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An experimental investigation of performance and exhaust emission of a diesel engine fuelled with Jatropha biodiesel and its blends

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Abstract
An experimental investigation has been carried out to examine the Performance parameters and exhaust emission of a diesel engine fuelled with diesel fuel, a Jatropha Biodiesel namely Jatropha oil methyl ester (JOME), its 20 percent (B20) and 50 percent (B50) blends as an alternative diesel engine fuel. JOME was prepared using Jatropha oil, methyl alcohol and potassium hydroxide as catalyst. Tests have been carried out in four cylinder direct injection diesel engine with different loading conditions. Performance parameters investigated are Brake thermal efficiency, Brake specific fuel consumption (BSFC) and Brake specific Energy consumption (BSEC), the emission parameters investigated are CO, HC, NOx, and smoke. Results showed that JOME pure or its blend both showed considerable reduction in emission except NOx. A fuel blend of 20 percent JOME showed approximately same BTE as that of neat Diesel fuel. The result showed that the Biodiesel derived from Jatropha oil Showed comparable performance and can be a good replacement to petroleum diesel.

Keywords: Biodiesel; Jatropha; Exhaust emission; Biodiesel blending; Renewable energy.

1. Introduction
The global environmental change and the issue for long-term availability of traditional oil resources necessitate creating the substitute energy sources that give engine performance at par with the conventional fuel. Among the substitute energy sources, biodiesel holds good guarantees as an eco-friendly substitute fuel.
Biodiesel is an alternative, renewable, clean diesel fuel made by conversion of the vegetable oils, waste animal fats to esters via transesterification with methanol or ethanol using catalyst. The reaction results in the generation of methyl esters (if methanol is used) and ethyl esters (if ethanol is used). These esters commonly known as Fatty acid methyl esters (FAME) have shown promise as biodiesel, due to improved viscosity, higher volatility, higher cetane number and combustion behavior relative to triglycerides, and can be used in conventional diesel engines without significant modifications [1-4].
With the development of the use of biodiesel around the world, biodiesel produced from different feed stocks have intensively examined on the diesel engines by many researchers. These research point out that biodiesel from different feed stocks displays approximately same results [5, 6] or very little performance variations [7, 8]. It improves fuel lubricity [9, 10] and causes reductions on harmful

regulated emission when compared with the neat diesel [11-17]. On the other hand, their disadvantages include their higher viscosity, higher pour point, lower calorific value and lower volatility relative to petroleum diesel fuel. Furthermore, their oxidation stability is lower, they are hygroscopic, and as solvents, they may cause corrosion of components, attacking some plastic materials used for seals, hoses, paints and coatings. It shows increased dilution and polymerization of engine sump oil, thus requiring more frequent oil changes. For all the above reasons, it is generally accepted that blends of standard Diesel fuel with 10% or up to 20% (by volume) vegetable oils or bio-diesels can be used in existing Diesel engines without any modifications, but there are concerns about the use of higher percentage blends that can limit the durability of various components, leading to engine malfunctioning [18].

In the present investigation, biodiesel and its blends prepared from Jatropha oil was used for the study. The oil is widely available in India. Furthermore the use of non-edible vegetable oils like Jatropha oil is of importance because of the great need for edible oil as food. The main objective of this experimental study is to determine the performance and exhaust emission parameter while using Jatropha oil methyl ester as a fuel in a DI diesel engine. The results for JOME (Jatropha oil methyl ester) were compared with those for diesel fuel.

1.1 Jatropha oil

Most of the biodiesel producing countries use readily available edible oil seed products as feedstock, for example sunflower and rapeseed in European countries, soybean in the USA, palm oil in Malaysia, and coconut in Philippines. Currently, about 84% the world biodiesel production is met by rapeseed oil. The remaining portion is from sunflower oil (13%), palm oil (1%) and soybean oil and others (2%). Since more than 95% of the biodiesel is made from edible oil, food resources are actually being converted into automotive fuels. There are many claims that a lot of problems may arise by converting edible oils into biodiesel. It is believed that large-scale production of biodiesel from edible oils may bring global imbalance to the food supply and demand market [19]. In order to overcome this devastating phenomenon, research has been made/conducted to produce biodiesel by using non-edible oils like Jatropha.

