# Jatropha oil methyl ester as diesel engine fuel - an experimental investigation

## S. Jaichandar[1*] and K. Annamalai[2]

[1]Department of Automobile Engineering,
VelTech Technical University, Chennai, India
[*]Email: jaisriram18@yahoo.com
Phone: +919444984748
[2]Department of Automobile Engineering, Anna University,
Chennai, India

## ABSTRACT

The use of jatropha oil as a fuel for diesel engines is gaining more interest. Biodiesel is defined as a transesterified alternative fuel obtained from vegetable oils or animal fats having properties comparable to those of diesel. In the present investigation a methyl ester derived from jatropha oil (JOME) was considered as fuel. This paper presents a comparative study on the use of JOME and its blends of 20 and 50% on a volume basis with standard diesel as a source of fuel for a compression ignition engine. The engine tests were carried out at 0%, 25%, 50%, 75% and 100% load using a single-cylinder, four-stroke, constant speed diesel engine to study the performance, emission and combustion characteristics of these fuels. The results showed a 21% reduction in smoke, 17.9% reduction in HC emissions and 16% reduction in CO emissions for 20% JOME, with a 3.8% increase in $NO_x$ emission at full load. JOME and its blends showed a slight decrease in thermal efficiency and increase in the specific fuel consumption but at an acceptable level. There was a 2.8% decrease in brake thermal efficiency for the 20% JOME blend at full load. Among the blends, 20% JOME showed better results compared to 50% JOME and can be used as an alternative fuel in DI diesel engines.

*Keywords*: Biodiesel; Diesel engine; Emissions; Fuel consumption; Thermal efficiency.

## INTRODUCTION

The energy needs of the world are increasing rapidly. The large increase in the number of automobiles in recent years has resulted in greater demand for petroleum products. The increase in energy demand, decrease in petroleum-based fuel reserves, increase in pollution caused by them and increasing fuel prices have focused attention on alternative sources of energy [1-5]. With crude oil reserves estimated to last only a few decades, there has been an active search for alternative fuels. Such alternative fuels in use today are bio-alcohols, hydrogen, natural gas and biodiesel [6-11]. Among the various alternative fuels under consideration, biodiesel derived from vegetable oils is the most promising alternative fuel to petroleum-based diesel fuel (PBDF) [12-15]. The advantages of biodiesel fuels are that they are renewable, can be produced locally, are cheap, have higher lubricity, a higher cetane number, minimal sulphur content and are less polluting for the environment compared to diesel fuel [16]. On the other hand, their disadvantages include the higher viscosity and pour point, and lower calorific value and volatility. Furthermore, their oxidation stability is lower, they are hygroscopic, and as solvents may cause corrosion in various engine components.

Large numbers of studies on the performance, combustion and emission using raw vegetable oils and methyl or ethyl esters of sunflower oil [17], palm oil [7, 18-20], mahua oil [21], karanja oil [22, 23], soybean oil [24-27], rapeseed oil [28, 29] and rubber seed oil have been carried out on compression ignition (CI) engines. Studies have shown that the use of vegetable oils in the neat form is possible but not preferable. The high viscosity of vegetable oils and their low volatility affects the atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, injector coking and piston ring sticking. Although transesterification reduces the viscosity of biodiesel [30] the viscosity was still found to be 60–85% higher than PBDF. Biodiesel has different but comparable fuel properties to those of diesel. Examples of these are the cetane number, heating value, density, and bulk modulus. Each respective fuel property changes the combustion and performance characteristics of biodiesel compared to diesel [16, 31, 32]. Hence, in order to obtain better performance from biodiesel it has to be blended with petroleum-derived diesel before it can be used in any diesel engine without modification [33]. As far as India is concerned, the use of non-edible oils for the production of biodiesel is found to be best suited given the insufficient supply of edible oils and the cost of their production. The planning commission of India has launched a biofuel project in 200 districts from 18 states in India. It has recommended two plant species, viz. jatropha (Jatropha curcas) and pongamia (Pongamia pinnata) for biodiesel production [11, 34-36]. Of these, Jatropha curcas, an excellent shrub having natural spread across the globe, is a promising biofuel crop ideally suited for growing in the wastelands of our country. Greater potential exists in India for bringing millions of hectares of wasteland under extensive plantation of jatropha, virtually converting unproductive lands into green oil fields. Jatropha has a long productive life of around 40 years and yields the biodiesel source, the seed, from the third year onwards.

In the present investigation, jatropha oil methyl ester was prepared from crude jatropha oil by transesterification using alkaline catalyst (single stage conversion) and its properties were determined. The performance and emission characteristics of JOME and its diesel blends were studied on a four-stroke single-cylinder direct-injection (DI) engine to check their feasibility as CI engine fuel.

