Performance and Exhaust Emission Analysis of Direct Injection Diesel Engine using Pongamia Oil Compared for Conventional Diesel

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Abstract: *The use of biodiesel, the methyl esters of vegetable oils are becoming popular due to their low environmental impact and potential as a green alternative fuel for diesel engine. The aim of this study is to potential use of Pongamia oil methyl ester as a substitute for diesel fuel in diesel engine. Various proportions of Pongamia and Diesel (B25, B50, B75, and B100) are prepared by transesterification process on volume basis and used as fuels in a four stroke single cylinder direct injection diesel engine to study the performance and emission characteristics of these fuels and compared with neat diesel fuel. The engine tests have been carried out with the aim of obtaining brake thermal efficiency, BSFC, Emission levels and the behavior of the diesel engine running on Pongamia oil and its blend. This blend B25 substantially reduces the CO emission and emission of NOx in exhaust gases. When biodiesel was used as the fuel, acceptable changes occurred in the performance values. The maximum brake mean effective pressure (BMEP) obtained with the biodiesel was slightly higher than that obtained with the diesel fuel, with the difference being just slight under maximum power. While biodiesel increase the maximum engine power, it reduces the brake specific fuel consumption. Changes of maximum cylinder pressure have occurred at the same magnitude for both fuels for the same engine speeds. The overall analysis has shown that biodiesel has potential as an alternative fuel in conventional internal combustion engines.*

Keywords: Pongamiaoil, Transesterification, Methylester, Emission, Performance

1. Introduction

"Biodiesel fuel" is a renewable, biodegradable, mono alkyl ester combustible liquid fuel derived from agricultural plants seed oils or animal fats. "In its neat form, biodiesel contains little or no sulphur or polynuclear aromatic hydrocarbons and has a high cetane number. When burned in a diesel engine, biodiesel reduces PM, CO, and HC emissions. The nature of the PM emissions also changes. When compared to diesel fuel, biodiesel fuelled engines produce PM with a higher volatile organic fraction and lower non-volatile organic or carbon fraction. However, biodiesel also tends to increase emissions of NOx. There are some technical issues remaining concerning the use of higher blend levels. These include the potential for poor oxidative stability, incompatibility with fuel system low-temperature flow properties, and increased oxides of nitrogen (NOx) emissions. However, numerous studies have shown that modern diesel engines require no modifications and have no problems using biodiesel fuel. Today several fuel blends and emission control techniques were evaluated. There are two types of vegetable oils (i) edible vegetable oils and (ii) non-edible vegetable oils.

Observations show that methyl ester of non-edible vegetable oils are almost comparable to the diesel engine performance, Rao et al., [5] studied on Pongamia, jatropha and neem methyl esters as biodiesel on CI engine and observed that their diesel blends showed reasonable efficiencies, lower smoke, CO and HC. Pongamia methyl ester showed better performance compared to jatropha and neem methyl esters. T. Bhakar et al. [6] observed that Jatropha oil in low heat rejection (L.H.R) engine gave better performance and lower smoke emissions compared to the normal diesel engine.

Anbumani and Singh [7] investigated the use of esterified vegetable oils as bio-fuel for CI engine. They observed that among the different vegetable oils used in their studies, esterified sunflower oil blend at 15% by volume with diesel fuel exhibited best combustion and performance in terms of total fuel consumption, specific fuel consumption and brake thermal efficiency etc. Vegetable oils have high viscosity and low volatility that affects the atomization and spray pattern of fuel. That leads to incomplete combustion and severe carbon deposits, injector choking and piston ring sticking. There are various methods to reduce the viscosity like emulsification, pyrolysis, blending with diesel, transesterification etc. In the present study the use of non-edible vegetable oil (Biodiesel) in diesel engine to save the environment as well as to ensure independency of fuel resources is discussed. Many researchers have been shown interest to develop technology on non-edible vegetable oils to make it practically viable and comparable with diesel oil.

