Experimental studies on the performance and emission characteristics of a compression ignition engine fuelled with jatropha oil methyl ester

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ABSTRACT

In this work, biodiesel obtained from jatropha seedsare used as alternative fuel to diesel in stationary diesel engines. The oil obtained from the jatropha seeds are trans-esterified to get biodiesel. The biodiesel obtained has good ignition ability due to its relatively high cetane number compared to that of conventional diesel fuel. The oxygen component in the biodiesel fuel has the effect of reducing the pollutant concentration in exhaust gases due to better burning of the fuel in the engine. But the viscosity of biodiesel is very high compared to diesel and this affects its atomization and penetration characteristics and hence it is blended with diesel while being used as an alternate fuel in diesel engines. Performance and emission tests of Jatropha Oil Methyl Ester (JOME) and their blends (80%, 60%, 40%, 20%) with diesel were carried out on a direct injection compression ignition engine at constant speed and at variable load conditions. The experimental results show that all the blends can be used as fuels for diesel engine without any major modification in the engines. It is also seen that the carbon monoxide, unburnt hydrocarbon and soot emissions are less at all loads for the blends compared to diesel fuel while oxides of nitrogen emissions are slightly higher. Tradeoff between oxides of nitrogen and soot emissions for various percentage of JOME in blends show that 19% of JOME blend are observed to be optimum considering both NOx and soot emissions. At the rated power output (4.4 kW) the NO_x emissions are 7.46 g/kWh and the soot emissions are 120 mg/m^3 for 19% JOME compared with diesel the NO_x emissions are 7.25 g/kWh and the soot emissions are 166 mg/m^3.

Keywords: Biodiesel;jatrophaoil methyl ester;emission analysis;compression ignition engine;optimum blend.

INTRODUCTION

The energy requirements are more and at the same time the resources depleting very fast. The crisesare caused due to huge dependence on non-renewable energy resources fossil fuels[1]. If the fossil fuel production remains constant, it is estimated that the reserves will be depleted soon. Due to the running down of the petroleum reserves and the growing environmental concerns, there is an extensive demand for non-conventional sources of energy [2]. Augmented regulations for particulate matter and NOx, and also the issues raised on the emission of greenhouse gases like CO_2 are the reasons for bio-fuels being subjected to demanding research work all over the world[3]. Biodiesel

derived from the transesterification of fats and oils is a possible fuel for diesel engines[4]. Properties of this fuel is comparable to that of diesel and can be used directly to run the existing diesel engines or as a blend with crude oil diesel [5]. Biodiesel is renewable, biodegradable and non-toxic[6]. With diesel it increases fuel lubricity and operates in compression ignition engines with little or no modification [7]. Furthermore, biodiesel offers compensations regarding engine wear, cost and availability[8][9]. Pollutants produced are less harmful than fossil fuels[10]. Biodiesel has lesser sulphur content, lesser 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 [11].

The transesterification process is based on the chemical reaction of a triglyceride with an alcohol in the presence of a catalyst potassium hydroxide, producing biodiesel and glycerin[12].Castor, palm, sunflower, pea nut and soybean oils can be used as biodiesel sources(Valente, Da Silva, Pasa, Belchior, & Sodre, 2010), but all 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 [14] renewable raw material is a very important requirement for economic production of biodiesel.

Among the vegetable oils, jatropha oil has very good properties. It is non-edible oil, its calorific value and cetane number are higher compared to many others. The jatropha can grow anywhere, suitable for all conditions. Based on the studies available it is the best substitute available at present to fossil fuel[15]. This paper presents experimental results of 100% JOME and 80%, 60%, 40% and also 20% JOME blends with diesel on the performance and emission characteristics of the engine. This work brings out the possibility of partial replacement of diesel to reduce the dependence of petroleum-based diesel fuel.

PROPERTIES OF METHYL ESTERS

Most modern diesel engines have direct injection fuel systems which are more sensitive to fuel spray quality than indirect injection engines and they require a fuel with properties that are closer to diesel fuel. Table 1 shows the fuel properties of JOME and Diesel fuel. The composition of fatty acids present in JOME as provided by the suppliers is given in Table 2. There is no long-chain hydrocarbons ranging from C:20 to C:22 in JOME. It is also observed that 25.6% of JOME comprises of saturated fatty acid methyl esters.

Table 1. Fuel Properties of Biodiesel from JOMEand Diesel fuel

Fuel Property	Unit	Source	Diesel	Limits as per IS 15607-2005 ASTM D6751	JOME
Density at 15°C	kg/m^3	Measured	830	860-900	882
Kinematic Viscosity at 40°C	cSt	Measured	3.52	1.9-6.0	4.5
Flash Point	^{o}C	Measured	54	120 min	160
Calculated Cetane Index	-	Measured	50	-	54

Calorific Value	MJ/kg	Measured	43.5	-	39.64
Element O	wt. %	Given by Supplier	-	-	10.8

Table 2. Comparison of the Fatty Acid Composition (wt %) of Jatropha Oil Methyl Esters (JOME)

Types of Fatty Acids	Chemical Structure	Type	JOME*
Myristic Acid	C14:0	S	0.70
Palmitic Acid	C16:0	S	15.30
Palmitoleic Acid	C16:1	US	-
Heptadecanoic Acid	C17:0	S	-
Stearic Acid	C18:0	S	9.60
Oleic Acid	C18:1	US	40.60
Linoleic Acid	C18:2	US	33.40
Linolenic Acid	C18:3	US	0.30
Arachidic Acid	C20:0	S	-
Eicosadienoic Acid	C20:2	US	-
Eicostetraenoic Acid	C20:4	US	-
Eicospentaenoic Acid	C20:5	US	-
Behenic Acid	C22:0	S	-
Docosapentaenoic Acid	C22:5	US	-
Docosahexa-Enoic Acid	C22:6	US	-
Saturated Fatty Acids (S)	C14-C18		25.60
Unsaturated Fatty Acids (US)	C18:1,2,3		74.30
Long Carbon-chain Fatty Acid	C20-C22		-
(*provided by the supplier)			

Since biodiesel has different physical and chemical properties compared to petroleum-based diesel fuel, it will affect the engine performance and emission when used without engine modification. All the properties of biodiesel meet ASTM D 6751-02 specifications[16]. JOME contain 10.8% of oxygen by weight and have higher cetane numbers compared to Diesel[17]. Viscosity is an important property that affects flow and atomization characteristics of liquid fuel. In general, kinematic viscosity increases with increase in saturated longer chain fatty acids[18]. From Table 1, it can be observed that JOME have higher kinematic viscosity than diesel. Its viscosity and specific gravity are higher than those of diesel and hence fuel quantity, injection timing, and spray pattern of biodiesel are different from those of diesel[19]. Compared to diesel, methyl esters of jatropha oil have poor injection and atomization characteristics, but offer better lubrication and protection for fuel injection equipments[19].