The genus name Jatropha derives from the Greek word jatr´os (doctor) and troph´e (food), which implies medicinal uses. The first commercial applications of Jatropha were reported from Lisbon, where the oil imported from Cape Verde was used for soap production and for lamps.

Jatropha is a small tree or large shrub, which can reach a height of three to five meters, but under favorable conditions it can attain a height of 8 or 10m. The plant shows articulated growth, with a morphological discontinuity at each increment [20]. Figure 1 shows Jatropha plant in Energy park of Rajiv Gandhi Proudyogiki Vishwavidyalaya (R.G.P.V.).

Jatropha plant bears fruits from second year of its plantation and the economic yield stabilizes from fourth and fifth year onwards. The plant has an average life with effective yield up to 50 years. Jatropha gives about 2 kg of seed per plant in relatively poor soils. The seed yields have been reported as 0.75–1.00 kg per plants thus the economic yield can be considered to range between 0.75 and 2.00 kg/plant and 4.00 and 6.00 MT per hectare per year depending on agro-climatic zone and agriculture practices. One hectare of plantation on average soil will give 1.6 MT oil [21]

There are several advantages with Jatropha. Firstly, it is easier to harvest than large tree and has much shorter gestation period. Secondly, the seed collection period of Jatropha does not coincide with the rainy season in June–July, when most agricultural activities takes place. This makes it possible for people to generate additional income in the slack agricultural season. Thirdly, it is resistant to common pests and not consumed by the cattle. Fourthly, the by-products of biodiesel are also quite useful as bio fertilizer and glycerin. Fifthly, it require very few nutrients to survive and therefore can be grown on less fertile land. [22]. In addition to being a source of oil, Jatropha also provides a meal that serves as a highly nutritious and economic protein supplement in animal feed, if the toxins are removed [23].

Since India has a large waste land area suitable for Jatropha cultivation, it can supply large volume of biodiesel, in fact, nearly half a dozen states of India have reserve a total of 1.72 million hectares of land for Jatropha cultivation and small quantities of Jatropha biodiesel are already being sold to the public sector oil companies [22].

Figure 1. Jatropha plant in energy park of R.G.P.V.

2. Experimental

2.1 Production of Jatropha oil methyl ester

Jatropha oil was heated to about 60^0C in a Biodiesel reactor shown in Figure 2 with a capacity of about 10L. 40% Methanol (99.9% pure) and 0.75% potassium hydroxide was mixed separately to dissolve and added to the heated 10L Jatropha oil in the reactor. After the mixture was stirred for around 1.3 hours at a fixed temperature of about 60^0C, it was allowed to separate layers of glycerol and ester. Once the heavy black glycerol layer was settled down, the methyl ester layer formed at the upper part of the reactor. Glycerol followed by Jatropha oil methyl ester separated from the bottom part of the reactor through a valve. The yield of Jatropha oil methyl ester was approximately 85 percent. After that, a gentle washing process using heated distilled water was carried out to remove some unreacted remainder of methanol and catalyst which if not removed can react and damage storing and fuel carrying parts. During washing ester present react with water and can form soap. Two to three gentle washing was required to remove unreacted remainder but it may leads to loss of esters. After washing two distinct layer formed with bottom layer having water and impurities settled down and removed. The upper layer is of Jatropha biodiesel. A heating process at about 60^0C was applied for removing water contained in the esterified Jatropha oil and finally, left to cool down

2.2 Fuel properties

The fuel properties were determined and are listed in Table 1, for Jatropha oil methyl ester and diesel.

2.3 Experimental set up

The experimental setup shown in Figure 3 consists of a four cylinders, four stroke, naturally aspirated diesel engine, an engine test bed with hydraulic dynamometer. The specifications of the test engine are given in Table 2. The test bed contains instruments for measuring various parameters such as engine load, air flow by anemometer, gas temperatures by K type thermocouples. The fuel consumption was determined by weighing the fuel on an electronic scale. For the analysis of the exhaust gases, Eurotron green line gas analyzer and AVL 437 smoke meter was used.

