# Emission and Combustion Characteristics of Java Plum Seed Biodiesel on DI Diesel Engine.

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## Abstract

In this study, the combustion and emission characteristics of biodiesel produced from Java plum seed oil and its blends and diesel fuel were compared. The experiments were performed in a single-cylinder direct injection diesel engine at steady-state conditions over the constant RPM (1500 RPM). During the experiments, the specific fuel consumption (SFC), pollutant emissions like hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen NOx) and smoke, and in-cylinder pressures were measured. The experimental results showed that, biodiesel blends had a 26.79 - 24% reduction in brake thermal relative to diesel fuel. On the other hand, Java plum seed biodiesel drastically increases CO, HC and smoke, while the NOx emission decreased. The combustion analysis showed that the addition of Java plum seed biodiesel to diesel fuel reduced the ignition delay period and also reduced the premixed peak. These results showed that Java plum seed biodiesel and its blends could be used without any modifications as an alternative fuel in diesel engine.

**Keywords:** Methyl ester, Transesterification, Biodiesel, Emission, Combustion

### 1. Introduction

Biodiesel is described as fatty acid methyl or ethyl esters from vegetable oils or animal fats as an alternative fuel of diesel. It is renewable, biodegradable, non toxic and oxygenated fuel [1,2]. Even though many researches pointed out that it might help to decrease greenhouse gas emissions, improve income distribution and promote sustainable rural development [3-6]. The primary cause is being deficient in of new knowledge about the influence of biodiesel in diesel engines. For instance, the reduction of engine power, as well as the increase of fuel consumption for biodiesel, is not as a large amount as anticipated; the early research conclusions have been reserved, it is more prone to oxidation for biodiesel, which may result in mysterious gums and sediments that can plug the fuel filter, and thus it will influence engine durability [7,8]. In the automotive sector, the higher oxides of nitrogen (NOx) and HC emission from the diesel engine are its main problems with respect to air pollution. In this perspective, the reductions in HC and CO emissions from the engine can be obtained by the use of biodiesel. But, NOx emissions are slightly increased for the biodiesel blended diesel fuel [9-13]. High viscosity, surface tension and density of biodiesel influence atomization by increasing the mean fuel droplet size, which in turn increases the spray tip penetration. The higher the mean droplet size of biodiesel is because of the lower Weber number [14]. Many researchers have found that the viscosity and density are affected the atomization, where as density is the lowest on mean droplet size and consequently to get better fuel atomization viscosity should be the first alternative of a fuel's physical property to be decreased [15-17]. The above mentioned problem can be solved by blending biodiesel with diesel fuel, which will decrease the viscosity of the fuel. India is a hot country and has a suitable climate for the development of the Java plum tree. India has potential for the growth of Java plum trees and these trees are cultivated in forests and waste lands. The growth of Java plum trees in waste lands also reduces soil erosion and lead to enhance of rain fall. The seeds obtained from Java plum trees are crushed in an explore to get the oil. The present investigation is carried out to describe the complete production process, analysis of thermo-physical properties and working characteristics of Java plum seed biodiesel in a direct injection compression ignition engine.

### 2. Biodiesel Production and Property Analysis

#### 2.1 Transesterification

The reaction mechanism for alkali catalyzed transesterification was formulated as three steps. Transesterification is the process of conversion of the triglyceride with an alcohol in the presence of a catalyst to form esters and glycerol. Vegetable oil is subjected to chemical reactions with alcohol like methanol or ethanol in the presence of a catalyst. Since the reaction is reversible, excess methanol is required to reduce the activation energy, thereby shifting the equilibrium to the product side. The triglyceride present in the vegetable oil is converted into biodiesel. Among the alcohols used for the transesterification reaction are methanol and ethanol. However, when methanol is processed, methyl esters are formed, whereas ethanol produces ethyl esters. Both these compounds are biodiesel fuels in different chemical combinations. The mechanism of the transesterification reaction scheme is illustrated by Figure 1. Transesterification of rapeseed oil produces ester whose properties is comparable with those of diesel fuels. Schematic diagram of biodiesel plant is shown in Figure 2. The properties of the diesel fuel and the Java plum seed biodiesel are summarized in Table 1.