Heating value is an important property of fuel which determines the amount of power generated per unit of fuel consumed. Heating values of JOME and Diesel are 39.64 MJ/kg and 43.5 MJ/kg respectively[20]. As the higher heating value of JOME are about 8.87% less than that of diesel it causes some power loss and the amount of fuel to be injected into the combustion chamber is also higher to produce the same power. Due to the presence of oxygen content in JOME, carbon and hydrogen

percentages are lower in them compared to diesel and the reduced hydrocarbon content leads to its lower heating value compared to diesel[21].

Cetane number is a good indicator of quality of fuel for use in C.I. engines. Higher cetane number reduces ignition delay[22]. Cetane number depends upon the molecular structure. Fuels with longer straight-chain hydrocarbons have higher cetane number. The presence of branched chain structure reduces the cetane number[22]. A related parameter, Cetane index, is calculated from fuel density and distillation test[23]. Cetane index provides a reasonably close approximation to cetane number. The higher the cetane index, higher is the cetane number[24]. As observed from Table 1 calculated Cetane index for JOME is higher compared to diesel fuel. The higher cetane number of biodiesel results in a shorter ignition delay and advances the combustion timing. The ignition delay, which is the time between the start of injection and the start of combustion, will be affected when the injection timing or the start of injection is varied[25].

EXPERIMENTAL SETUP

The tests are 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 3. Figure 1 shows the schematic diagram of the experimental set-up. The intake manifold of the engine is modified to fit the primary fuel injector. Fuel was pressurized from 0-6 bar using an electronic fuel pump and injected into the intake manifold using a Multi-Point Fuel Injection (MPFI) fuel injector. AVL 415 Variable Sampling Smoke meter is used to measure the particulate matter in the exhaust. MRU delta 1600 L Exhaust Gas Analyzer is used to measure HC, CO and NOx emissions. AVL 615 Indimeter system is used to get pressure crank angle diagram at various loads using piezoelectric pressure transducer and 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,.

Table 3. Test Engine Specifications

Item	Description
Make and Model	: Kirloskar, TAF1 make
General Details	: Four stroke, compression ignition, constant speed, vertical, air cooled, direct injection
Number of Cylinders	: one
Bore	: 87.5 mm
Stroke	: 110 mm
Swept Volume	: 661 cc
Clearance Volume	: 36.87 cc
Compression Ratio	: 17.5:1
Rated Output	: 4.4 kW at 1500 rpm
Rated Speed	: 1500 rpm
Type of Injection Pump	: Mechanical
Nozzle Holes	: 3 holes
Spray Hole Diameter	: 0.25 mm
Nozzle Opening Pressure	: 200 bar
Cone Angle	: 110°
Type of Injector	: Mechanical

Needle Lift	:	0.25 mm
Fuel Injection Timing	:	23 ^{o}CA bTDC
Fuel Injection Duration	:	20 - 30 ^{o}CA
Type of Combustion Chamber	:	Hemispherical Open Combustion Chamber without offset with 52 mm diameter on top. Bowl volume is approximately 40 cm^3
Valve Timing		
Intake Valve Opening	:	4.5°CAbTDC
Intake Valve Closing	:	35.5°CA aBDC
Exhaust Valve Opening	:	35.5°CAbBDC
Exhaust Valve Closing	:	4.5°CA aTDC

Experimental Procedure

The engine is started with diesel and allowed to warm up till steady state conditions are achieved. Engine speed, fuel consumption rate, exhaust emissions (HC, CO, and NO$_X$), smoke intensity, pressure-crank angle diagram and exhaust gas temperature are measured at various loads. The experiment is repeated at various loads with JOME fuel and also various percentages of JOME blends with diesel. Experiments were conducted with 20%, 40%, 60%, 80% JOME blends with diesel and 100% JOME.Errors and uncertainties in the experiment are important to determine the accuracy of the results obtained. So, instruments/analyzers were selected carefully and the percentage uncertainties of various parameters are given in Table 4.Experiments were conducted for 25 set of readings to evaluate the uncertainty of any measured parameter (x) with same operating conditions. From the measured parameter, the mean value (xm) and standard deviation (σ) were obtained and uncertainty is calculated using the following equations:

$$\text{Uncertainty of measured quantity} = \Delta x = (2\sigma/xm)*100 \tag{1}$$

The Uncertainties in the calculated parameters (function of measured independent parameters) are evaluated by using the expression

$$\Delta\text{he Uncsqrt } [(\Delta x/x)^2 + (\Delta y/y)^2] \tag{2}$$

Table 4.List of Instruments and their Range, Accuracy, and Uncertainties

S.No	Instruments	Range	Accuracy	Percentage Uncertainties
1	Gas analyzer	CO : 0-10 %,	±0.01% vol.	± 0.5
		HC : 0-20,000ppm,	± 1 ppm	± 5.0
		NO$_x$: 0-5,000 ppm	± 1 ppm	± 10.0
2.	Smoke Meter	0 – 31,999 mg/m^3	± 0.02 mg/m^3	±5
3.	Thermocouple (K Type)	0–1000 ^{o}C	± ^{o}1	±0.15
4.	Speed Measuring Unit	0–9,999 rpm	± 10 rpm	±0.1
5.	Load Indicator	0-100kg	± 0.1 kg	±0.2
6.	Volumetric Fuel	0-100cc	± 0.1cc	± 1

	Flow Meter			
7.	Manometer	0-50cc	±1mm	±1
8.	Pressure pickup	0–250 bar	± 0.1	± 0.1
9.	Crank angle encoder	0-360°CA	± 1°CA	± 0.2
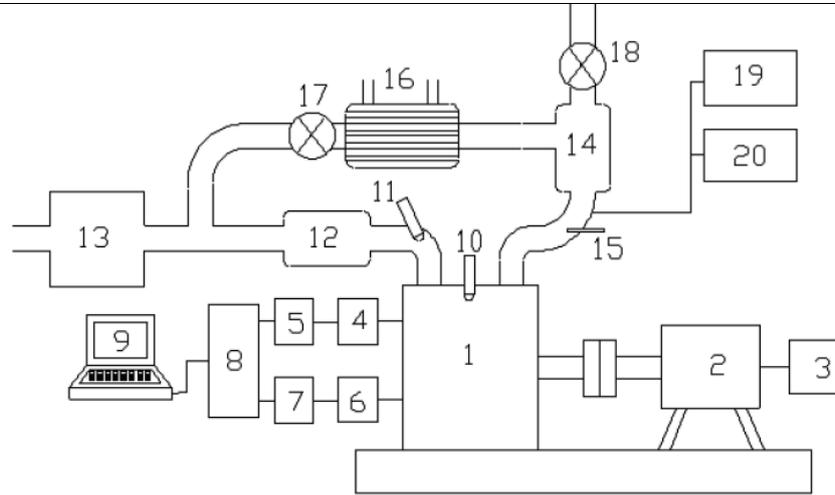
Figure 1. Experimental Setup

