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EXPERIMENTAL INVESTIGATIONS ON A JATROPHA OIL METHYL ESTER FUELLED DIESEL ENGINE

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ABSTRACT

Biodiesel is a non-toxic, biodegradable and renewable fuel with the potential to reduce engine exhaust emissions. The methyl ester of jatropha oil, known as biodiesel, is receiving increasing attention as an alternative fuel for diesel engines. The biodiesel is obtained through transesterification process. Various properties of the biodiesel thus developed are evaluated and compared in relation to that of conventional diesel oil. In the present investigation neat jatropha oil methyl ester (JME) as well as the blends of varying proportions of jatropha oil methyl ester (JME) and diesel were used to run a CI engine. A four stroke diesel engine having compression ratio of 17.5: 1 and developing 5.2 kW at 1500 rpm was used. Experiments were initially carried out on the engine at all loads using diesel to provide baseline data. Significant improvements in engine performance and emission characteristics were observed for JME fuel. The addition of jatropha methyl ester (JME) to diesel fuel has significantly reduced HC, CO, CO_2 and smoke emissions but it increases the NO_X emission slightly. The maximum reduction in smoke emission was observed by 35 % in case of neat biodiesel operation as compared to diesel. The unburned hydrocarbon emission was drastically reduced by 53 % for neat biodiesel operation.

KEYWORDS

Biodiesel, jatropha oil methyl ester, diesel engine, performance, emissions.

INTRODUCTION

The concept of using biomass based fuel specifically, vegetable oil based methyl ester, as a diesel fuel alternative is not new. Rudolf Diesel himself demonstrated that his engine could run on vegetable oil fuels. Since then various vegetable fuels and their ester has been tested as a diesel fuel alternatives. With the increased availability of petroleum based fuels, studies on biomass–based fuels decreased. During the oil shock era of the 1970s, interest in these fuels again resurfaced.

Diesel engines are widely used as power sources for heavy and medium duty applications because of their good fuel economy and low emissions of unburned hydrocarbons (HC) and carbon monoxide (CO). However, diesel engines usually exhaust higher amounts of particulate matter (PM) than spark ignition engines. Many alternative diesel fuels have been shown to have better exhaust emissions than traditional diesel fuel. Alkyl esters of vegetable oils and animal fats, called biodiesel, hold promise as fuel alternatives for diesel engines. A number of researchers [1-21] have shown that biodiesel has fuel properties and provides engine performance that is very similar to diesel fuel. The primary incentive for using biodiesel is that it is a nontoxic, biodegradable, and renewable fuel. Further advantages over petroleum-based diesel fuel include a high cetane number, low sulfur, low aromatics, low volatility and the presence of oxygen atoms in the fuel molecule. These features of biodiesel lead to its greatest advantage, which is its potential for emission reduction including CO, HC, solid carbon particles

(SOL) and PM. A number of research studies have proved the positive benefits of biodiesel on diesel engine emissions. To improve air quality, severe emission regulations have been applied to diesel engines. The severe emission regulations in the world have placed design limitations on heavy-duty diesel engines. The trend towards cleaner burning fuel is growing worldwide. Recent studies indicate that the cetane number, aromatic content and type, sulfur content, distillation temperature, and density are important factors for emission control. Reduction in the aromatic content and/or the removal of heavy fractions, or the use of lighter fuel is considered to be effective for this purpose. The demand for gasoline and middle distillates including diesel fuel is increasing but with a sharp decrease in the demand for heavy fuels. It is thus difficult to reduce the aromatic content and heavy fraction in diesel fuel to meet this demand [1, 2, 3, 4, 5].

A change of trend in the design of internal combustion engines is currently taking place owing to the increasing market of diesel engine vehicles. This technological turn is also related to the appearance of new environmental policies, user requirements and technical advances. In spite of this progress, the search for a compromise between engine performance (efficiency and effective power) and emission is still going on. In particular the particulate and nitrogen oxide emissions have attracted much attention, since their stringent legal limitations greatly affect the engine design.

In India great emphasis is placed on public transport, especially in large cities. Thus all major cities operate large fleets of urban busses, mainly powered by diesel engines. The particulate emission from these diesel busses giving cause for some public concern as it is considered carcinogenic. However, political interest is currently being shown in reducing CO_2 emissions from the transport sector as a whole, making diesel busses with their good fuel economy almost inevitable. Diesel fuel made from biomass (biodiesel) might offer a solution to this dilemma. Biodiesel is, in principle, CO_2 neutral. When plants grow they absorb CO_2, and after they are harvested, converted into biofuel and burned, CO_2 is produced. Ideally a closed CO_2 circuit arises. Biofuels are more CO_2 friendly than conventional gasoline or diesel fuels.