$CH_2OOCR$ | | $CH_2OH$
|
$CHOOCR$ + $3CH_3OH$ ---------> $3CH_3OOCR$ + $CHOH$
| *(Catalyst NaOH)* |
$CH_2OOCR$ | | $CH_2OH$
*Triglyceride* *Methanol* *Methyl Esters*
*Glycerol*

**Figure 1** Mechanism of transesterification process

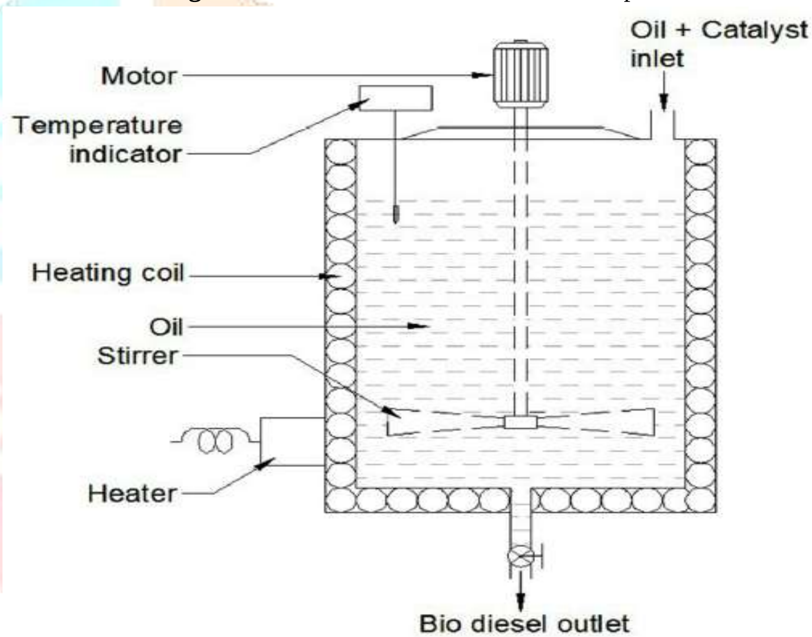


**Figure 2** Schematic diagram of Biodiesel Plant

**Table 1** Properties of diesel and biodiesel blends

| Properties | Specific gravity@ 15/15 (C (GM/cc) | Kinematic Viscosity @ 40 (C (CST) | Flash Point (°C) | Fire Point (°C) | Gross calorific value (Kcals/kg) | Density @ 15 (C (GM/cc) |
|---|---|---|---|---|---|---|
| **Diesel** | 0.835 | 2.56 | 44 | 48 | 10,660 | 0.834 |
| **Java plum seed Biodiesel 100%** | 0.8896 | 5.2 | 78 | 90 | 9960 | 0.8935 |

**2.2 FTIR Analysis**

The FTIR spectrum of diesel and Java plum seed methyl ester are shown in Figure 3 and 4. From the Figures, there are two bands that correspond to the methyl and methylene groups in the area between 2920 and 2856 $cm^{-1}$; the first peak is recognized to the stretching vibrations of the terminal $CH_2$ group in the olefins. The second peak corresponds to stretching, vibration and contraction of the C-H and $CH_2$ bonds of the ethylene and methyl groups. These bands show similarity between diesel fuel and methyl esters. The most pertinent folding vibrations of the methyl groups are consistent with the phase folding deformation (between 1350 - 1400 $cm^{-1}$ bands) and the beyond degenerate phase folding deformation (between 1450 - 1470 $cm^{-1}$ bands). The folding ascends from twisting and matching that seem at low frequencies. The methylene group offerings scissors vibrations at 1457 $cm^{-1}$. Based on the above discussion, it is clear that both diesel and Java plum seed methyl ester are saturated hydrocarbons and the presence of hydrocarbon group C-H indicates that it has a potential as a fuel for diesel engine.