1	Diesel Engine	11	Premixed fuel injector
2	Electrical Dynamometer	12	Mixing chamber
3	Dynamometer Controls	13	Air flow measurement
4	Pressure pickup	14	Settling chamber
5	Charge amplifier	15	Thermocouple
6	TDC position sensor	16	EGR Cooler
7	TDC amplifier circuit	17	EGR Valve
8	A/D Card	18	Back pressure control valve
9	Personal computer	19	Exhaust gas analyzer
10	Main Injector	20	AVL smoke meter

The following notations are used in this chapter:
- JOME and 100% JOME - Jatropha oil methyl ester
- xx % JOME – xx refers to the percentage of JOME in the blend of JOME and Diesel

RESULTS AND DISCUSSION

Specific Energy Consumption (SEC) and Brake Thermal Efficiency (BTE)
Figure 2 and 3 show the variation of specific energy consumption and brake thermal efficiency respectively with brake power for diesel, 20%, 40%, 60%, 80% JOME and JOME. Specific energy consumption and brake thermal efficiency are inversely proportional to each other. SEC is the input energy required to develop unit power output and by comparing methyl esters with diesel, methyl esters are showing comparatively higher values of SEC.
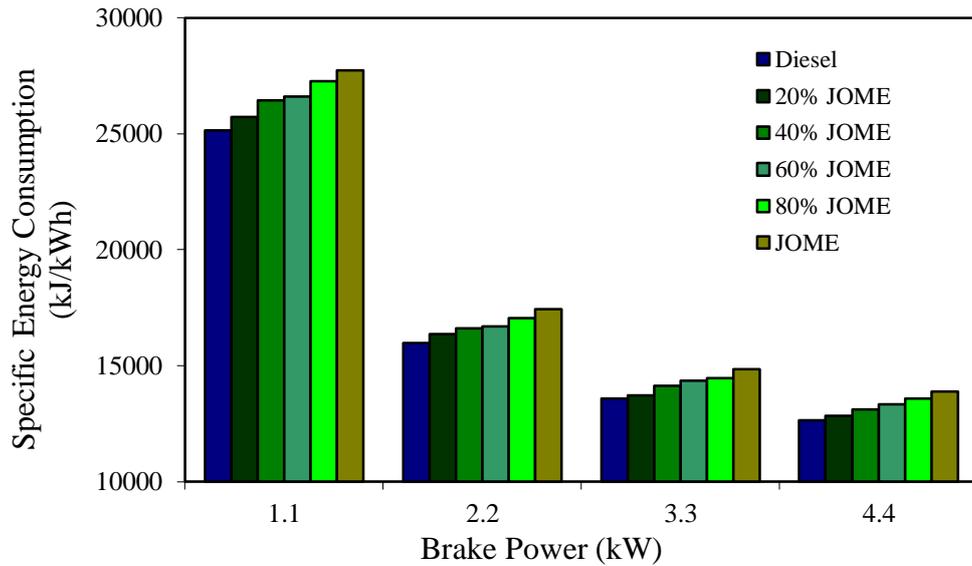
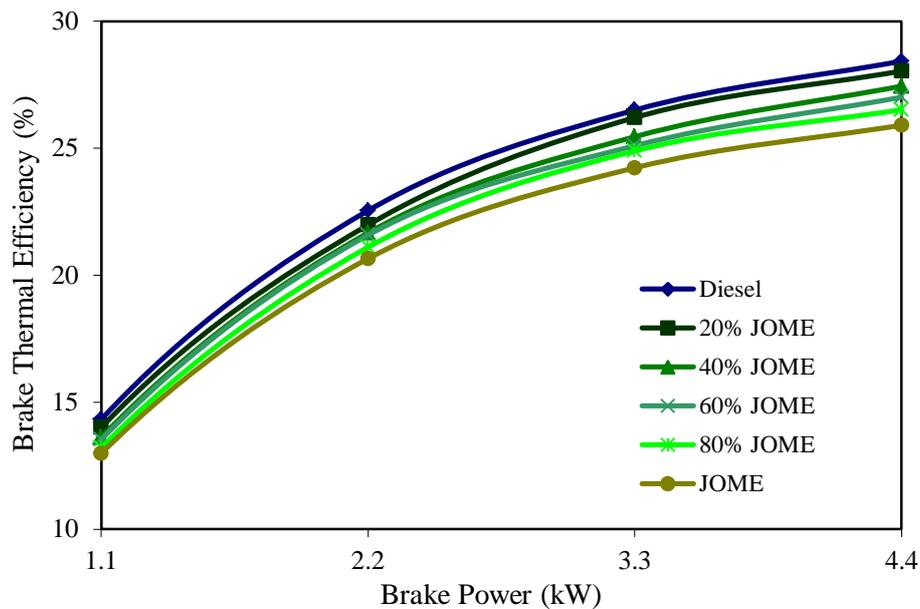Figure 2. Variation of Specific Energy Consumption with Brake power

Figure 3. Variation of Brake Thermal Efficiency with Brake Power

SEC is higher and hence brake thermal efficiency is lower for the methyl ester and their blends at all power outputs compared to diesel. At rated power output (4.4 kW) the Specific Energy Consumption of various fuels tested varies from 12,661.27 kJ/kWh to 13,894.25 kJ/kWh and the brake thermal efficiency varies from 28.43% to 25.91%. Higher kinematic viscosities of JOME blends (4.5 cSt) compared to that of diesel (3.52 cSt) result in poor atomization, vaporization and dispersion of fuel in the combustion chamber. Lower calorific value of JOME blends (39,640 kJ/kg) compared to diesel (43,500 kJ/kg) result in higher fuel consumption of blends compared to diesel at all the power outputs resulting in higher SEC and lower brake thermal efficiency.