The conferences of Rio de Janeiro 1992, Berlin 1995, Geneva 1996 and Kyoto 1997, subsequently ratified by the conference of Buenos Aires in 1998, have resulted in the promulgation of directives aiming to reduce the global emission of greenhouse gases by 5% compared to the 1990 levels [6]. In order to reach these goals without restricting the economic growth of the individual countries concerned, it will be necessary to follow some fundamental guidelines, including:

- Improvement of production processes;
- Increased efficiency;
- Use of alternative energy sources.

The results obtained so far show that the biofuel has good overall behavior, with performance and emission levels comparable to diesel fuel. The most significant result obtained in various experimental investigations is the higher emission of nitrogen oxides, which can only be explained after obtaining a thorough understanding of the phenomena characterizing the combustion process. However severe engine deposits, injector coking and ring sticking have been detected in long term usage when neat vegetable oil was used. Recently transesterification to form methyl, ethyl or butyl ester has been used as a means to reduce the long terms effects. In particular methyl esters derived by the reaction between triglycerides and methanol. The process gives generally a high purity product with very small content of sulphur (up to 10- 20 ppm) and a cetane number that is very similar to that of commercial fuels. Because of the absence of sulphur in the product and the presence of oxygen in their formula these fuels are considered very promising to reduce pollutants. Moreover it is quite interesting to observe that, in a global balance, these fuels can limit the rise of CO_2 in the atmosphere because of their vegetable origin. The necessity of a drastic reduction of the pollutant emission in urban areas justifies the interest to evaluate the potential offered by alternative fuels, such as natural gas or esterified vegetable oils [7, 8].

In particular the actual ability of methyl esters to reduce regulated or non-regulated emissions generated by in service engines has not been fully clarified. On contrary, the effects of vegetable oils on particulate production have not been well assessed. A recent review on the argument shows that some authors, when comparing vegetable oils with commercial diesel fuels, claim a reduction in particulate when vegetable oils are used while, someone show the rise of it when biofuels are employed. Over the last years, emissions of fine particles from internal combustion engines have received increased attention due to their negative effects on human health [1-21].

Although slightly more viscous, biodiesel has all of the essential properties of diesel fuel. One of the most important of these properties is the cetane number. The cetane number is a measure of the ignition quality of the fuel and is dependent on a number of factors, such as molecular weight, structure and volatility.

The jatropha curcas tree is found all over India. In many places the leaves are lopped for green manure, the seed cake is also used as fertilizer; the oil itself has fungicidal properties and is a traded non-edible vegetable oil. A lot of work was subsequently done on vegetable oil before and during the Second World War. The only constraint seems to have been cost factor. Fossil fuel was then much cheaper. Today this constraint has been removed. With the price of diesel on the rise, the future of vegetable oil and their ester is bright.

Simple alcohols are used for transesterification and this process is usually carried out with a basic catalyst (NaOH, KOH) in the complete absence of water. The bonding of alcohol and organic acid produces ester. An excess of alcohol is needed to accelerate the reaction. With methyl alcohol glycerol separation occurs readily. If water is present, soap is the bi-product, which results in decreasing yield of ester. In the esterification process alcohol combines with triglyceride molecule from acid to form glycerol and ester. The glycerol is then removed by density separation. Esterification decreases the viscosity of oil, making it similar to diesel fuel in characteristics.

In this work jatropha oil methyl ester (JME) was investigated for its performance and emissions in a diesel engine. Tests were conducted at 1500 rpm for various loads. Performance of the engine with diesel as fuel was used as the basis for comparison. Parameters like thermal efficiency, brake specific energy consumption, brake specific fuel consumption, cylinder peak pressure, exhaust gas temperature, smoke, unburned hydrocarbons (HC), carbon monoxide (CO) and NOx emissions were evaluated.

NOMENCLATURE

BSEC = Brake Specific Energy Consumption
BSFC = Brake Specific Fuel Consumption
CO = Carbon monoxide
CO_2 = Carbon dioxide
D = Fuel containing 100 percent diesel
HC = Hydrocarbons
HSU = Hartridge Smoke Unit
JME 20 = Fuel containing 20 percent biodiesel and 80 percent diesel fuel
JME 40 = Fuel containing 40 percent biodiesel and 60 percent diesel fuel
JME 60 = Fuel containing 60 percent biodiesel and 40 percent diesel fuel
JME 80 = Fuel containing 80 percent biodiesel and 20 percent diesel fuel
JME 100 = Fuel containing 100 percent biodiesel
NOx = Oxides of nitrogen
O_2 = Oxygen
ppm = Parts Per Million
Vol = Volume
CI = Compression Ignition
TDC = Top Dead Centre