Figure 2. Biodiesel reactor

Table 1. Fuel properties of diesel and JOME

Properties	Test Method	Diesel	JOME
Kinematic viscosity @40^0 C, cSt	D445	2.4	5.8
Density@15^{0}c, kg/m^3	D1298	822.4	893.2
Flash Point, ^{0}C	D93	67	167
Net Calorific Value, MJ/kg	D240	42.7	38.92
Water and sediments % volume	D2709	0.01	0.02
Sulfer, %wt	D4294	0.28	Nil

Figure 3. Experimental setup

Table 2. Test engine specification

Make	Force Motors
Cylinder Number and type	Four, Four stroke
Bore(mm)	78
Stroke(mm)	95
Compression Ratio	18.65:1
Rated Power (H.P.)	27
Rated speed	2200 rpm.

2.4 Experimental test procedure

The engine was allowed to reach its steady state by running it for about 10 minutes. The engine was sufficiently warmed up and stabilized before taking all readings. After the engine reached the stabilized working condition, the load applied, fuel consumption, brake power and exhaust temperature were measured, the values were recorded thrice and a mean of these was taken for comparison. The engine performance and Exhaust emissions were studied at different loads. The brake specific fuel consumption, brake specific energy consumption and thermal efficiency were calculated. The emissions such as CO, HC, and NOx were measured using exhaust gas analyzer and smoke with smoke meter. These performance and emission characteristics for different fuels are compared with the result of baseline diesel.

3. Result and discussion

The test fuels used during this study were neat Jatropha oil methyl ester, a neat diesel, and blends of 20 and 50 percent JOME by weight with the diesel fuel. Experiments were conducted at a constant speed of 2000 rpm and by varying the loads.

3.1 Brake specific fuel consumption

Figure 4 shows the variation of Brake specific fuel consumption (BSFC) with BMEP of the tested fuels. The brake specific fuel consumption was decreased with increase in load. It was observed from the figure

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that the BSFC is increased proportionally to the JOME content. The B20, B50 and B100 reported 2.33, 10.37 and 21.07 percent average increased fuel consumption than the neat diesel fuel. The reason of higher BSFC of JOME and its blend was due to lower calorific value and the higher densities of JOME and blends caused higher mass injection for the same volume.

