Analysis Of Engine Performance And Emissions Characteristics Of Produced Neem Oil Biodiesel And Its Blends

Keshav Raj, Navdeep Sharma Dugala, Gyanendra Singh Goindi

Abstract: The depletion of petroleum fuels and increasing greenhouse emissions, the use of biodiesel has begun. Biodiesel is a renewable energy fuel obtained from vegetable oils and animal fats. The purpose of this research work studies all aspects related to biodiesel production and investigation of its fuel properties. Generally, Neem seeds contain 30-40% oil. A two-step transesterification process is used for biodiesel production from raw Neem oil. The engine performance and emission test were conducted with several biodiesel blends i.e. B10, B20, B30 on VCR engine.

Index Terms: Biodiesel production, Emissions, Engine performance, Fuel consumption, Neem oil methyl ester, Transesterification, VCR engine.

1 INTRODUCTION
The increasing number of vehicles and the rapid depletion of global oil reserves have led to a strong requirement for fuel and petroleum products [1]. The energy requirement in the whole world over the past two eras has embodied all the countries to look for alternative sources for energy [2]. In some emerging countries like India, biodiesel is produced from edible and non-edible feedstocks. These sources can be available in large quantities in the country [3]. Using biodiesel as engine fuel has reduced the PPM, CO and HC emissions in exhaust gases [4]. Biodiesel serves as an alternative to diesel fuel. Jatropha, Karanja, Sunflower and Rapeseed are some of the most common sources for biodiesel production at present considered as replacements for diesel fuel. These plant seeds or fruits are renewable, innocuous, eco-friendly and clean fuels that could be employ directly or by blending with diesel to run diesel engines. Biodiesel mission in India mainly focuses on Jatropha oil because of its comprehensive benefits such as adaptability, need low chemical or organic fertilizer and supply of water to lands, pesticide refusal, etc. But these assumptions were somehow rejected. Therefore, diversifying biodiesel feedstocks is important for sustainable and continuing fuel supply [5]. Neem has caught the attention of other non-edible oils as a viable feedstock to produce biodiesel. Biodiesel production from non-edibles feedstocks was examined and it was found that Neem oil could be the best substitute because of ample availability and better fuel quality. The financial valuation has also revealed that biodiesel produced from neem seeds oil is beneficial. Many researchers concluded in their research that using raw vegetable oils as fuel could reduce the performance of engine and NOx emissions. On the other hand, HC and CO emissions will increase [6]–[9]. Sekhar et al. [10] support the biodiesel produced from neem oil seeds as a feasible substitute for petroleum diesel. Jindal et al. [11] examined the results of the performance of an engine, design

The most effective engine performance is noted at 250 bar injection pressure and CR of 18:1 at which brake specific fuel consumption enhances by 10% and brake thermal efficiency enhances by 9%. A high compression ratio causes a rise in HC emission and exhaust gas temperature whereas drop-in smoke and carbon monoxide emissions. Heroor et al. [12] produced biodiesel from Neem seeds by transesterification method and discover that this fuel is a clean-burning and has a good lubricant property and could be used in an unmodified engine. The performance of engine and emission characteristics were also studied for different biodiesel blends. It was found that using neem oil biodiesel can reduce smoke and carbon monoxide emissions significantly while slightly changing in nitrogen oxide emissions. Muralidharan et al. [13] studied the BTE and observed that BTE is slightly higher in B40 blend with waste cooking oil as compared to diesel fuel at high CR. They also studied the effect of compression ratio on, combustion pressures, consumption of fuel, and exhaust emissions and found the optimum CR which provides the finest engine performance. The results show the lower heat release rate, high-pressure rate, longer ignition delay, and higher mass fraction burnt at higher CR for waste cooking biodiesel compared to diesel fuel. B40 blend sample gives maximum BTE and less CO and hydrocarbons and increases in NOx emissions. Neem (Azadiracta indica) is a non-edible oil plant from mahogany family Meliaceae. Neem oil is obtained from neem seeds and fruits. It is an evergreen tree that is widespread in the Indian subcontinent and grows in tropic and semi-tropic regions. India has a large availability of the Neem tree. India has approximately one hundred million hectares of wastelands, which can be used to cultivate the Neem tree. Neem seeds contain about 40-60% oil content. Yearly neem oil production is approximate to be 30 thousand tons in India [5]. From the wide literature survey, it was noticed that a lot of effort has been done for improvement in CI diesel engine performance run by biodiesel and biodiesel blends. However, it was noted that there has been a very limited study done on the VCR engine using Neem oil biodiesel fuel. The effects of different engine loads on engine performance and emissions parameters along with combustion