TRANSESTERIFICATION PROCESS

The molecular weight of jatropha oil is 887.7 gm/mole. Every kilogram of jatropha oil requires 240 grams of methanol (6:1 molar ratio to oil). For transesterification in laboratory, 2 kg of jatropha oil was taken in a round bottom flask; 24 gm of NaOH was dissolved in 480 gm of methanol in a separate vessel, which was poured into round bottom flask while stirring the mixture continuously using constant stirring mechanism. The mixture was stirred and maintained at 65°C for 1 hour and then allowed to settle under gravity in a separating funnel. Ester formed the upper layer in the separating funnel and glycerol formed the lower layer. About 1.65 kg of ester and 0.85 kg glycerol was separated from a mixture. The separated ester was mixed twice with 0.5 kg of hot water and allowed to settle under gravity for 24 h. The catalyst got dissolved in water, which forms lower layer, and was separated. Moisture was removed from this purified ester using silica gel crystals. The ester was then blended with petroleum diesel oil in various concentrations for preparing biodiesel blends to be used in CI engine for conducting experiments.

EXPERIMENTAL SETUP

The Schematic of the experimental setup is shown in Fig.1. Engine details are given in Table 1. A 661 CC Kirloskar make TV1 single cylinder 4-Stroke water-cooled diesel engine having a compression ratio of 17.5: 1 and developing 5.2 kW at 1500 rpm was used. An eddy current dynamometer was used for loading the engine. A high-speed digital data acquisition system in conjunction with a piezoelectric transducer was used for obtaining cylinder pressure versus crank angle data. An infrared exhaust gas analyzer was used for the measurement of HC/CO in the exhaust. For measuring NOx, an electrochemical analyzer was utilized. Smoke levels were obtained using a Hartridge smoke meter. Experiments were initially carried out on the engine at all loads using diesel to provide baseline data. The engine was stabilized before taking all measurements. Various blends of different proportions of Jatropha Oil Methyl Ester (JME) and diesel were used to run this single cylinder engine.

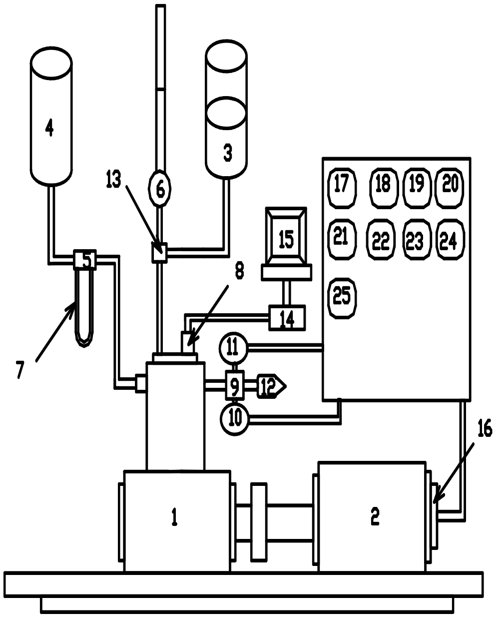

Fig. 1 Experimental Setup Schematic

LEGEND

1.Engine	14.Amplifire
2.Dynamometer	15.Data Acquisition System with Computer
3.Fuel Tank	16.TDC Encoder
4.Air Surge Tank	17. Stop Watch
5.Orifice Plate	18. Rotameter
6.Burette (Diesel)	19. Inlet Water Temperature to Engine
7.Manometer	20. Outlet Water Temperature from Engine
8.Pressure Transducer	21. Outlet Water Temperature from Calorimeter
9.Exhaust Gas Sampling Chamber	22. Exhaust Gas Temperature from Engine
10.Smoke Meter	23. Exhaust Gas Temperature from Calorimeter
11.Emission Analyzers	24. Loading Switch
12.To Exhaust	25. Speed Indicator
13. 3-Way Valve	

Table 1 Engine Specifications

Engine	KIRLOSKAR TV1.
General Details	Four Stroke, CI, Water-cooled, single cylinder
Bore X Stroke	87.5 mm X 110 mm
Compression Ratio	17.5:1
Rated Output	5.2 kW at 1500 rev/min
Fuel Injector Opening Pressure	200-205 bar
Injection Timing	23° before TDC
Fuel Injection Type	Mechanical Individual Pump and Nozzle System, Mico & Bosch make, Direct Injection

RESULTS AND DISCUSSIONS

BIODIESEL CHARACTERIZATION

Several tests were conducted to characterize biodiesel in relation to diesel oil in order to evaluate various physical, chemical and thermal properties. The various properties of biodiesel and diesel are shown in Table 2.