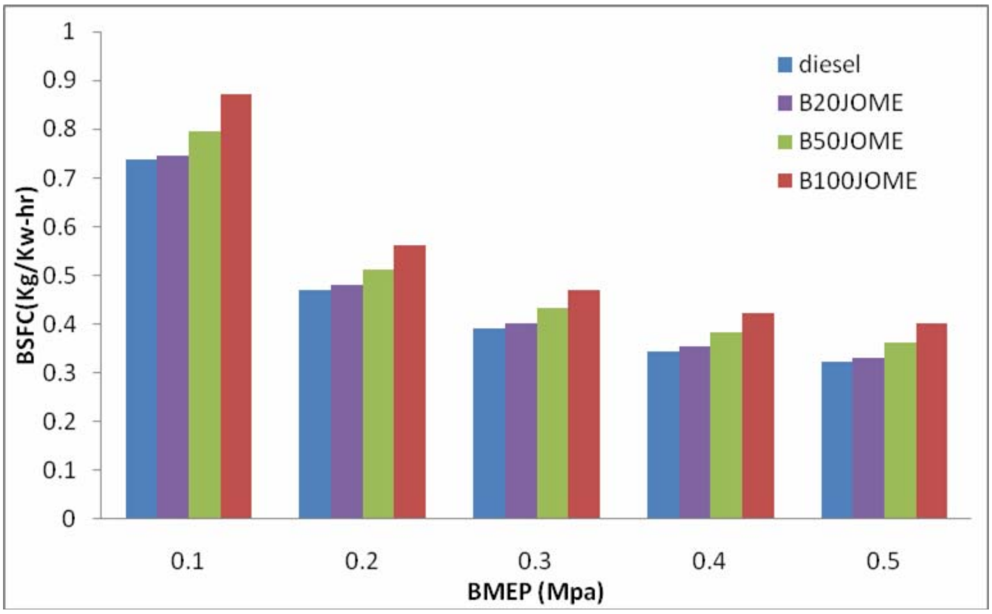

Figure 4. Variation of BSFC with BMEP

3.2 Brake specific energy consumption

The Figure 5 shows the variation of BSEC with BMEP. The Brake specific fuel consumption (BSFC) is not a reliable parameter for comparing two fuels of different calorific value. Hence brake specific energy consumption (BSEC) is more suitable for the purpose, which takes into account both mass flow rate and calorific value of the fuel. The values of BSEC were decreased with the increase in load. The possible reason could be the percentage increase in fuel required to drive the engine is less than the percentage increase in brake power due to the reduction in heat losses at higher loads. B20, B50 and B100 blend showed 0.58, 5.62 and 10.4 percent average higher energy consumption. B20 JOME showed approximately same BSEC as that diesel. This indicates that fuel energy consumption of B20 JOME is almost similar as that of neat diesel fuel. The possible reason of similar energy consumption of B20 could be the improved combustion due to the oxygen molecules. While the increase in the energy consumption, of higher blends could be the higher viscosity, density and lower volatility resulted in higher amount of fuel injected than the diesel fuel, which affects the formation of mixture and leads to more dominating diffusion combustion phase.

3.3 Brake thermal efficiency

The variation of brake thermal efficiency (BTE) with BMEP is represented in Figure 6. The values of BTE were increased with increasing load in all cases. This was due to reduction in heat losses at higher load. The BTE of neat JOME and 50 percent blends showed comparatively lower brake thermal efficiency. 20 percent blend showed almost same BTE at smaller load and slightly lower BTE at higher loads compared to diesel fuel. B20 blend was reporting approximately 0.57 percent average lower BTE. The possible reason of approximate similar BTE can be promoted combustion due to oxygen content of the JOME. The additional lubrication provided by the JOME can reduce the frictional losses [24]. The B50 and B100 JOME showed average 5.3 and 9.36 percent reduction in BTE respectively. This reduction can be attributed to the lower calorific value which leads to increase in the specific fuel consumption. The increase in fuel consumption requires the increase of volume and duration of fuel injection. Since the fuel was injected at fixed injection timing more fuel was injected during the expansion stroke and leads to more diffusion combustion.