Exhaust Gas Temperature (EGT)

The exhaust gas leaving the cylinder determines the extent of temperature reached during the combustion process. With increase in load, the temperature of the exhaust gases increases for all the fuels. It is also observed from the Figure 4, that the exhaust gas temperature increases with percentage of methyl ester in the fuel for all the loads.
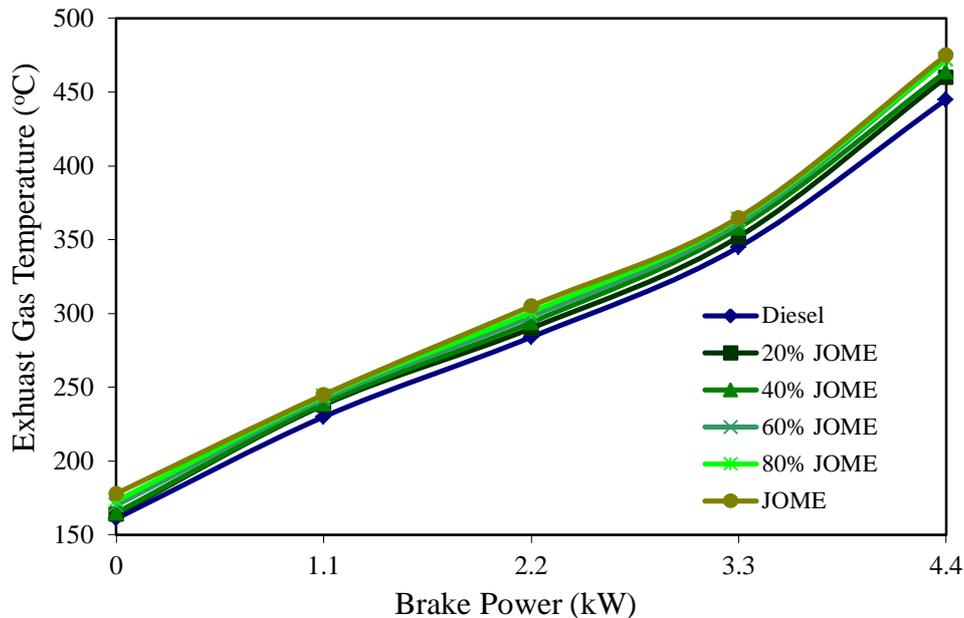

Figure 4. Variation of Exhaust Gas Temperature with Brake power

This may be due to the oxygen content of the methyl esters, which improves combustion.Intrinsic oxygen present in the fuel about 10.8 % by wt. in JOME will help the combustion process. The oxygen in biodiesel finds it easy to participate in the combustion reaction. The addition of biodiesel to diesel provides more oxygen to the combustion reaction and promotes complete combustion. Also the poor fuel atomization and vaporization due to higher viscosity of the methyl esters and their blends results in late burning of injected fuel and results in higher exhaust gas temperature [26]. At rated power output (4.4 kW) the Exhaust Gas Temperature of various fuels tested varies from 475ºC to 445ºC.

Hydrocarbon Emissions (HC)

Figure 5 shows that the variation of HC emissions with brake power. It can be seen that with increase in brake power, HC emissions increases for all the test fuels and there has been considerable reduction of HC emissions for JOME and JOME blends than diesel. A significant reduction in UBHC emissions is noticed for both the methyl esters and their blends at all the power outputs compared to diesel.
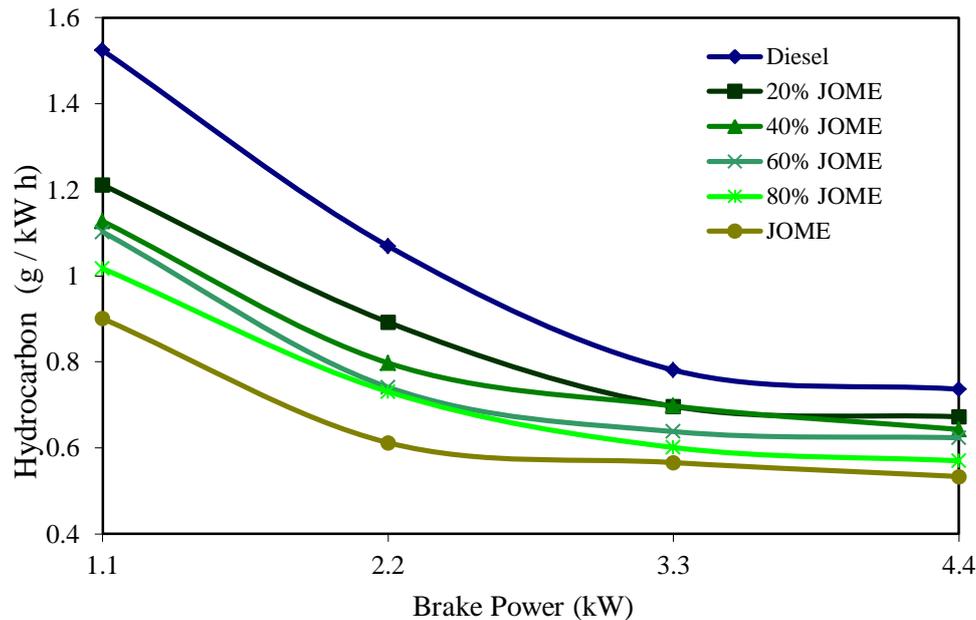
Figure 5. Variation of Unburnt Hydrocarbon with Brake Power

This may be due to their intrinsic oxygen content of JOME (10.8% by wt.) whereas, diesel does not have oxygen[27]. The addition of methyl ester to diesel increases the oxygen content enhancing the combustion reactions resulting in high combustion temperature which lowers UBHC emissions [28]. The oxygen in biodiesel finds it easy to participate in the combustion reaction. The addition of biodiesel to diesel provides more oxygen to the combustion reaction and promotes complete combustion especially for those areas at the core of the fuel spray [29]. The oxygen surrounding the fuel droplets would take relatively larger time to assist the combustion of fuel droplet[30]. The reduction of UBHC in CI engines is also due to lower content of carbon to hydrogen ratio than the normal diesel due to the presence of oxygen in its molecular structure. With methyl esters having higher Cetane Index (CI) than diesel, delay period gets reduced and it leads to effective combustion which reduces HC emissions to a greater extent[31]. At rated power output (4.4 kW) the Unburnt Hydrocarbon of various fuels tested varies from 0.7366 g/kWh to 0.534 g/kWh.