Table 2 Properties of Biodiesel and Diesel

Properties	Diesel	JME
Density (kg/m^3)	840	870
Calorific Value (kJ/kg)	43000	38980
Viscosity at 40^{0}C (cSt)	4.0	4.5
Flash Point (^{0}C)	47	130
Cetane Rating	48	54.9

PERFORMANCE

The variation of brake thermal efficiency with brake mean effective pressure for various blends of Jatropha oil methyl ester is shown in Fig. 2. The brake thermal efficiency is similar as compared to diesel at part and full load. This may be attributed to complete combustion because of oxygenated fuel. The brake thermal efficiency with biodiesel is about 31.7% for JME 100 where as it is about 31.6% with diesel at 600 kPa bmep. As the JME percentage increases the brake thermal efficiency slightly decreases at full load and it is similar at part load. Hereafter biodiesel blends are referred as JME 20, JME 40, JME 60, JME 80 and JME 100.

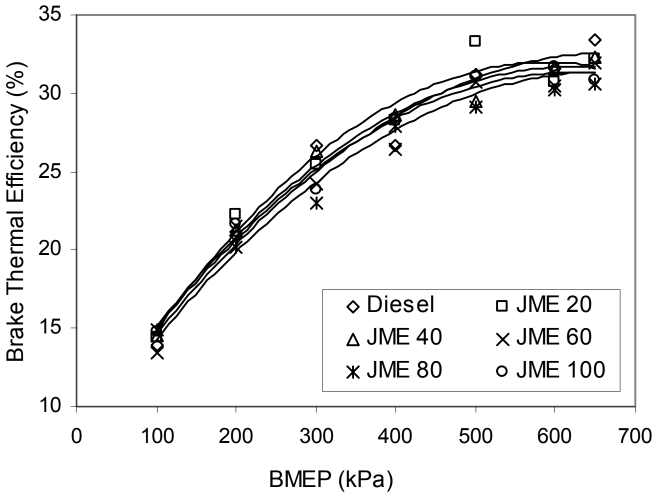

Fig. 2 Variation of Brake Thermal Efficiency with Brake Mean Effective Pressure for various blends of JME

The brake specific energy consumption is the product of brake specific fuel consumption and calorific value of fuel. The brake specific energy consumption is slightly higher as compared to diesel at all loads as shown in Fig. 3. This may be due to lower calorific value of biodiesel. The BSEC is increased by 9% for JME 100 than diesel at full load. As the JME percentage increases the brake specific energy consumption increases at various loads. The BSEC is about 11.17519 MJ/kWh, 11.18698 MJ/kWh, 11.26920 MJ/kWh and 11.80441 MJ/kWh for JME 20, JME 40, JME 60 and JME 80 respectively at full load.

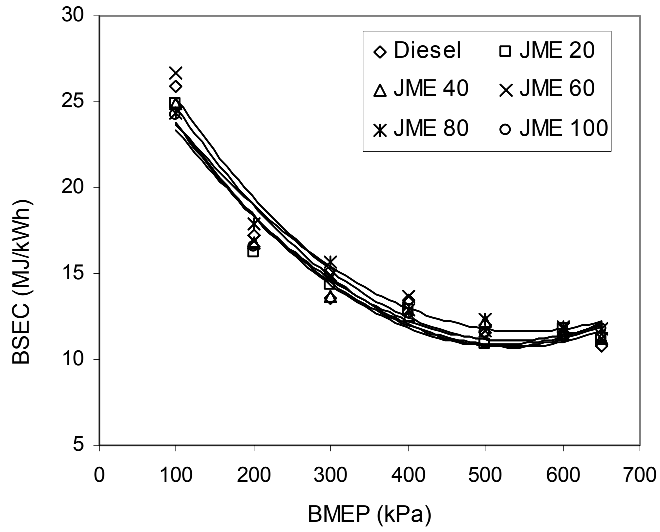

Fig. 3 Variation of Brake Specific Energy Consumption with Brake Mean Effective Pressure for various blends of JME

The variations of cylinder peak pressure for various blends of biodiesel are shown Fig. 4. The variations of cylinder pressure with crank angle are shown in Fig 5. The rate of cylinder pressure rise with crank angle is shown in Fig 6. The peak pressures, variations of cylinder pressure, rate of cylinder pressure rise are similar for biodiesel and its blends as compared to diesel. There is a difference of about 0.2 MPa between the peak pressures with the JME100 and diesel at full load. This difference decreases for lower blends of biodiesel. Peak pressure, variations of cylinder pressure, rate of cylinder pressure rise depends on the combustion rate in the initial stages, which in turn is influenced by the amount of fuel taking part in the uncontrolled combustion phase. The delay period and the mixture preparation rate govern the uncontrolled or the premixed combustion phase. As the viscosity of biodiesel is similar to diesel and this lead to similar atomization and mixture preparation with air during the ignition delay period which is responsible for similar trend of peak pressure.