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characteristics of Neem oil biodiesel have not been deliberate broadly. Hence, this paper is dedicated to discovering the best Neem biodiesel blend sample which can provide the best performance. In the experimentation, Neem oil biodiesel and its blends are selected as fuel for the VCR engine. There are three biodiesel blends sample i.e. B10, B20, and B30 blends are prepared from Neem biodiesel (B100) and diesel fuel mixture and these investigations are done. The engine performance, emissions characteristics of VCR engine using B10, B20, B30, B100 blends, and diesel fuel at 14:1 compression ratio for different load tests on 0 kg, 3 kg, 6 kg, and 9 kg.

2 PREPARATION OF NEEM OIL BIODIESEL

Biodiesel is produced by the transesterification method. In the transesterification method, animal fats or vegetable oils are reacted with methanol or ethanol (alcohol). To increase the rate of chemical reaction, some catalyst was added.

2.1 Transesterification of Fuel

A measured quantity, i.e. 1 litre of crude neem oil was taken in a conical flask and heated up to 75°C on an electric heater. A mixture of methanol (300 ml) and H₂SO₄ (1% by vol.) was prepared in a flask and added gradually in crude neem oil when it reached 75°C. The blend was stirred continuously for 30 minutes on a magnetic hotplate stirrer at a constant temperature of 50°C. After that the mixture was poured into a separate funnel and allowing the solution to settle down the impurities and after 8-9 hours settled impurities were removed from the remaining oil. This remaining oil was again measured and then preheated up to 75°C. A mixture of methanol (300 ml) and NaOH (1% by wt.) was prepared in a flask and added gradually in preheated remaining oil when it reached 75°C. The blend was stirred continuously for 30 minutes on a magnetic hotplate stirrer at a constant temperature of 50°C. After that, this blend was poured into a separating funnel to settle down the impurities and after 6-7 hours settling down a layer of glycerol was found at the bottom of the funnel which was separated and removed from the oil. The remaining is the neem oil methyl ester (biodiesel). After that we prepare B10, B20 and B30 biodiesel blends to study its physicochemical properties, engine performance and emission parameters and they were compared with standard diesel.

3 PHYSICOCHEMICAL PROPERTIES OF NEEM OIL BIODIESEL

Significant properties of neem oil biodiesel and its blends samples such as density, kinematic viscosity, calorific value, fire and flash point, pour and cloud point, iodine value, the acid value was measured in the chemistry lab and compared with standard diesel (see Table 1). These fuel samples are used in engine performance and emission tests and compared with standard diesel.

### Table 1: Physicochemical properties of biodiesel fuel as per ASTM D6751 specifications

<table>
<thead>
<tr>
<th>Properties</th>
<th>Units</th>
<th>B10</th>
<th>B20</th>
<th>B30</th>
<th>B100</th>
<th>Raw Neem Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>835</td>
<td>845</td>
<td>858</td>
<td>881</td>
<td>918</td>
</tr>
<tr>
<td>Kinematic</td>
<td>cSt</td>
<td>3.06</td>
<td>3.20</td>
<td>3.84</td>
<td>5.72</td>
<td>43.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>viscosity (at 40°C)</th>
<th>kJ/kg</th>
<th>45.55</th>
<th>45.06</th>
<th>42.07</th>
<th>38.4</th>
<th>34.1</th>
<th>44.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud point</td>
<td>°C</td>
<td>3.1</td>
<td>4.2</td>
<td>4.3</td>
<td>8</td>
<td>13</td>
<td>-12</td>
</tr>
<tr>
<td>Pour point</td>
<td>°C</td>
<td>1</td>
<td>1.2</td>
<td>1.3</td>
<td>-1</td>
<td>7</td>
<td>-8</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>59</td>
<td>65</td>
<td>78</td>
<td>172</td>
<td>214</td>
<td>55</td>
</tr>
<tr>
<td>Fire point</td>
<td>°C</td>
<td>65</td>
<td>72</td>
<td>81</td>
<td>176</td>
<td>227</td>
<td>60</td>
</tr>
</tbody>
</table>