## METHODS AND MATERIALS

### Production of Jatropha Oil Methyl Ester

To prepare jatropha oil methyl ester, the transesterification reaction was performed on raw jatropha oil. Transesterification is a chemical process of transforming large, branched, triglyceride molecules of vegetable oils and fats into smaller, straight chain molecules, very similar in size to the molecules of the species present in diesel fuel. The process takes place by chemically reacting the raw jatropha oil with methyl alcohol in the presence of catalyst. Biodiesel from jatropha was produced in a laboratory-scale setup, which consists of a heating mantle, reaction flask and mechanical stirrer. As a first step, the FFA content in the oil was estimated. Since the FFA of the raw oil was less than 5%, a single-stage base transesterification process using methanol as reagent and KOH as catalyst was followed to produce biodiesel from jatropha oil [37, 38]. 1000 ml of the vegetable oil was taken in the reaction vessel. About 18 gm of KOH was mixed with 200 ml of methyl alcohol in a beaker. The mixture was added to the reaction vessel. Figure 1 shows the schematic diagram of the small-scale biodiesel production setup.

1. Stand
2. Stirrer Motor
3. Stirrer
4. Seal for stirrer
5. Three mouthed Reaction Vessel
6. Electric Heater
7. Oil Bath
8. Temperature probe
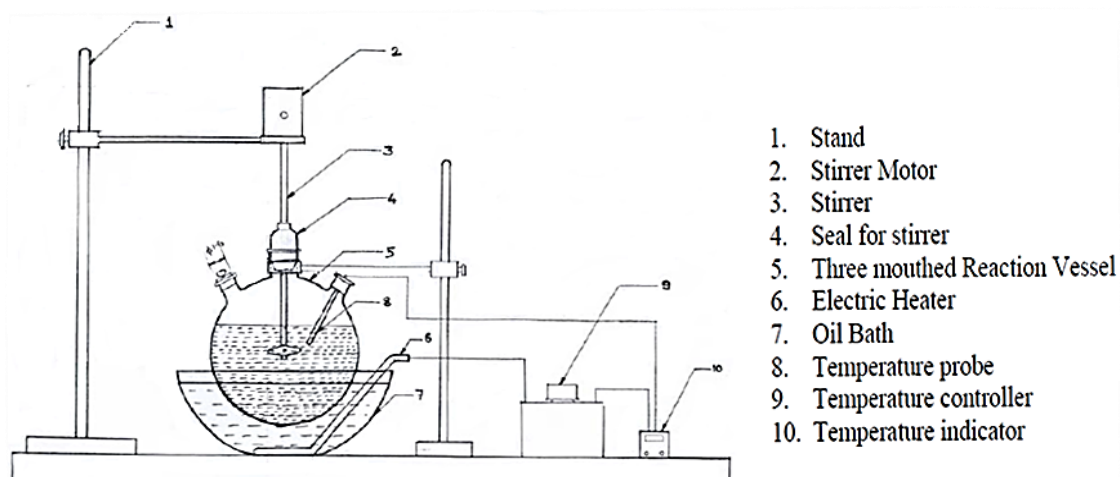9. Temperature controller
10. Temperature indicator

Figure 1. Schematic diagram of small-scale biodiesel production setup

The reactor was immersed in a constant-temperature water bath maintained at 60°C and agitated vigorously with a mechanized stirrer. The temperature is maintained for about two hours with continuous stirring of the contents in the reaction vessel. The contents were allowed to settle in the vessel. After settling, the lower layer of glycerol was separated. The liquid remaining in the vessel was impure methyl ester which was washed with clean warm water to remove the impurities. Finally, the methyl esters were heated to 110°C to remove moisture present in them. Figure 2 shows the biodiesel production flow-chart. The properties of the raw jatropha oil and jatropha oil methyl ester were determined. The properties of the standard diesel oil, raw JOME and its 20% and 50% blends are given in Table 1. Most of the properties of JOME and its blends, like the calorific value, viscosity, density, flash point, cloud point and pour point, were comparable with those of diesel. However, the viscosity of the JOME was found to be about 44.1% higher and the calorific value was 2.9% lower, when compared to standard diesel.
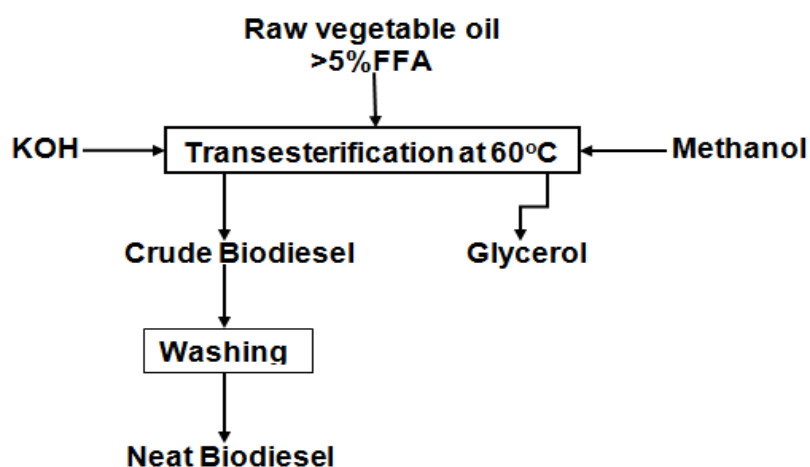