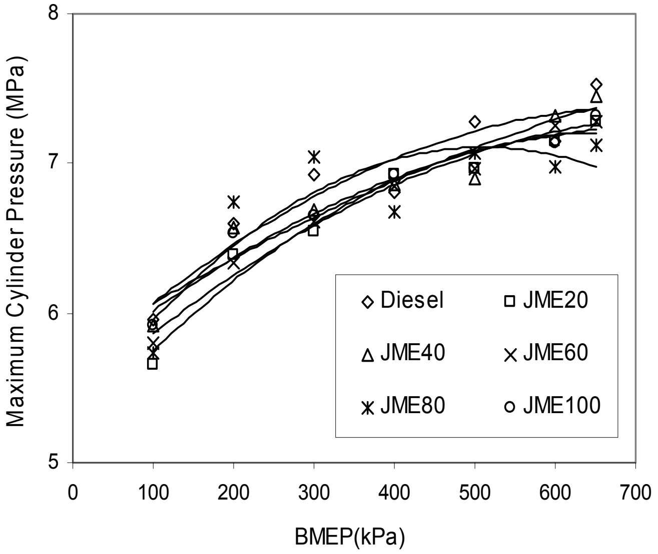

Fig. 4 Variation Maximum Cylinder Pressure with Brake Mean Effective Pressure for various blends of JME

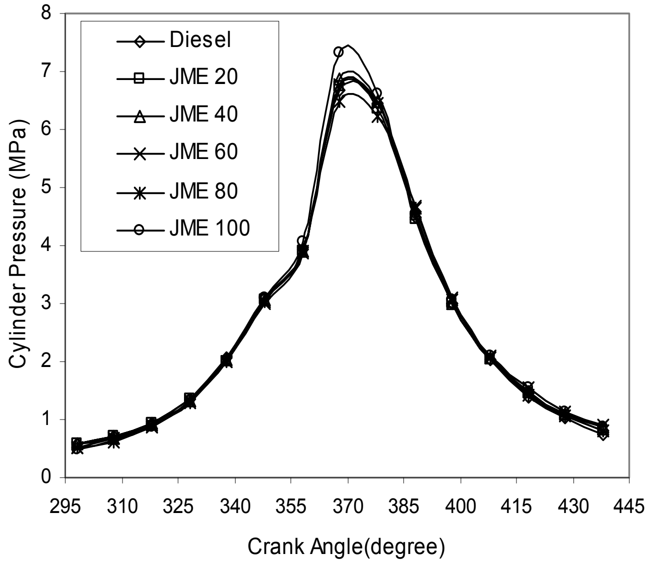

Fig. 5 Variation of Cylinder Pressure with Crank Angle for various blends of JME at Full Load (650 BMEP)

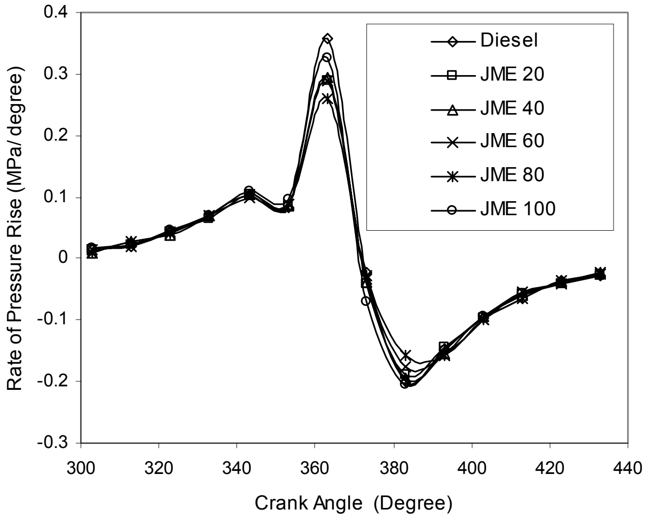

Fig. 6 Variation of Rate of Cylinder Pressure Rise with Crank Angle for various blends of JME at Full Load

The variation of exhaust gas temperature for various blends of biodiesel and diesel is seen in Fig.7. Exhaust gas temperature is similar with blends of biodiesel as diesel due to similar combustion. The maximum temperature of exhaust is 400 ^{0}C with JME 100 and 404 ^{0}C with diesel at full load. The similar trend is observed for JME 20, JME 40, JME 60 and JME 80.

