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# Performance and emissions characteristics of a diesel engine with various injection pressures using biodiesel

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**Abstract**

This paper presents the suitability of Pongamia methyl ester oil as a source of renewable fuel substituting petrodiesel in CI engine. The properties of esterified Pongamia oil are closer to diesel properties. In the present work, experiment is conducted in a single cylinder direct injection diesel engine fuelled with diesel and 100% Pongamia methyl ester as fuel at different injection pressure at varying loads. The injection pressures are varying from 180 bar to 220 bar. The performance parameters like brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and exhaust emissions (CO, HC, NOx and smoke) were measured and analyzed. The results indicated that the brake thermal efficiency is increased about 1.5% for 100% PME at 220 bar injection pressure. The BSFC, CO and Smoke were decreased about 7%,33% and 25% respectively for 100% PME at 220 bar compared to 180 bar injection pressure. The nitrogen oxide emission (NO) was increased about 10% for 100% PME with 220 bar injection pressure. However pure Pongamia methyl ester (by volume) can be used at higher injection pressure safely in a conventional CI engine without any engine modification that could help in controlling air pollution.

**Keywords:** Biodiesel, Diesel engine, Pongamia methyl ester.

## Introduction

Fuels derived from crude oil have been the major source of world's energy and transportation sector. It is predicted that fossil sources will be depleted in the near future and increase the production of synthetic fuels derived from non-petroleum sources like biomass and biofuels. Biofuels are environmentally friendly, similar to petrol and diesel in combustion properties. Biodiesel is produced from vegetable oil, used frying oil and animal fat with an alcohol such as methyl alcohol or ethyl alcohol. This chemical reaction requires a catalyst, usually a strong base such as sodium or potassium hydroxide, and produces a new chemical compounds called methyl or ethyl esters.

A large amount of research has been carried out on the performance of engines fueled with biodiesel, including biodiesel produced from soya, sunflower, cotton seed and rapeseed oil. However, there is limited data regarding biodiesel produced from *Pongamia pinnata* seed oil. With the large amount of pinnata produced in India, it is important to investigate engine performance using biodiesel from pongamia oil, as well as analyzing the exhaust emissions produced.

With the rapid development of rural agricultural production and rapid growth of local industry in India, the discrepancy between demand and supply of energy has become an increasingly acute problem. Reduction of engine emissions is a major research aspect in engine development with the increasing concern over environmental protection and the stringent exhaust gas regulation (Rosca *et al.,* 1997; Lapuerta *et al.,* 2008).

Biodiesel can serve several purposes: lubrication, which is seen with blends of two to five percent biodiesel; fuel supplement, which is seen with blends in the area of twenty percent biodiesel (B20); and as a stand-alone fuel, when pure biodiesel (B100) is used. As mentioned previously, blends such as B2 or B5 can be utilized as a lubricating fuel in place of high Sulphur fuel. Most engine manufacturers warrant engines for use with these small percentage blends, and many manufacturers require that new vehicles leave a lot with these types of blends (Heywood, 1998).

From the previous work on vegetable oils, it was observed that the use of them and their blends with diesel is a viable alternative to use in CI engines. However, it is required to reduce the viscosity of these by some means such as preheating, blending, or transesterification, etc., to use them straight in the conventional CI engines without any major modifications (Ganesan *et al.,* 1994; Canakci *et al.,* 2001; Pramanik *et al.,* 2003). In addition, PME is renewable in nature, which is available in many parts of the world and appears to be very attractive to use in CI engines. In this work, straight PME was chosen because it is available in India abundantly. It is also relatively inexpensive and almost non-edible. Therefore PME becomes a good source of energy.

Pandian *et al.* (2009) studied experimentally the performance of a pongamia methyl ester with twin cylinder diesel engine at various injection timings like $18^o$, $21^o$, $24^o$, $27^o$ and $30^o$ bTDC. They reported that the BSFC and NOx are decreased with retarding the injection at $18^o$ bTDC .But the CO and HC are increased with retarding the injection timing and it decreases with advancing the injection timing. Shivakumar *et al*. (2010) have studied the performance and emission characteristics of a diesel both experimentally and theoretically by artificial neural networks at different compression ratios. They reported that the BTE of 20% Pongamia methyl ester blend is closer to diesel fuel. The CO, HC and smoke were reduced for biodiesel blends for higher compression ratios. The NOx emissions were increased for higher compression ratios.

