PERFORMANCE AND COMBUSTION CHARACTERISTICS OF SINGLE CYLINDER DIESEL ENGINE FUELED WITH BLENDS OF KARANJA BIODIESEL AND DIESEL

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ABSTRACT

The experimental investigation is made to estimate the combustion and performance characteristics of direct injection diesel engine using different blends of karanja methyl ester with diesel. The Karanja biodiesel is mixed with diesel in proportions of 20%, 50% and 100% by volume and studied under various loading conditions i.e. at No load, 25%, 50%, 75% and full load in diesel engine. The combustion parameters were found close to that of diesel. The blend of karanja biodiesel performed complete and smoother combustion process than diesel. The various parameters values like brake thermal efficiency, and heat equivalent to useful work were recorded nearest to diesel. The fuel air ratio also recorded higher than diesel. Whereas the mean gas temperature for pure karanja biodiesel was higher than diesel which is on account of complete combustion on account of 10-12% fuel bound oxygen. On the basis of brake thermal efficiency, KB20 blend was found to be the best blend.

Keywords: Karanja Methyl Ester, Engine Combustion and Performance.

1. INTRODUCTION

During first half of the 20th century, the exhaust gas emissions of internal combustion engines were not recognized as problem, due to lower number of automobiles (diesel engine vehicles). As the number of automobiles grew along with world population; the air pollution become an ever increasing problem. This put a major restriction on the engine design during the 1980s and 1990s. During 1940s due to technological advancements, emissions have been reduced by over 90% but they are still a major problem for the environment due to exponential increase of automobile population [1]. The increasing cost of petroleum is another concern for
developing countries as it will increase their import bill. The world is also presently confronted with the twin crisis of fossil fuel depletion and environmental degradation. Fossil fuels have limited life and the ever increasing cost of these fuels has led to the search of alternative renewable fuels for ensuring energy security and environmental protection. Using straight vegetable oil in diesel engine is not a new idea. Rudolf Diesel first used peanut oil as a fuel for demonstration of his newly developed compression ignition (CI) engine in year 1910. Certain edible oils such as cottonseed, palm and sunflower can be used in diesel engines. These oils are not cost effective to be used as an alternative fuel in diesel engines at present. Some of the non-edible oils such as mahua, castor, neem (Azadiractaindica), Karanja (Pongamia pinnata), jatropha (Jatrophacurcas) etc. can be used in diesel engines after some chemical treatment. For longer life of the engine these oils cannot be used straightway. The viscosity and volatility of these vegetable oils is higher and these can be brought down by a process known as “transesterification”. Biodiesel has a higher cetane number than fossil diesel, no aromatics and comprise up to 10% more oxygen by weight. The characteristics of biodiesel reduce the emissions of carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) in the exhaust gas as compared with fossil diesel [2-5].

Aggarwal et al. [6] observed that the thermal efficiency of the engine improved, brake specific fuel consumption reduced and a considerable reduction in the exhaust smoke opacity was observed.

Nagarhalli et al., [23] experiment result shows that the CO emissions were slightly higher, HC emissions decreased from 12.8% for B20(biodiesel blend with diesel in 20%) and 2.85 % for B40, NO\textsubscript{X} emissions decreased up to 39% for B20 and 28% for B40. The efficiency decreased slightly for blends as compare to fossil diesel. Many researches have used Methyl esters of Pongamia pinnata [7,8], mahua oil [9], repessed oil [10], linseed oil [11], soybean oil [12,13], jatropha [14], cottonseed [15-17], and palm oil [18] reported the performance and emission characteristics in diesel engines. Barnwal [19] have discussed about prospects of biodiesel production from vegetable oil in India. They have also given the yield and production cost of various methyl esters, in general non-edible oils. The methyl esters of non-edible oil are much cheaper than petroleum diesel.

India has about 80-100 million hectares of wasteland which can be used for Karanja plantation. Karanja is a forest based tree-borne non-edible oil with a production potential of 135000 million tones [20]. In many parts of India, this tree is also known as Pongamia, belongs to the family of Leguminaceae. It is a medium sized tree that attains a height of about 18m and a trunk diameter greater than 50cm. The fresh extracted oil is yellowish orange to brown and rapidly darkens on storage [21].

The objective of this paper is to investigate the performance and emission characteristics of single cylinder, four stroke, and water cooled diesel engine with diesel and blends of Karanja biodiesel and diesel in proportions of 20%, 50% and 100% by volume and studied under various loading conditions i.e. at No load, 25%, 50%, 75% and full load in direct injection diesel engine.