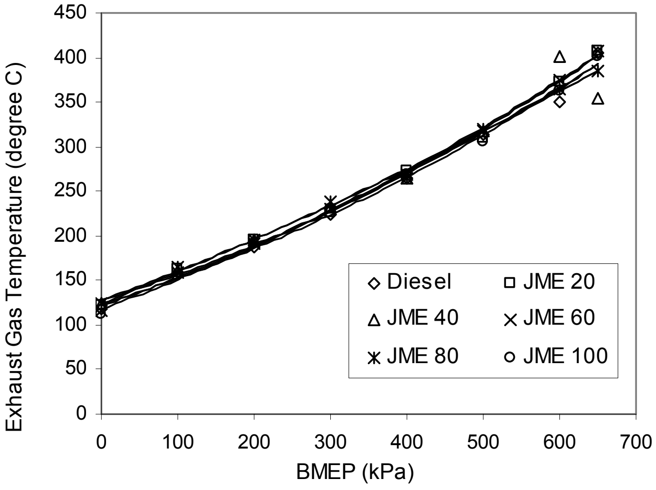

Fig. 7 Variation of Exhaust gas temperature with Brake Mean Effective Pressure for various blends of JME (650 BMEP)

The brake specific fuel consumption is not a very reliable parameter to compare the two fuels as the calorific value and the density of the blend follow a slightly different trend. Hence brake specific energy consumption is a more reliable parameter for comparison. However this parameter is also compared in the present study to compare volumetric consumption of the two fuels. The BSFC increases for various blends of biodiesel than diesel as shown in Fig. 8. The BSFC is higher for JME 100 than other blends. This is due to lower calorific value of biodiesel and its blends. As the JME percentage increases the brake specific fuel consumption increases at various loads.

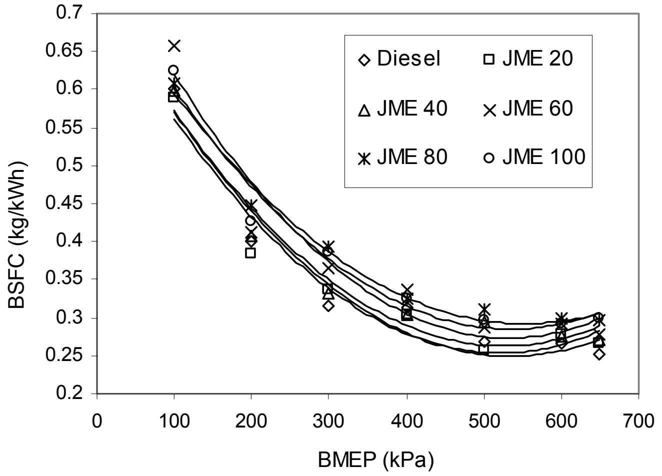

Fig. 8 Variation of Brake Specific Fuel Consumption with Brake Mean Effective Pressure for various blends of JME

EMISSIONS

In case of various blends of biodiesel smoke emission is less as compared to diesel as seen in fig. 9. The maximum reduction in smoke emission was observed by 35 % in case of neat biodiesel operation as compared to diesel at full load. The smoke density levels are lower with JME 20 and JME 40 at all loads. The diesel has lower levels from 100 to 400 BMEP as compared to JME 60, JME 80 and JME 100. This may be due to improper mixture formation for higher blends due to higher viscosity and higher density of JME at part load condition. Highest particulate concentrations are found in the core region of the fuel spray where local equivalence ratios are very rich. At higher loads the smoke levels are lower due to the higher temperature and complete combustion. As the JME percentage increases the smoke emission decreases at full load.

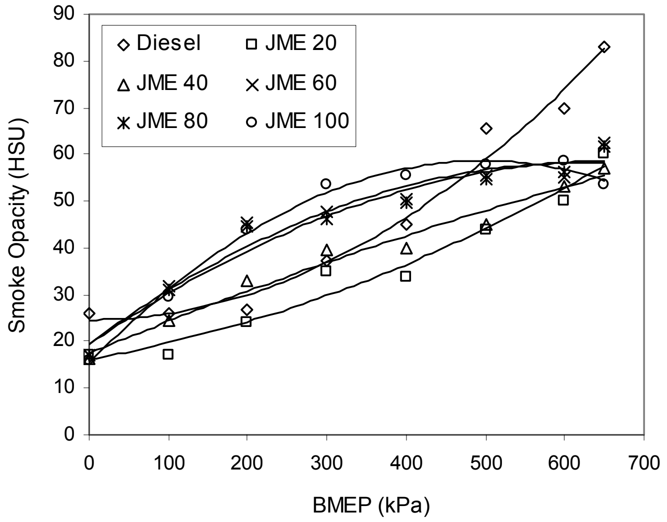

Fig. 9 Variation of Smoke Opacity with Brake Mean Effective Pressure for various blends of JME

The CO emission was slightly reduced at lower loads as shown in Fig. 10. The CO emissions are similar for various blends of JME.