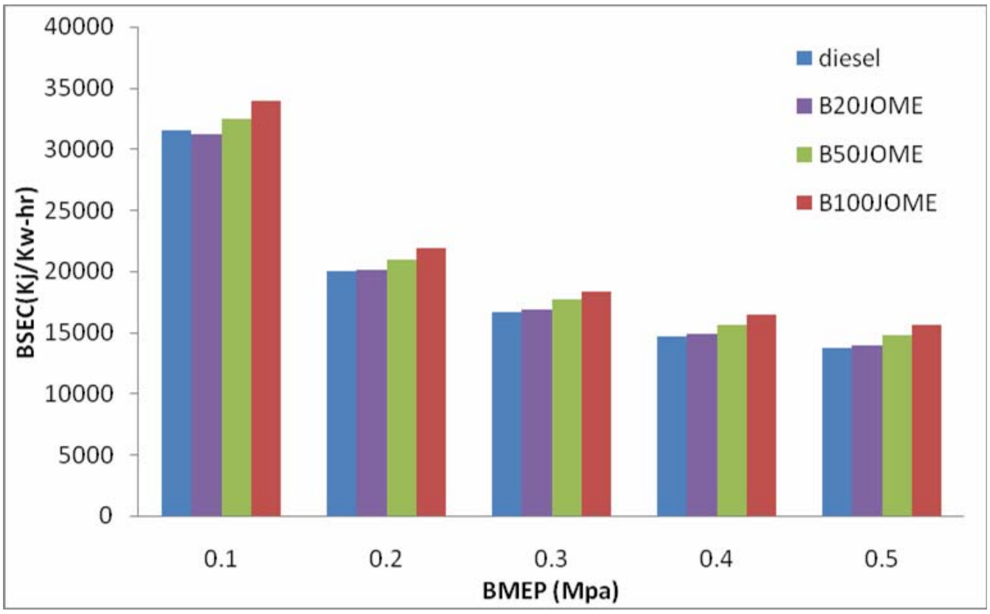

Figure 5. Variation of BSEC with BMEP

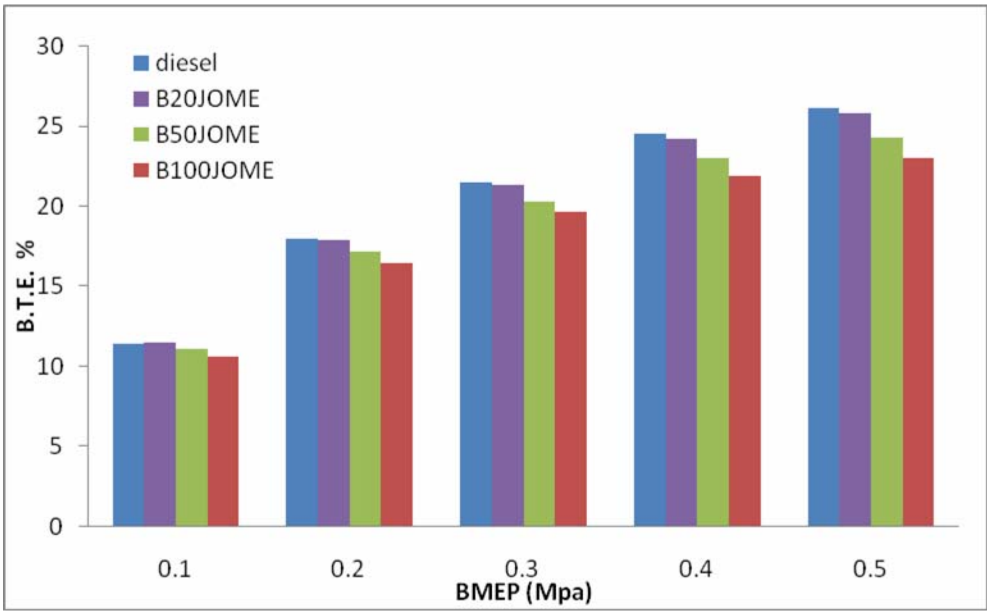

Figure 6. Variation of brake thermal efficiency with BMEP

3.4 Exhaust gas temperature

The Figure 7 shows the variation of Exhaust gas temperature with the BMEP. Increasing the load showed increase in the exhaust gas temperature. This is due to the higher amount of fuel injected at higher load. JOME and its blends showed higher exhaust gas temperature than the diesel fuel. The 20, 50 and 100 percent JOME blend showed average 3.8, 10.2 and 16.4 percent increased temperature compare to average diesel temperature. This can be due to the higher amount of fuel injected during combustion which indicates the higher heat loss in the form of exhaust gas temperature.

3.5 Carbon monoxide emission

The Figure 8 shows the variation of Carbon monoxide (CO) Emission with the BMEP. The CO emission is an ideal emission product assessor. It was observed that the increasing the load decreases CO emission. Increasing the concentration of Biodiesel leads to reduction in CO Emission. B20, B50 and B100 JOME showed 4.5, 9.2 and 13 percent average reduction in CO compared to neat Diesel fuel. The possible reduction of CO emission can be due to reduction in air fuel ratio due to increase of BSFC, leading to increase in temperature of combustion chamber. The presence of oxygen molecules in the JOME can also play a valuable roll mainly in the fuel rich regions. It may be also possible due to lesser C/H ratio and higher in cylinder temperature of JOME.

