Effect of Jatropha Methyl Ester on the Performance of an Off-Road CI Engine

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Abstract

In this paper the prospects of Jatropha methyl ester (JME), as an alternative fuel for compression ignition engines has been studied. JME was developed using acid and base catalysts and 95.8 % conversion efficiency was obtained by applying two step transesterification method. The chemical, physical, and thermodynamic properties of JME were determined, which were analogous to those of mineral diesel. The fuel, in blended form, was used in a four stroke, three cylinders, water cooled naturally aspirated stationary diesel engine. The performance of the engine was evaluated by using blends of JME with diesel in various ratios at loads ranging from 8 to 89%. The experimental results showed that the blend of 25% JME and 75% diesel (J25) exhibited the best results for optimum load of 82%, which were: about 6% increase in brake specific fuel consumption, 29% decrease in CO, 3% decrease in HC, and about 2.5 % increase in NO_x, as compared to mineral diesel.

Keywords : Jatropha oil; Biodiesel; CI Engines; Exhaust Emission

Introduction

The importance of compression ignition (CI) engine has been established for many years but its significance is increasing rapidly now days. It is being used in power plants, construction industry, and agriculture, industrial, and transportation sectors. Generally the CI engines are used to develop large power and are preferred because of their higher thermal efficiency and longer life.

In general, the engines are fueled with mineral diesel, the reserves of which are depleting rapidly. It is anticipated that the reserves of mineral diesel will be exhausted in next 40 years (Global Reports and Publications 2007).

The other problem associated with diesel fuel is deterioration of the environment. Combustion of too much fuel creates global warming, green house effect, and damaging the ozone layer. The exhaust gasses produced as a result of combustion of mineral fuels are also health hazardous i.e. damaging nervous, circulatory, and respiratory systems and are also causing skin diseases.

Serious efforts are needed to be done to save the future of our next generation. The scientists and researchers are reviewing the prospects of use of biodiesel as fuel for CI engines, which is obtained by modifying the chemical structure of algae, vegetable oils and animal fats. The fuel is recyclable and degradable, available in every season and every where in the world at economical rates. Lower amount of CO_2, CO and un-burnt HC is found in the tail pipe of the engines, whereas the exhaust emissions are absolutely free from oxides of sulfur (Yuan, et. al. 2008, Phan and Phan, 2008). Unfortunately a bit higher amount of NO_x is observed in the exhaust emissions (Yage, et. al. 2008).

More than 300 vegetable oils have been identified which can be used to fuel the CI engines, which includes edible, non-edible and used cooking oils. Jatropha oil can be one of the best possible feedstock, which can be used to develop biodiesel (shahid and jamal 2011). It is non-edible oil, which can be grown in barren areas; less water and care is needed to grow this plant. But the problem associated with the use of jatropha oil to fuel the CI engines is its higher viscosity and specific gravity, and lower calorific value. The oil is chemically modified so as its physical properties become comparable with those of mineral diesel.

The modified oil is called biodiesel which can be used to fuel CI engines, in pure and blended form without any modification to be made to the engine. It has been reported that there is a reduction of about 68% in CO, 19% in CO_2, 8 % in soot, and 12% in un-burnt HC. However nearly 6 % increase in the amount of NO_x emission has been reported (Yuan, et. al. 2008, Rao et. al. 2008).

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In this paper, the prospects of jatropha oil as a substitute fuel for compression ignition engine has been studied.

Jatropha Plants

Jatropha plants have a wide variety with beautiful flowers, and have many species, but the most commonly grown in many parts of the world is Jatropha curcas. Pakistan has also started the plantation of Jatropha curcas. The average life of the plant is 50 years. Generally the plant height is 3 to 5 meters but can be up to 8 meters in favorable conditions. It can be grown in tropical areas and areas of heavy rains. Each plant yields 3 to 9 kg of fruit which contains 37% oil. The nuts are crushed to extract the oil.

Transesterification of Jatropha oil

The kinametic viscosity of jatropha oil is about 10 times higher as compared to mineral diesel, which is due to its complicated structure. The specific gravity of jatropha oil is 8-10% higher than that of diesel (Haldara et al. 2009). Various methods are applied to reduce the kinametic viscosity and specific gravity which includes pyrolysis, cracking, blending, micro-emulsification and transesterification.

Transesterification is most commonly used to modify the chemical structure of jatropha oil so as the kinametic viscosity is decreased from 38.1 to 3.8 cSt and specific gravity from 0.92 to 0.88 (Enweremadu and Mbarawa, 2009).

Mainly the jatropha curcas oil consists of triglycerides with a little content of diglyceride and monoglyceride. The triglycerides and diglyceride needs to be converted into monoglycerides and the byproduct glycerin has to be removed.

