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Performance and emission characteristics of compression ignition engine using methyl ester blends of jatropha and fish oil

K. Bhaskar[1], S. Sendilvelan[2*], V. Muthu[3] and S. Aravindraj[4]

[1,3]Department Automobile Engineering, Rajalakshmi Engineering College, Thandalam, Chennai- 602 105, India. Email: kbhaskar66@yahoo.co.in
[2]Department of Mechanical Engineering, Dr. M.G.R Educational and Research Institute, Chennai-600 095, India, *Email: sendilvelan.mech@drmgrdu.ac.in
[4]Automotive Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, Email: aravindrajsethu@gmail.com

ABSTRACT

In this work, biodiesel obtained from the transesterfication of Jatropha seeds and Fish wastes is used as an alternative fuel to diesel in stationary single cylinder diesel engines. The biodiesel obtained has good ignition ability due to its relatively high cetane number compared to that of conventional diesel fuel. The performance, combustion and emission tests using Jatropha Oil Methyl Ester (JOME), Fish Oil Methyl Ester (FOME) and their blends (20% JOME and 20% FOME) with diesel were carried out at constant speed and variable loads condition. The results showed that both blends could be used as fuels for diesel engine without any major modification on the engine. Carbon monoxide (CO), UBHC and smoke emissions were observed to be lesser at all loads for both the blends compared to diesel fuel, while NOx emission was slightly higher. JOME blend was found to be better than FOME blend.

Keywords: Diesel Engine Performance; Exhaust Emissions; FOME; Fuel Properties; JOME.

INTRODUCTION

Energy crisis has aggravated the world due to the rapid depletion of fossil fuels and environmental degradation [1]. Due to the reduction in the world's petroleum reserves and growing environmental concerns, there is an extensive demand for non-conventional sources of energy [2]. Augmented regulations on particulate matter and NOx, and also issues raised on greenhouse gas emission like CO_2 are the reasons for demanding research work on bio-fuels all over the world [3-6]. Biodiesel derived from the trans-esterification of fats and oils [7-11] is a possible fuel for diesel engines. The properties of this fuel is comparable to that of diesel and can be used directly to run existing diesel engines or as a blend with crude oil diesel [12]. Biodiesel is renewable, biodegradable and non-toxic. With diesel, it increases fuel lubricity and operates in compression ignition engines with little or no modification [13]. Furthermore, biodiesel offers compensations regarding engine wear, cost and availability [14, 15]. Pollutants produced are less harmful comparatively [16, 17]. Biodiesel has low sulphur content, low aromatic content and oxygen containing compounds due to which the emissions of SO_2, CO_2, HC and PM are reduced. Besides, it has good ignition ability in engine owing to its high cetane number compared to that of conventional diesel fuel [10, 18-23].

The trans-esterification process is based on the chemical reaction between a triglyceride with an alcohol in the presence of a catalyst, potassium hydroxide, to produce biodiesel and glycerin. Castor, palm, sunflower, peanut and soybean oils can be used as biodiesel sources [24], but all of these are used for cooking purposes. Hence, instead of using edible oils for the production of biodiesel, non-edible oils can be used for the same. Low cost [25, 26] renewable raw material is a very important requirement for economical production of biodiesel. Biodiesel produced from waste fish oil is a very good and low cost alternative to petroleum diesel [27]. The fish processing industry generates large quantities of tissue waste and byproducts which are either discarded or retailed at low values for fertilizer or animal feeds [28]. A better way to utilize these byproducts is to convert them into biodiesels for use in diesel engines [29]. India has one of the longest coastal areas in Asia and has excellent potential for fish and fish products including Fish meal and Fish oil [30]. Locally produced fish oil biodiesel blend fuels have the potential to create sustainable energy supply for use in remote regions, together with dramatic cost savings and reduced dependence on imported petroleum products [31]. Easy-to-manufacture [32], cleaner-burning fish oil biodiesel and its blends could potentially replace or reduce traditional diesel fuel requirements in India. This paper presents the experimental results of using 20% JOME and 20% FOME blend on the performance and emission characteristics of the engine. This work brings out the possibility to partially replace diesel to reduce dependence on petroleum-based diesel fuel. The use of animal fat to produce biodiesel has attracted public interest recently. The search for aquatic sources for energy production makes economic sense as well as ecological sense [33]. Also, the fish oil obtained has long carbon chain fatty acids which makes combustion to be efficient and reduces carbonaceous emissions greatly [34]. In addition to the purified fish oil obtained from the wastes in the fishing industry, caustic soda is added. Eventually methanol is produced. One kg of fish oil waste can produce up to 1.13 lts of bio-diesel [35]. Glycerine is a valuable byproduct obtained, which is used for pharmaceutical and cosmetic purposes [36]. In Alaska, roughly 8 million gallons of fish oil is produced each year. Most of the oil is used as boiler fuel for drying the fish meal, while smaller quantities are blended with diesel and used for power production [37]. In 2005, the Food and Agricultural Organization (FAO) estimated the world fish production at 142 million tons, of which 25% is destined for producing fish meal and oil [38]. In 2008, the amount of wastes was around 50% of the total fish production and the oil produced ranged from 40-65% [39]. Based on the above literature survey, the use of J20 and F20 blends with diesel was investigated in this work. The experimental results showed that the above blend can be used as a partial replacement for diesel to reduce dependence on petroleum-based diesel fuel.