Carbon Monoxide Emissions (CO)
Figure 6 shows the variation of carbon monoxide emissions with brake power. With increase in brake power, CO emission increases for all the test fuels. CO emissions results due to lack of oxygen during combustion. In general, the CO emissions are low for diesel engines as they are operated with lean mixtures. With methyl esters where oxygen content is higher, it leads to efficient and effective combustion. Therefore, a CO emission reduces for all the blends comparatively. The methyl esters are having higher cetane index due to which combustion quality will be good which reduces the CO emissions considerably[32]. As the percentage of methyl ester in the blend increases it is observed that the CO emission decreases. The CO emission also depends upon the carbon to hydrogen ratio and in-cylinder temperature.
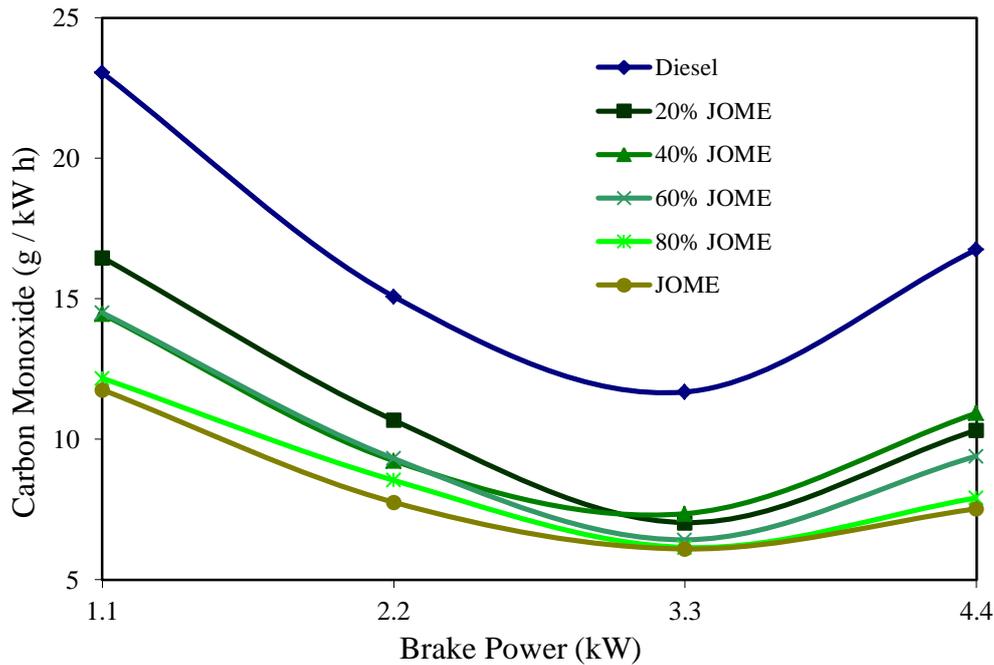
Figure 6. Variation of Carbon Monoxide with Brake Power

In the case of JOME and JOME blends, carbon to hydrogen ratio is comparatively lower and the in-cylinder temperature is higher compared to diesel. These factors reduce the formation of carbon monoxide [28]. It can be observed that CO decreases with increase in power output except at rated power for all the fuels tested. At rated power, the quantity of fuel injected is more while the quantity of air inhaled is constant and this may result in an increase in CO emission for all the fuels tested. At rated power output (4.4 kW) the Carbon-Monoxide emissions of various fuels tested varies from 16.75 g/kWh to 7.53 g/kWh.

NOx Emissions

The variation of NOxemission with power output for various fuels tested is shown in Figure 7. Oxides of Nitrogen (NO_x) consist of Nitric oxide (NO) and Nitrogen dioxide (NO_2). Nitric oxide is predominant in the oxides of nitrogen produced inside the engine cylinder. NO_2/NO in a diesel engine is approximately in the ratio of 0.1 to 0.3 [33]. Oxides of Nitrogen emissions (NO_x) emissions are higher for the methyl ester and its blend compared to diesel[34]. The exhaust gas temperatures are higher for JOME at all the power outputs compared to diesel. NO formation also occurs through the nitrogen present in the fuel. The fossil fuels do not contain nitrogen or very negligible amount of nitrogen. Hence, the amount of NO formed from the fuel is very low and it is observed that NO increases slowly with increasing temperature and increased NO levels can occur at increased flame temperatures.
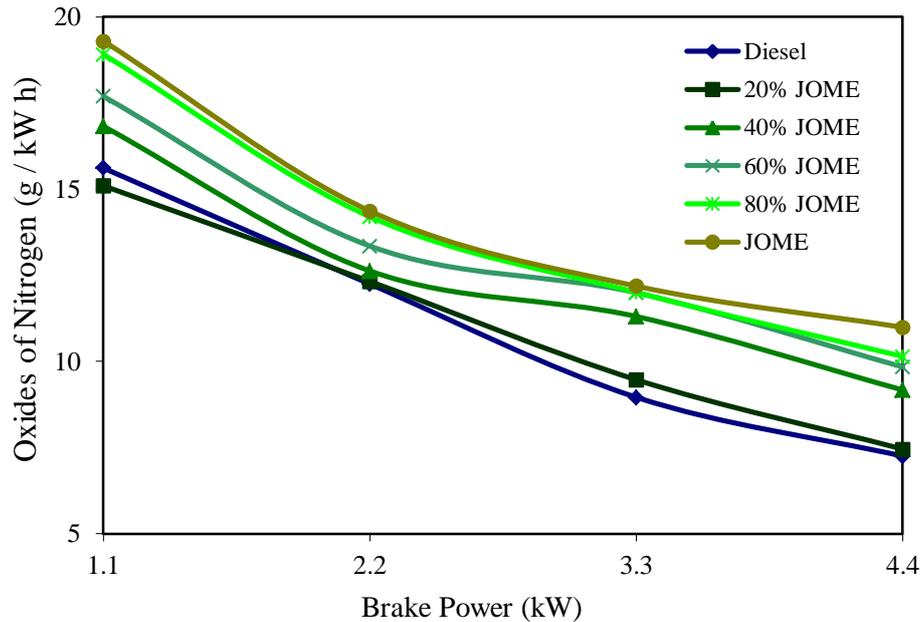
Figure 7. Variation of Oxides of Nitrogen with Brake power

For diesel, the NOx emissions vary from 15.6 g/kWh at 20% of rated power output to 7.45 g/kWh at rated power output. For 20% JOME, 40% JOME, 60% JOME, 80 JOME and JOME the variations are from 15.09 to 7.456 g/kWh, 16.82 to 9.17 g/kWh, 17.7 g/kWh to 9.84 g/kWh, 18.9 g/kWh to 9.84 g/kWh and 19.29 g/kWh to 10.98 g/kWh respectively.