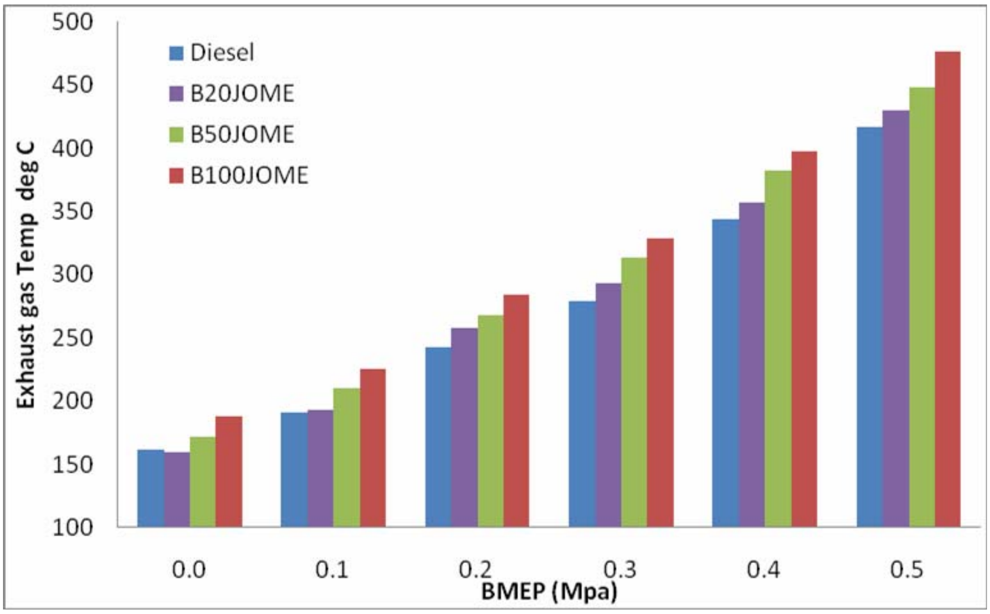

Figure 7. Variation of exhaust gas temperature with BMEP

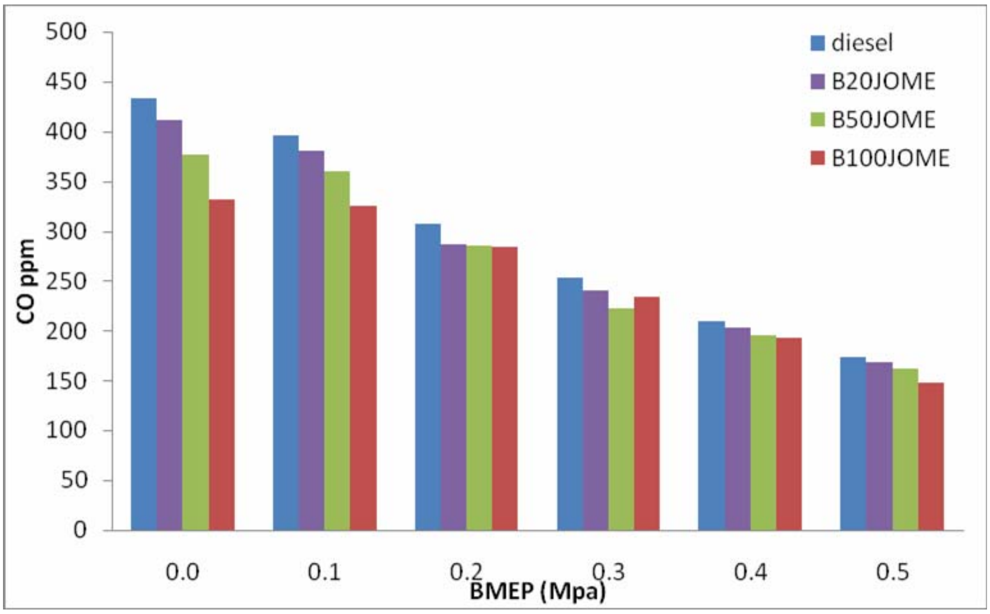

Figure 8. Variation of carbon monoxide emission with BMEP

3.6 Unburned hydrocarbon emission

Figure 9 shows the variation of Unburned Hydrocarbon (HC) Emission with the BMEP. It was observed that the increasing the load increases HC emission and the blending of JOME with diesel fuel decreases the hydrocarbon emission. Diesel fuel showed highest HC emission where as B100 showed lowest. The 20, 50 and 100 percent JOME blend showed average reduction of 9.8, 14.5 and 16.5 percent respectively compared to diesel fuel. The reduction in HC emission is the indicative of cleaner combustion. Rakopoulos et al. [25] concluded in to their review that HC emissions decreased as the oxygen in the combustion chamber increased, either with oxygenated fuels or oxygen-enriched air. Some of the researchers suggested the higher cetane number of biodiesel [6, 26] reduces the combustion delay, and such a reduction has been related to decreases in HC emissions [27, 28].