In this present investigation Pongamia methyl ester is selected for the test and it's suitability as an alternate fuel is examined. This is accomplished by blending of Pongamia bio diesel with diesel in B25(25:75), B50(50:50), B75(75:25) and 100% on volume basis. Then the performance and emission characteristics of diesel engine using various blends and compared the results with those of near diesel fuel. The properties that determine the performance of biodiesel in a stationary diesel engine includes; mass flow rate, torque, input power, brake power, brake mean effective pressure, specific fuel consumption, break thermal efficiency and the relationship between pressure and time. These were investigated. From theoretical models, the graphs of mass flow rate versus engine speed, specific fuel consumption

versus engine speed, and torque versus engine speed, break thermal efficiency versus engine speed and pressure versus time for both the biodiesel and conventional diesel were obtained.

2. Experimental Setup

The Present study was carried out to investigate the performance and emission characteristics of Pongamia methyl esters in a stationary single cylinder diesel engine and to compare it with diesel fuel. The tests were conducted on a four stroke, water cooled, single cylinder, direct injection diesel engine having a rated power output of 5.2kW at a constant speed of 1500 rpm. The engine was coupled with eddy current dynamometer to measure power output. The specifications of the engine are given in Table 1, and the schematic of the experimental setup is shown in Figure 1. AVL smoke meter was used to measure the smoke density of the exhaust from diesel engine and the exhaust emissions like HC, CO, CO2 and NOx were measured by AVL exhaust gas analyzer. The engine was operated on diesel first and then on methyl ester of Pongamia. The different fuel blends and mineral diesel were subjected to performance and emission tests on the engine. The engine and dynamometer were interfaced to a control panel, which is connected to a computer. This computerized test rig was used for calculating the engine performance characteristics like brake thermal efficiency, brakes specific fuel consumption and for recording the test parameters like fuel flow rate, temperatures, air flow rate, load etc.

The engine was warned up and before taking all readings the engine was allowed to come at steady state condition. All the observations are taken thrice to get a reasonable value. The performance data were then analyzed from the graphs regarding thermal efficiency, brake specific fuel consumption and smoke density of all fuels.
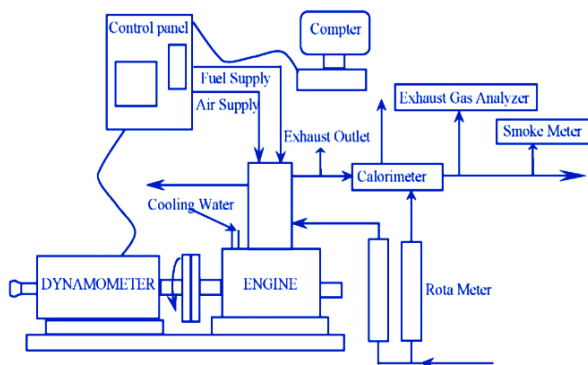
Figure 1: Schematic diagram of experimental setup

Table 1: Specification of engine

Type of engine	Four stroke single cylinder diesel engine
Bore	87.6mm
Stroke	110mm
Compression ratio	17.51:1
Rated speed	1500
Rated power	7HP (5.2kW)@1500 rpm
Displacement volume	661.5cm^3

Table 2: Properties of test fuels

Fuel	Viscosity (cSt)at 38^0C	Density kg/m3at 38^0C	Calorific value kJ/kg	Flash point ^0C
Diesel	3.85	831	42850	56
Pongamia oil	29.8	267	37255	206
B25	3.9	842	42096	102
B50	4.2	851	41360	116
B75	4.35	859	40650	123
B100	4.46	872	39890	174

Engine Performance Equations

Torque

Engine torque is measured by the dynamometer. The engine is clamped on a test bed and the shaft is connected to the dynamometer rotor. The torque can be found as follow:

$$\tau = \frac{P}{\varpi} \; or \; \tau = \frac{60P}{2\pi N}$$

Where:

P=Power (kW)
N=Angular Speed (rpm)
τ=Torque (Nm)

Input Power is given by the

IP=mQ$_{net}$
Where:
IP=Input Power(kW)
Q$_{net}$=is the lower calorific value of the fuel.

