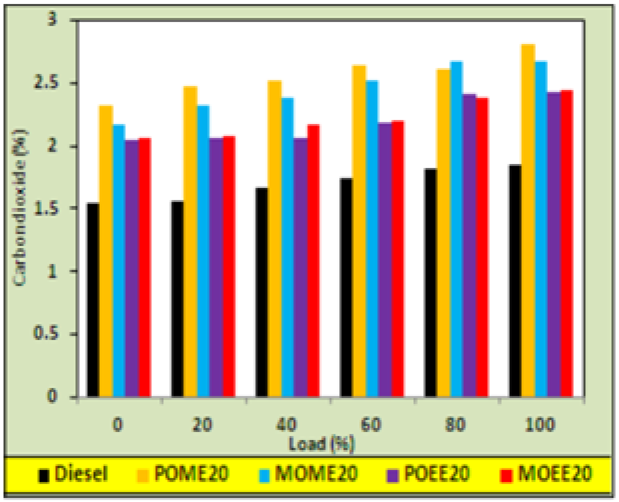


Fig 13: Carbon dioxide variation with Load

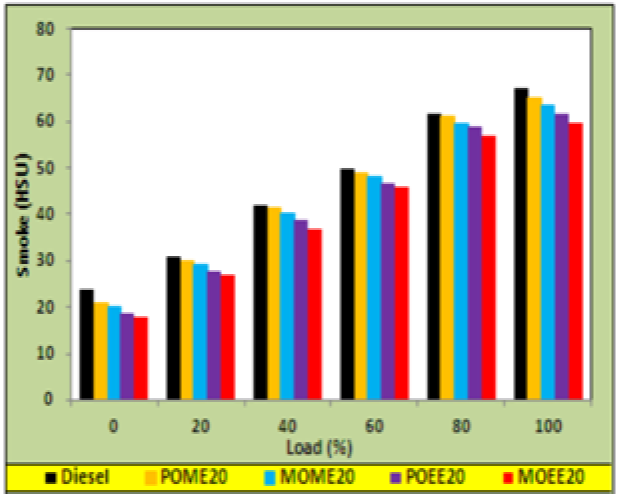


Fig 14: Smoke variation with Load

V.CONCLUSIONS

The experiments were conducted on diesel engine with B20 blend fuel of methyl and ethyl ester of Pongamia oil (POME20, POEE20), Mahua oil (MOME20, MOEE20) and the results were compared with conventional diesel fuel.

- Brake thermal efficiency of biodiesel blend was found to be slightly less than that of diesel fuel at all load conditions.
- The carbon monoxide (CO), smoke and HC emissions of engine were decreased with biodiesel blend.

- Brake thermal efficiency of Pongamia and Mahua oil methyl esters at 20% in diesel is nearly diesel fuel when compared with ethyl esters blends.

- Methyl ester of Pongamia and Mahua oil blends with diesel performing better with low *BSFC* than ethyl esters.

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