3.1 Density

Biodiesel fuels are being tested in diesel engines. High density causes inappropriate atomization of fuel in the engine. The fuel density was determined with the capillary stopper relative density bottle volume of 50 ml. This formula is followed to calculate the density of fuel:

$$ \text{Density} = \frac{W_3 - W_1}{W_2 - W_1} \times \rho_{\text{water}} $$

$W_3=$ Wt. of an empty bottle

$W_2=$ Wt. of the bottle with water

$W_3=$ Wt. of the bottle with sample

Fig. 1 shows the density of B10, B20, B30 blends, B100 (Neem biodiesel), raw Neem oil and standard diesel. The outcomes reveal that the density of all Neem biodiesel blends was lower than raw neem oil and higher than petroleum diesel. Among other samples, B10 has a lower density.

3.2 Kinematic Viscosity (KV)

Kinematic viscosity indicates the internal resistance of oil to flow by gravity force. It also indicates the rate of momentum transferred through a fluid. The kinematic viscosity of the oil is generally measured at 40°C to determine the flow property. The viscosity of biodiesel determines the stability of fuel during storage. Petroleum diesel fuel has a lower viscosity than the viscosity of vegetable oils. Higher KV can cause a reduction in the injection rate of fuel which results in low engine efficiency. The KV of oil was calculated by the Redwood Viscometer No. 1 apparatus. The formula for calculating KV is given as:

$$ \text{Kinematic Viscosity} = 0.26 \times t - (179/t) \quad \text{for} \quad 34 < t > 100 $$

$$ \text{Kinematic Viscosity} = 0.24 \times t - (50/t) \quad \text{for} \quad t > 100 $$
Fig. 2 shows the KV of B10, B20, B30, B100, raw Neem oil, and petroleum diesel fuel. The study reveals that KV of raw neem oil is very high.

3.3 Calorific Value (CV)
The calorific value of oil indicates the amount of energy that liberates when the unit amount of fuel burns. The higher calorific value of the fuel is advantageous for an IC engine. Usually, biodiesel has a low CV than diesel because biodiesel has high oxygen content that's why it has lesser (about 10%) amount of energy compared to diesel fuel. Fig. 3 shows that the CV of B100 is lower than standard diesel and raw Neem oil has lesser value among all the samples. B10 and B20 have slightly the same calorific value.

3.4 Flash Point
The lowest temperature for which the fuel vapors will start getting flashes or the fuel would ignite if it came in contact with flame is called the flash point. The formula to calculate the flash point is given as:

\[ \text{Flash Point} = \frac{t_p - (p - 760)}{30} \]

where

- \( t_p \) = flash point (at pressure = p)
- \( p \) = the recorded pressure when experiments were performed

Fig. 4 illustrates the comparison of the flash point of diesel with crude Neem oil, its biodiesel along with its blends prepared in different proportions. The results revealed that the flash point for raw Neem oil was much higher than petroleum diesel. The value of the flash point of B10 and B20 blend is slightly near to the diesel fuel. We can see that raw Neem oil has a maximum flash point among other samples.

3.5 Fire Point
The minimum possible temperature at which fuel vapors start to a continuous burning minimum for 5 seconds after igniting by a fire source, is called fire point. Fig. 5 shows that the fire point of B10 and B100 and raw Neem oil is much higher than petroleum diesel. The fire point of B10 and B20 is slightly near the flash point of diesel fuel. From the figure, raw Neem oil has a maximum fire point among other samples.