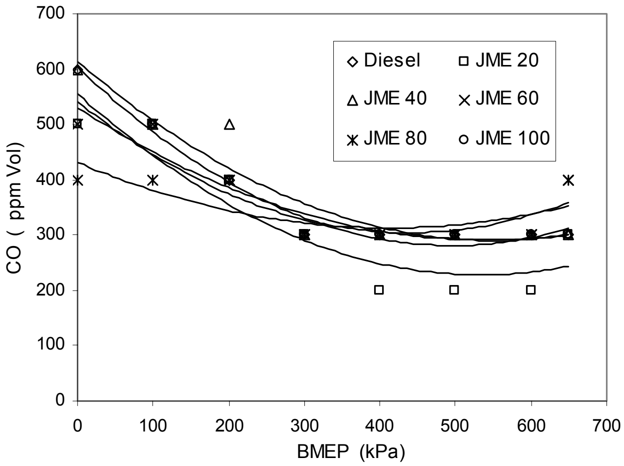

Fig. 10 Variation of Carbon Monoxide with Brake Mean Effective Pressure for various blends of JME

There is a significant reduction in HC emission for all blends of biodiesel as compared to diesel at part and full loads as shown Fig. 11. HC emission was further reduced with an increase in blending of JME for various loads. The unburned hydrocarbon emission was drastically reduced by 53 % for neat biodiesel operation.

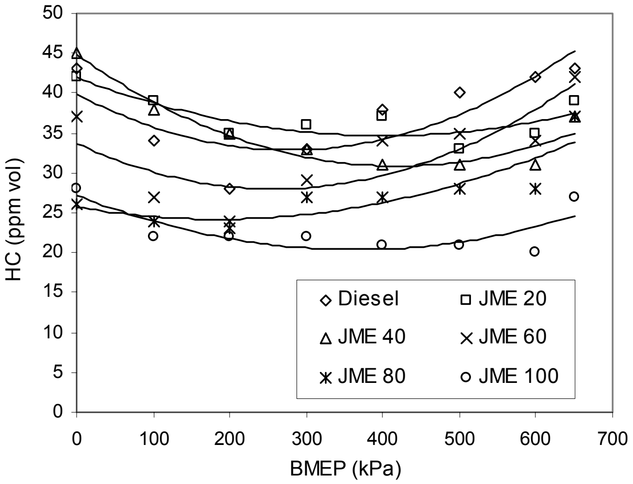

Fig. 11 Variation of Unburned Hydrocarbons with Brake Mean Effective Pressure for various blends of JME

It is seen in Fig. 12 that the CO_2 emission was decreased at higher loads, which is main compound for global warming. The trend of CO_2 emission is similar for various blends of JME.

It is shown in Fig. 13 that the O_2 content in the exhaust is more with biodiesel blend due to the reason that fuel itself contains oxygen. The trend of O_2 emission is similar for various blends of JME. This may improve conversion efficiency of catalytic converter if provided.

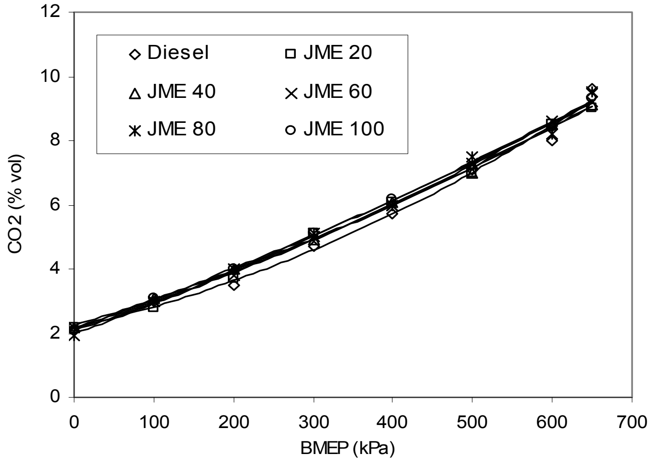

Fig. 12 Variation of Carbon Dioxide with Brake Mean Effective Pressure for various blends of JME

