ABSTRACT

The world energy demand has witnessed uncertainties in two dimensions. The scarcity and depletion of conventional petroleum sources are causes of great concern worldwide. Combustion of fossil fuels has led to unprecedented rise in the global CO₂ level, leading to global warming. Therefore, efforts are underway in several countries to search for suitable alternative fuels that are environment friendly. Vegetable oils of non-edible nature are such alternative fuels, which can form part of potential solution. Vegetable oils, due to their agricultural origin, are able to reduce CO₂ emissions to the atmosphere along with import substitution of petroleum products.

In the present research, experiment were designed to study the effect of reducing Neem oil's high viscosity by increasing the fuel temperature and thereby its effect on combustion and emission characteristics of the engine. Experiments were also conducted using various blends of Neem oil with mineral diesel to study the effect of reduced blend viscosity on emissions and performance of diesel engine. A single cylinder, four stroke, constant speed, water cooled, direct injection diesel engine typically used in agricultural sector was used for these experiments. The experimental data was analyzed for various performance and emission parameters such as brake thermal efficiency, brake specific fuel consumption (BSFC), smoke opacity and emissions of CO₂, CO, and HC. While operating the engine on Neem oil (preheated and blends), performance and emissions parameters were found to be very close to mineral diesel for lower blend concentrations. However, for higher blend concentrations, performance and emissions were observed to be slightly inferior to that of mineral diesel.

INTRODUCTION

The advent in civilization is closely related to improvements in transportation systems. Diesel engines have provided power plants for personalized and public transportation systems (passenger cars, buses etc.), goods transportation systems (trucks etc.), ships, railway locomotives, non-road equipments (farming and construction equipments) and in almost every type of industry due to its economy of operation, reliability and durability [1].

Diesel engine is most fully developed and proven engine with higher fuel economy and hence emits lower greenhouse gases. However diesel engine is also one of the largest contributors to environmental pollution problems worldwide. In recent years, the issues of steadily increasing fuel cost, decreasing petroleum reserves, air pollution and market competitiveness have motivated research for higher fuel economy and less polluting alternative fuels. Also the pressure for significant improvements in fuel economy has been underlined by the Kyoto Protocol to reduce greenhouse gas emissions. Countries which do not have enough petroleum resources are facing a foreign exchange crisis, mainly due to import of crude petroleum. Hence, it is necessary to look for alternative fuels, which can be produced domestically.

Alternative fuels should be easily available at low cost, environment friendly and techno-economically...
competitive. For the developing countries, fuels of bio-origin provide a feasible solution to the twin crises of fossil fuel depletion and environmental degradation. Vegetable oils of non-edible nature are such alternative fuels, which can form part of potential solution. In 1930’s and 1940’s, vegetable oils were used as diesel engine fuels during emergency situations. There has been renewed interest to utilize vegetable oil as diesel fuel after the oil-shocks of 1970’s and the 1991 gulf war.

Plenty of experimental work has been carried out in various countries for utilization of vegetable oils in compression ignition engines. Depending upon local availability, climate and soil conditions, several nations are looking for different vegetable oils as diesel fuel replacement e.g., soybean oil in the United States, rapeseed and sunflower oils in Europe and China, palm oil in Southeast Asia (mainly Malaysia and Indonesia), coconut oil in Philippines etc [2,3]. India is producing host of non-edible oils such as linseed, castor, jatropha, karanja (Pongamia glabra), neem (Azadirachta indica), palash (Butea monosperma), kusum (Schlelechera trijuga) etc. Many of these oils are not being adequately utilized, and it has been estimated that some plant-based and forest derived oils have a much higher production potential [4].

Vegetable oils have comparable energy density, cetane number, heat of vaporization, and stoichiometric air/fuel ratio with mineral diesel. These are biodegradable, non-toxic, and significantly reduce pollution. Vegetable oils have low sulfur content and enhanced lubricity properties [5-6]. Bio-fuels are considered CO₂ neutral. When Bio-fuels are burned, the atmosphere is not burdened with additional fossil CO₂ emissions, since CO₂ has already been assimilated during growth of these crops in the photo-synthesis process [7-8]. Therefore, substituting petroleum fuels with vegetable oils/derivatives can reduce dependence on oil imports, improve air quality, and mitigate greenhouse gases [9].