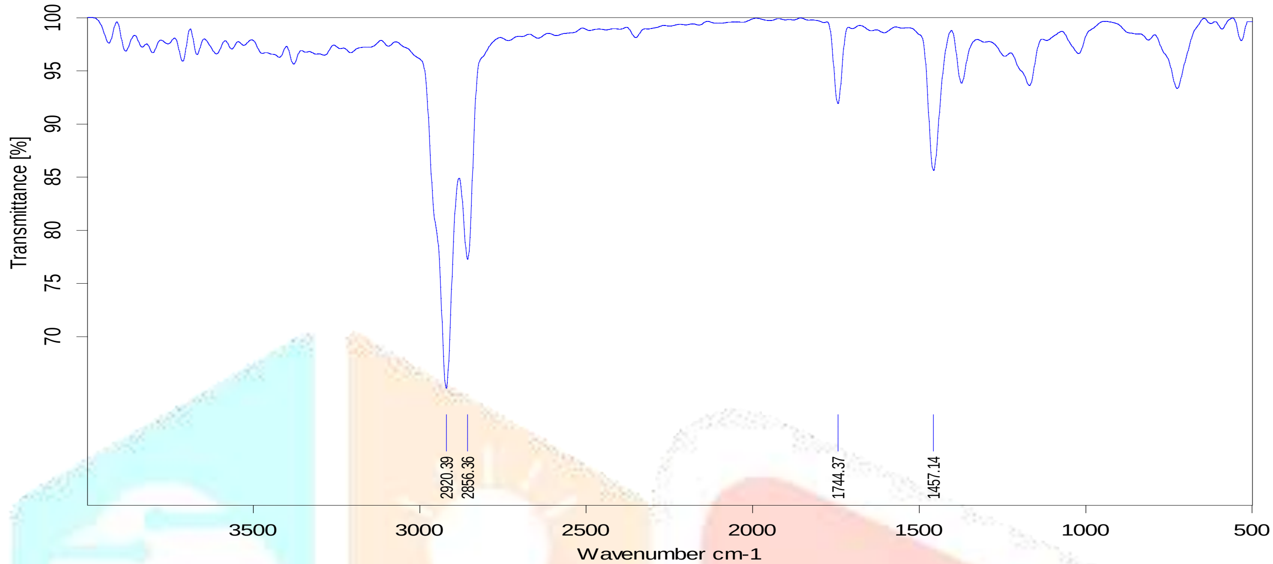


**Figure 3** FTIR spectrum of diesel fuel

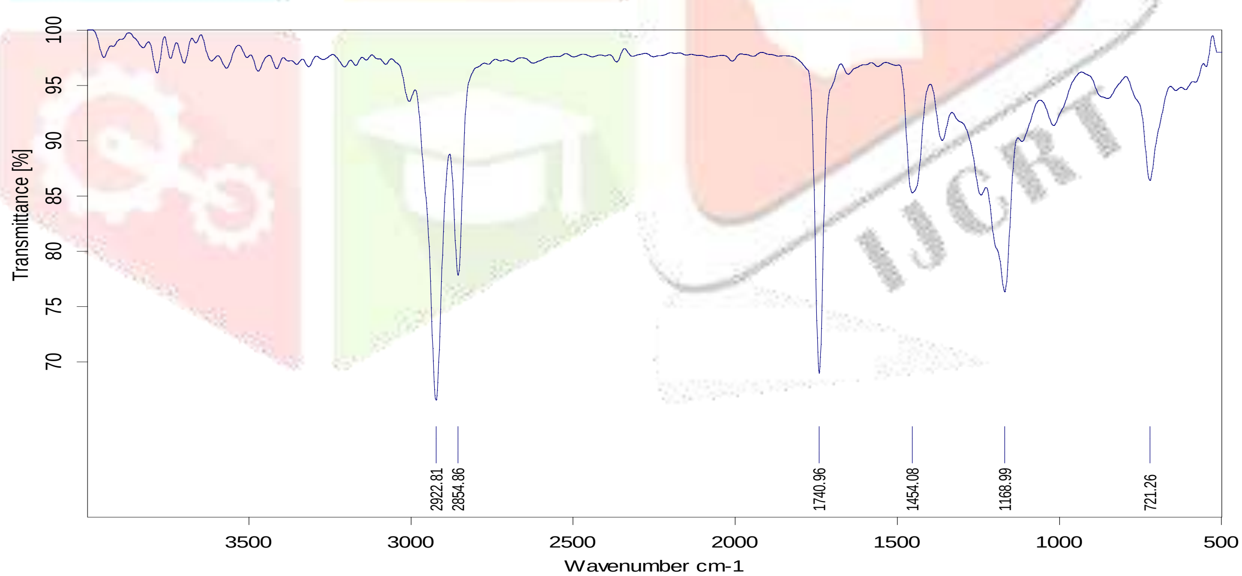


**Figure 4** FTIR spectrum of Java plum seed methyl ester

### 3. Experimental Setup

The diesel engine used for experimentation is Kirloskar TV1, single cylinder, water cooled engine coupled to eddy current dynamometer with computer interface. The detailed specification of the engine is shown in Table 2. A data acquisition system is used to collect and analyze the combustion data like in-cylinder pressure and heat release rate during the experiment by using AVL transducer. The tests are conducted at the rated speed of 1500 RPM. In every test, exhaust emission such as nitrogen oxides (NOx), hydrocarbon (HC), carbon monoxide (CO) and smoke are measured. From the initial measurement, brake thermal efficiency (BTE) and specific fuel consumption (SFC) with respect to brake power (BP) for different blends are calculated. The blends of biodiesel and diesel used were B20 and B40. B20 means 20 % biodiesel fuel and 80% of diesel fuel by volume. In order to study the effect of biodiesel blends on the engine combustion and emission characteristics, the injection timing was kept constant at 23° BTDC. The effect of biodiesel blends was studied and the results were compared with neat diesel.