2. EXPERIMENTATION

2.1. Experimental fuels

In this study, commercially available Karanja biodiesel purchased from a local company have used for analysis. The Karanja oil biodiesel was produced by transesterification process from Karanja oil with methanol using potassium hydroxides as catalyst. Table 1 shows the main properties of the blends. The calorific value of Karanja biodiesel is approximately 8.5% lower than that of diesel. The viscosity of biodiesel is evidently higher than that of diesel. In the study, three blends were prepared 20% (v/v) biodiesel blended with diesel fuel (denoted by KB20) as baseline fuel.
Table (1): Properties of diesel and Karanja biodiesel blends

<table>
<thead>
<tr>
<th>S.No</th>
<th>Properties</th>
<th>Diesel</th>
<th>KB20</th>
<th>KB50</th>
<th>KB100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density at 15°C (kg/m³)</td>
<td>826</td>
<td>836</td>
<td>852</td>
<td>884</td>
</tr>
<tr>
<td>2</td>
<td>Viscosity at 30°C (cSt)</td>
<td>2.67</td>
<td>3.16</td>
<td>4.28</td>
<td>7.16</td>
</tr>
<tr>
<td>3</td>
<td>Flash point (°C)</td>
<td>63</td>
<td>80</td>
<td>102</td>
<td>172</td>
</tr>
<tr>
<td>4</td>
<td>Fire point (°C)</td>
<td>78</td>
<td>92</td>
<td>127</td>
<td>194</td>
</tr>
<tr>
<td>5</td>
<td>Cloud point (°C)</td>
<td>6.9</td>
<td>8.2</td>
<td>11.7</td>
<td>15.1</td>
</tr>
<tr>
<td>6</td>
<td>Pour point (°C)</td>
<td>3.2</td>
<td>3.8</td>
<td>4.7</td>
<td>5.8</td>
</tr>
<tr>
<td>7</td>
<td>Calorific Value (MJ/kg)</td>
<td>42.00</td>
<td>40.788</td>
<td>38.97</td>
<td>35.94</td>
</tr>
</tbody>
</table>

2.2. Experimental setup and procedure

The experiment setup consists of a single cylinder, four-stroke direct injection diesel engine coupled with an eddy current dynamometer for obtaining different loading conditions. The engine setup includes all necessary instruments and sensors such as temperature sensors, pressure sensors, etc., for measuring cylinder pressure, injection pressure, temperature, power output, load, fuel, and air flow measurements. The computer was connected with the engine and electronic panel with the help of Engine soft software.

Tests were performed on a single cylinder, four-stroke, and direct injection diesel setup shown in figure 1. The main specifications of the test engine are given in table 2. In order to get different load conditions, the engine power output shaft is coupled to an eddy current dynamometer. The electronic panel with dynamometer loading unit is shown in figure 1. The schematic overview of the experimental setup is shown in figure 2. The speed of the engine is fixed at 1500 rpm. Cylinder pressure and injection measured versus crank angle were measured with the help of piezo sensor and crank angle sensor, and different temperatures were also measured with the help of temperature sensors as shown in table 2.

All tests were performed under steady state conditions for that engine was operated at least 10-20 minutes minimum so that the fuel of the previous test was consumed. The results related to engine combustion and performance characteristics were obtained with the blends and compared with diesel.

The experiments were carried out at five different load conditions (no load, 25%, 50%, 75%, and full loads) at 1500 rpm of the diesel engine test setup. The different parameters were evaluated at each load listed as below:

- Cylinder pressure per crank angle, bar
- Injection pressure per crank angle, bar
- Brake power, kW
- Indicated power, kW
- Fuel flow, kg/h
- Air flow, kg/h

The same experiment procedure was performed for all blends like KB100, KB50, and KB20. After getting all the required parameters, the combustion and performance characteristics are evaluated.
Figure (1): Experimental setup

Figure (2): Schematics overview of Experimental setup
Table (2): Engine specification

