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Experimental investigation of diesel engine performance using two different bio-diesel fuels

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Abstract

The present energy crisis caused by continuous depletion of scarce fossil fuels has resulted into global price hike of crude petroleum and is bound to affect the economy of many countries. Apparently vegetable oils have been gaining worldwide attention as an alternative energy source because they are environment friendly and renewable in nature. Moreover, it operates well in a conventional diesel engine with very few or no engine modifications and can also be blended with diesel while still achieving substantial reductions in emissions. In the present work the performance, emission and combustion characteristics of twin cylinder direct injection diesel engine using diesel and bio-diesel were studied at different load conditions and different injection timings. The engine run on diesel and two different bio-diesel by various blend ratios of B20, B40, B60, B80 blend of MEOJ (methyl ester of *Jatropha*),MEON(methyl ester of Neem oil) and B100 at 1500 rpm. This paper presents the result obtained for measurements of NOx and smoke density at different speed and load conditions for the two different bio-diesel and their blends with diesel. A combustion analysis was performed where heat release rate and maximum cylinder pressure were examined.

Keywords : bio-diesel, combustion, emission, *Jatropha*, neem oil, performance

INTRODUCTION

The necessity to cope with environmental pollution problems, the changes in petroleum distillate demands and strict requirement of modern diesel engine leads to improved diesel fuel quality. The development of biomass derived substitutes for diesel fuel is a possible attractive out let as it could help improve diesel fuel quality. Althrough during the last decade methanol and bio diesel become the best known liquid bio fuels a number of studies examined different chemical structures as possible bio fuels and recorded their pros and cons (Serdari *et al.*, 2000; Nazar *et al.*, 2004; Patterson *et al.*, 2006).

Bio-diesel is derived from the vegetable oil. Neat vegetable oils or their blends with diesel pose various long term problems in compression ignition engines *e.g.* poor atomization characteristics, injector choking, carbon deposits, injector pump failure etc. (Agarwal and Das, 2001). Some time the engines may fail when operated on neat vegetable oils continuously for a longer period. The properties of vegetable oil such as, high viscosity, low volatility are responsible for the problem. It has been observed that esterification is a very effective way to modify the vegetable oil structure and reduce the viscosity (Reddy and Ramesh, 2004).

Bio-diesel, appear to be highly popular, since their properties are similar to mineral diesel and can be used in conventional diesel engines without significant modifications (Suh *et al.*, 2008). India being predominantly agricultural country requires major attention for the fulfillment of energy demand of a farmers. Irrigation is the bottleneck of Indian agriculture, it has to be developed on a large scale. But at the same time diesel fuel consumption must be kept to minimum level because of the price of diesel and its scarcity. The increased use of diesel in agriculture and transportation sectors has resulted in diesel crisis.

VARIABLES AFFECTING TRANSESTERIFICATION

The most important variables affecting the yield of bio-diesel from transesterification are molar ratio of alcohol to oil, reaction temperature, catalyst and presence of moisture and free fatty acids.

The Effect of Reaction Temperature

The rate of reaction is strongly influenced by the reaction temperature. However, given enough time, the reaction will proceed to near completion even at room temperature. The maximum yield of esters occurs at temperatures ranging from 60 ºC to 90 ºC.

The Effect of Molar Ratio

Another important variable affecting the yield of ester is the molar ratio of alcohol to vegetable oil. To shift the Transesterification reaction in forward direction, it is necessary to use either an excess amount of alcohol or to remove one of the products from the reaction mixture. The second option is preferred and feasible and hence in this way, the reaction can be driven towards completion.

The Effect of Moisture and Free Fatty Acids

Starting materials used for alkali-catalyzed transesterification of triglycerides must meet certain specifications. The glyceride should have an acid value

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less than 1 and should be substantially anhydrous. If the acid value is greater than 1, more KOH is required to neutralize the free fatty acid. Presence of water causes soap formation, which consumes the catalyst and reduces catalyst efficiency. The resulting soaps cause increase in viscosity, formation of gels and make the separation of glycerol difficult.

Composition of Vegetable Oils

- Petroleum diesel fuel is a complex mixture of saturated, unsaturated, branched, non-branched, straight chain and aromatic molecules with carbon atoms ranging from 12 to 18. In contrast, vegetable oils are a mixture of organic compounds ranging from simple straight chain compounds to complex proteins, fat-soluble vitamins and fatty acids.
- Fatty acids vary in carbon chain length and in the number of unsaturated bonds (double - bonds). Vegetable oils are usually triglyceride with a number of branched chains of different length.
- Vegetable oils have nearly 10% lower heating value and several times higher viscosity compared to diesel oil.