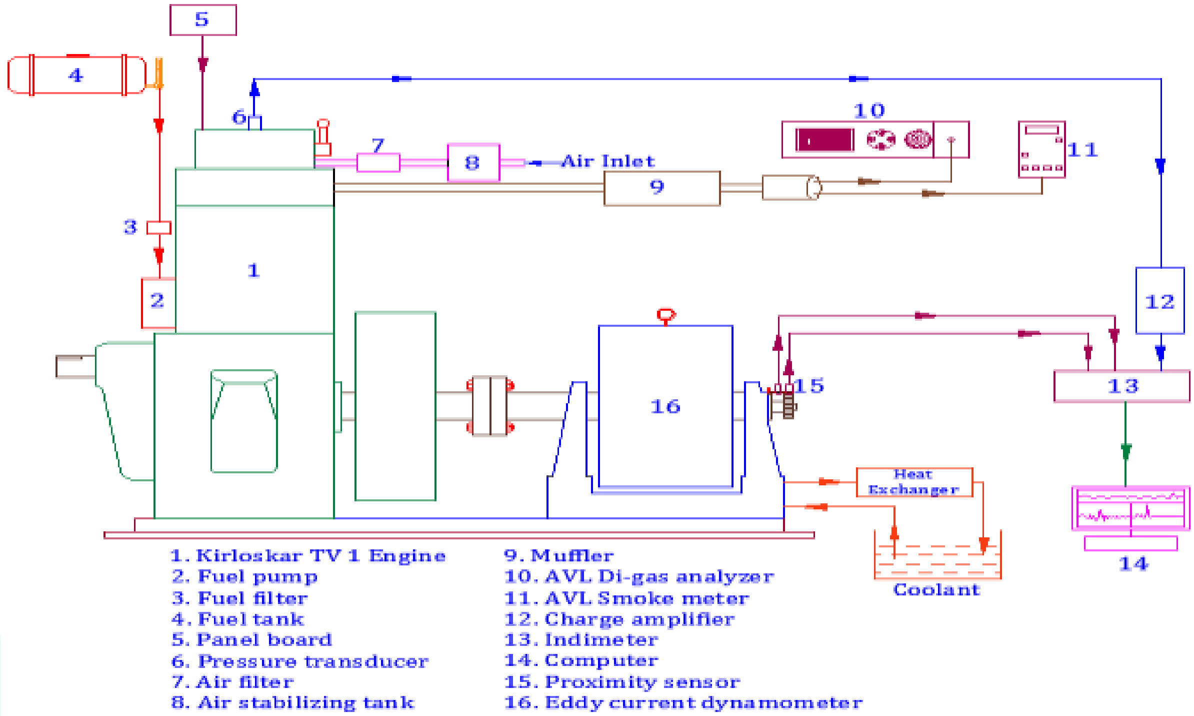


**Figure 5** Schematic diagram of the experimental setup

**Table 2** Specification of test engine

| | | |
|---|---|---|
| Make | : | Kirloskar TV – I |
| Type | : | Vertical cylinder, DI diesel engine |
| Number of cylinder | : | 1 |
| Bore X Stroke | : | 87.5 mm X 110 mm |
| Compression ratio | : | 17.5:1 |
| Speed | : | 1500 RPM |
| Rated brake power | : | 5.2 kW |
| Cooling system | : | Water |
| Fuel | : | Diesel |
| Injection Pressure | : | 220 bars |
| Ignition timing | : | 23° before TDC |
| Ignition system | : | Compression Ignition |

## 4. Result and Discussion

### 4.1 Performance Characteristics

Figure 6 shows the variations in brake thermal efficiency with respect to brake power. The Brake thermal efficiency (BTE) of neat diesel is more than other blends, i.e B20 has lower brake thermal efficiency followed by B40, B60, B80 and B100 respectively. The reason may be the higher viscosity of the Java plum seed biodiesel blends that leads to poor atomization in the injector. B20 has shown better results than other blends since it has lower viscosity when compared to other biodiesel blends. The BTE of blend B20 shows an increase of 8.04% when compared to B100 at full load.