Soot Emissions

Figure 8 shows that soot emissions increases with brake power. It is observed that JOME in its blends areshowing lower value of soot compared to diesel due to their higher oxygen content and higher cetane index which improve the combustion process. At rated power output (4.4 kW) the Soot emissions of various fuels tested varies from 166 mg/m^3 to 88 mg/m^3.

Diesel particulate matter consists of highly agglomerated solid carbonaceous material (soot), ash, volatile organic and Sulphur compounds resulting from incomplete combustion of hydrocarbons present in fuel; it is also partly contributed by the burning of lubricating oil. Soot is formed in locally rich regions during combustion. Most of the soot formed is subsequently oxidized [35]. A small fraction of the evaporated fuel and lubricating oil does not undergo oxidation and appear as soluble organic fractions (SOF) in the exhaust [36]. The increase in soot emission for diesel fuel is also due to higher boiling point and thermal stability of aromatic hydrocarbons present in it. In particular, the presence of branched and ring (multi-ring or poly) structure of diesel fuel can increase the soot levels [37]. Higher boiling point paraffin or aromatics adsorbed from particulates emitted by the engine are reported to increase volatile organic fractions [36].
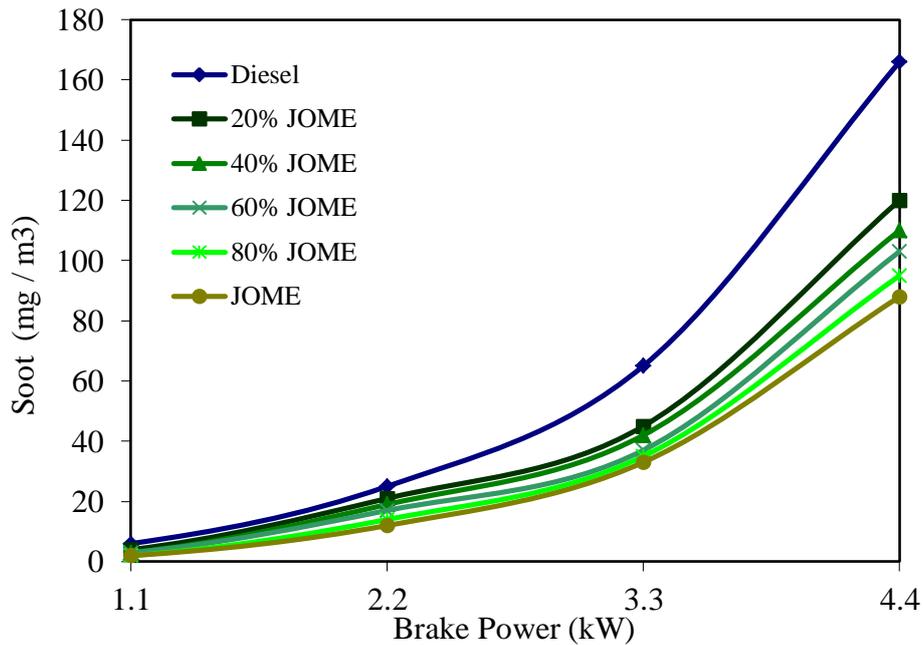
Figure 8. Variation of Soot with Brake power

AVL 415 Variable Sampling Smoke meter which gives smoke value in FSN and soot concentration in mg/m^3 is used to measure soot in the exhaust. Soot emissions for JOME are significantly reduced compared to diesel due to the following reasons:

- Their higher oxygen content [38].
- They have no aromatic compounds which are considered as soot precursors typically available in petroleum diesel fuel [39][37].
- In addition, oxygen atoms in fatty acid methyl esters bonds to carbon atoms, and therefore prevents carbon atoms from participating in soot growth reactions. The oxidation of fatty acid methyl esters and other oxygenated intermediates also forms OH radicals, which readily attack unsaturated hydrocarbons and prevent their participation in soot growth reactions. Reduced delay period of methyl esters and their blends advances the start of combustion and increases the residence time of soot particles at elevated temperature and promotes their oxidation [40].

Ignition Delay

Figures 9 show the variation of ignition delay with brake power in degree crank angle (CAD) for the fuels tested. The ignition delay is usually defined as the period from the start of injection to the start of combustion. Start of injection is given by the engine manufacturer as 23.4º bTDC (Static injection timing). The start of combustion is the point at which the heat release rate curve starts rising from zero determined from cylinder pressure data. Start of combustion is determined from the AVL indimodule. It is found that marginallylower ignition delays for all methyl ester blends[41]and methyl ester compared to diesel are due to their higher cetane index. At rated power output, the ignition delay of diesel, 20%, 40%, 60%, 80% JOME in the blends and JOME is determined to be 15.78, 14.86, 14.62, 14.45, 14.27 and 13.9ºCA respectively. The

ignition delay decreases with increase in percentage of methyl ester in the blend and this is attributable to their higher cetane index compared to diesel[42].
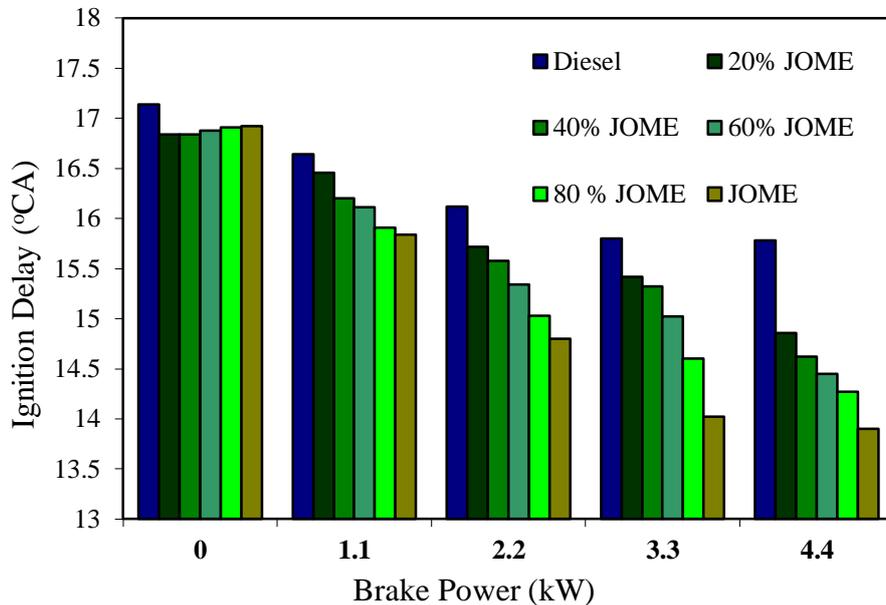

Figure 9. Variation of Ignition Delay with Brake Power

As the amount of biodiesel increases in the blend, the cetane index of the blend increases and this result in a decrease in ignition delay. The ignition delay decreases as the percentage of methyl esters in the blend increases due to the intrinsic oxygen (JOME–10.8%) present in them. Biodiesel usually includes a small percentage of diglycerides having higher boiling point compared to diesel. However chemical reactions during the injection of biodiesel at high temperature result in the breakdown of high molecular weight esters leading to the formation of gases of low molecular weight. Rapid gasification of these lighter fractions in the fringe of spray spreads out the jet and thus volatile combustion compounds get ignited earlier and reduce the delay period[43].Oleic fatty acid (40.60 %) and Linoleic fatty acid (33.40 %) methyl esters present in JOME split into smaller compounds when they enter the combustion chamber resulting in higher spray angles. Hence ignition takes place earlier [44].