EXPERIMENTAL SETUP

The tests were conducted on a single cylinder, four stroke, naturally aspirated, air-cooled diesel engine coupled with an electrical swinging field dynamometer. The detailed technical specifications of the engine are given in Table 1. Figures 1-2 show a photographic view and the schematic diagram of the experimental set-up. AVL 415 Variable Sampling Smoke meter was used to measure the particulate matter in the exhaust. MRU delta 1600 L Exhaust Gas Analyzer was used to measure HC, CO and NOx emissions. The AVL 615 Indimeter system was used to get the pressure crank angle diagram at various loads using a piezoelectric pressure transducer and an angle encoder and to process the same for getting various parameters such as heat release rate curve, peak pressure, angle of occurrence of peak pressure, imep, etc. Fuel consumption was calculated at any load from the measurement of time for 10cc of consumption. Exhaust gas temperature was measured using K-type thermocouple. All equipment were calibrated per the supplier's specifications before beginning the experiments.

Table 1. Test engine specifications

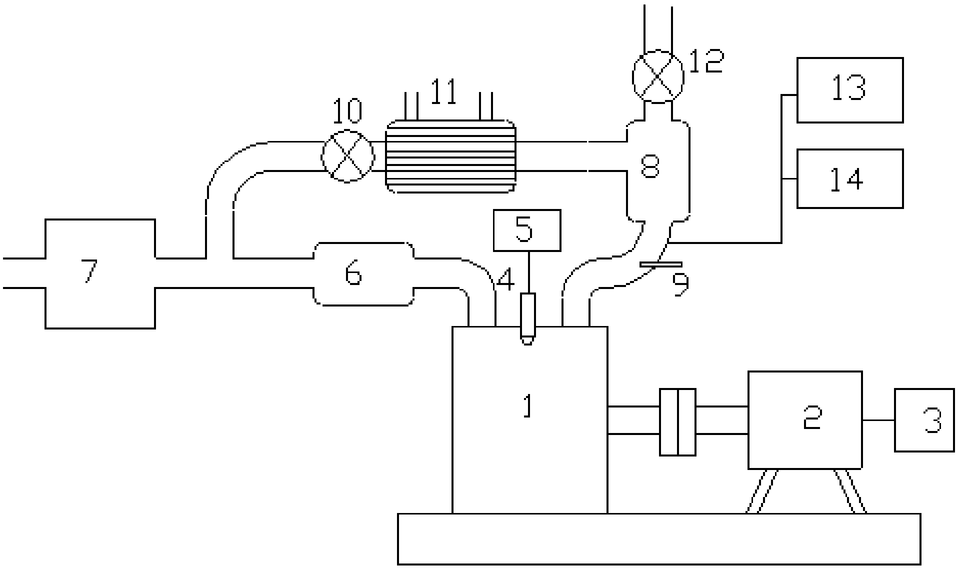
Specificaions	Description
Engine Type	Four stroke, Air cooled, stationary, constant speed, direct injection, CI engine
No. of cylinders	1
Maximum power	4.4 kW at 1500 rpm
Maximum torque	28 N-m at 1500 rpm
Bore	87.5 mm
Stroke	110 mm
Displacement	661.5cc
Compression Ratio	17.5: 1
Injection Timing	23.4^0 bTDC
Loading type	Swinging field dynamometer

Figure 1. Photographic view of the experimental setup.