Dorado *et al.* (2003) have tested the direct injection diesel engine with the use of olive oil methyl ester. It has been reported that the CO, $CO_2$, NOx emissions were significantly reduced compared to diesel fuel. It has also been reported that the $SO_2$ emissions were less because of biodiesel contain less sulphur content. Nazar *et al.* (2004) have studied the use of coconut oil as an alternative fuel in direct injection diesel engine. It has been reported that the peak thermal efficiency for coconut oil was 28.67% and for diesel. It was 32.51%. It has also been concluded that the smoke, CO, HC and NOx emissions were lower than diesel emissions while the exhaust gas temperature was higher than diesel.

Deepak Agarwal *et al.* (2006) have investigated the effect of linseed oil, mahua oil, and rice bran oil and linseed methyl ester in a diesel. It has been reported that brake specific fuel consumptions were higher for vegetable oil compared to diesel fuel. It has been concluded that the 20 % of linseed oil methyl ester blend was optimum that improved the thermal efficiency and reduced the smoke density. The objectives of the present study are to investigate the performance and emission characteristics of a single cylinder direct injection diesel engine with various nozzle opening pressures using Pongamia oil methyl ester blends as fuel. The measured values are analyzed and compared with the base engine.

Lakshminarayana Rao *et al*. (2008) have studied the combustion analysis of diesel engine with various blends of rice bran oil methyl ester and their results showed that the ignition delay, rate of heat release are decreases also HC and CO emissions are decreased and NOx emissions are slightly increased with increase in blends. Suresh Kumar et al studied the performance and emissions of diesel engine with *Pongamia pinnatta* methyl ester at various blends and they reveal that 40 % blends by volume provide better performance and improved exhaust emissions.

**Preparation of bio-diesel**

Trans esterification is a chemical process of transforming large, branched, triglyceride molecules of vegetable oils and fats into smaller, straight chain molecules, almost similar in size to the molecules of the species present in diesel fuel. The process takes place by the reaction of vegetable oil with alcohol in the presence of a catalyst. Pongamia oil contains high free fatty acids (FFA) upto 20 %. It requires two step processes to convert into biodiesel. The first step is acid-catalyzed esterification by using 0.5% $H_2SO_4$, alcohol 6:1 molar ratio with respect to the high FFA Pongamia oil to produce methyl ester by lowering the and the next step is alkali-catalyzed trans esterification (Malaya Naik, 2008).

In alkali-catalyzed trans esterification process, Pongamia oil react with methyl alcohol in the presence of catalyst (NaOH) to produce glycerol and fatty acid ester. The methyl alcohol (200 ml) and 8 gram of sodium hydroxide were taken in a round bottom flask to form sodium methoxide. Then the methoxide solution was mixed with Pongamia oil (1000 ml). The mixture was heated to $65^oC$ and held at that temperature with constant speed stirring for 2 hours to form the ester. Then it was allowed to cool and settle in a separating flask for 12 hours. Two layers were formed in the separating flask. The bottom layer was glycerol and upper layer was the methyl ester. After decantation of glycerol, the methyl ester was washed with distilled water to remove excess methanol. The transesterification improved the important fuel properties like specific gravity, viscosity and flash point. Table 1 lists the properties of diesel, Pongamia oil and its methyl ester. The properties of diesel, methyl ester of Pongamia oil are shown in Table.1.

*Table 1. Properties of diesel and Pongamia oil methyl ester*

| S.N | Properties | Diesel | PME |
|---|---|---|---|
| 1. | Density(kg $^{-3}$) | 830 | 890 |
| 2. | Calori1c value (MJ kg$^{-1}$) | 42.490 | 37.91 |
| 3. | Viscosity (cSt) | 4.59 | 6.87 |
| 4. | Cetane number | 45 -50 | 49 |
| 5. | Flash point ($^{\circ}$C) | 50 | 187 |

Experimental studies were performed in two sections; the first section is the preparation of Pongamia oil methyl ester and determination of its physical and chemical properties. The second section consists of engine performance tests with Pongamia oil methyl ester and comparison to diesel fuel.