<table>
<thead>
<tr>
<th>Maker</th>
<th>Kirloskar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>TV1</td>
</tr>
<tr>
<td>Details</td>
<td>Single cylinder, DI, Four stroke</td>
</tr>
<tr>
<td>Bore and Stroke</td>
<td>87.5 mm × 110 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.5:1</td>
</tr>
<tr>
<td>Cubic capacity</td>
<td>661</td>
</tr>
<tr>
<td>Rated power</td>
<td>5.2 kW @ 1500rpm</td>
</tr>
<tr>
<td>Orifice diameter</td>
<td>20 mm</td>
</tr>
<tr>
<td>Cooling</td>
<td>Water</td>
</tr>
<tr>
<td>Inlet valve opens</td>
<td>4.5° before TDC</td>
</tr>
<tr>
<td>Inlet valve closes</td>
<td>35.5° after BDC</td>
</tr>
<tr>
<td>Exhaust valve opens</td>
<td>35.5° before BDC</td>
</tr>
<tr>
<td>Exhaust valve closes</td>
<td>4.5° after TDC</td>
</tr>
<tr>
<td>Fuel injection starts</td>
<td>23° before TDC</td>
</tr>
<tr>
<td>Eddy current dynamometer</td>
<td>Model AG10, of Saj test plant Pvt. Ltd.</td>
</tr>
<tr>
<td>Drum brake diameter</td>
<td>185 mm</td>
</tr>
<tr>
<td>Piezo sensor</td>
<td>Make PCB Piezotronics, Model HSM111A22, Range 5000 psi, Diaphragm stainless steel type &amp; hermetic Sealed</td>
</tr>
<tr>
<td>Temperature sensor</td>
<td>Make Radix Type K, Ungrounded, Sheath Dia.6mmX110mmL, SS316, Connection 1/4&quot;BSP (M) adjustable compression fitting</td>
</tr>
<tr>
<td>Load sensor</td>
<td>Make SensotronicsSanmarLtd., Model 60001,Type S beam, Universal, Capacity 0-50 kg</td>
</tr>
<tr>
<td>Crank angle sensor</td>
<td>Make Kubler-Germany Model 8.3700.1321.0360 Dia: 37mm Shaft Size: Size 6mmxLength 12.5mm, Supply Voltage 5-30V DC, Output Push Pull (AA,BB,OO), PPR: 360, Outlet cable type axial with flange 37 mm to 58 mm</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

3.1. Combustion characteristics
3.1.1. Rate of pressure rise v/s crank angle
The rate of pressure rise plays very important role in engine combustion characteristics because it affect the smooth progress of combustion process. The variation of rate of pressure rise is shown in figure 3 from figure, we can easily observe that the rate of pressure rise increased with increasing loading conditions for all fuels. This is due to fact that the higher amount of fuel is injected at higher loading conditions. However, the rate of pressure rise was lower for the blends at higher load in comparison to that of diesel, due to probably lower calorific value of the blends.

With increasing the load, the more amount of fuel is also injected in engine cylinder and more amount of fuel is burned so that the cylinder peak pressure value also increased which contribute to rise of rate of pressure in the cylinder. The higher value of rate of pressure rise of some blends i.e. KB20 which have high value as compared to KB50 blend so that we should carefully consider the amount of Karanja biodiesel in diesel for minimizing the engine noise level, increasing the engine life and smoothness of combustion process. The high value of rate of pressure rise contributed to knocking, higher noise level and decreases the life of engine so that for any loading condition it should be less than 8 bar/degCA. From the figure 3 we can see that even at higher loads Karanja biodiesel and its blends have rate of pressure rise lower than 8 bar/degCA, which indicate that combustion of blends is smooth and it doesn’t cause knocking which helps to improve engine life.
3.1.2. Heat release rate vs crank angle

The heat release rate indicates how much heat is to be added in cylinder in order to produce the observed pressure and this method is used to analyses combustion behavior from the cylinder pressure data. The variation of heat release rate versus crank angle with different fuels and with different loads like No load, 25%, 50%, 75% and at full load were shown in figure 4. The heat rate increases with increased load condition.

At 25%, 50%, 75% and at full load condition the pure diesel has higher heat release rate than pure biodiesel and it blends with diesel, this is due the reason that blends have lower calorific value. With the increase in the load, there were two peaks of energy release found and second peak of lower magnitude, which indicates that at lower load, premixed combustion phase is more predominant whereas at higher load the diffusion phase of combustion is more dominant. Figure 4 shows the comparison of net heat release rate curve for diesel and Karanja biodiesel blends at different loads.
3.1.3. Mean gas temperature v/s crank angle

The mean gas temperature plays an important role in exhaust emission i.e. NO\textsubscript{X} because in air the amount of nitrogen is more as compared to other.