3.6 Cloud Point
It is the temperature were wax crystals start to occur when the oil is cooled under close controlled conditions during the test. Generally, biodiesel has a high cloud point than diesel. Fig. 6 shows that the CP of raw Neem oil, B100, and its blends sample is higher than petroleum diesel. B20 and B30 have an approximately equal cloud point value. It is noted that raw Neem oil has maximum and diesel fuel has the minimum cloud point comparing with other samples.
3.7 Pour Point
It is the temperature were wax content start to make a gel solution of the fuel. So, pour point is the lowest temperature were fuel starts flowing. Generally, biodiesel has a high pour point than diesel. It was observed that raw Neem oil has the highest and diesel fuel has the lowest pour point comparing with other samples. Also, B20 and B30 Neem oil blends have an approximately equal pour point value.

3.8 Oxidation
Oxidation of fuel specifies the degree of oxidation of an atom in a chemical compound. The fuel quality could be reduced by oxidation. The rate of oxidation of unsaturated oils is probably high. Oxidation of fuel is affected by the moisture, presence of dust particles, air exposure, and heat. Using oxidized oil as fuel effect in bad lubrication and could damage fuel filters. The injection of fuel is also affected by oxidized oils because it has a higher viscosity.

4 EXPERIMENTAL SETUP
The experimental test was performed on a 4-stroke single cylinder CI diesel engine. The technical description of the VCR engine is given in Table 2. The engine was run at 1500 rpm of constant speed with CR of 14:1. Eddy's current dynamometer is used in loads variation. Engine was tested with B100 (pure biodiesel), B10 (up to 10% biodiesel), B20 (up to 20% biodiesel), and B30 (up to 30% biodiesel). An AVG-500 Airvisor 5- gas analyzer was used for emission characteristics of exhaust gases. Different engine performance parameters such as SFC, BP, BTE and emission characteristics such as CO, NOX, HC, and CO2 emissions were evaluated experimentally, and results were represented in the graph with respect to different loads.

Table 2: Description of the engine used in the experiment

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cylinder</td>
<td>Single</td>
</tr>
<tr>
<td>2</td>
<td>Engine type</td>
<td>Kirloskar</td>
</tr>
<tr>
<td>3</td>
<td>Power rating</td>
<td>5.2 KW at 1500 RPM</td>
</tr>
<tr>
<td>4</td>
<td>Type of cooling</td>
<td>Water cooling</td>
</tr>
<tr>
<td>5</td>
<td>Stroke</td>
<td>110 mm</td>
</tr>
<tr>
<td>6</td>
<td>Bore</td>
<td>87.5 mm</td>
</tr>
<tr>
<td>7</td>
<td>Capacity</td>
<td>661 cc</td>
</tr>
<tr>
<td>8</td>
<td>Compression ratio</td>
<td>14:1</td>
</tr>
<tr>
<td>9</td>
<td>Dynamometer</td>
<td>Eddy current dynamometer</td>
</tr>
<tr>
<td>10</td>
<td>Starting</td>
<td>Hand start with a cranking handle</td>
</tr>
</tbody>
</table>

5 RESULT AND DISCUSSION
5.1 Engine Performance

5.1.1 Specific Fuel Consumption (SFC)
SFC measures the fuel efficiency of an engine that produces power by fuel combustion. Lower SFC is considered as best fuel for an engine. Fig. 8 illustrate the disparity in SFC of neem oil biodiesel and its different blends as a function of loads at the compression ratio of 14:1. From the figure, it is observed that the SFC of B30 is lower than the others. It is found that as an increase in loads after 3 kg, specific fuel consumption decreases for all fuel samples.

Fig. 8. Loads vs specific fuel consumption of biodiesel and blends at CR 14:1

5.1.2 Brake Thermal Efficiency
Fig. 9 illustrates the comparison of brake thermal efficiency for Neem oil biodiesel and its blends at CR 14:1. The figure shows that BTE of Neem oil biodiesel and its blends are increased as an increase in loads. BTE is the ratio output power to the produced energy by the fuel combustion in the engine. The fuel is converted into heat energy. In the figure,
an increase in load increases BTE. Brake thermal efficiency of B30 is better to compare to other blend samples.

![Graph showing Load vs Brake Thermal Efficiency](image1)

**Fig. 9.** Loads vs brake thermal efficiency of biodiesel and blends at CR 14:1

### 5.1.3 Brake Power

Fig. 10 illustrate the comparison in brake power of neem oil biodiesel and its blends as a function of loads at the compression ratio of 14:1. From the graph, it is observed that brake power diesel fuel is higher compared to others. This is because of the high calorific value of diesel.