Figure 2. Biodiesel production flow-chart

Table 1 Properties of diesel, biodiesel from jatropha and their blends.

| Oil | Kinematic viscosity (cSt) | Density (kg/m$^3$) | Calorific value (MJ/kg) | Flash Pt (°C) | Cloud Pt (°C) | Pour Pt (°C) |
|---|---|---|---|---|---|---|
| Diesel | 2.9 | 850 | 44 | 76 | 6.5 | 3.1 |
| 100% JOME | 4.18 | 873 | 42.73 | 148 | 10.2 | 4.2 |
| 50% JOME | 3.59 | 857 | 43.33 | 113 | 7.3 | 3.4 |
| 20% JOME | 3.02 | 852 | 43.75 | 88 | 6.9 | 3.3 |

**Test Equipment**

The test engine used was the Kirloskar, single-cylinder four-stroke air-cooled diesel engine, developing 4.4 kW at 1500 rpm. This engine was coupled to an eddy current dynamometer with control system. A chromel–alumel thermocouple in conjunction with a digital temperature indicator was used for measuring the exhaust gas temperature. The cylinder pressure was measured by a piezoelectric pressure transducer fitted on the engine cylinder head and a crank angle encoder fitted on the flywheel. Both the pressure transducer and encoder signal were connected to the charge amplifier to condition the signals for further processing. UBHC, CO and $NO_x$ emissions were measured using a 5-gas analyser. The smoke intensity was measured with the help of a Bosch smoke meter. A 2-inch diameter filter paper was used to collect smoke samples from the engine, through the smoke sampling pump for measuring smoke intensity. Figure 3 shows the schematic diagram of the experimental setup.
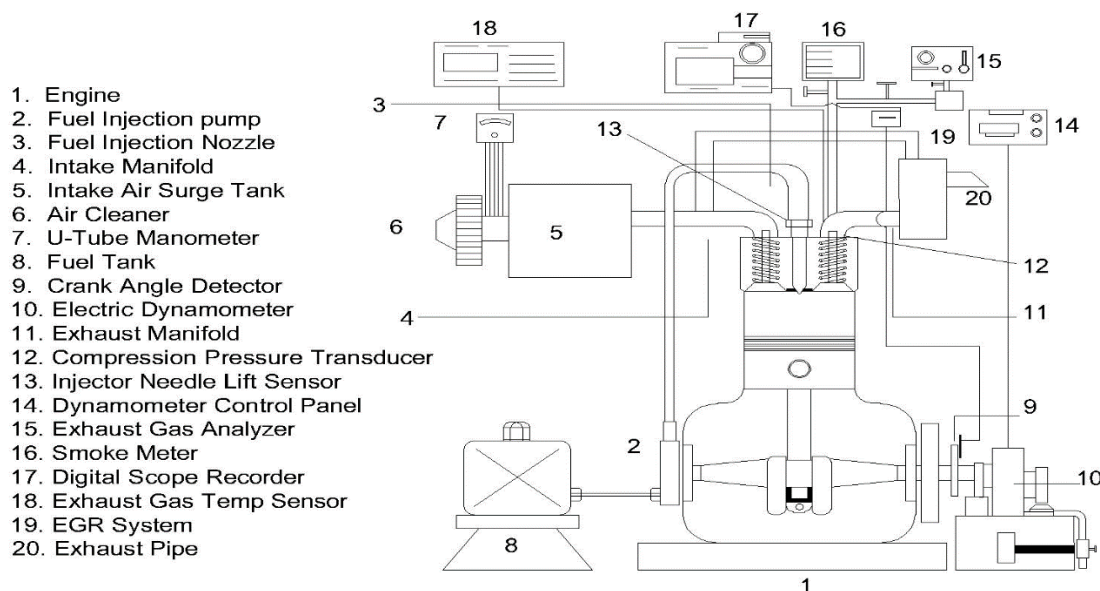
1. Engine
2. Fuel Injection pump
3. Fuel Injection Nozzle
4. Intake Manifold
5. Intake Air Surge Tank
6. Air Cleaner
7. U-Tube Manometer
8. Fuel Tank
9. Crank Angle Detector
10. Electric Dynamometer
11. Exhaust Manifold
12. Compression Pressure Transducer
13. Injector Needle Lift Sensor
14. Dynamometer Control Panel
15. Exhaust Gas Analyzer
16. Smoke Meter
17. Digital Scope Recorder
18. Exhaust Gas Temp Sensor
19. EGR System
20. Exhaust Pipe