FUEL PROPERTIES

Properties of diesel *vs* bio-diesel used in the study are given in Table 1 (Source: Laboratory evaluation at ITALAB –Chennai, India)

Table 1. Properties of diesel *vs* bio-diesel used in the study

Test Property	Diesel	Bio-diesel used in the study	
		MEOJ	MEON
Density at 15° C kg/m^3	826.8	868.2	887.5
Kinematic Viscosity at 40°C	3.68	4.36	5.05
Flash Point (PMCC) °C, (min)	90	138	168
Gross Colorific value k.cal/kg	10896	10280	10220
Pour point °C	4.5	4	3
Sulphur, mg/kg, (max)	30	12	23
Carbon Residue (Ramsbottom), % by mass,	0.03	0.03	0.51
Moisture by D&S method %	Nil	0.14	0.12
Inorganic acidity	Nil	Nil	Nil
Cetane Number (min)	53	55	53
Acidity as mg of KOH/gm	0.30	0.12	0.27

MEOJ - Methyl Ester Of *Jatropha;* MEON - Methyl Ester Of Neem Oil

EXPERIMENTAL PROCEDURE

The experiments were done on neat diesel and mixture of biodiesel in a DI Diesel engine. The engine is a 10 Hp, 1500 rpm, Twin cylinder, 4-stroke, water cooled, over head value, vertical diesel engine. The schematic diagram of the experimental setup is shown in figure 1. The engine specifications are given in table 2. The engine was run at its rated speed. The engine speed was

Table 2. Specification of engine

Make	:	Simpsons S 217
Type	:	Vertical inline diesel engine, 4 stroke, water cooled, twin cylinder
Displacement	:	1670 cc
Bore × Stroke	:	91.4 mm × 127 mm
Compression ratio	:	18.5:1
Firing order	:	1, 2
Fuel	:	Diesel engine
Rated brake power	:	7.46 kW
Max. torque	:	10.3 Nm @ 1500 rpm
Ignition system	:	Compression Ignition
Ignition timing	:	24° bTDC (rated)
Injection pressure	:	240 kgf/cm^2
Fuel Injection pump	:	MICO inline, with mechanical governor and flange mounted
Inlet valve opens	:	13° bTDC
Exhaust valve closes	:	10° bTDC
Dry weight	:	200 kg
Dimensions	:	489mm × 536mm × 756mm
Starting	:	Battery

Test Engine

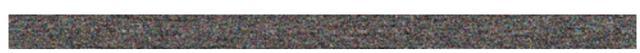

Figure 1. Experimental apparatus and measuring system

controlled by governor. The engine runs on neat diesel and four different blends of biodiesel namely B20, B40, B60, and B80 and (B100). It is coupled with a swing field electrical dynamometer. AVL 444 Di-gas analyzer was used to measure the oxides of nitrogen. AVL 437 smoke meter was used to measure the density of exhaust gases. AVL combustion analyzer was used to analyze the combustion characteristics.

RESULTS AND DISCUSSION

Performance Characteristics

Engine performance characteristic are the major criteria that governs the suitability of a fuel. This study is concerned with the evaluation of fuel consumption and brake thermal efficiency of the diesel and bio-diesel blends.

Fuel consumption

The fuel consumption of the engine operating on the different fuels is plotted in figure 2 at different loads. Overall, diesel exhibited the best fuel consumption whilst B20 MEOJ is almost similar and the slightly lower values might be due to their lower calorific value and poor spray characteristics.

Figure 2. Fuel consumptions *vs* Brake power

Brake Thermal Efficiency

Figure 3 shows the brake thermal efficiency with respect to brake power. The thermal efficiency is lower for all bio-diesel blends compared to diesel. The break thermal efficiency of B20 MEOJ is nearly similar to that of diesel. Higher viscosity and lower volatility leads to poor mixture formation and hence lower thermal efficiency.

Figure 3. Brake thermal efficiency *vs* Brake power

Emission Characteristics

Various emission characteristics like smoke density, NOx, and particulate matter, were analyzed as they have a direct impact on pollution and on the phenomena of global warming.

Smoke Density

Variation of smoke density for different fuels are shown in figure 4. Bio-diesel smoke reducing effect could be attributed to its displacement of aromatic and short chain paraffin hydrocarbons and its higher oxygen content compared with diesel. It is concluded B20 MEOJ oil has low smoke density.

Figure 4. Smoke density *vs* Brake power

Oxides of Nitrogen Emission

Variation of the NOx with brake power is shown in figure 5. NOx formation is highly dependent on temperature and availability of Oxygen. There are several reported results of slight increase in NOx emissions for bio-diesel. It is quite obvious that with bio-diesel, due to improved combustion, the temperature in the combustion can be expected to be higher and with the higher amount of oxygen present, it leads to formation of higher quantity of NOx. NOx emission is lower in B 20 MEOJ compared to all other fuels.

Figure 5. Oxides of nitrogen *vs* Brake power

Particulate matter

Figure 6 shows the variation of particulate matter with brake power particulate matter. Particulate matter emissions of B20 MEOJ is lower compared to diesel and B40 MEON. The oxygen content of bio-diesel helps to reduce the formation of particulate matter during the diffusion combustion phases, while the higher oxygen content of methanol will further reduce the particulate matter.