Peak Pressure
It is observed that for both the methyl esters and their blends the peak pressure increases and occurs later compared to diesel as the percentage of methyl esters in the blend increases. Figure 10 show the variation of peak pressure with brake power for diesel, 20%,40%, 60%, 80%JOME in the blend and JOME. The peak pressure is observed to increase with increase in percentage of methyl ester [45][46] and decrease is also observed [47] [48]. The results of the present study show that the peak pressure increases with increase in power output for both the methyl esters and their blends as the oxygen content of methyl esters is higher compared to diesel and the amount of fuel burned increases with increase in power output[49] [50].
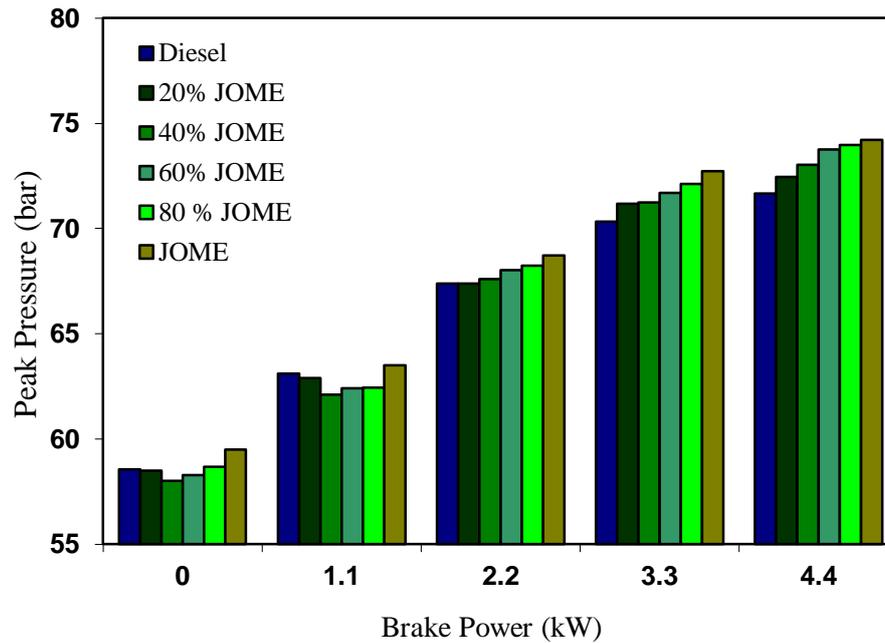
Figure 10. Variation of Peak Pressure with Brake Power

The peak pressure at various power outputs is higher for JOME and its blends compared to diesel. The peak pressure at rated power output is 71.66 bar for diesel, 72.46 bar, 73.02 bar,73.76 bar,73.96 bar and 74.2 bar for 20%,40%,60%,80% JOME in the blend andJOME respectively.The brake thermal efficiency of 20% JOME is marginally lower than that of diesel. It can be observed that CO, HC and soot emissions are lower while NO_x emissions are higher for 20% methyl ester blends compared to diesel as shown in Figure 11. An optimum percentage of methyl esters in the blend are necessary as simultaneous reduction of soot and NO_x is desirable. The variation of soot and NO_x values normalized with respect to baseline diesel operation at rated power output for various percentages of JOME is shown in Figures 12. 19% JOME are observed to be optimum considering both NO_x and soot emissions. The cost of operation per hour at rated power output, various emissions and brake thermal efficiency at rated power output are given in Table 5.

The JOME are procured in the open market at Rs. 90/-($1.5) per liter when compared to Diesel at Rs.54/- ($0.9) per liter. The cost of methyl esters is likely to come down in the near future with mass production whereas the cost of diesel fuel will increase continuously. From the present experimental results, it can be concluded that 20% JOME can be successfully used in existing diesel engines without any modifications.
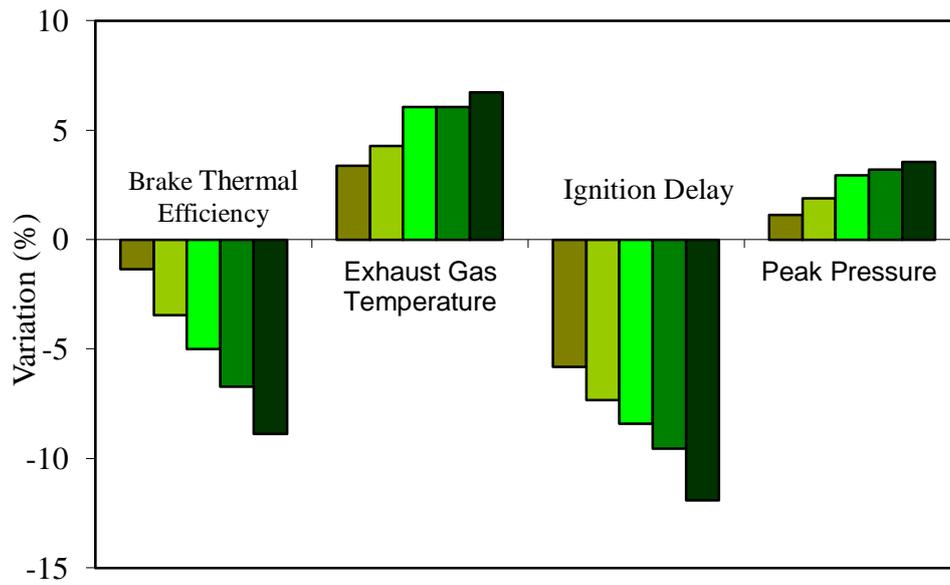
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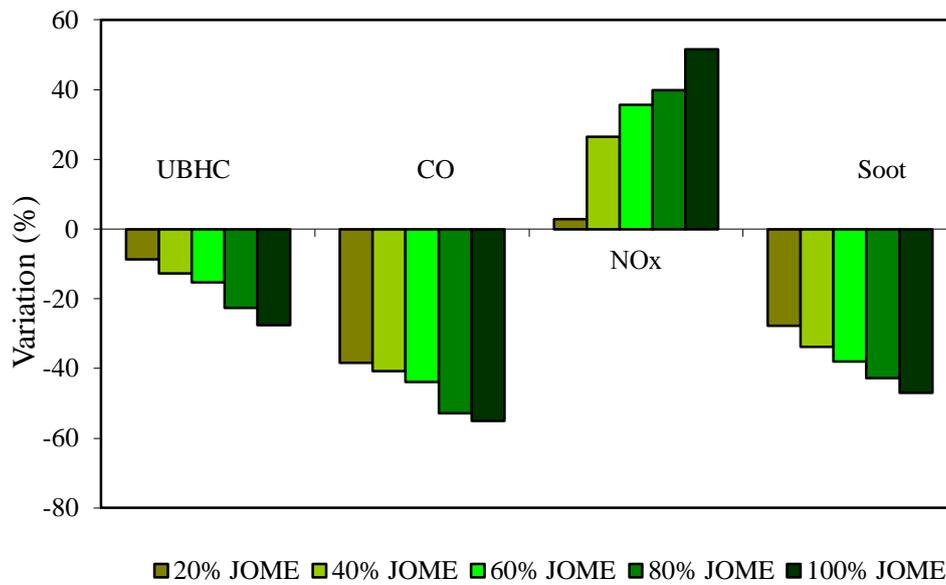
(b)