In this study, jatropha oil was treated with methanol in the presence of acid catalyst, with which its acid number was reduced from 3.6 to 1.1 mg KOH/g.

It was then reacted with methanol in the presence of NaOH catalyst for about two hours. The reaction was carried out at the temperature of 65±2°C. Pale yellow oil was floating above the thick dark brown glycerol. The glycerol or glycerine settled in the bottom of tank was removed and the pale yellow oil, named as jatropha methyl ester (JME) or biodiesel was separated. Although stiochiometric value of methanol to oil is 13 yet due to reversibility of the reaction higher amount of methanol (about 20%) is used to shift the balance of reaction toward the product side (Ban-Weiss et. al. 2007). The excess amount of methanol remained present in JME which was recovered with the help of distalisation method.

The PH value of JME was found to be 10, which was due to the presence of NaOH. The JME was washed with normal hot water repeatedly, to remove the NaOH till its PH value was reduced to 7.05, showing the neutrality of JME.

The physical, chemical, and thermodynamic properties of JME were tested and compared with those of mineral diesel as shown in Table 1.

Experimental Setup

The fuel was tested in a four strokes, three cylinder, direct injection, water cooled, naturally aspirated engine. The engine was connected to a three phase A.C electric generator. The required instrumentation was installed to measure the fuel flow rate, speed. The engine exhaust was measured with a five gas exhaust gas analyzer (IMR 3000), as shown in Figure 1.

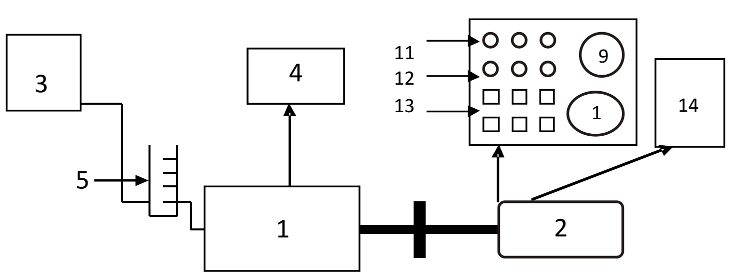

Figure 1: Schematic Diagram of Experimental Setup

1.	Diesel Engine	2.	Electric Generator	3.	Fuel Tank
4.	Graduated Glass Cylinder	5.	Tachometer	6.	Speed Controller
7.	Volt meters	8.	Ammeters	9.	Load Control Switches
10.	Load Bank	11.	Exhaust Gas Analyzer		

Results and Discussion

Blends of JME with diesel in ratios of 5, 10, 25, 50 and 75%, named as J5, J10, J25, J50 and J75 correspondingly, were prepared. Engine performance and exhaust emissions were evaluated using the blended fuel for the loads varying from 8 to 89% at a constant speed of 1500 rpm.

1. Effect of JME on Brake Specific Fuel Consumption

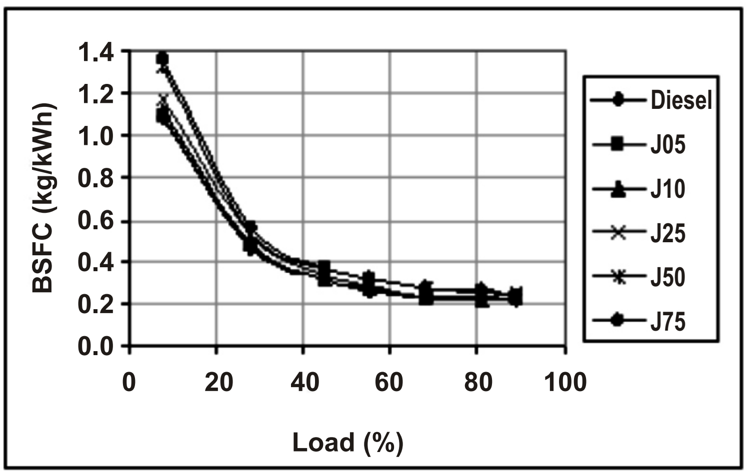

Figure 2: Effect of load on BSFC for various ratios of JME

It can be observed from Figure 2 that the amount of fuel consumed per unit brake power, known as brake specific fuel consumption (BSFC), decreases as load increases, which is due to the improvement in combustion phenomenon for higher loads. The decline is very sharp from 8 to 28% loads, and then it decreases gradually up to 65% load and becomes almost constant afterword.

The value of BSFC increases with the increase of ratio of JME in the blends for all loads. The reason is that the calorific value of JME is lower as compared to that of diesel, as shown in Table 1. However, the difference is not notable for J5, J10, and J25, particularly for optimum load of 82%.