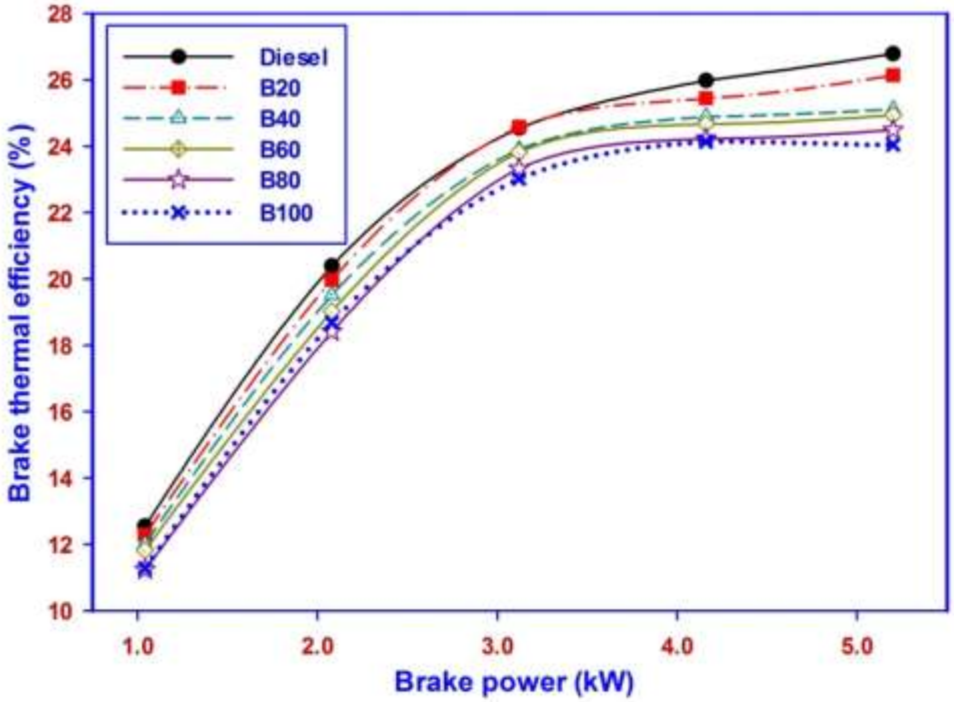


**Figure 6** Brake thermal efficiency against brake power

**4.2 Emission Characteristics**

Figure 7 shows the variations of oxides of nitrogen with brake power. The oxides of nitrogen (NOx) emission after combustion is less in diesel fuel compared to Java plum seed biodiesel and its blends. From the graph it is clear that the NOx emission in B20, B40, B80 and B100 are less when compared with neat diesel. The reason is the reduced combustion temperature that prevails inside the combustion chamber due to the higher heating value of the Java plum seed biodiesel blends. The blend B100 has shows a decrease of NOx emission 18.06% when compared to that of diesel fuel at full load.

The variation in HC emission with brake power results is shown in Figure 8. The HC emission was increased to 102, 97.3, 92, 89.2 and 88 ppm for the B100, B80, B60, B40 and B20 blends, respectively. A possible explanation for the increment in the HC emission, when fueling with biodiesel and its blends is that lower calorific value and a certain number of the Java plum seed biodiesel compared with the diesel fuel. The reason may cause an incomplete combustion of fuel, increase the HC emission [9,13]. The HC emission increased 26.29% compared to that of diesel when B100 used as fuel.

The variation in CO emission with brake power is shown in Figure 9. An average of 0.26% and 0.24% CO emission increment were observed in 20% and 40% Java plum seed biodiesel blends, respectively. CO emission becomes highly significant, when the cylinder temperature is low and the in-cylinder combustion is incomplete. CO emission for all Java plum seed biodiesel blends are in incomplete combustion. A lower cetane number of biodiesel blends exhibits a longer ignition delay and allows longer combustion duration. Then the viscosity of biodiesel comes into play, which reduce the combustion process. The CO emission was 0.28% for diesel fuel and it was reduced to 0.38% by volume when B100 used as fuel.

Smoke emission is the visible product of diesel engine emission. The comparison of smoke emission of B20, B40, B60, B80, B100 and diesel fuel with respect to brake power is shown in Figure 10. From the graph, it is observed that smoke emission of Java plum seed biodiesel and its blends are significantly higher than that of neat diesel at all load conditions. However, when the load increases to maximum level, smoke emission is increased for Java plum seed biodiesel and its blends with diesel. The formation of local rich mixtures of fuel in the combustion chamber due to high viscosity and density of biodiesel blends results in poor atomization.