Suitability of vegetable oils as diesel engine fuels depend on their physical, chemical and combustion characteristics as well as type of engine used and operating conditions [10]. Vegetable oils contain substantial oxygen in their molecular structure, which improves their combustion characteristics. They have high viscosity due to large molecular weight and bulky molecular structure. The viscosity of liquid fuels affect flow properties as well as spray atomization, vaporization, and air/fuel mixture formation. Higher viscosity also has an adverse effect on combustion of vegetable oils in existing diesel engines, fuel pumps and injectors. Temperature significantly affects the viscosity of vegetable oils. It has been reported that viscosity of vegetable oils and fats decreases linearly with increase in temperature [11].

Short-term engine performance tests have indicated good potential for most vegetable oils. Vegetable oils and their derivatives in diesel engines lead to substantial reductions in sulfur, carbon monoxide (CO), poly aromatic hydrocarbons (PAH), smoke, noise, and particulate emissions [7,12-16]. However, increased oxygen content generally results in increased BSFC, NOₓ and HC emissions [3,12,17-20]. In addition, higher viscosity of vegetable oils (35–45 cSt at 40°C) as against mineral diesel (4.0 cSt at 40°C) leads to problems in pumping and atomization, ring-sticking, carbon deposits on the piston, cylinder head, ring grooves, etc [4,21]. Also, higher viscosity is responsible for various undesirable combustion features of straight vegetable oils. Therefore, vegetable oils have to be modified to bring their combustion related properties closer to diesel. Four techniques are proposed to reduce the viscosity of vegetable oils; namely heating/ pyrolysis, dilution/blending, micro-emulsion, and transesterification [22-23].

Undoubtedly, transesterification is well accepted and best suited method of utilizing vegetable oils in CI engine without significant long term operational and durability problems. However, this adds extra cost of processing because of the transesterification reaction. In rural and remote areas of developing countries, where grid power is not available, vegetable oils can play a vital role in decentralized power generation for irrigation and electrification. In these remote areas, different types of vegetable oils are grown/produced locally but it may not be possible to chemically process them due to logistics problems in rural settings. Hence using heated or blended vegetable oils is an attractive proposition. The dilution of various vegetable oils with diesel has been studied and engine tests were carried out by several researchers [24-28]. Caterpillar (Brazil) used pre-combustion chamber engines with a blend of 10% vegetable oil while maintaining same power output without any modifications in the engine [24]. It has been reported that use of 100% vegetable oil is also possible with minor fuel system modifications [29]. Heating is another way to reduce the viscosity of vegetable oil before use in diesel engines [30].

Neem oil is selected for present investigation, as it is available in surplus quantities and is non-edible in nature. Present study is aimed at exploring technical feasibility of straight Neem oil in direct injection compression ignition engine without any hardware modification.

**Neem (Azadirachta Indica):** Neem grows well in all agro-climatic zones except in high altitudes, cold regions and dam sites. It is hardy but frost susceptible tree and cannot withstand excessive cold especially during seedling and sapling stage. According to an estimate, Neem trees in India bear about 3.5 million tones of kernels (figure 1) every year. From this, about 0.7 million tones of oil may be recovered. Neem oil is non-drying and it resists degradation better than most vegetable oils.
Neem tree is used to meet the local demand for timber, fodder, fuel wood and used for various medicinal purposes. Powdered leaves are a major component used in facial cream. Neem has demonstrated considerable potential as a fertilizer and soap manufacturing. Considering the versatile nature, usage & growing global importance of Neem, United Nations declared it as the "Tree of the twenty first century".

In the present investigations, Neem oil has been appropriately utilized by heating and blending for operating diesel engine. Periodic cleaning of the fuel injector nozzle is necessary to ensure satisfactory spray characteristics. Starting and stopping the engine with diesel while running the engine with vegetable oil eliminates filter clogging problems.

**EXPERIMENTAL SETUP**

High viscosity of Neem oil is the main problem in its usage in unmodified form in a diesel engine. Therefore, it is necessary to reduce the fuel viscosity before injecting in the engine. High viscosity can be reduced by heating the fuel using waste heat of exhaust gases from the engine and also by blending Neem oil with diesel. Several tests were conducted on Neem oil and mineral diesel in order to assess their physical, chemical and thermal properties. Various test procedures followed and the instruments used are given in table 1 [31-34].