![Graph showing Load vs Brake Power](image2)

**Fig. 10.** Loads vs brake power of biodiesel and blends at CR 14:1

### 5.2 Emission Characteristics

An experimental test of engine exhaust gas emissions were performed for hydrocarbons (ppm), carbon dioxide (% volume), carbon monoxide (% volume), nitrogen oxides (% volume) and smoke density (HSU) gases were performed for B10, B20, B30, B100 and standard diesel at 0, 3, 6, and 9 kg loads and discussed here.

#### 5.2.1 Carbon Monoxide (CO) Emissions

Fig. 11 illustrates the disparity in emissions of CO emissions of B10, B20, B30, B100, and standard diesel fuel against different loads. CO emissions are formed from partial combustion of fuel where the oxidation process does not take place perfectly. In the biodiesel fuel, CO is converted into CO\(_2\) because of extra oxygen presence in the fuel. The CO emissions are low for neem oil blends compared with diesel. In the figure, it is clear that CO emissions of B10 and B20 blends are high compared with the B30 blend.

![Graph showing Load vs CO Emissions](image3)

**Fig. 11.** Variation in emissions of CO vs Loads for Neem oil biodiesel and its blend

#### 5.2.2 Hydrocarbon (HC) Emissions

Fig. 12 shows the disparity in emissions of hydrocarbon emissions of Neem oil biodiesel and its blends against loads. HC emissions are formed of partial combustion of fuels because of deficient temperature presence near the cylinder wall. Fig. 14 shows, HC emissions increase as an increase in loads for the B100 sample.

![Graph showing Load vs HC Emissions](image4)

**Fig. 12.** Variation in emissions of HC vs Loads for Neem oil biodiesel and its blend

#### 5.2.3 Nitrogen Oxide (NO\(_x\)) Emissions

Fig. 13 shows the disparity in NO\(_x\) emissions versus loads for Neem oil biodiesel and its blends and diesel.

![Graph showing Load vs NO\(_x\) Emissions](image5)

**Fig. 13.** Variation in emissions of NO\(_x\) vs Loads for Neem oil biodiesel and its blend
Usually, nitrogen oxides do not react with oxygen in the engine because of the high temperature inside the cylinders which causes NOx emissions. It can be seen that Neem oil biodiesel blends produce a smaller amount of NOx emissions compared with diesel fuel.

5.2.4 Carbon Dioxide (CO2) Emissions

Fig. 14 demonstrates the disparity in CO2 emissions of Neem oil biodiesel blends and standard diesel with different loads. A high value in CO2 emissions indicates the complete burning of fuel in the engine. CO2 emissions are also related to exhaust gas temperature. It is noted that B100 had Maximum CO2 emissions value and diesel has low CO2 emissions value.

Fig. 14. Variation in emissions of CO2 vs Loads for Neem oil biodiesel and its blend

7 CONCLUSIONS

The experimental investigation of engine performance and emission characteristics was conducted on the VCR engine. At first, engine performance was determined with diesel fuel under different load conditions and after that performance of the engine was compared with Neem oil biodiesel (B100) and its different blends (B10, B20, B30). The outcomes are summarized as follows:

1. The experimentation results showed that specific fuel consumption for sample blends was lower as compared to diesel and it was found to be lowest for the B30 sample blend.
2. The brake thermal efficiency of sample blends was found to be higher than diesel and the sample blend B30 had the highest BTE than all other tested biodiesel blend samples. Therefore, B30 can be selected as the best sample of Neem Oil biodiesel blended with diesel.
3. CO2 and CO emissions of neem oil biodiesel (B100) were found to be lower than other samples but HC and NOx emissions were found to be quite high.
4. B10 demonstrated lower exhaust gas emissions and higher engine performance as compared to its sample blends and pure diesel fuel.
5. The CO2 emission of B10, B20, and B30 was found to be higher than diesel and they had values near to each other. Whereas the emissions of B100 is very high among all tested sample.

6. The physicochemical properties result of B10, B20 and B30 are almost same. The difference between their values is small.

8 REFERENCES