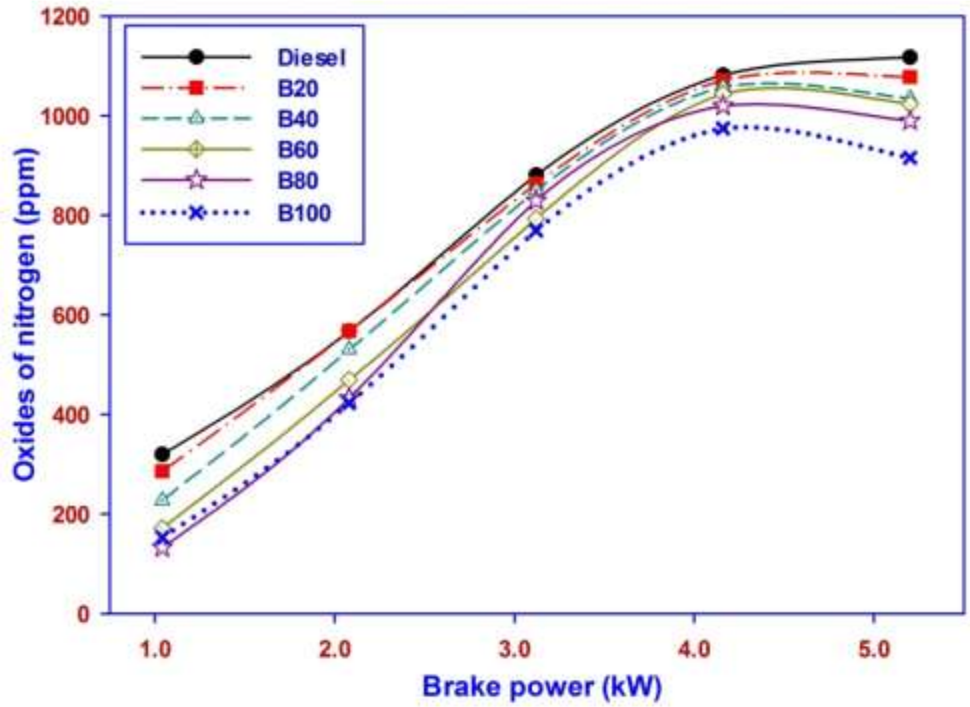


**Figure 7** Oxides of nitrogen emission against brake power

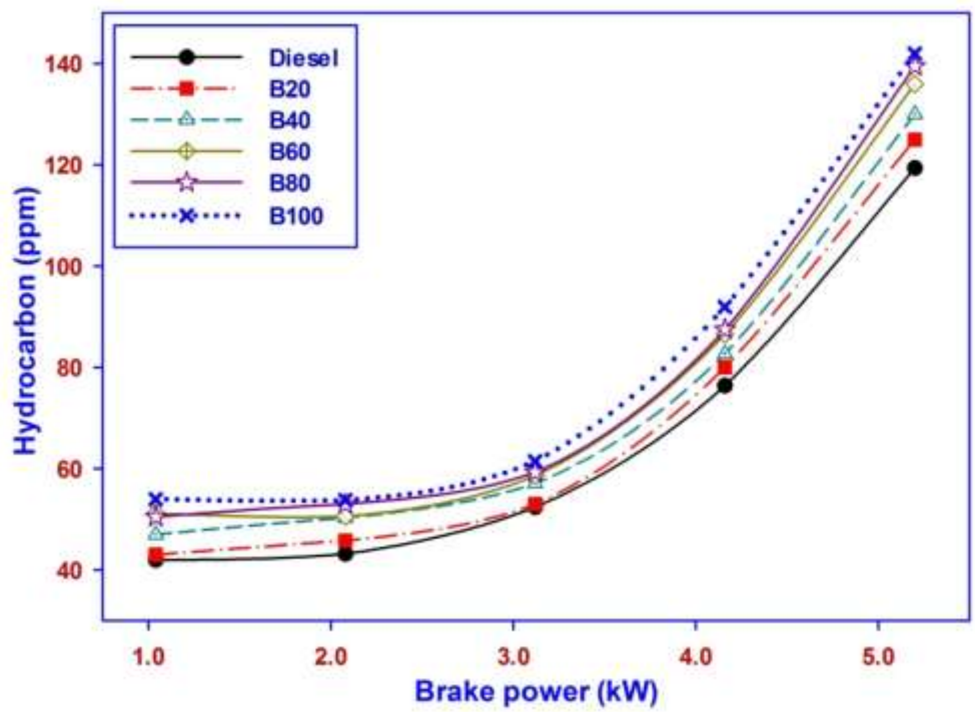


**Figure 8** Hydrocarbon emission against brake power

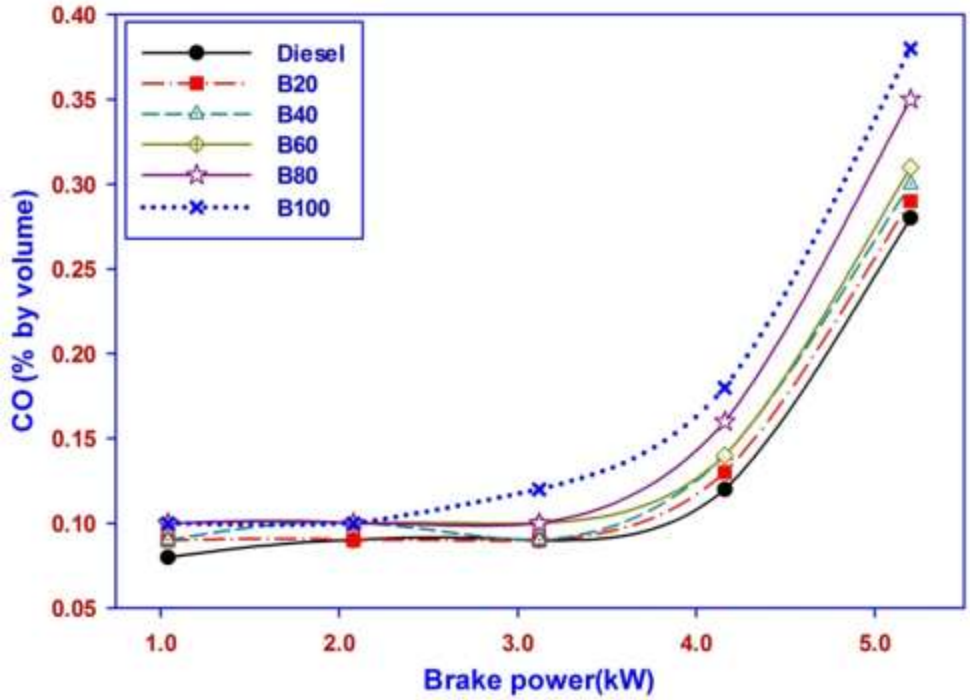


**Figure 9** Carbon-monoxide emission against brake power

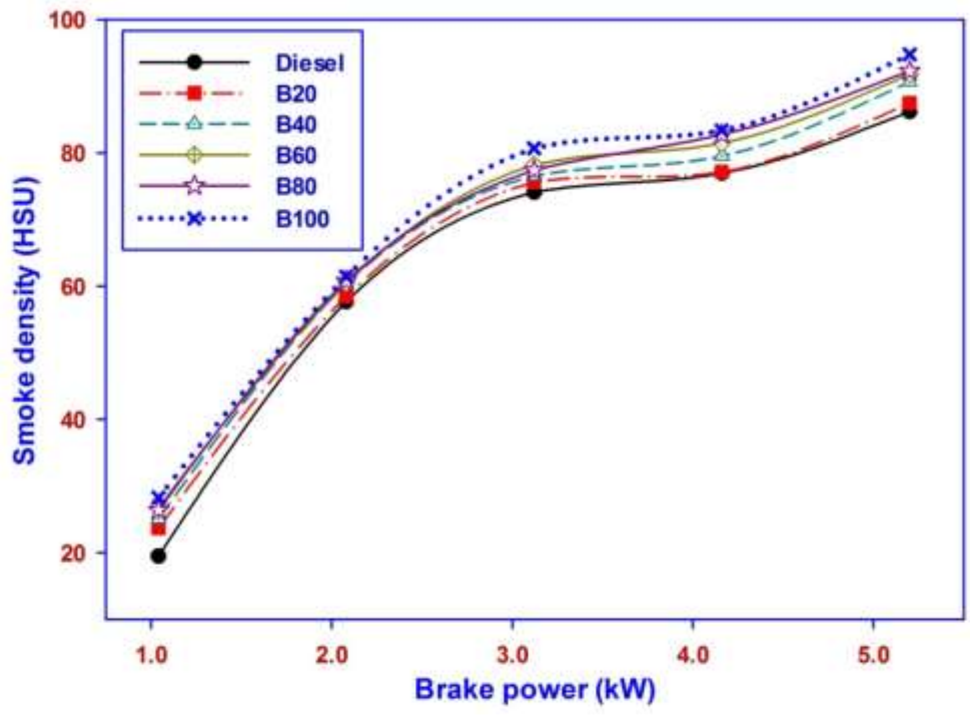


**Figure 10** Smoke density against brake power

**4.3 Combustion Characteristics**

The variation in in-cylinder pressure against crank angle is shown in Figure 11. The peak pressure for the Java plum seed biodiesel and its blends is lower than that of the diesel fuel due to the poor atomization, which decelerates the combustion and cause for the lower cylinder gas pressure. However, the variation between the B20 and diesel fuel is marginal. It is observed that the occurrence of peak pressure is advanced with the addition of Java plum seed biodiesel, which supplies oxygen and promotes the complete combustion of fuel. The maximum in-cylinder pressure of 50.862 bar was found in the case of diesel fuel and it was 44.644 kg/kW-hr for B100 fuel.

The addition of Java plum seed biodiesel blends advances the occurrence of the peak heat release rate when comparing with the diesel fuel and the variation of heat release rate with the crank angle is shown in Figure 12. After the combustion starts, the heat release rate increases and reaches to the maximum value. The addition of Java plum seed biodiesel decreases the ignition delay and accelerates earlier start of combustion, which results in the lower heat release rate and progression of the peak heat release rate. The maximum heat release rate is observed as 118.32 kJ/m$^3$deg for the diesel fuel, whereas it is 94.32 kJ/m$^3$deg for the B100.