Figure 3. Schematic diagram of the experimental setup

**Test Fuels and Method**

Four fuels were tested in this study: a neat 100% JOME, diesel fuel, and blends of 50 and 20% JOME by volume in the diesel fuel. To start with, the performance, emissions and combustion tests were carried out using diesel fuel at various loads for the standard engine with manufacturer recommended fuel injection pressure and fuel injection timing of 200 bar and 23° bTDC respectively. This performance and the combustion and emissions values were considered as baseline values throughout the experimentation for comparison with the results obtained from tests with 100% JOME, 50% JOME and 20% JOME. The engine tests were carried out at 0%, 25%, 50%, 75% and 100% load and at a constant engine speed of 1500 rpm.  In order to have a meaningful comparison of emissions and engine performance, tests were performed under the same operating conditions, i.e., the engine speed, torque, temperature and pressure conditions were maintained.

## RESULTS AND DISCUSSION

Jatropha oil methyl ester and its blends were used separately as the fuel for a compression ignition engine without any engine modifications. The performance and emissions of the engine with diesel, blends of biodiesel and diesel and neat biodiesel are presented and discussed below.
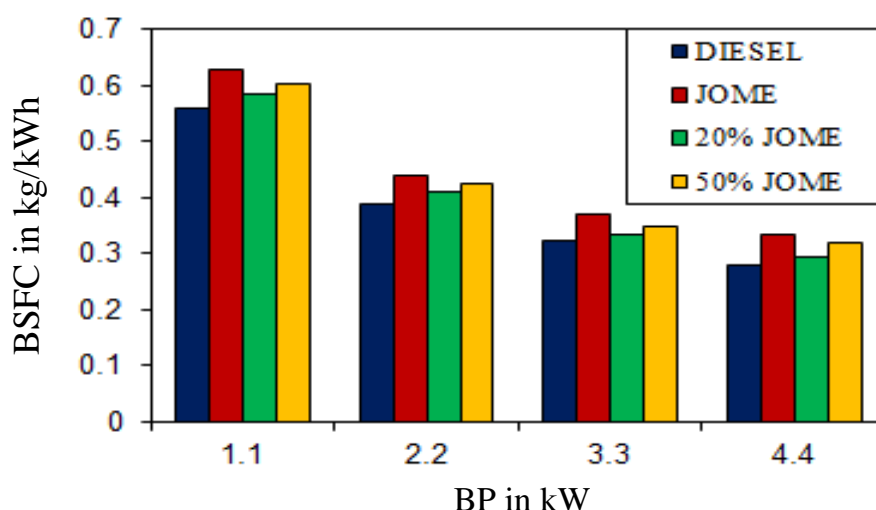


Figure 4. Variations of BSFC

**Brake Specific Fuel Consumption**

The brake specific fuel consumption (BSFC) is the ratio between the mass of fuel consumption and brake power. Figure 4 shows the BSFC of JOME, various blends of JOME with diesel, and diesel. At full load, JOME showed the highest fuel consumption. The BSFC for JOME and its blends was slightly higher than that of PBDF. The BSFC, in general, was found to increase with the increasing proportion of JOME in the PBDF. This can be attributed to the fact that the test engine had a mechanically controlled in-line type fuel injection pump; the engine load was controlled by the fuel injection volume. For the same volume, more JOME, based on the mass, was injected into the combustion chamber than that of PBDF due to its higher density. The BSFC for JOME, 50% JOME and 20% JOME, was higher than that of diesel by about 19.6%, 14%, and 5.4% respectively at full

load operation. Because the calorific value of the biodiesel fuel was lower than that of diesel, the BSFC of JOME and its blends was higher than that of diesel [39, 40].