Experimental Procedure

The engine was started with diesel and allowed to warm up until steady state condition was achieved. Engine Speed, fuel consumption rate, exhaust emissions (HC, CO, and

NO_X), smoke intensity, pressure-crank angle diagram and exhaust gas temperature were measured at various loads. The experiment was repeated with blends of Jatropha and Fish oil at no load, 25%, 50%, 75% and 100% of the rated power output at a constant speed of 1500 rpm.



1	Diesel Engine	8	Settling chamber
2	Electrical Dynamometer	9	Thermocouple
3	Dynamometer Controls	10	EGR Valve
4	Main Injector	11	EGR Cooler
5	Fuel flow measurement	12	Back pressure control valve
6	Mixing chamber	13	Exhaust gas analyzer
7	Air flow measurement	14	AVL smoke meter

Figure 2. Schematic diagram of the experimental setup.

Error Analysis

Errors and uncertainties in the experiment are important to determine the accuracy of the results. So, instruments were carefully selected and the uncertainty percentages of various parameters are given in Table 2.

RESULTS AND DISCUSSION

Brake Thermal Efficiency

Figure 3 shows the variation of brake thermal efficiency with brake power, which was found to increase with increasing brake power as observed by investigators [27, 28, 30]. The brake thermal efficiency for 20% JOME and 20% FOME blends were slightly lower than that of diesel at all loads. At any load, the energy input given by (mass flow rate of fuel x calorific value) was higher for biodiesel blends compared to diesel. Hence the brake thermal efficiency was lower for biodiesel. The engine was operated under constant injection timing. As methyl esters and their blends had smaller ignition delay, combustion was initiated well before TDC was reached. This increased the compression work and reduced the brake thermal efficiency of the engine [40]. The start of heat release occured well before TDC for methyl esters and their blends [41], which causes appreciable deviation from the ideal cycle, hence lower thermal efficiency. Blends of both methyl esters showed the same trend, but with a difference that the brake thermal efficiency was slightly higher for blends of JOME due to higher oxygen content, and hence better combustion.

Table 2. List of instruments and their range, accuracy, and uncertainty.

Sl. No.	Instruments	Range	Accuracy	Percentage of uncertainty
1	Gas analyzer			
	CO	0 – 15.00%	±0.06%	±5%
	Hydro carbon (HC)	0 – 20000 ppm n-hexane	±0.12ppm	±5%
	NOx	0 – 2000 ppm	±5 ppm	±5%
2	Smoke meter	0 – 32000 mg/m^3	± 0.01 mg/m^3	±5%
3	K type Thermocouple used for Exhaust Gas Temperature measurement	0–1000	±^{o}1	±0.15
4	Speed measuring unit	0–9,999 rpm	5 ± 10 rpm	±0.1
5	Pressure pickup	0–250 bar	± 0.1	± 0.1
6	Crank Angle encoder	0-360 ^{o}	±1^o	± 0.2

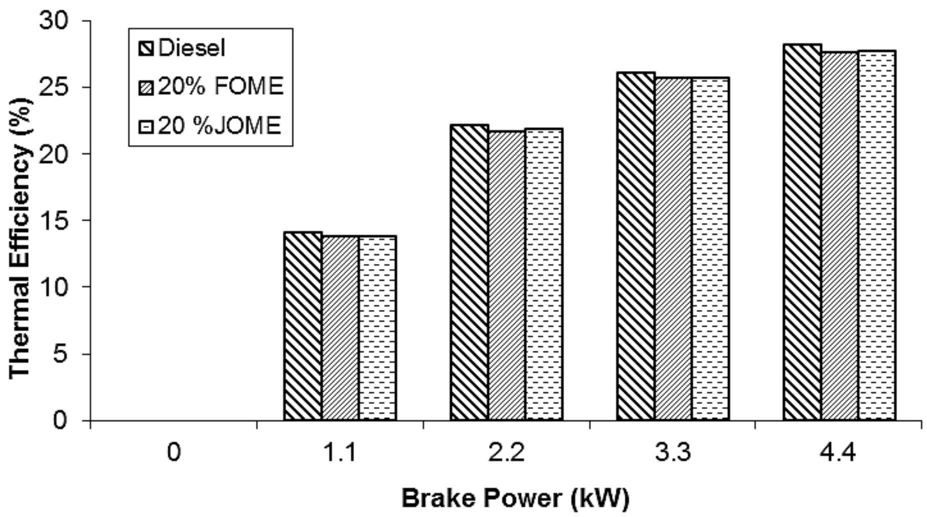


Figure 3. Variation of brake power against thermal efficiency.