*Experimental setup*

The performance and exhaust emission tests were carried out in a constant speed, direct injection diesel engine. The specifications of the test engine are listed in Table 2.

*Table 2.Test engine specifications*

| | |
|---|---|
| Engine | Kirloskar, AV-I, |
| Power | 3.68 kW |
| Bore (mm) | 80 |
| Stroke(mm) | 110 |
| Compression ratio | 16.5:1 |
| Speed (rpm) | 1500 |
| Injection pressure(bar) | 180 |
| Injection timing | $23^o$bTDC |

The engine was coupled with rope dynamometer consisting of a loading platform to provide the brake load. Two separate fuel tanks were used for the diesel fuel and fried cooking oil methyl ester. The fuel consumption was determined by measuring the time taken for a fixed volume of fuel to flow into the engine. The exhaust

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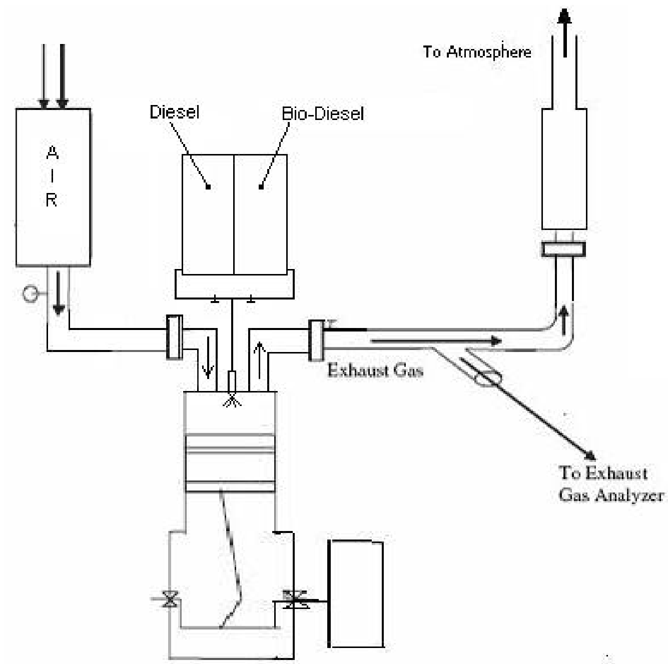
*Fig. 1. Schematic representation of experimental setup*




emissions were measured by the AVL 444 five gas analyzer and the smoke opacity were measured by Bosch smoke meter. The schematic of the experimental set up as shown in Fig.1.

**Results and discussion**

*Brake thermal efficiency*

The variation of Brake thermal efficiency with load for diesel and neat biodiesel are shown in Fig. 2. In all the cases brake thermal efficiency is increased with an increase in load with increase in nozzle opening pressure. This can be attributed to reduction in heat loss and increase in power with increase in load. It is observed that the higher brake thermal efficiency is obtained for 220 bar with 100% biodiesel compared with the other two injection pressures. The BTE for diesel, PME with 180 bar, 220 bar and 220 bar are 30.45%, 25.65%, 26.52% and 27.24% respectively at full load. The increase in BTE may be due to better atomization and vaporization biodiesel fuel at higher injection pressure, resulting in better combustion.

*Brake specific fuel consumption*

The variation of brake specific fuel consumptions with load for diesel and neat biodiesel are shown in Fig. 3. For all cases BSFC reduces with increase in load. The reverse trend in the BSFC may be due to increase in biodiesel percentage ensuring lower calorific value of fuel. Another reason for the change in BSFC in biodiesel in comparison to petroleum diesel may be due to a change in the combustion timing caused by the biodiesel's higher cetane number as well as injection timing. The BSFC for diesel, PME with 180 bar, 220 bar and 220 bar are 0.242 kg/kWh, 0.275 kg/kWh, 0.265 kg/kWh and 0.256 kg/kWh respectively at full load. The decrease in BSFC may be better atomization and vaporization biodiesel fuel.