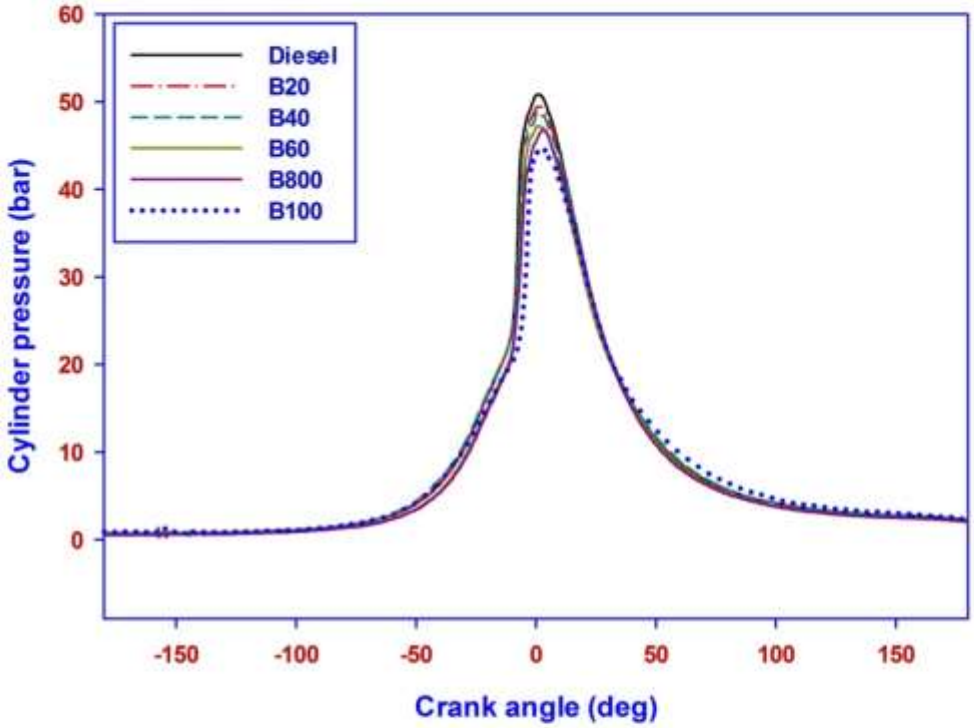


**Figure 11** In-cylinder pressure against crank angle

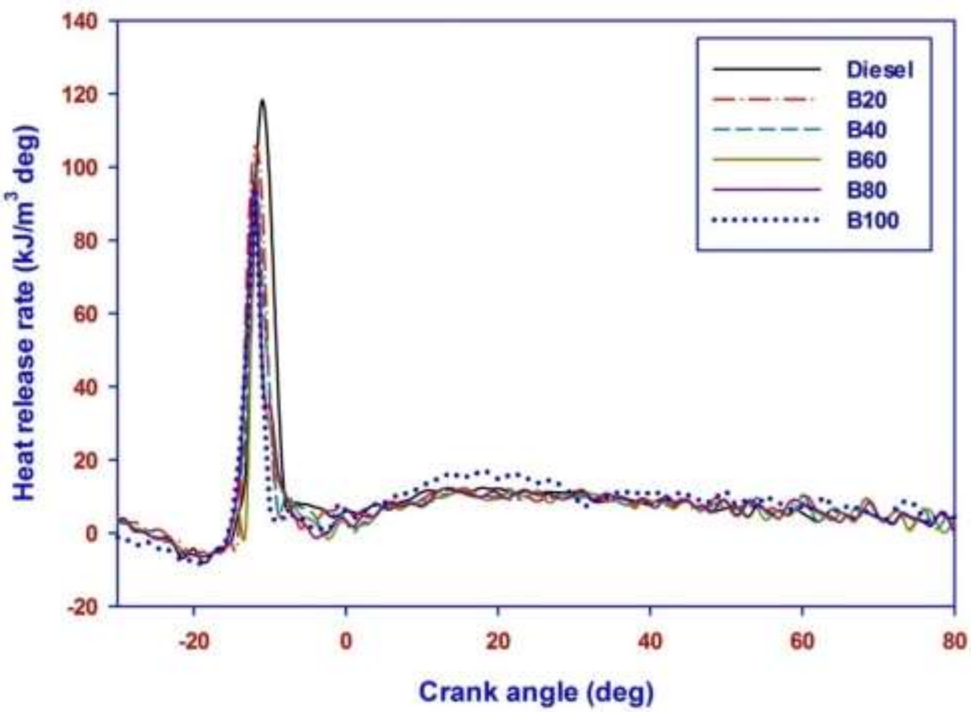


**Figure 12** Heat release rate against crank angle

## 5. Conclusions

The following conclusions are drawn based on this experimental investigation on diesel engine when Java plum seed biodiesel and its blends were used as fuel.

- An average of 4% BTE decrease was observed in 100% Java plum seed biodiesel. Viscosity, density, and a certain number of the Java plum seed biodiesel played vital role in engine performance.
- An average of 0.26% CO and 102 ppm HC emission increment were observed in 100% Java plum seed biodiesel and an average of 0.16% CO and 56 ppm HC emission reductions were observed for 20% blend compared with diesel fuel.
- The $NO_x$ emission is decreased by 3.57% to 18.06% for the addition of 20% to 100% Java plum seed biodiesel, respectively. Diesel fuel exhibited a moderate level of NOx emission. It was observed that higher viscosity and density are the most desirable properties of biodiesel for lower $NO_x$ emission**.**
- Lower in-cylinder pressure and lower heat release rate was found in all the biodiesel cases.

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