Brake Specific Energy Consumption

Figure 4 shows the variation of brake specific energy consumption with brake power. BSEC is the input energy required to develop a unit power output and by comparing methyl esters with diesel, methyl esters showed comparatively higher value of BSEC. The slight increase was due to lower calorific value of the esters compared to diesel [42]. When comparisons were made between 20% FOME and 20% JOME, 20% FOME showed slightly higher value, which is attributed to higher density of FOME (Table 3).

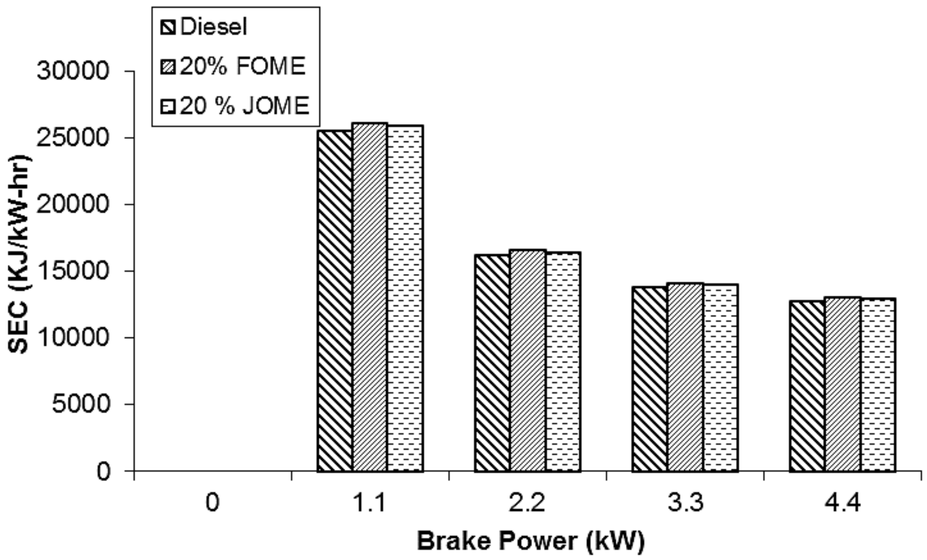


Figure 4. Brake power versus SEC.

Table 3. Comparison between the fatty acid composition (wt %) of fish oil methyl esters and jatropha oil methyl esters (as provided by the suppliers).

Types of Fatty Acids	Chemical Structure	Type	JOME	FOME
Myristic acid	C14:0	S	0.70	4.98
Palmitic acid	C16:0	S	15.30	19.42
Palmitoleic acid	C16:1	US	-	6.43
Heptadecanoic acid	C17:0	S	-	1.74
Stearic acid	C18:0	S	9.60	3.80
Oleic acid	C18:1	US	40.60	20.22
Linoleic acid	C18:2	US	33.40	3.20
Linolenic acid	C18:3	US	0.30	1.20
Arachidic acid	C20:0	S	-	3.56
Eicosadienoic acid	C20:2	US	-	0.45
Eicostetraenoic acid	C20:4	US	-	2.20
Eicospentaenoic acid	C20:5	US	-	7.80
Behenic acid	C22:0	S	-	1.25
Docosapentaenoic acid	C22:5	US	-	3.25
Docosahexa-enoic acid	C22:6	US	-	18.25
Saturated fatty acids	C14-C18		25.60	33.37
Unsaturated fatty acids	C18:1,2,3		74.30	24.62
Long carbon-chain fatty acid	C20-C22		-	36.76

Exhaust Gas Temperature

The exhaust gas leaving the cylinder determines the extent of temperature reached during the combustion process [43]. With increasing load, the temperature of the exhaust gases increased for all of the fuels. It was also observed that the exhaust gas temperature increased with percentage of methyl ester in the fuel for all of the loads (Figure 5). This may be due to the oxygen content in methyl esters, which improved combustion [44]. Also, poor fuel atomization and vaporization due to higher viscosity of methyl esters and their blends resulted in late burning of the injected fuel and higher exhaust gas temperature [45].