High value of mean gas temperature leads to formation of more amount of NO\textsubscript{X} so that the mean gas temperature should be lower for less emission of NO\textsubscript{X}. At no load condition the diesel have high value of mean gas temperature as compared to other fuels but for all the rest loading conditions i.e. at 25%, 50%, 75% and full load the Karanja biodiesel and its blends have greater value than diesel because of 10% more amount of oxygen contained in Karanja biodiesel than diesel so that the proper combustion takes place and record high value of mean gas temperature. Figure 5 was shown the behaviour of mean gas temperature for increasing loading condition for all fuels with increased loading condition the more amount of fuel is injected which leads to high cylinder pressure and heat released rate which ultimately leads to higher value of mean gas temperature.

![Figure 5](image-url)

Figure (5): Mean gas temperature v/s Load

3.2. Performance characteristics

3.2.1. Brake thermal efficiency

The variation of brake thermal efficiency with loads for different fuels is presented by figure 6. In all the cases, brake thermal efficiency increased with increased value of load. This may be attributed to reductions in heat losses and increase in power with increase in load. The brake thermal efficiency at 25% load for diesel, KB100, KB50 and KB20 was 13.98%, 15.80%, 17.46% and 16.67% respectively. At 25% load, the Karanja biodiesel and its entire blends have higher brake thermal efficiency than diesel. This is because Karanja biodiesel have 10-11% more oxygen content than diesel which help in better combustion in engine and advanced injection of fuel due to higher bulk modulus and density of Karanja biodiesel. At 50% load, diesel and karanja biodiesel have same brake thermal efficiency and KB50 and KB20 also have same thermal efficiency but at 75% of load the brake thermal efficiency of Karanja biodiesel recorded less value this is because of lower calorific value of Karanja biodiesel than diesel.

At full load, diesel, KB100, KB50 and KB20 have 29.2%, 28.92%, 30.77% and 31.072% brake thermal efficiency respectively. The higher brake thermal efficiency may be due to additional lubricity provided by blends i.e. KB50 and KB20. Among all the blends KB20 can be considered to the best blend on the basis of its higher brake thermal efficiency.
3.2.2 Fuel air ratio

The variation of fuel air ratio at different loads and fuels was shown in figure 7. Fuel air ratio plays an important role in engine performance. The fuel air ratio at higher loads is more for the blends in comparison with diesel increased on account of lower calorific value of the blends and also increased mass of fuel injected due to injection advance. For all loading condition KB100 is recorded higher value than all other Karanja biodiesel blend as well as the pure diesel, the reason behind this is the higher density of Karanja biodiesel and lower calorific value than diesel.
3.2.3 Heat equivalent to useful work

The variation of heat equivalent to useful work for different loads and fuels was shown in figure 8. It has been observed that with increased loading condition the heat equivalent to useful work increased. But for all loading conditions the KB100 recorded fewer values than diesel this is because of its lower calorific value than diesel. At higher loads the performance of biodiesel blends is approaching that of diesel on account of better combustion due to presence of high fuel bound oxygen as well as reduced friction losses.

![Figure (8): Heat equivalent to useful work v/s Load](image)

4. CONCLUSIONS

In this study on the basis of analysis of the experiments results on single cylinder direct injection diesel engine fuelled with Karanja biodiesel-diesel fuel blends, the following conclusions can be arrived at:

1. The physical properties of KB20 i.e. density, fire point, cloud point are having not much difference with diesel. But KB50 and KB100 have higher difference than diesel.
2. Rate of rise in pressure for various Karanja biodiesel blends are less than pure diesel and these values are also less than 8 bar/degCA which indicate the smooth combustion progress and due to this the noise level is decreased and life of engine will increased.
3. The Karanja biodiesel have 10-12% more oxygen content which contribute to better combustion but even than at all load condition heat release rate is less than diesel because of lower calorific value, density and higher viscosity. Due to high density and viscosity resultin inferior atomization and vaporization which lead to reduction in fuel air mixing rate.
4. Mean gas temperature for KB100 at all load condition was recorded higher than diesel which contribute to more NOX emission. It is due to better combustion on account of the fact that biodiesel has 10-12% fuel bound oxygen.
5. KB20 recorded higher brake thermal efficiency than diesel. The reason for it proper combustion and advanced injection of fuel and high oxygen content than diesel. At full load, KB20 and KB50 have 31.072% and 30.77% brake thermal efficiency.
6. KB20 recorded less fuel air ratio than diesel for all load conditions.
7. At 50%, 75% and full load the KB20 has higher heat equivalent to useful work than diesel.

REFERENCES