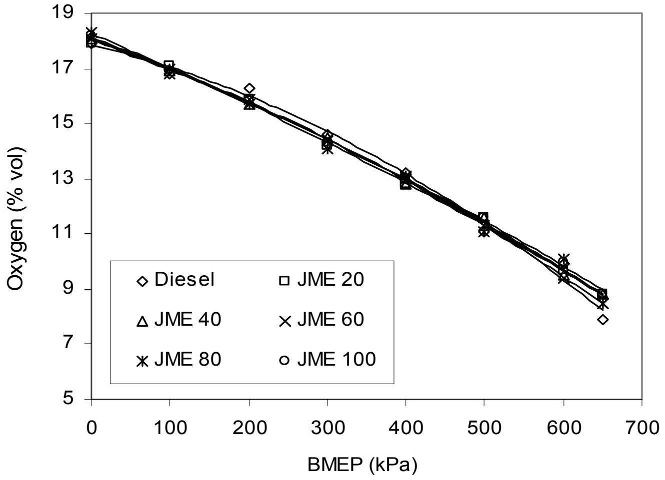

Fig. 13 Variation of Oxygen with Brake Mean Effective Pressure for various blends of JME

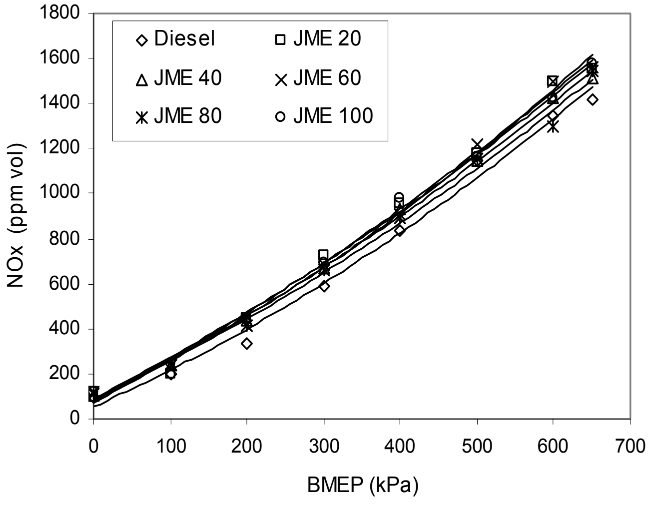

Fig. 14 Variation of Oxides of Nitrogen with Brake Mean Effective Pressure for various blends of JME

Biodiesel leads to slightly higher NOx levels as compared to diesel as shown in Fig. 14. As the JME percentage increases the NOx levels increases for various loads. This is mainly due to the higher burning rate of biodiesel and its blends, which leads to a higher peak temperature and increased O_2 concentration with JME fuels. The average increase in NOx emission is 5% for blends of biodiesel as compared to diesel. This may be attributed to complete combustion of oxygenated fuel.

SUMMARY & CONCLUSIONS

Transesterification is a process, which brings about a change in the molecular structure of the vegetable oil molecules, thus bringing down the viscosity of vegetable oils. The density and viscosity of the jatropha oil methyl ester formed after transesterification were found to be very close to petroleum diesel oil. The flash point of JME was higher than that of diesel oil.

The use of JME can be effective in existing diesel engines. JME as partial diesel substitutes can go a long way in conservation measure, boosting farm economy, reducing dependence on diesel fuel.

The brake thermal efficiency with biodiesel is about 31.7% for JME 100 where as it is about 31.6% with diesel at 600 kPa bmep. The similar observations were noted for all blends of JME at other loads. This may be attributed to complete combustion because of oxygenated fuel.

The BSEC is increased by 9% for JME100 than diesel at full load. The similar trend is observed for JME 20, JME 40, JME 60 and JME 80. The BSEC is about 11.17519 MJ/kWh, 11.18698 MJ/kWh, 11.26920 MJ/kWh and 11.80441 MJ/kWh for JME 20, JME 40, JME 60 and JME 80 respectively at full load. The brake specific energy consumption is slightly higher as compared to diesel at all loads. This may be due to lower calorific value of biodiesel.

No significant variation was noticed in the exhaust gas temperature with blends of biodiesel as compared to diesel fuel. The peak pressure, variation of cylinder pressure, rate of cylinder pressure rise is similar for biodiesel blends and diesel.

The maximum reduction in smoke emission was observed by 35 % in case of JME 100 operation as compared to diesel. There is a significant reduction in smoke emission for all blends of biodiesel at full load.

The unburned hydrocarbon emission was drastically reduced by 53 % for JME 100. There is a significant reduction in HC emission for all blends of biodiesel as compared to diesel at all loads. Marginal reduction was noticed at lower blends of JME for CO emission. The CO_2 emission decreases at higher loads. Biodiesel leads to slightly higher NOx levels as compared to diesel.

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