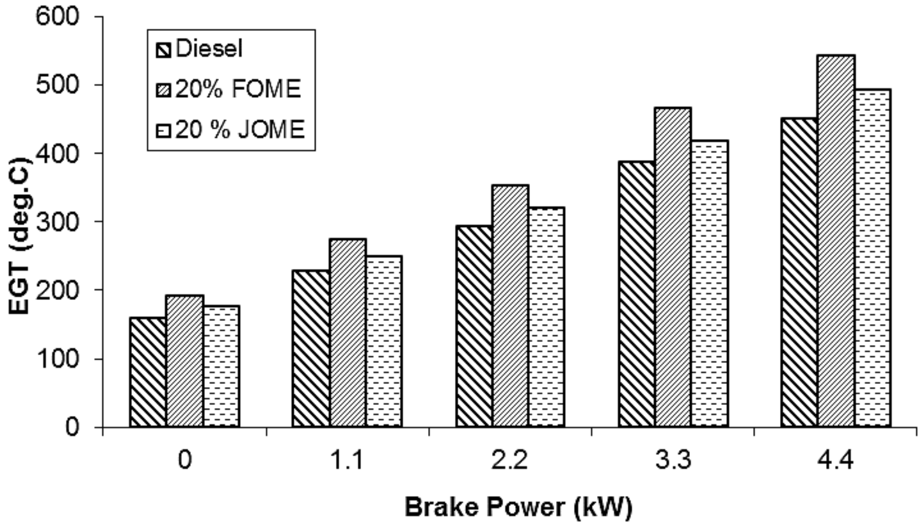


Figure 5. Brake power versus EGT.

Table 4. Fuel Properties of Biodiesel from FOME, JOME and Diesel fuel (Measured).

Fuel Property	Units	Diesel	Limits as per IS 15607-2005 ASTM D6751	JOME	FOME
Density at 15 ºC	kg/m^3	830	860-900	882	890
Kinematic Viscosity at 40 ºC	cSt	3.52	1.9-6.0	4.5	5.2
Flash Point	ºC	54	120	160	157
Calculated Cetane Index	-	50	-	54	52.4
Higher Heating Value	MJ/kg	-	-	39.64	40.54
Element O	wt%	-	-	10.8	8.1
(Given by Supplier) Acid Number	mg KOH/g	0.2	0.5 max	0.14	1.32

Hydrocarbon Emissions

Figure 6 shows the variation of HC emission with brake power. It can be seen that with increasing brake power, HC emission increased for all test fuels, and there was reduction in HC emission for 20% JOME and 20% FOME blends compared to diesel due to the presence of oxygen content in their molecular structure which leads to efficient combustion [46]. With methyl esters having higher Cetane Index (CI) than diesel, the delay period was reduced and led to effective combustion, which reduced HC emission to a greater extent [47]. HC emission for 20% JOME was lesser than 20% FOME as the oxygen content by weight for J20 was greater than 20% FOME (Table 4).

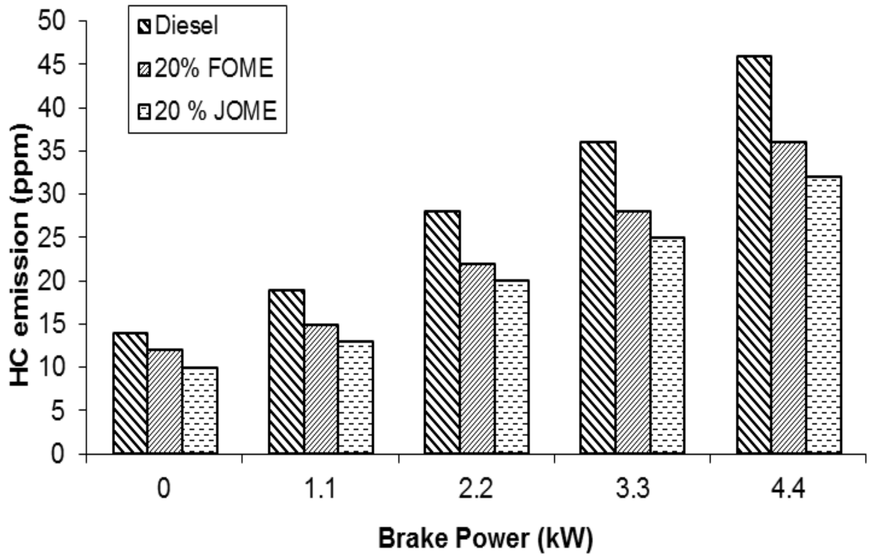


Figure 6. Brake power vrsus HC emission.