The mass flow rate is calculated by multiplying the volumetric flow rate with density of the fuel

$$m = \frac{V}{t} \times 1 \times 10^{-3} \times \rho \times \mu$$

Where:

m=Mass Flow Rate of Fuel(kg/s)
V=Volume Flow Rate of Fuel(cm^3/s)
ρ=Density of Water(kg/cm^3)
μ=Specific gravity(kg/cm^3)

Break mean effective pressure

Using the practical way to calculate BMEP (psi) since the torque and engine displacement are known then later converting to the unit back to "bar". The equation to use is given as;

$$\text{BMEP} = \frac{150.8 \times \text{torque} \; (\text{lbft})}{Displacement \; (ci)}$$

Brake specific fuel consumption (BSFC)

$$\text{BSFC} = \frac{m}{\text{BP}}$$

Where mass flow rate=fuel consumption (L/s) x Specific gravity (Kg/L)

Thermal efficiency

With break power and input power, efficiency of the engine can be calculated using

$$\eta_{BT} = \frac{bp}{IP} \times 100$$

3. Results and Discussion

The tests were conducted on a direct injection diesel engine for different blended of Pongamia methyl ester with diesel. Analysis of performance parameters and emission characteristics such as brake power, brake specific fuel consumption brake thermal efficiency, exhaust gas temperature, hydrocarbon, carbon monoxide, carbon dioxide, oxides of nitrogen etc are determined.

3.1. Brake Thermal Efficiency

In Fig2 the brake thermal efficiency is plotted against brake power for diesel, Pongamia methyl ester and its blends and neat diesel at constant speed of the engine. It was observed that with the increase of the load brake thermal efficiency increase in all cases. At medium load condition BTE of B50 was slightly higher than the neat diesel but at the full load condition BTE of neat diesel were only 1.5% higher than 25B and 5.5% higher than B100.
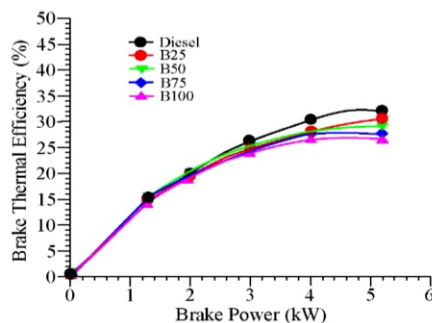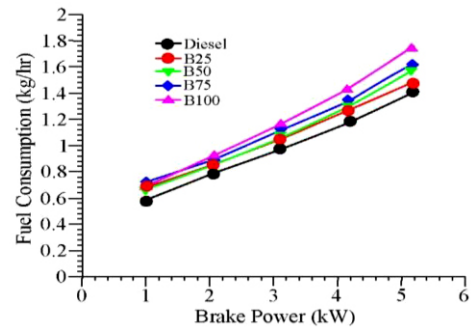

Figure 2: Variation of brake thermal efficiency with brake power

3.2. Fuel Consumption

The variation of fuel consumption with brake power for different blends of biodiesel and neat diesel are shown in fig.3 at constant speed. It was observed that consumption of fuel increases with the increase of brake power. The diesel fuel consumption was less in all load conditions due to the high calorific value of diesel than the diodiesel blends. At low load condition biodiesel B100 consumption was 0.08kg/hr higher than neat diesel and at full load condition it was 0.36kg/hr higher than neat diesel due to low calorific

value of biodiesel B100. For B25 blend fuel consumption was slightly higher than neat diesel fuel.

Figure 3: Variation of fuel consumption with brake power

3.3. Specific Fuel consumption (SFC)

The variation of specific fuel consumption with brake power for different blends of biodiesel and neat diesel are shown in fig.4 at constant speed. From graph it is observed that the specific fuel consumptions decreased with the increase of brake power. The specific fuel consumption of biodiesel blends is higher than the neat diesel in all load conditions due to high viscosity of the biodiesel blends. The specific fuel consumption for B25 blend is closer to the neat diesel fuel.
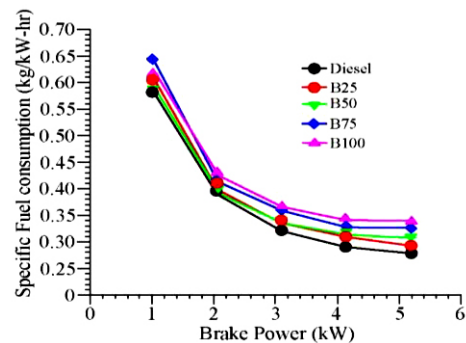
Figure 4: Variation of specific consumption with brake power