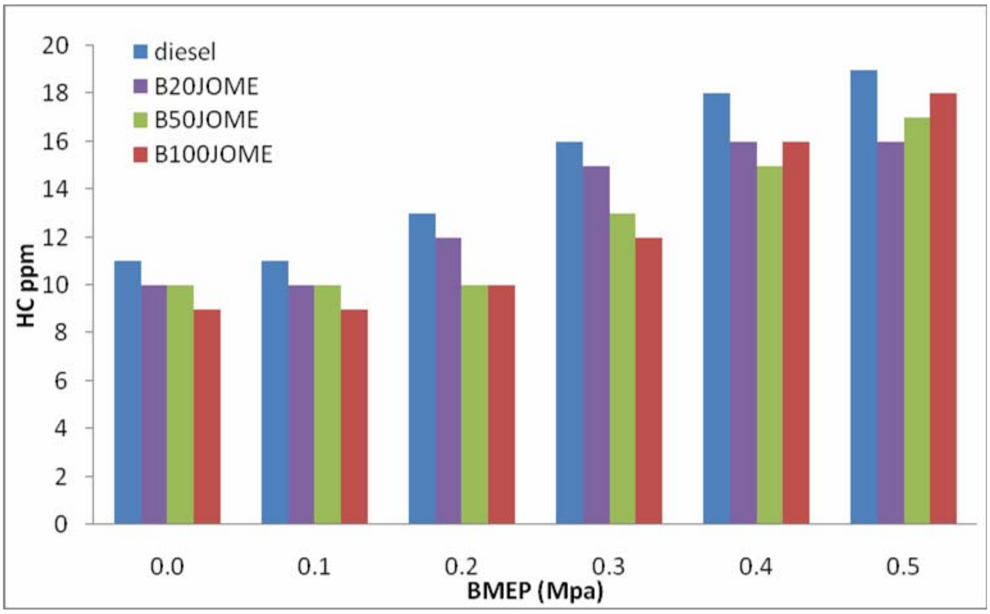

Figure 9. Variation of unburned hydrocarbon emission with BMEP

3.7 Nitrogen oxide emission

The Figure 10 shows the variation of Nitrogen oxides (NOx) emission with the BMEP. NOx emission increased with the engine load. The diesel fuel showed lowest NOx emission and the blending with JOME showed increased NOx emission. Comparatively higher NOx emission was observed at higher load. The 20, 50 and 100 percent blend showed an average of 4.9, 12.9 and 19.6 percent increase NOx compared to diesel fuel. The increase in the NOx emission may be attributed to injection advance due to physical properties of biodiesel (viscosity, density, compressibility, sound velocity). The Injection of biodiesel results in quicker pressure rise produced by the pump due to the higher bulk modulus, quick propagation towards the injectors due to its higher sound velocity, and less leakage in the pump due to its higher viscosity leading to an increase in the injection line pressure. Thus needle opens at an earlier point than the diesel fuel. The advance start of injection leads to higher ignition delay this leads to higher pressure and temperature peaks. Higher temperature peaks leads to increased NOx formation [29-31].