Carbon-Monoxide Emissions

Figure 7 shows the variation of carbon monoxide emissions with brake power. With increasing brake power, CO emission increased for all test fuels. CO emission resulted from the lack of oxygen during combustion. Methyl esters with higher oxygen content produced efficient and effective combustion [48] and higher cetane index [45], leading to lower CO emission. Lower carbon to hydrogen ratio of methyl esters also results in lower CO emission. By comparing 20% JOME and 20% FOME, CO emission was lower for Jatropha blend as 20% JOME has 10.8% oxygen content compared to 8.1 % oxygen content of 20% FOME. Higher cetane index of 20% JOME compared to 20% FOME also contributed to lower CO emission.

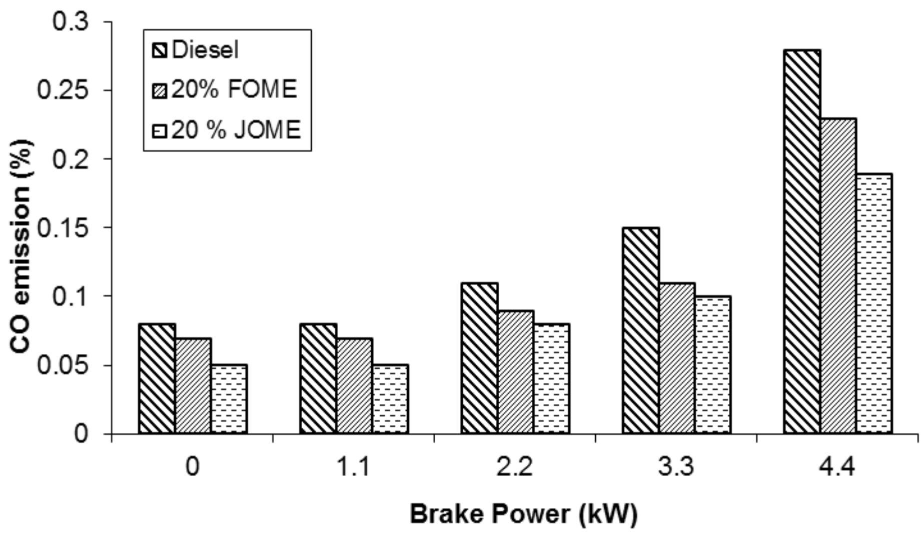


Figure 7. Brake power vs CO emission

NO_x Emission

The NOx emission of diesel and the methyl esters are shown in Figure 8. It was found that NOx emission increased with brake power for all of the fuels tested. By comparing J20 and F20 with diesel, methyl esters showed higher value of NOx emission. This is mainly due to higher oxygen content of methyl esters [49]. The oxygen content of diesel, JOME and FOME was 0.3%, 10.8% and 8.1% respectively. Because of higher oxygen content and increased energy input (mass flow rate of fuel x Calorific Value) combustion was better as observed in higher exhaust temperature [50]. As NOx emission increases with cylinder temperature and oxygen availability, it is higher for the methyl esters [51]. The 20% FOME showed higher value of NOx compared to 20% JOME as it contains unsaturated fatty acids including C20:5 and C22:6 and long carbon-chain methyl ester fatty acids in higher proportion than in the Jatropha oil methyl esters. (Table 4)