Figure 6. Particulate matter *vs* Brake power

Combustion analysis

Cylinder Pressure

The comparison of cylinder pressure with crank angle is as shown in figure 7. The value with B 20 blend of MEOJ is highest compared to other fuels. As the diesel quantity in the blends increases, the amount of fuel taking part in the uncontrolled combustion stage of the mixture reduces, which result in a higher pressure rise. The cylinder pressure depends upon burned fuel fraction during the premixed burning phase.

Heat Release

The variation of heat release rate with crank angle is shown in figure 8. The heat release rate is higher in B20 MEOJ compared to other fuels. This is because the atrophy oil methyl ester ignition delay was higher as compared to ignition delay for diesel as a fuel on a constant speed diesel engine.

Figure 7. Cylinder pressure *vs* Crank angle

Maximum Cylinder Pressure with Number of Cycles

Variation of peak pressure with crank angle is shown in figure 9. The maximum pressure is higher for B20 MEOJ compared to other fuels. Cylinder pressure characterizes the ability of the fuel to mix well with air and burn. High peak pressure corresponds to large amount of fuel burned in premixed combustion stage.

Figure 8. Heat release rate *vs* Crank angle

Optimum injection timing for diesel and bio-diesel

The injection timing was varied for the two blends B20 and B40 each of MEOJ, and MEON to optimize the injection timing in steps 2 from 24 to 30 for the best blend based on performance, combustion and emission. The optimum injection timing of 26 bTDC for B40 MEOJ and B20 MEON is based on the performance and emission characteristics.

Figure 9. Cylinder pressure *vs* Number of cycles

Fuel consumption

The variation of fuel consumption with brake power is shown in figure 10. The B20 MEON is higher in fuel consumption compared to others. Due to oxygen content and consequently lower calorific values of the fuels containning bio-diesel this behavior was expected.

Brake Thermal Efficiency

The variation of brake thermal efficiency with brake power is shown in figure 11. The brake thermal efficiency is higher in B40 MEOJ compared to other fuels when the engine is operating on bio-diesel. The properties of the fuels are modified with the presence of methanol which leads to decrease in the viscosity and Cetane number. There are two factor changes in brake thermal efficiency. The methanol will increase the ignition delay, leading to a larger percentage of fuel burned in the premixed mode. This will lead to increase in the brake thermal efficiency. The methanol in the fuel will tend to lower the combustion temperature, leading to a decrease in the brake thermal efficiency.

Figure 10. Fuel consumption *vs* brake power

Figure 11. Brake thermal efficiency *vs* Brake power

Emission Parameter

Smoke Density

Comparison of smoke density with brake power is shown in figure 12. The smoke density is minimum in B 20 MEON compared to other fuels. Smoke density for bio-diesel blends is also noticed to be generally lower than that of diesel. This is due to oxygenated nature of bio-diesel where more oxygen is available for burring which reduces the smoke density.

Figure 12. Smoke density *vs* Brake power

Oxides of Nitrogen Emission

Variation of oxides of nitrogen with brake power is shown in figure 13. The NOx results from the oxidation of atmospheric nitrogen at high temperature inside the combustion chamber of the engine. The NOx is higher in bio-diesel. The NOx emission is lower with diesel when compared to other fuels.

Figure 13. Oxides of Nitrogen Emission *vs* brake power

Particulate matter

Variation of particulate matter with brake power is shown in figure 14. The particulate matter is found to be lower in B 40 MEOJ compared to other fuels. Rich air fuel mixtures in the localized regions of the combustion chamber will lead to particulate emissions.

Combustion Analaysis

Figure 14. Particulate matter *vs* brake power

Cylinder Pressure

Figure 15 shows the cylinder pressure with crank angle. The peak pressure for B40 MEOJ has shown maximum pressure. As the diesel quantity in the blends increases the amount of fuel taking part in the uncontrolled combustion, it results in pressure rise.

Figure 15. Cylinder pressure *vs* Crank angle

Heat Release Rate

Variation of heat release rate is shown in figure 16. The heat release rate was higher for B40 MEOJ compared to other fuels. The advance injection timing is better for B40 MEOJ. The reason for this is due to the increased combustion taking place during the diffusion phase.

Figure 16. Heat release *vs* Crank angle

Maximum Cylinder Pressure

Variation of peak pressure is shown in figure 17. The peak pressure for B40 MEOJ has shown maximum pressure followed by diesel fuel. This is due to the poor combustion rate.

Figure 17. Maximum cylinder pressure *vs* Number of cycles.

CONCLUSION

The performance, emissions and combustion characteristics of diesel engine using bio-diesel have been as follows.

- The B20 is for MEOJ and B40 for MEON gave the optimal results on performance and emission.
- The brake thermal efficiency in B20 MEOJ is close to that of the diesel.
- Smoke density and particulate matter is lower in bio-diesel compared to diesel at all load conditions.
- NOx for bio-diesel was 952 ppm and for diesel 526 ppm .Hence the Nox values for biodiesel is higher.

- Cylinder pressure is higher in B20 MEOJ compared to diesel.
- On the whole methyl ester blend is found to have satisfactory performance similar to diesel engine fuel.

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