**Table 1: ASTM Methods and Instrument to Measure Various Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Method</th>
<th>Instrument</th>
<th>Make</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>D 1298</td>
<td>Density Meter</td>
<td>Xebex Intl., Japan</td>
</tr>
<tr>
<td>Kinematic Viscosity</td>
<td>D 445</td>
<td>Kinematic viscometer</td>
<td>Setavis, UK</td>
</tr>
<tr>
<td>Cloud &amp; Pour Point</td>
<td>D 97</td>
<td>Cloud &amp; Pour Point Apparatus</td>
<td>Petroleum Instruments, India</td>
</tr>
<tr>
<td>Flash &amp; Fire Point</td>
<td>D 93</td>
<td>Pensky-Martens</td>
<td>Petroleum Instruments, India</td>
</tr>
</tbody>
</table>

A typical engine system widely used in the agricultural sector has been selected for present engine experiments. A four stroke, single cylinder, constant speed, water cooled, direct injection diesel engine (Make: Kirloskar Oil Engines Ltd. India, Model: DM-10) was used. The detailed specifications of the engine are given in table 2. The engine operated at a constant speed of 1500 rpm. Fresh lubricating oil was filled in oil sump before starting the engine experiments. The engine is coupled with a single phase, 220 volts AC alternator. The alternator's performance is evaluated by finding out the copper losses, armature current losses, and friction & windage losses. All these losses were considered while analyzing the engine data. The alternator is used for loading the engine through a resistive load bank. The load bank consists of eight heating coils (1000 watts each). A variac was connected to one of the heating coils so that load can be controlled precisely by controlling voltage in one of the coils of load bank. The schematic layout of the experimental setup is shown in figure 2.

**Table 2: Engine Specifications**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Kirloskar Oil Engine Ltd, India</td>
</tr>
<tr>
<td>Engine Type</td>
<td>Vertical, 4-stroke, single cylinder, constant speed, direct injection, water cooled, compression ignition engine</td>
</tr>
<tr>
<td>Rated power</td>
<td>7.4 kW at 1500 rpm</td>
</tr>
<tr>
<td>Bore / stroke</td>
<td>102 / 116 (mm)</td>
</tr>
<tr>
<td>Displacement volume</td>
<td>0.948 liters</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.5</td>
</tr>
<tr>
<td>Start of fuel injection</td>
<td>26° BTDC</td>
</tr>
<tr>
<td>Nozzle opening pressure</td>
<td>200-205 bar</td>
</tr>
<tr>
<td>BMEP at 1500 rpm</td>
<td>6.34 (kg/cm²)</td>
</tr>
</tbody>
</table>
The main components of the experimental setup are two fuel tanks (diesel and Neem oil), fuel conditioning system, heat exchanger, exhaust gas line, by-pass line, and performance and emissions measurement systems. The engine is started with diesel fuel and after engine warms up, it is switched over to Neem oil. After concluding tests with Neem oil, the engine is again switched back to diesel before stopping the engine until the Neem oil is purged from the fuel line, injection pump and injector in order to prevent deposits and cold start problems. A shell and tube type heat exchanger was used to preheat the Neem oil using waste heat of the exhaust gases.

In order to control the temperature of Neem oil within a range of 90-100°C, a by-pass valve was provided in the exhaust gas line before the heat exchanger. By-pass of exhaust gas prevents the oil temperature to increase beyond specified limit. A k-type thermocouple was provided in the exhaust line to measure the temperature of the exhaust gases. Voltmeter and ammeter were used to measure the voltage and current consumed by the load in the load bank. Exhaust gas opacity was measured by smoke meter (Make: AVL Austria, Model: 437).

The exhaust gas composition was measured using exhaust gas analyzer (Make: AVL India, Model: DIGAS 444). It measures CO₂, CO, and HC by non-diffractive infrared radiation (NDIR) and oxygen by electrochemical method.