*Fig. 2. Variation of Brake thermal efficiency with BP*

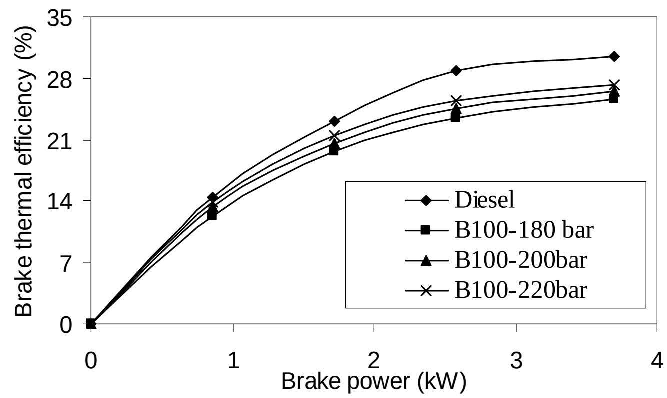
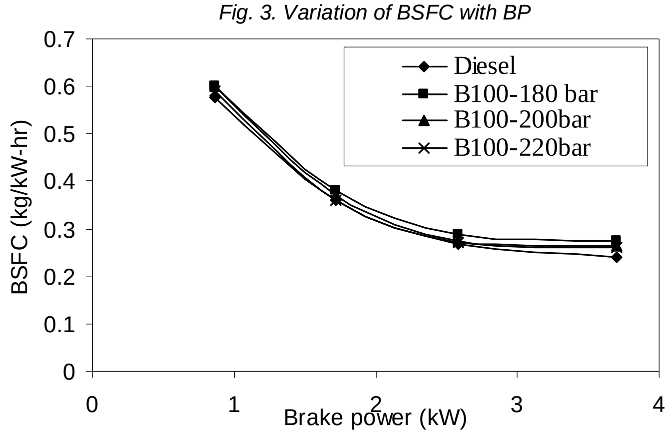



*Fig. 3. Variation of BSFC with BP*




*Carbon monoxide emission (CO)*

Fig. 4 shows the plots of carbon monoxide (CO) emissions of PME and diesel fuel operation at different load conditions and different NOP. The plots show reducing CO emissions at higher loads when running on 100% PME. The decrease in carbon monoxide emission for biodiesel is due to more oxygen molecule present in the fuel and more atomization of fuel due to higher NOP as compared to that of diesel. The CO emissions for diesel, PME with 180 bar, 220 bar and 220 bar are 0.06 % Vol, 0.045% Vol, 0.035% Vol and 0.03% Vol respectively at full load. The decrease in CO emission may be due to better vaporization biodiesel fuel at higher injection pressure and more oxygen present in the biodiesel, resulting in complete combustion.