3.4. Exhaust Gas Temperature (EGT)

The variation of exhaust gas temperature with brake power for different blends of biodiesel and neat diesel are shown in fig.5. From the graph it is observed that the exhaust gas temperature increases with the increase of the brake power. The exhaust gas temperature of the biodiesel blends in all load condition is higher than the neat diesel fuel due to high flash point temperature and high viscosity of the biodiesel. The exhaust gas temperature of biodiesel B100 is 60.50C higher than diesel fuel.
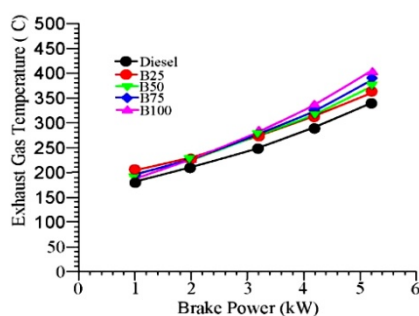
Figure 5: Variation of exhaust gas temperature with brake power

3.5. Smoke Density (HSU)

The variation of smoke density with brake power for different blends of biodiesel and neat diesel are shown in fig.6 at constant speed 1500 rpm. From the graph it is observed that the smoke density increases with the increase of brake power and smoke density of biodiesel blends are higher than neat diesel. This is due to high specific gravity and high density of the biodiesel blends than diesel fuel. At full load condition smoke density of B25 is closer to diesel fuel and smoke density of B100 is 24(HSU) higher than diesel.
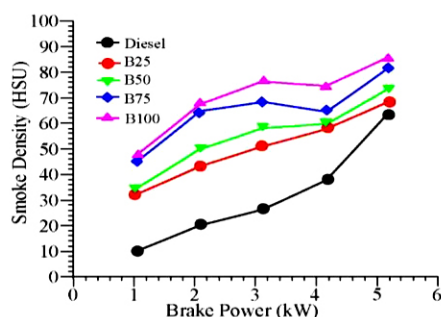

Figure 6: Variation of smoke density with brake power

3.6. Hydrocarbon Emission (HC)

The variation of hydrocarbon emission with brake power for different blends of biodiesel and neat diesel are shown in fig.7 at constant speed 1500 rpm. Form the graph it is observed that the hydrocarbon emission of different blends of biodiesel blends is less than the neat diesel fuel due to the less amount of carbon and hydrogen content of the biodiesel blends. The hydrocarbon emission of biodiesel blend B50 is closer to diesel and lowest hydrocarbon emission is observer for B100 biodiesel blend.
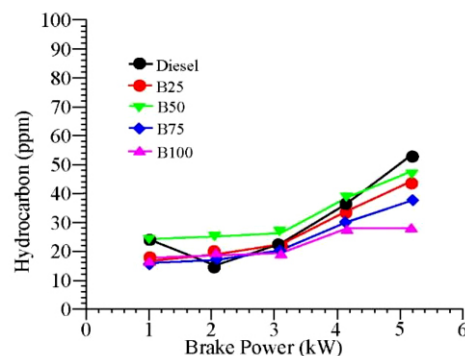

Figure 7: Variation of hydrocarbon emission with brake power

3.7. Carbon Monoxide Emission (CO)

The variation of carbon monoxide emission with brake power for different blends of biodiesel and neat diesel are shown in fig.8 at constant speed 1500 rpm. From the graph it is observed that the carbon monoxide emission increases with the increase of the brake power of the engine. At low load condition CO emission of all the blends is less than diesel. At full load condition CO emission of biodiesel blends B50, B75 and B100 are higher than diesel due to incomplete combustion of blends into the combustion chamber. CO emission of B25 is 3% lower to neat diesel fuel at full load condition.
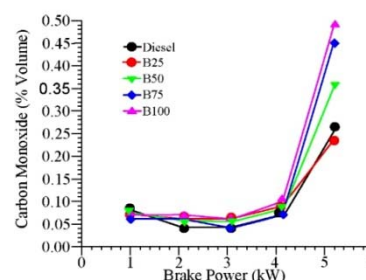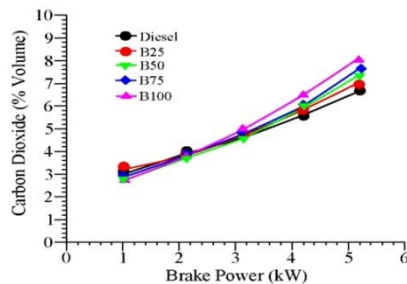