2. Effect of JME on Carbon Monoxide Emission

Carbon monoxide (CO) is a colorless and odorless gas which is the most dangerous pollutant emission that destroys the nervous, circulatory, and respiratory systems. It causes sickness, headache, nausea, fatigue, dizziness, and even fatal (http://www.epa.gov/iaq/co.html 2012).

Carbon monoxide is produced when insufficient air/oxygen is available during combustion of fuel or insufficient time is available for combustion. The presence of CO in the exhaust emissions of engine indicates that the thermal efficiency has been reduced.

It can be observed from Figure 3 that the amount of CO increases with the increase of load using diesel and blends of diesel and JME. For instance, in case of use of diesel, CO increases from 80 to 180 ppm as load increases from 8 to 55% and then increases sharply till 68% load. Finally the curve becomes smooth till peak value of 310 ppm for 89% load.

The amount of CO decreases as the ratio of JME increases in the blends and the lowest amount of CO is found in the

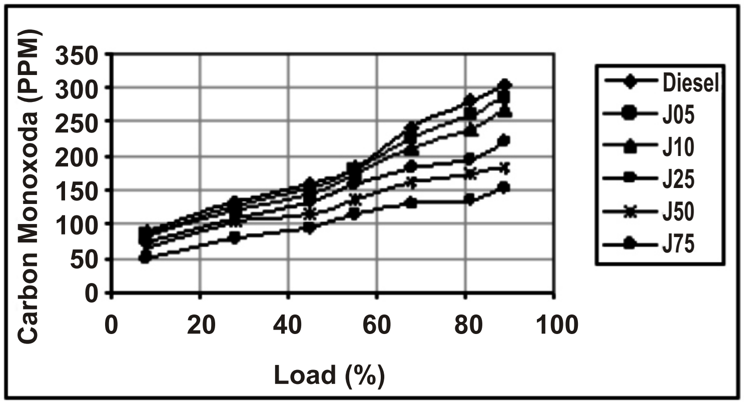

Figure 3: Effect of load on CO Emission for various ratios on JME

exhaust emissions when the engine is fueled with J75. For example its amount is reduced from 80 to 51 ppm and 310 to 150 ppm for extreme loads of 8 and 89% respectively.

The reason of decrease in CO in the exhaust emissions when CI engine is fueled with blends of JME is the presence of oxygen in biodiesel.

Combustion quality of JME fuel improves, as compared to diesel due to its higher cetane number which reduces the ignition delay and increases the combustion duration due to which amount of CO emission is reduced. Moreover the presence of oxygen in JME fuel improves the combustion. Huang et al. 2008 and Jindal et al. 2010 also reported the similar type of results.

3. Effect of JME on Total Hydrocarbon Emission

Although the presence of THC is not as harmful as CO yet a few of its compounds affect the nervous system. Breathing in presence of toluene (a compound of THC), with concentration of higher than 100 ppm, for several hours may cause fatigue, headache, nausea, and drowsiness (Draggan 2010).

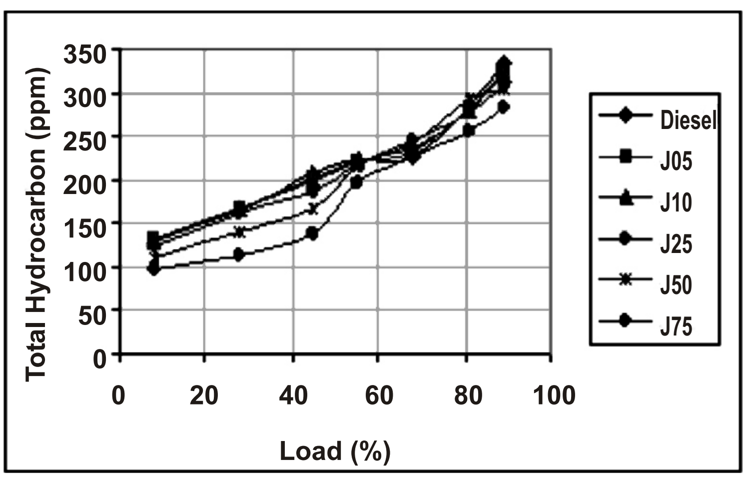

Figure 4: Effect of load on THC emission for various ratios of JME

It can be observed from Figure 4 that the amount of THC emission increases with the increase of load, in case of use of diesel as well as all blends of diesel and JME. For instance the amount of THC emission is 132 ppm, for 8% load, which increases to 333 ppm for 89% loads.

Fortunately, the amount of THC emission decreases with the increase of ratio of JME in the blends. For 8% load, 2 to

28% decrease in the amount of THC emission can be observed, as the ratio of JME in the blends is increased from 5 to 75%, respectively. Almost similar type of pattern can be observed for other loads. Some researchers also showed similar type of trends (Reddy and Ramesh 2006, Puhan et. al. 2005).
The reason of reduction of THC emission is the same, as has already been discussed, that the combustion quality is improved when JME is added in the fuel.
The combustion phenomenon can further be improved by modifying engine operating parameters like injection timing and injection pressure and making certain modifications in the injection system.