**EXPERIMENTAL TEST MATRIX**

The engine was run for 49 hours in seven non-stop cycles of seven hours each at the rated speed for preliminary run. Experiments were conducted for optimizing fuel injection pressure for diesel and Neem oil. Finally, performance and emissions tests were conducted for diesel, preheated Neem oil, unheated Neem oil, and Neem oil blends. These tests were conducted in two phases. In first phase, tests were conducted by pre-heating the Neem oil with baseline data for diesel. In the second phase, tests were conducted using blends of Neem oil with mineral diesel. For this purpose, several blends of varying concentrations were prepared ranging from 0% (mineral diesel) to 100% (Neem oil) through 10%, 20%, 30%, 40%, 50%, and 75%.

**RESULTS AND DISCUSSION**
Neem oil and diesel were characterized for their physical, chemical and thermal properties and results are shown in Table 3.

**Table 3: Properties of Mineral Diesel and Neem Oil**

<table>
<thead>
<tr>
<th>Property</th>
<th>Mineral Diesel</th>
<th>Neem Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>840±1.732</td>
<td>911±1</td>
</tr>
<tr>
<td>API Gravity</td>
<td>36.95±0.346</td>
<td>23.82±0.17</td>
</tr>
<tr>
<td>Kinematic Viscosity at 40°C (cSt)</td>
<td>2.44±0.27</td>
<td>32.27±0.67</td>
</tr>
<tr>
<td>Cloud Point (°C)</td>
<td>3±1</td>
<td>12±1</td>
</tr>
<tr>
<td>Pour Point (°C)</td>
<td>-6±1</td>
<td>7±1</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>71±3</td>
<td>218±2</td>
</tr>
<tr>
<td>Fire Point (°C)</td>
<td>103±3</td>
<td>229±2</td>
</tr>
<tr>
<td>Conradson Carbon Residue (%)</td>
<td>0.1±0.0</td>
<td>0.7±0.1</td>
</tr>
<tr>
<td>Ash Content (%)</td>
<td>0.01±0.0</td>
<td>0.03±0.0</td>
</tr>
<tr>
<td>Calorific Value (MJ/kg)</td>
<td>45.343</td>
<td>39.111</td>
</tr>
<tr>
<td>Carbon (%)</td>
<td>80.33</td>
<td>74.86</td>
</tr>
<tr>
<td>Hydrogen (%)</td>
<td>12.36</td>
<td>10.43</td>
</tr>
<tr>
<td>Nitrogen (%)</td>
<td>1.76</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen (%)</td>
<td>1.19</td>
<td>12.42</td>
</tr>
<tr>
<td>Sulfur (%)</td>
<td>0.25</td>
<td>0</td>
</tr>
</tbody>
</table>

Higher viscosity of Neem oil was reduced by (i) heating and (ii) blending the Neem oil with mineral diesel. Viscosity of Neem oil and diesel was measured at different temperatures in the range of 40-100°C (figure 3). Viscosity of Neem oil decreases remarkably with increasing temperature and it is close to diesel at temperature above 90°C (within ASTM limits). Therefore, Neem oil should be heated to approximately 90°C before injecting it in CI engine. Viscosity of diesel was 2.44 cSt at 40°C. For Neem oil, viscosity was found below 6 cSt at a temperature above 90°C.

Viscosity of various blends of Neem oil and diesel were evaluated at 40°C (figure 3). Viscosity of Neem oil decreases after blending. The viscosity of 30:70 and 20:80 blends was slightly higher than diesel but these blends are within ASTM limits for viscosity at 40°C. Density of Neem oil was found higher than that of diesel. Cloud point for Neem oil was found to be 12°C which is comparatively higher than diesel. Higher cloud point affects the engine performance and emissions adversely under cold climatic conditions. Pour point for Neem oil was found 7°C. Flash point of Neem oil was found to be 218°C whereas it was 71°C for diesel hence Neem oil is extremely safe to handle.

Five elements (C-H-N-O-S) are important for any fuel because they affect the calorific value of the fuel, emissions and engine performance. Low sulfur content of Neem oil results in lower SOₓ emissions. Presence of oxygen in Neem oil improves combustion and emissions but reduces the calorific value of the fuel. Nitrogen content of Neem oil also affects the NOₓ emissions.

**Optimum Fuel Injection Pressure for Different Fuels:** Optimum fuel injection pressure is that nozzle opening pressure, at which engine shows maximum efficiency and minimum BSFC. Engine was operated at different fuel injection pressure (180, 200, 220, and 240 bar). BSFC, thermal efficiency, and smoke opacity were measured/ calculated at different fuel injection pressure for diesel.