**Brake Thermal Efficiency**

Thermal efficiency is the ratio between the power output and the energy introduced through fuel injection. Figure 5 shows the brake thermal efficiency of JOME and its blends. The brake thermal efficiency (BTE) of JOME and its blends was lower compared to that of diesel. At the rated load, the BTE of JOME was lower than that of PBDF by 8.5%. The BTE of blends of JOME lie between those of diesel and JOME at all loads. The decrease in BTE at full load was 2.8% for 20% JOME and 5.25% for 50% JOME. The slight reduction of BTE with JOME and its blends can be attributed to the poor spray characteristics, poor air fuel mixing, higher viscosity, lower volatility and lower calorific value of biodiesel fuel than that of conventional diesel [41]. Apart from the factors stated earlier, another reason for the lower BTE could be that, since the engine was operated under constant injection advance and JOME had a smaller ignition delay [42], combustion was initiated well before TDC was reached. This increased the compression work and caused more heat loss and thus reduced the brake thermal efficiency of the engine.
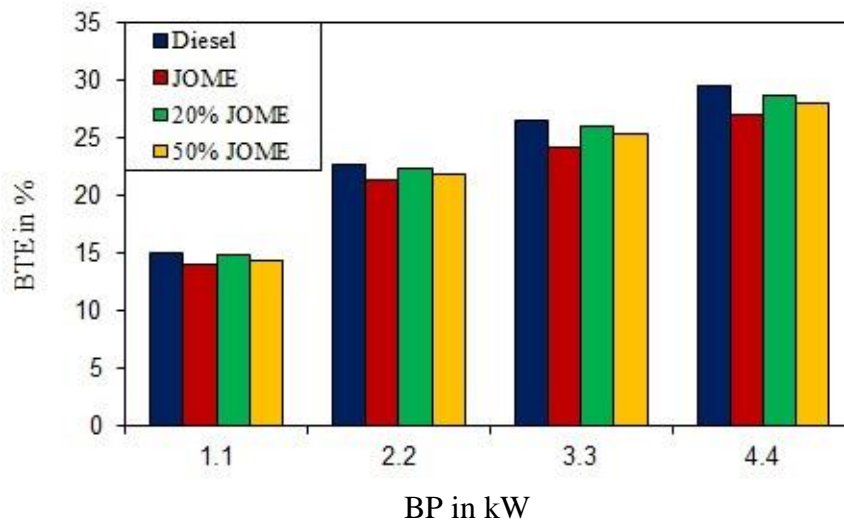


Figure 5. Comparison of BTE

**Unburnt Hydrocarbons Emission**

The unburnt hydrocarbon emissions with JOME and its blends are compared with diesel in Figure 6. UBHCs are the result of incomplete combustion of fuel and quenching of flame near the combustion chamber walls. These unburnt species are collectively known as UBHC emissions. UBHC emissions were reduced over the entire range of loads for JOME and its blends. They decreased with increase in the level of JOME in the blend. Since biodiesel is an oxygenated fuel [43, 44], it promotes combustion and results in a reduction in UBHC emissions. The UBHC emissions of JOME relative to diesel decreased by 57.5% at the rated load operation. 20% JOME and 50% JOME produced less HC emissions by 17.91% and 48.6% respectively at full load compared to those of standard diesel.
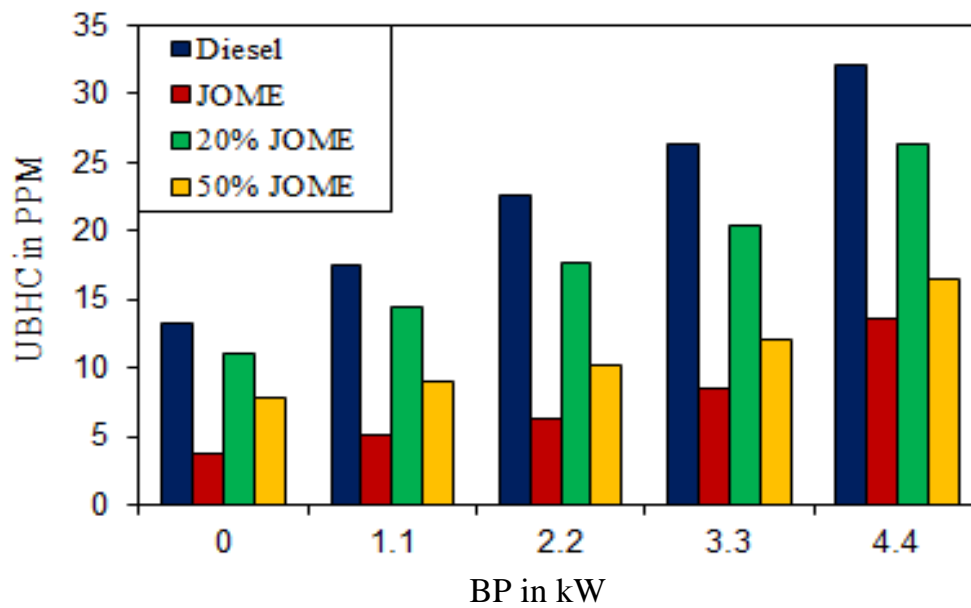
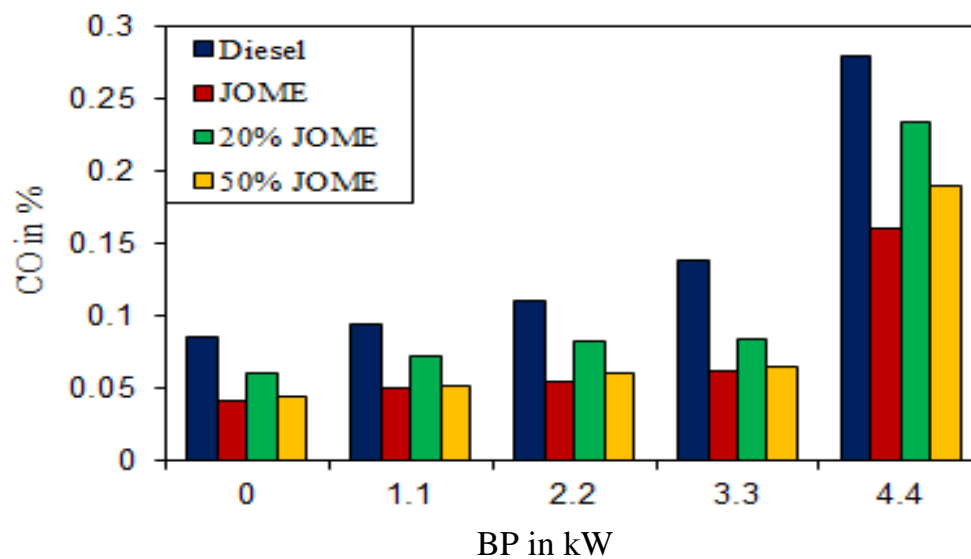Figure 6. Variations of UBHC emission