Figure 8: Variation of carbon monoxide emission with brake power

3.8. Carbon Dioxide Emission (CO$_2$)

The variation of carbon dioxide emission with brake power for different blends of biodiesel and neat diesel are shown in fig.8 at constant speed 1500 rpm. From the graph it is observed that the carbon dioxide emission increases with the increase of the brake power. At low load condition the carbon dioxide emission of B50, B75 and B100 is less than neat diesel due to elemental oxygen content by the vegetable oil. At full load condition CO2 emission is higher due to complete combustion of the fuels.

Figure 9: Variation of carbon dioxide emission with brake power

3.9. Oxides of Nitrogen Emission (NO$_X$)

The variation of oxides of nitrogen (NOx) emission with brake power for different blends of biodiesel and neat diesel are shown in fig.9 at constant speed 1500 rpm. From the graph it is observed that the NOx emission of all the biodiesel blends is higher than the diesel and increases with the increase of the brake power due to the high combustion temperature in the combustion chamber for extra oxygen molecules of biodiesel and high cetane number of the biodiesel blends. At high load condition NOx emission is same of biodiesel of biodiesel blend B75 and neat diesel.
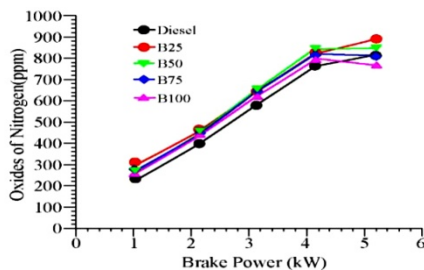
Figure 10: Variation of oxides of nitrogen with brake power

3.10. Oxygen (O$_2$)

The variation of oxygen with brake power for different blends of biodiesel and neat diesel are shown in fig.10 at constant speed 1500 rpm. From the graph it is observed that the level of oxygen decreases with the increase of brake power. At full load condition the biodiesel blends of B25, B50, B75, and B100 have lower oxygen level due to complete combustion of the biodiesel blends. At low load condition oxygen level of the blend B25 is higher level of oxygen at all load condition.
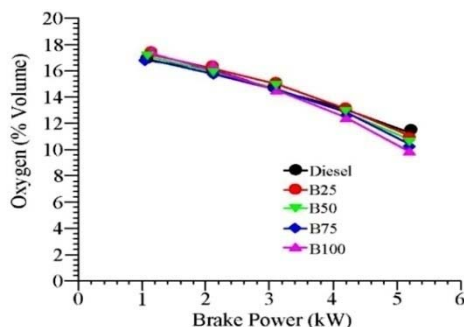
Figure 11: Variation of oxygen with brake power

4. Conclusion

A four stroke water cooled single cylinder direct injection diesel engine was run successfully using Pongamia oil and its blends (B25, B50, B75 and B100) as fuel. The performance and emission characteristics have been analyzed and compared to baseline diesel fuel. The following conclusions are made with respect to the experimental results.

a) At full load condition brake thermal efficiency of the biodiesel blends were marginally lower than the neat diesel fuel.
b) Specific fuel consumption for B25 blend was close to neat diesel fuel at full load condition.
c) Exhaust gas temperature of biodiesel blends were higher than neat diesel fuel at all load conditions and EGT of B100 was 60.5^{0}C higher than diesel fuel at full load condition.
d) The smoke density of the Pongamia oil blends was higher than the neat diesel fuel at all load conditions.
e) There was 24% reduction of hydrocarbon of B100 than neat diesel at full load condition.
f) There was 4% reduction of CO emission of B25 than neat diesel at full load condition.
g) There was 2% reduction of NO$_x$ of B25 blend than neat diesel at full load condition.

Pongamia oil, a biodiesel is renewable and biodegradable. Its B25 blend performance and emission characteristics are closer to diesel. So it can be used as substitute of diesel without modification of the engine hardware.

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