BSFC decreases as the fuel injection pressure increases from 180 bar to 200 bar while operating the engine on mineral diesel (figure 4). Further increase in fuel injection pressure results in increased BSFC.

Thermal efficiency was found to increase with increasing fuel injection pressure from 180 bar to 200 bar (figure 4). However, increase in fuel injection pressure from 200 bar to 240 bar showed decrease in thermal efficiency. Similarly, increase in fuel injection pressure from 180 bar to 200 bar resulted in decreased smoke opacity (figure 4). However, further increase in fuel injection pressure from 200 bar to 240 bar showed increased smoke opacity. The increase in smoke opacity is possibly because of insufficient mixing/ combustion of fuel with air. Based on BSFC, thermal efficiency, and smoke opacity, 200 bar was found optimum fuel injection pressure for diesel.

BSFC, thermal efficiency, and smoke opacity were measured/ calculated at different fuel injection pressure for preheated Neem oil. BSFC for heated Neem oil (100% SVO) was lowest at 200 bar (figure 5). BSFC for Neem oil was 0.28 kg/kW-hr at 200 bar and at 72% rated load. It was 0.293 kg/kWh, 0.29 kg/kWh, and 0.302 kg/kWh.
kg/kWh at 180 bar, 220 bar, and 240 bar respectively at similar engine load.

![Graph of BSFC vs Engine Load](image1)

![Graph of Thermal Efficiency vs Engine Load](image2)

![Graph of Smoke Opacity vs Engine Load](image3)

**Figure 4: Effect of Fuel Injection Pressure on Engine Performance Parameters of Diesel Fuelled CI Engine**

Thermal efficiency was highest at 200 bar fuel injection pressure (figure 5). Smoke opacity was lowest 26.8% at 200 bar at 72% rated load (figure 5). Based on BSFC, thermal efficiency, and smoke opacity, 200 bar was found optimum fuel injection pressure for Neem oil.

![Graph of BSFC vs Engine Load for Preheated Neem Oil](image4)

![Graph of Thermal Efficiency vs Engine Load for Preheated Neem Oil](image5)

![Graph of Smoke Opacity vs Engine Load for Preheated Neem Oil](image6)

**Figure 5: Effect of Fuel Injection Pressure on Engine Performance Parameters of Preheated Neem Oil Fuelled CI Engine**

**Effect of Fuel Inlet Temperature on Emissions and Performance of Engine**

Engine tests were conducted for performance and emissions using unheated Neem oil, preheated (90° C) Neem oil. The baseline data was generated using mineral diesel. The analyzed data is presented graphically in figure 6.

Diesel fuel operation shows lowest BSFC (figure 6). Lower calorific value of Neem oil leads to increased fuel consumption in order to maintain similar energy input to the engine. Thermal efficiency of preheated Neem oil was found slightly higher than diesel (figure 6). The possible reason may be improved fuel atomization and combustion along with additional lubricity of Neem oil.
Thermal efficiency for unheated Neem oil was slightly lower than diesel. The possible reason may be higher fuel viscosity. Higher fuel viscosity results in larger fuel droplets followed by inadequate mixing of fuel and air. Exhaust gas temperatures of the preheated Neem oil was found to be increased over other fuels (figure 6).

Figure 6: Engine Performance and Emission Parameters for Neem Oil (Unheated and Preheated) vis-à-vis Mineral Diesel
Figure 7: Engine Performance and Emissions Parameters for Neem Oil Blends vis-à-vis Mineral Diesel
Smoke opacity for Neem oil was greater than that of diesel (figure 6). The greater smoke opacity percentage of Neem oil is mainly due to bulky molecules of hydrocarbons. Heating Neem oil result in lower smoke opacity compared to unheated oil but it is still higher than diesel. The emissions of CO$_2$ were noted to increase as the viscosity of the fuel increases (figure 6). Increase in viscosity results in decrease in spray cone angle, which leads to reduction of the amount of air entrainment in the fuel spray. This is possibly affecting combustion characteristics of the fuel. At lower loads, CO emissions were nearly similar for all the fuels but at higher loads, CO emissions were higher for unheated Neem oil compared to diesel (figure 6). This is possibly a result of poor spray atomization and non uniform mixture preparation of Neem oil. Figure 6 shows that diesel fuel operation produced lower HC emissions compared to Neem oil. Heating the Neem oil reduces the HC emissions compared to unheated Neem oil.