Figure 7. Variations of CO emission

**Carbon Monoxide Emission**

Carbon monoxide (CO) is an intermediate combustion product and is predominantly formed due to the lack of oxygen and incomplete combustion of fuel. Usually, high CO emissions are formed with fuel-rich mixtures, but as diesel combustion occurs with a lean mixture and has an abundant amount of air, the CO from diesel combustion is low. Figure 7 shows that carbon monoxide emissions were greatly reduced with the addition of JOME to diesel. They decreased with increase in the percentage of JOME in the blend. The lowest CO emissions were obtained for the JOME. It was noticed that CO varied from 0.085% by volume at low load to 0.28% by volume at full load for diesel and for JOME it varied from 0.042% by volume at low load to 0.16% by volume at full load.

Similarly, at full load, CO emissions for 20% JOME (0.235% by volume) and 50% JOME (0.19% by volume) were lower than those of diesel. CO is predominantly formed due to the lack of oxygen [45]. Since JOME is an oxygenated fuel, it led to better combustion of fuel, resulting in the decrease in CO emission. Reduction in CO emission is a strong advantage in favour of JOME.
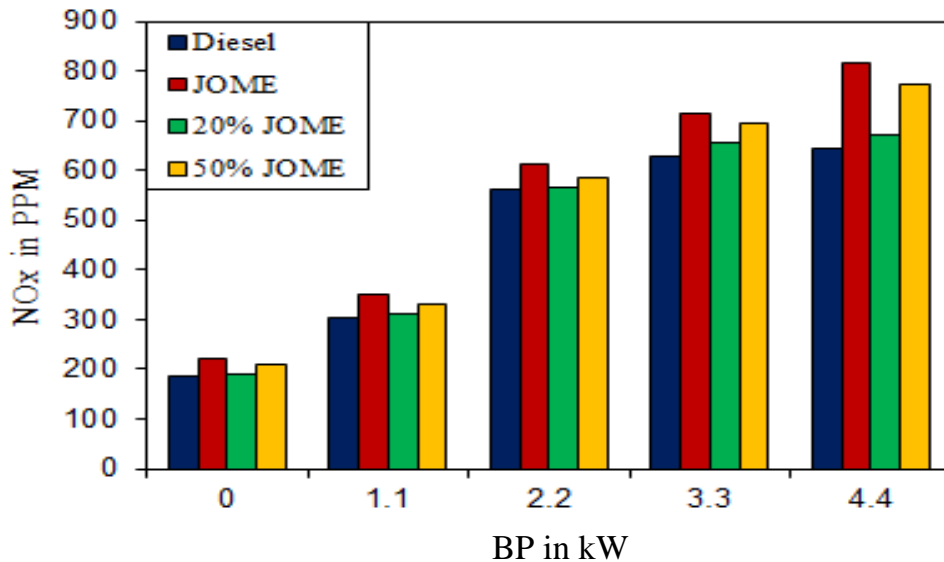


Figure 8. Comparisons of $NO_x$ emissions

**Nitrogen Oxides Emission**
Figure 8 shows an increase in the emission of oxides of nitrogen ($NO_x$) with increase in the percentage of JOME in the fuel. Increases of 26.6%, 19.8% and 3.8% in $NO_x$ emissions for the JOME, 50% JOME and 20% JOME respectively were observed at full load compared to diesel. The $NO_x$ increase for JOME can be attributed to the oxygen content of the JOME, since the oxygen present in the fuel may provide additional oxygen for $NO_x$ formation [43, 44]. Another reason for the increase in $NO_x$ could be the possibility of higher combustion temperatures arising from improved combustion. It has to be noted that a larger part of the combustion was completed before TDC for JOME and its blends compared to diesel due to their lower ignition delay [42]. So it was highly possible that higher peak cycle temperatures were reached for JOME and its blends compared to diesel. However $NO_x$ can be controlled by adopting Exhaust Gas Recirculation and by employing suitable catalytic converters.