4 Effect of JME on Oxides of Nitrogen Emission

Oxides of nitrogen (NO_x) are very serious precarious pollutant emission. These are produced when the temperature inside the cylinder becomes higher than 1500ºC and its formation rate increases exponentionally when temperature becomes higher than 1800ºC. It reacts with water and forms nitric acid which makes corrosion on the tips of piston and cylinder. The higher concentration of NO_x in the environment may be one of the causes of acid rains.
The amount of NO_x increases for higher loads which are due to combustion of higher amount of fuel. Generally higher amount of NO_x are produced in the exhaust emissions of the engine when it is fueled with biodiesel(Nabi et. al. 2009).
It can be observed from Figure 5 that the amount of NO_x emission increases from 22 to 210 ppm as load increases from 8 to 82 %, because the rate of NO_x formation increases for higher loads due to rapid increase in temperature.
Unfortunately, the amount of NO_x emission increases when diesel fuel is replaced with biodiesel. Its value increases with the increase of ratio of JME in the blends. For instance the amount of NO_x emission is found to be 240.5, 241.5, 244.0, 256.0, and 270.7 ppm when engine is fueled with J5, J10, J25, J50, and J75, respectively, as compared to 239.5 ppm in case of use of diesel, for 89 % load.

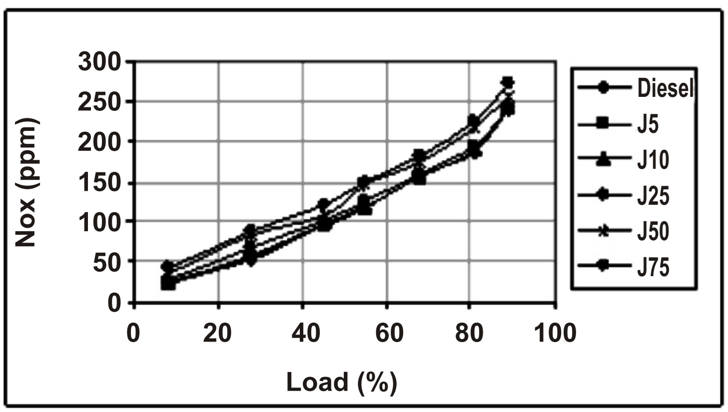

Figure 5 : Effect of load on No_x Emission for various ratios of JME

Almost similar type of trend is found for others loads. The increase of NO_x emission is due to the improvement of combustion quality, which has already been discussed. Less amount of soot is produced in case of use biodiesel, as compared to diesel (Ban-Weiss et. al. 2007). The soot is a source of dissipating heat, the temperature inside cylinder rises when less soot is formed, due to which higher amount of NO_x is produced.
It can be concluded that the difference in NO_x production is not big up to J25. Some other researchers also reported similar type of results (Yage, et. al. 2008, Kegl 2008). Hence it is suggested that the use of blend of diesel and JME with a ratio higher than 25% should be avoided. However, higher ratio of JME in blends can be used by modifying the fuel injection system and/or using after treatment, catalytic conversion, and exhaust gas re-circulation methods.

Table 1 : Properties of Diesel and JME.

Property	Unit	Diesel	JME	ASTMD6751-02
Density at 20 °C	Kg/m^3	850	890	870-890
Kinematic	mm^2/s	3.6	3.8	1.9 to 6.0
Viscosity at 40°C				
Flash Point	°C	68	195	> 120
Pour Point	°C	-6	-8	-15 to 10
Calorific Value	MJ/kg	42	38.5	--

Table 2 : Engine Specifications

Make/Type	Perkins/AD 3.152
Volumetric efficiency	85%
Bore	91.4 mm
Stroke	127.0 mm
Injection Timing	17° BTDC
Injection Pressure	190 bars
No. of cylinders/ Nozzles	3
No. of orifices in each Nozzle	4
Brake mean effective pressure	7.157 bars
Maximum engine power @ 1500 rpm	37 kW

Conclusions:

Jatropha curcas oil has sufficient potential to be used as feedstock for biodiesel.

The oil can be used after modifying the chemical structure via transesterification method.

JME can be successfully used to run a compression ignition engine.

The brake specific fuel consumption increases by 6% when J25 is used as fuel.

JME is an environmental friendly fuel. There is a decrease of about 29% in CO and 3% in THC, at optimum load of 82%, in case of use of J25 fuel.

There is about 2.5% increase in NOx when J25 is used as fuel at optimum load of 82%.

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