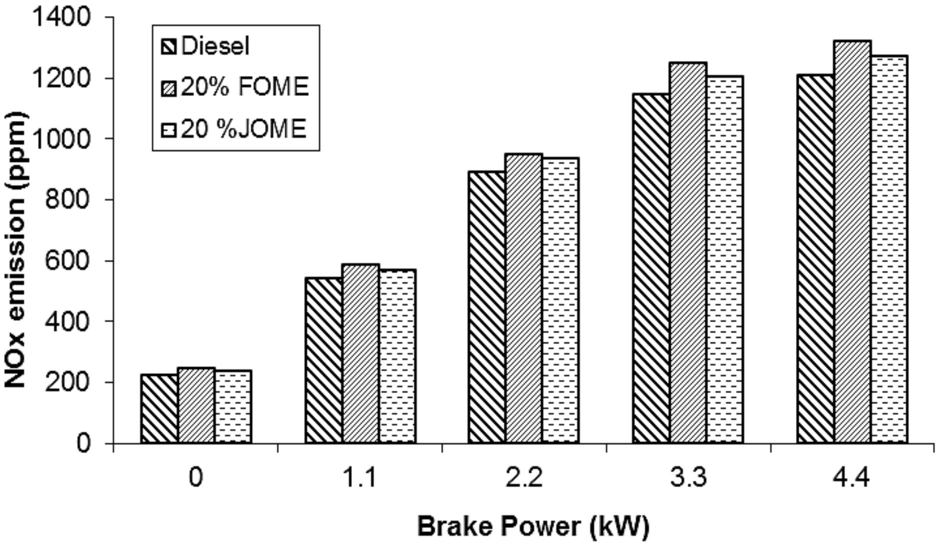


Figure 8. Brake power vs NO_x emission

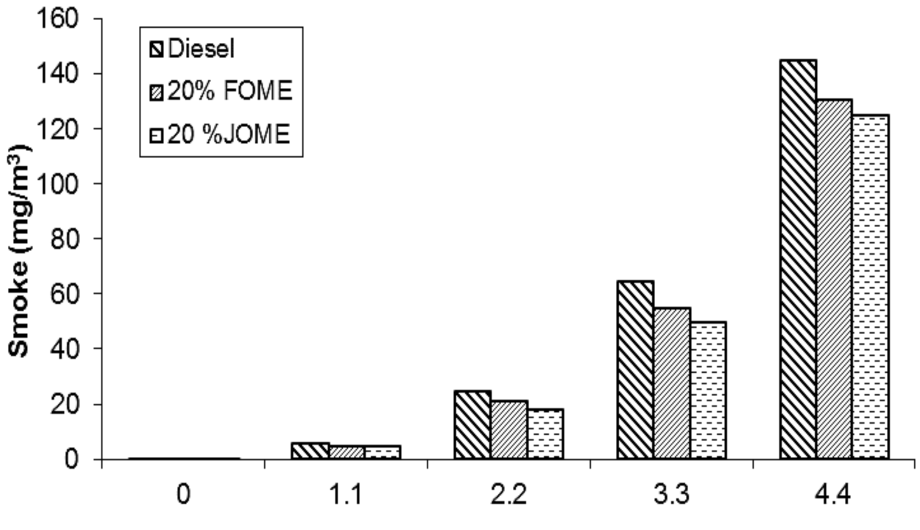


Figure 9. Brake power vs Smoke.

Smoke Emissions

Figure 9 shows that smoke emissions increasesd with brake power. It was observed that 20% JOME and 20% FOME showed lower value of smoke compared to diesel due to higher oxygen content and higher cetane index, which improved the combustion process [52]. By comparing 20% FOME and 20% JOME, 20% FOME showed higher value of smoke due to higher kinematic viscosity and density, which affects the volatilization and atomization process of the fuel particles [53]. In addition, FOME has long carbon chains fatty acids in the range of C20-C22 which is considered to be larger than those of JOME and hence F20 showed greater value of smoke.

CONCLUSION

The engine performance and emission characteristics of 20% JOME and FOME blends were investigated and compared with those of normal diesel fuel. It was seen that the engine can be run without any modification to these fuels. The results of this study are summarized as follows:

1. The brake thermal efficiency of the engine with these fuels was slightly lower than that of diesel. The efficiency of JOME was higher than that of FOME at all loads.
2. HC, CO and PM emissions of these fuels were lower compared to those of diesel ,and JOME was better than FOME in this regard.
3. Exhaust gas temperature and NOx were higher for these fuels compared to diesel. FOME results in the highest EGT and largest NOx emission at all loads. NOx emission can be reduced by other means such as EGR, retarded injection timing, higher injection pressure.
4. FOME can be produced economically in the coastal regions where discarded fish parts are available cheaply.

Scope for future work:

1. A longer duration of study using these fuels and their effects on carbon deposits on various parts of engine and lubrication oil contamination.
2. The test can be extended to multi cylinder engines which are commonly used in automobiles.

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