Figure 11.Comparison of JOME and its Blends with Diesel at Rated Power Output (a) Percentage Variation of Performance and Combustion Parameters (b) Percentage Variation of Emissions
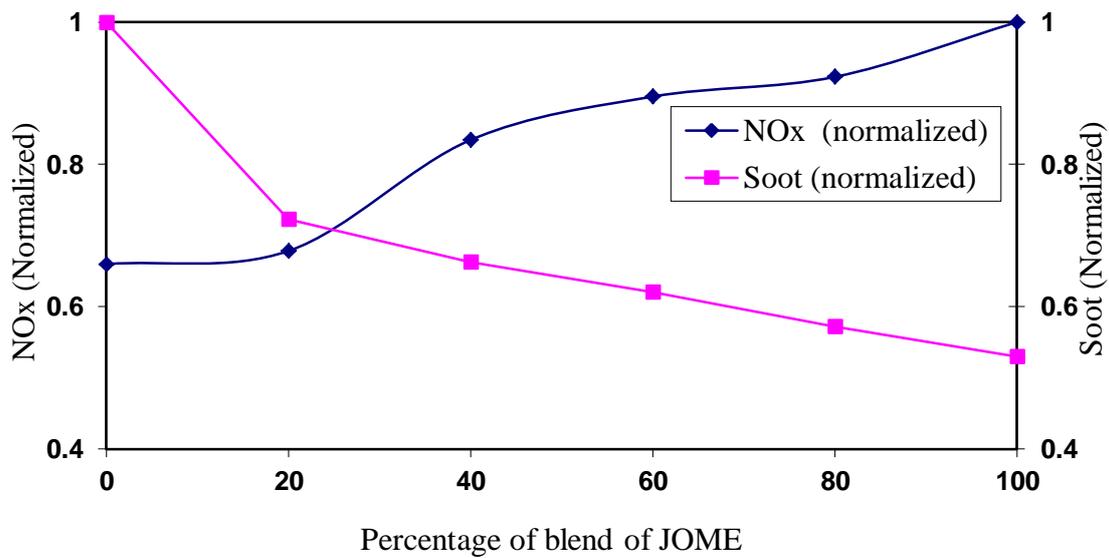
Figure 12.Tradeoff between Oxides of Nitrogen and Soot Emissions for VariousPercentage of JOME in Blend

Table 5. Comparison of 20% JOME and Diesel Fuel at Rated Power

Parameters	Unit	Diesel	20% JOME
Carbon Monoxide (CO)	g/kW h	16.75	10.33
Unburnt Hydrocarbon (UBHC)	g/kW h	0.74	0.67
Oxides of Nitrogen (NO_x)	g/kW h	7.25	7.46
Soot	mg/m^3	166	120
Brake Thermal Efficiency	%	28.4	28.1
Cost Per Litre	INR ($)	54 (0.87)	61(0.98)
Cost Per Hour at Rated Power Output	INR ($)	83 (1.33)	96 (1.54)

(1 US dollar ($) = INR 62)

CONCLUSION

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

1. Brake thermal efficiency of the engine with these fuels is found slightly lower than that of diesel. Brake thermal efficiency decreases marginally as the methyl

ester in the blend increases. At rated power output (4.4 kW) the specific energy consumption of various fuels tested varies from 12,661.27 kJ/kWh to 13,894.25 kJ/kWh and the brake thermal efficiency varies from 28.43% to 25.91%.

2. Peak pressure is marginally higher for methyl ester at rated power output. The peak pressure at rated power output is 71.66 bar for diesel, 72.46 bar, 73.02 bar,73.76 bar,73.96 bar and 74.2 bar for 20%,40%,60%,80% JOME in the blend and JOME respectively.

3. HC, CO and soot emissions of these fuels are lower compared to those of dieseland decrease as the percentage of methyl esters in the blend increases. At rated power output (4.4 kW) the carbon monoxide emissions of various fuels tested varies from 16.75 g/kWh to 7.53 g/kWh and the unburnt hydrocarbon of various fuels tested varies from 0.7366 g/kWh to 0.534 g/kWh. The soot emissions of various fuels tested varies from 166 mg/m^3 to 88 mg/m^3.

4. Exhaust gas temperature and NOx are observed to be higher for these fuels compared to diesel and increasing the percentage of methyl ester in the blend increases NOx emission. For diesel, the NOx emissions vary from 15.6 g/kWh at 20% of rated power output to 7.45 g/kWh at rated power output. For 20% JOME, 40% JOME, 60% JOME, 80 JOME and JOME the variations are from 15.09 to 7.456 g/kWh, 16.82 to 9.17 g/kWh, 17.7 g/kWh to 9.84 g/kWh, 18.9 g/kWh to 9.84 g/kWh and 19.29 g/kWh to 10.98 g/kWh respectively.

5. JOME have higher viscosity compared to diesel. Hence, better lubricity than diesel fuel which will reduce the need for lubricity additives being added to diesel fuel.

6. JOME can be produced economically in the coastal regions where discarded parts of fish are available cheaply.

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