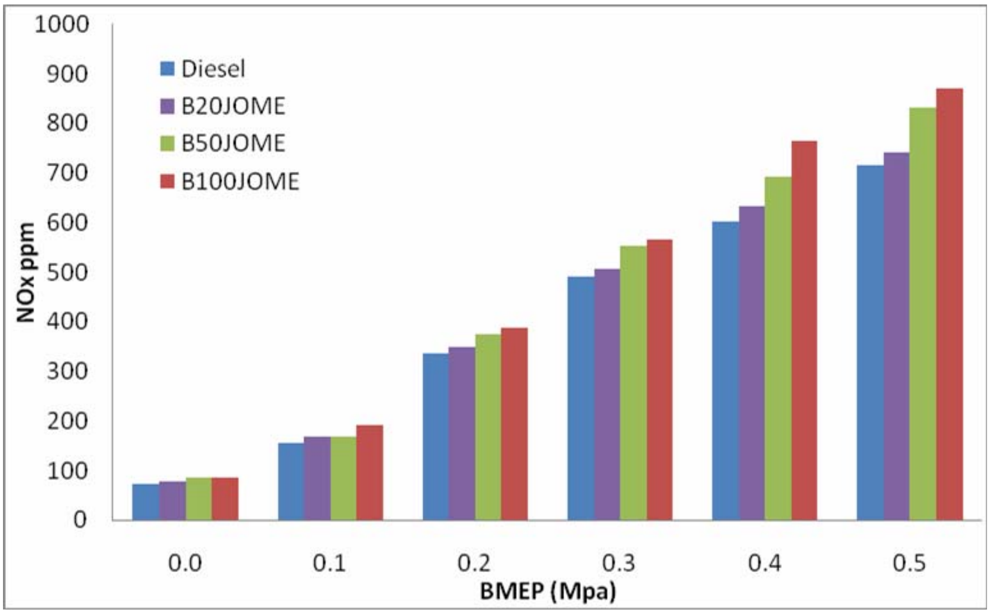

Figure 10. Variation of nitrogen oxide emission with BMEP

3.8 Smoke emission

Figure 11 shows the variation of Smoke emission with the BMEP. It was observed that the increasing the load increases smoke emission. As seen for all the fuels under consideration, when operating at light load, the smoke opacity is low, However, during transition to medium and heavy loads, it increases rapidly. The blending of JOME with diesel fuel decreases the smoke emission. The 20, 50 and 100 percent blend showed average reduction of 4.71, 6.02 and 9.75 percent respectively compared to diesel fuel. The possible reason of smoke reduction could be attributed to the oxygen content of the biodiesel molecule, which enables more complete combustion even in regions of the combustion chamber with fuel-rich diffusion flames [32-34], and promotes the oxidation of the already formed soot.

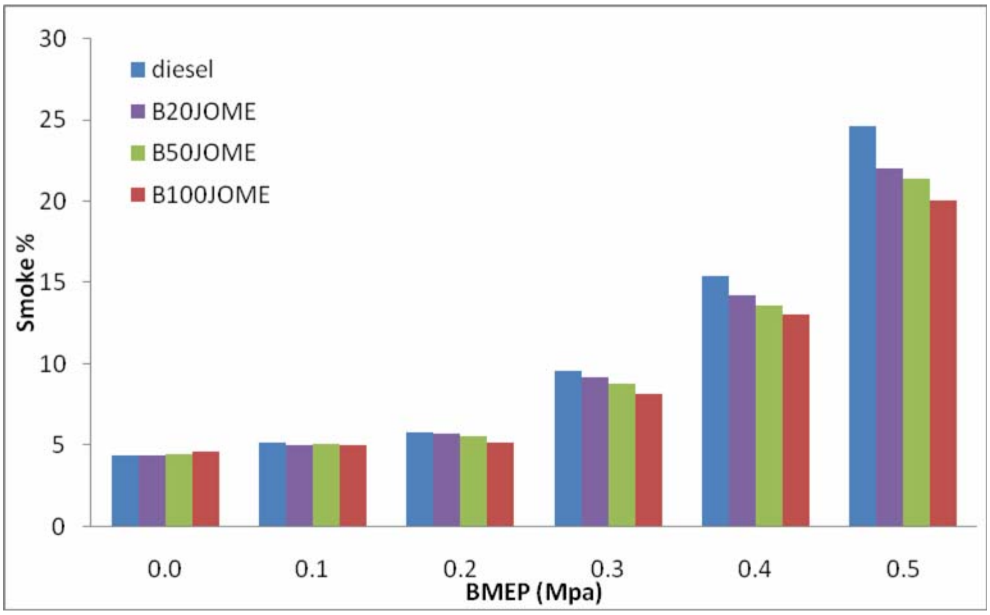

Figure 11. Variation of smoke emission with BMEP

4. Conclusion

In this study, biodiesel was prepared in our laboratory from Jatropha oil. The fuel properties of Jatropha biodiesel was compared with the Diesel fuel. The fuel properties of Jatropha biodiesel were found to be higher than diesel fuel. The Performance and emission parameters of JOME and its blends were compared with diesel fuel. Based on the experimental study, the main result of are summarized as follows.

- The Brake specific fuel consumption increases and Brake specific energy consumption decreases with the increase of JOME in the blend. Neat JOME showed highest of 21 percent average increase in BSFC however the 20 percent blend showed approximately same energy consumption as that of Diesel fuel.
- The Brake thermal efficiency was found to be decrease with the increase of JOME in the blend. The thermal efficiency of 20 percent blend was approximately same as that of Diesel fuel. Neat JOME showed highest of 9.3 percent average reduction in thermal efficiency.
- The Exhaust gas temperature of JOME and its blends was found to be higher than the neat diesel fuel.
- The emission of JOME and its blends showed reduction in carbon monoxide, Hydrocarbon and smoke emissions where as NOx emission was found higher compared to diesel.
- The 20 percent blend of JOME showed higher average reduction in CO, HC, and Smoke in comparison to average increase in NOx.

From these findings, it is concluded that Jatropha oil methyl ester could be safely blended with diesel and may be considered as diesel fuel substitutes. The use of bio fuels as I.C. engine fuels can play a critical role in serving the developed and developing countries to reduce the environmental impact of fossil fuels.

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