**Smoke**
Figure 9 shows the smoke intensity of diesel, JOME and its blends. The use of JOME, 50% JOME and 20% JOME caused a reduction in smoke in the range of 56%, 47% and 21% respectively with respect to diesel at the rated load. A vast reduction in smoke intensity was observed with increase in the percentage of JOME in the blend, especially at high loads. JOME and its blends as fuel in diesel engines significantly reduce smoke. This was due to more complete combustion and the presence of oxygen in the JOME [3]. Other reasons for smoke reduction when using biodiesel can be attributed to the lower C/H ratio and absence of aromatic compounds as compared with diesel.
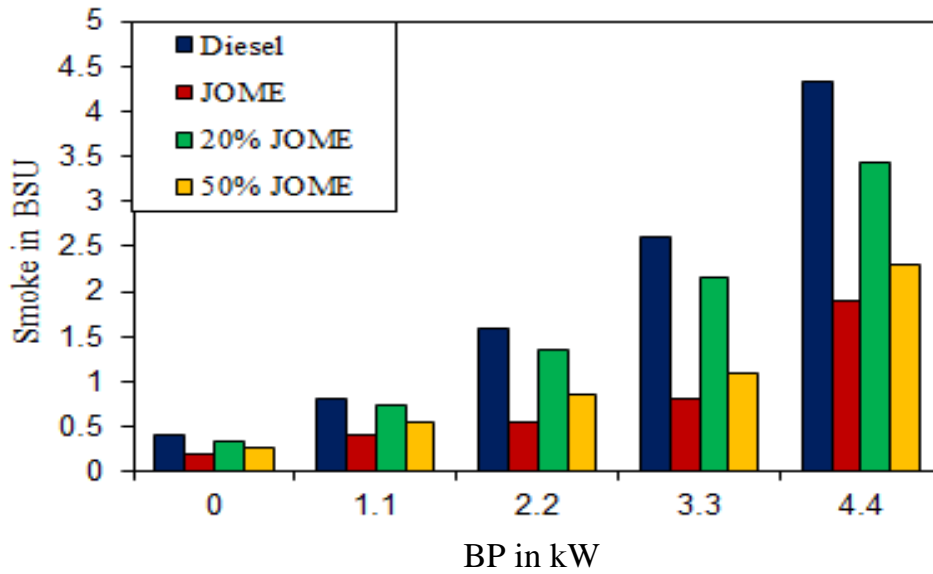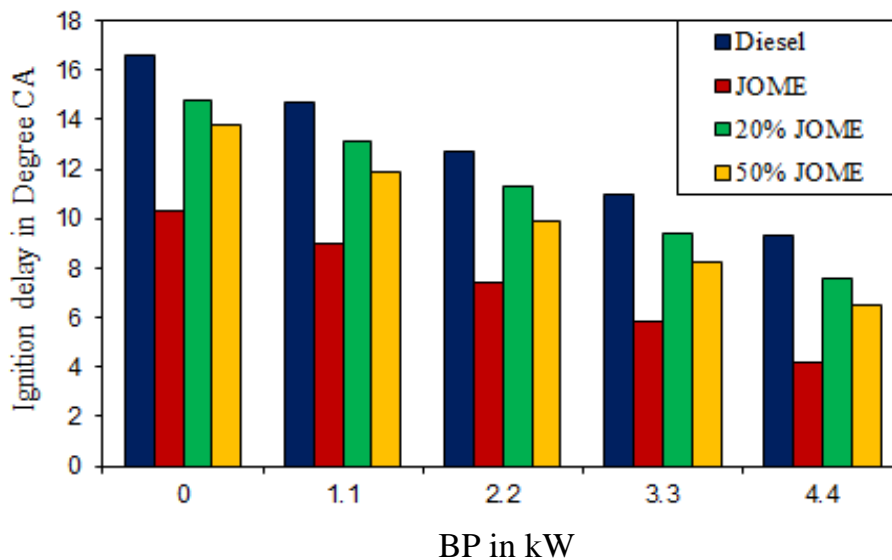
Figure 9. Comparison of smoke emissions



Figure 10. Variations of ignition delay

**Ignition Delay**

Ignition delay of fuel is a significant parameter in determining the knocking characteristics of CI engines. The cetane number of a fuel, which indicates the self-igniting capability, has a direct impact on ignition delay. The higher the cetane number, the shorter the ignition delay, and vice versa. Figure 10 shows the ignition delay of diesel, JOME and its blends. The ignition delays for JOME, 50% JOME and 20% JOME fuel were 5.14º CA, 2.85º CA and 1.75º CA shorter respectively than that of the diesel-operated engine at full load operation. It was observed that the ignition delay periods of JOME and its blends were significantly shorter than that of diesel and decreased with the increase in % JOME in the blend. This was due to the fact that the oleic and linoleic fatty acid methyl esters present in the JOME split into smaller compounds when it enters the combustion chamber, resulting in higher spray angles and hence causing earlier ignition