All the experimental results suggest that heating the Neem oil using exhaust gas improves its engine performance and emissions and bring its combustion properties close to mineral diesel.

**Emissions and Performance Tests with Neem Oil Blends:**

Blends of varying concentrations were prepared ranging from pure diesel to 100% Neem oil through 10%, 20%, 30%, 50%, and 75% (Nxx: xx indicates percentage of Neem oil in the Neem diesel blend). Performance and emissions tests were conducted using these blends (unheated) and baseline data was generated using mineral diesel.

BSFC of Neem blends is higher than diesel (figure 7). N10 and N20 blends have BSFC very close to that of diesel. But for other blend concentrations, BSFC was higher because of lower calorific value of the Neem oil. Thermal efficiency for N10 and N20 blends was found higher than diesel (figure 7). For all other blends, it was lower than mineral diesel. The possible reason for improved thermal efficiency may be more complete combustion due to presence of oxygen in fuel molecule. Further increase in proportion of Neem oil in blend increases viscosity, which results in lower thermal efficiency. Figure 7 shows that exhaust gas temperature is higher with Neem oil blends than diesel. This is due to slower rate of combustion of Neem oil because of its high viscosity which results in higher exhaust gas temperature.

Smoke opacity at 85% rated load is 37.4% with Neem oil (N100) as sown in figure 7. The smoke opacity with diesel is 12.8% at the same load. As the proportion of Neem oil increases in the blend, smoke opacity also increased. The smoke opacity for N10 and N20 is very close to diesel. CO$_2$ for diesel was found 5.5% at 85% rated load (figure 7); the corresponding value for N100 was 7.2%. CO$_2$ emissions increase with the increase of proportion of Neem oil in the blend.

CO emissions were significantly higher for N100 at higher loads (figure 7). This may be due to lower air-fuel ratio compared to diesel. CO emissions were higher for Neem oil blends also but the increase in CO was very low. HC emissions were significantly higher for N100 over the other fuels as can be seen from figure 7. As the Neem oil concentration is decreased in blends, HC emissions are found to decrease.

**CONCLUSION**

The main objective of the present investigation was to reduce the viscosity of Neem oil an bring it close to that of conventional fuel to make it suitable for use in an unmodified CI engine and to evaluate the performance of the engine with modified oils. Diesel and Neem oil were characterized for various physical, chemical and thermal properties. Neem oil viscosity was reduced by heating it and also by blending it with mineral diesel. It was found that heating the Neem oil to 90-100°C is adequate to bring down the viscosity in close range to that of diesel. Viscosity of Neem oil blends (up to 30%) was found closer to diesel. Reduced viscosity allows the use of Neem oil as diesel substitute. Optimum fuel injection pressure for preheated Neem oil as well as mineral diesel was found to be 200 bar.

The performance and emissions tests were conducted with diesel, preheated Neem oil, unheated Neem oil, and blends of Neem oil at different loads and constant speed (1500 rpm). From the experimental results obtained, Neem oil is found to be a promising alternative fuel for diesel engines. It can be directly used as straight vegetable oil as a full replacement of diesel fuel and do not require any major modification in the engine. BSFC and exhaust gas temperatures for unheated Neem oil were found to be higher compared to diesel and preheated Neem oil. Thermal efficiency was slightly lower for unheated Neem oil compared to preheated Neem oil and diesel. CO$_2$, CO, HC, and smoke opacity were higher for Neem oil compared to diesel. These emissions were found to be closer to diesel for preheated Neem oil. For blends, BSFC and exhaust gas temperature were found higher for all blends compared to diesel. Thermal efficiency was found close to diesel for Neem oil blends and even lower for 10 and 20% blends of Neem oil. Emission parameters such as smoke opacity, CO$_2$, CO, and HC were found to have increased with increasing proportion of Neem oil in the blends compared to diesel.

Since preheated Neem oil and its blends (N10 and N20) showed performance characteristics close to diesel, it can be concluded that either preheating or blending the Neem oil can be used for its use in compression ignition engines in rural areas for agriculture, irrigation and electricity generation. Modified maintenance schedule may however be adopted to control carbon deposits formed during long term usage of Neem oil.
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