*Fig. 4. Variation of CO emissions with BP*

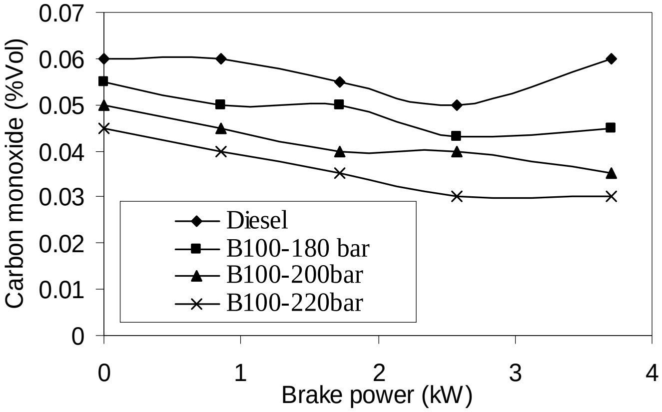



*Fig. 5. Variation of NO emissions with BP*

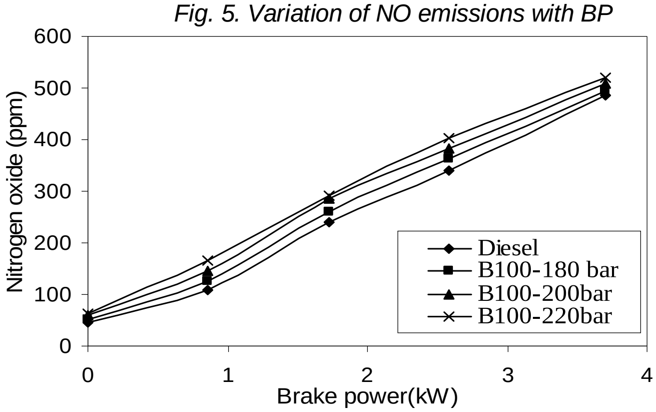
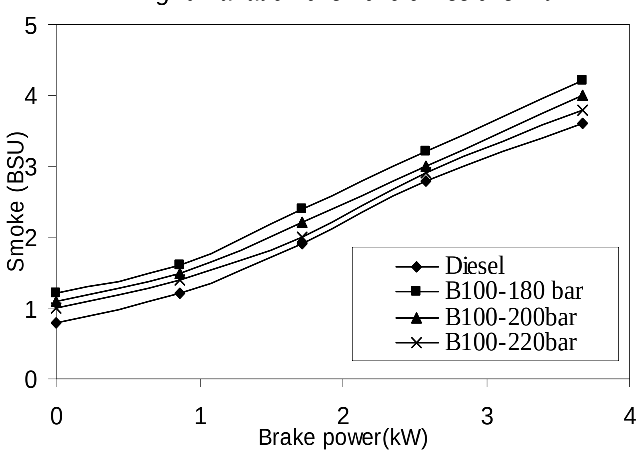



*Fig. 6 Variation of smoke emissions with BP*




*Nitrogen oxide emission (NO)*

The variation of nitrogen oxide emissions at different engine load and different injection pressures are presented in Fig. 5. The formation of nitrogen oxides is significantly influenced by the cylinder gas temperature and the availability of oxygen during combustion. It is observed that the NO emissions increased with increase in load and increase in nozzle opening pressures. This may be due more oxygen atoms present in the biodiesel and better atomization of biodiesel particles by the higher injection pressures resulting in higher NO emissions. The NO emissions for diesel, PME with 180 bar, 220 bar and 220 bar are 486 ppm, 495ppm, 508 ppm and 520 ppm respectively at full load. The increase in NO emission may be due to higher injection pressure and more oxygen present in the biodiesel, resulting in increased peak combustion temperature.

*Smoke emission*

The variation of smoke emissions at different engine load and different injection pressures are presented in Fig. 6. The exhaust of the CI engines contains solid carbon particles that are generated in the fuel-rich zones within the cylinder during combustion. These are seen as exhaust smoke and cause an undesirable odorous pollution. The smoke emission increases with an increase in the load for all fuels. The smoke density decreased with increase in nozzle opening pressures more oxygen atom present in the biodiesel, resulting in better combustion of biodiesel. The smoke value for diesel, PME with 180 bar, 220 bar and 220 bar are 3.6 BSU, 4.2 BSU, 4 BSU and 3.8 BSU respectively at full load. The 10% decrease in smoke may be due to better atomization and vaporization of biodiesel at higher injection pressure and more oxygen present in the biodiesel, resulting in complete combustion.

## Conclusions

The brake thermal efficiency is increased by 1.5% for NOP 220 bar for neat PME compared with 180 bar pressure. The brake specific fuel consumptions are decreased by 7% for NOP 220 bar for neat PME compared with 180 bar pressure. The CO and Smoke emissions are decreased about 33% and 25% for PME at 220 NOP compared with 180 bar pressure. The NO emissions are increased about 10 % for PME at NOP 220 bar compared with 180 bar pressure. On the whole, it can be concluded that the engine can be run in 220 bar NOP and giving better performance and reduction in emission.

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