[3]. This indicates that JOME and its blends had a higher cetane number compared to diesel. It was noticed that for all test fuels the reduction in ignition delay increased with the increase in load. This was due to the higher combustion chamber wall temperature and reduced exhaust gas dilution at higher loads [45].
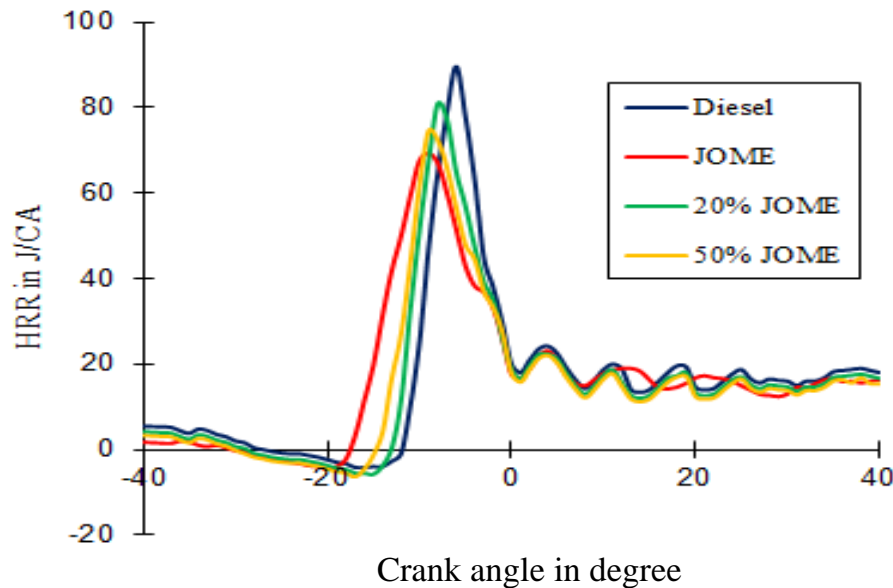


Crank angle in degree

Figure 11. Comparisons of heat release rate

**Rate of Heat Release**

A thorough knowledge of the heat release pattern of a fuel is essential for the analysis of $NO_x$ formation inside the combustion chamber and the cooling system requirements of the engine [46]. The comparison of heat release rate variations for JOME and its blends with diesel is shown in Figure 11. It was observed that the maximum heat release rate of 89.69 J/deg CA was recorded for diesel at 6° bTDC, while JOME recorded its maximum heat release rate of 69.481 J/deg CA at 8°b TDC. As the percentage of JOME in the blend increased, the maximum heat release rate decreased and the crank angle at which it took place advanced.

**CONCLUSIONS**

The fuel properties of JOME and its blends were comparable to those of diesel. Experiments were performed using a DI diesel engine to investigate the performance, emissions and combustion characteristics of biodiesel fuel derived from jatropha oil. The following conclusions were obtained.

i). Due to the lower calorific value of JOME, the specific fuel consumption increased and the brake thermal efficiency decreased with increase in the percentage of JOME in the fuel.

ii). Due to the higher oxygen content in the JOME, emissions of CO and UBHC decreased with increase in the percentage of JOME in the blend. It was also observed that there was a significant reduction in smoke intensity. The higher oxygen content in the JOME resulted in better combustion and increased the

combustion chamber temperature. This increased the $NO_x$ emission of JOME compared to diesel.

iii). The ignition delay of JOME and its blends was found to be less than that of diesel. With increase in the percentage of JOME in the blend, the maximum heat release rate decreased.

iv). The results show a 2.8% decrease in brake thermal efficiency for the 20% JOME blend at full load. There was a 17.9% reduction in HC emissions and a 16% reduction in CO emissions, 21% reduction in smoke for the 20% JOME blend, with a 3.8% increase in $NO_x$ emission.

The present analysis reveals that biodiesel from jatropha oil is quite suitable as an alternative to diesel. From the combustion analysis it was found that the performance of the 20% JOME blend was as good as that of diesel. Taking these facts into account, a blend of 20% JOME can be used as a suitable alternative fuel in DI diesel engines.

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## NOMENCLATURE

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|---|---|---|---|
| JOME | jatropha oil methyl ester | PBDF | petroleum-based diesel fuel |
| 20% JOME | blend of 20% JOME with diesel fuel by volume | 50% JOME | blend of 50% JOME with diesel fuel by volume |
| CI | compression ignition | DI | direct injection |
| BSFC | brake specific fuel consumption | FFA | free fatty acid |
| BTE | brake thermal efficiency | UBHC | unburned hydrocarbons |
| CO | carbon monoxide | bTDC | before top dead centre |
| $NO_x$ | oxides of nitrogen | CA | crank angle |