Performance, Emission and Combustion Characteristics of Modified Diesel Engine Fuelled with Neem Oil Methyl Ester (NOME)

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Abstract

This experimental study paper investigates the performance of diesel engine powered with neem oil methyl ester (NOME). The engine operating conditions such as injection timing (IT), injector opening pressure (IOP) and nozzle holes were varied and better operating conditions were reported. The engine was always operated at 1500 rpm with CR of 17.5. For diesel engine operation with NOME, it could be revealed that IT of 27°BTDC, and IOP of 240 bar yield better performance in terms of higher brake thermal efficiency (BTE) with reduced emissions. Injector of 5 hole yielded better results as compared to other injectors tested.

Keywords

Neem Oil Methyl Ester (NOME); Injection Strategies; Performance; Emission Characteristics

Introduction

Use of biodiesel and different methods of using them in normal diesel engine has been given in several works [1-3]. The fossil resources are not considered as sustainable energy resources as they exhaust soon and emit large amount of harmful emissions leading to the environment pollution besides effecting human health. Therefore, it has become necessary to explore alternative renewable fuels [4]. Diesel engines used due to their higher thermal efficiency, excellent drivability. In spite of their advantages, they gives out more oxides of nitrogen (NOx) and smoke emissions. With stringent emission norms laid by different agencies, it has become a prime importance to control these pollutants from the engines [5]. To shoot these problems, several research worldwide worked with different strategies and fuel combinations [6, 7]. Biodiesel has a significant potential as fuel for compression ignition (CI) engines. Several countries uses different edible oils such as palm, soybean and non-edible oils such as Jatropha curcas, pongamia pinnata, linseed for biodiesel production to power CI engine [8-12]. The use of such biodiesels for CI engines reduces carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) emissions. The utilization of these biodiesel for CI engines is not sufficient against their requirement. The product from tyre paralysis are oil, carbon black and pyro gas [13]. A reduction in the BTE with 30%, 40% and 50% TPO in the blend at full load was reported in the literature [14]. Smaller fraction of Desulfurized tyre oils with diesel could yield lower CO, HC and smoke emission but slightly higher than neat diesel [15]. Specific fuel consumption (SFC) of plastic oil blends was higher than the diesel and carbon dioxide (CO₂), CO and NOx were also found higher [16].

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Several researchers have tested CI engine using various biodiesel fuels at different IT and IOP. With advancement or retardation in the IT, cylinder pressure and temperature inside the combustion chamber were observed [7]. Significant reduction in NOx emission from CI engine using diesel and biodiesel was observed when IT was retarded [17, 18]. When IT was retarded during engine operation, gradual decrease in cylinder pressures and temperatures were observed [19]. The effect of variation in IT on the performance of the CI engine has been investigated with an advanced IT of 40° before top dead center (BTDC) when waste cooking oil is used as an alternative fuel and reported better efficiency, reduced CO and higher NOx emissions [20], on contrary retarded IT has favored the performance of diesel engine with Honge biodiesel has been reported [21]. By retarding IT and increasing IOP up to 230 bar has given good engine performance with cotton seed oil methyl ester [22, 23]. It has been reported that CO, HC and PM emissions were reduced by about 14.2%, 13.26% and 9.3% respectively when IT was advanced to 24.5°CA BTDC with pyrolysis oil and JOME blend [24]. Similarly, various investigations have been carried out experimentally on CI engine with different fuel combinations at different IOP. At increased IOP, better performance was reported [19, 21, 22, 25, 26]. From the detailed literature survey carried out, very limited work is available on combined effect of IT, IOP and injector nozzle geometry on the performance studies with NOME powered CI engines. Therefore, experimental study were carried out diesel engine powered with NOME with different injection parameters and nozzle holes.

Materials and Methods

2.1 Fuels Used in Current Experimental Study

The properties of NOME were measured at Bangalore Test House Laboratory, Bengaluru, India. Table 1 summarize the properties of fuels used.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Properties</th>
<th>Diesel</th>
<th>NEEM OIL</th>
<th>NOME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density(kg/m³)</td>
<td>840</td>
<td>912</td>
<td>875</td>
</tr>
<tr>
<td>2</td>
<td>Energy density(kJ/kg)</td>
<td>43,000</td>
<td>39,100</td>
<td>39,500</td>
</tr>
<tr>
<td>3</td>
<td>Viscosity at 40°C(cSt)</td>
<td>2-5</td>
<td>20.5</td>
<td>5.77</td>
</tr>
<tr>
<td>4</td>
<td>Flash point (°C)</td>
<td>75</td>
<td>234</td>
<td>158.25</td>
</tr>
<tr>
<td>5</td>
<td>Cetane Number</td>
<td>45-55</td>
<td>41.63</td>
<td>46</td>
</tr>
<tr>
<td>6</td>
<td>Carbon Residue(%)</td>
<td>0.1</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Pour point (°C)</td>
<td>-5</td>
<td>-2</td>
<td>-----</td>
</tr>
</tbody>
</table>

2.2 Experimental Set-up and Methodology

Experimental setup used for the present work is depicted in Figure 1. Initially the experimental tests were carried out on CI engine to optimize IT, at different loading conditions. Various IT of 19°, 23°, 27° and 31° BTDC for engine operation with NOME were selected. The engine was always operated at 1500 rpm with injector of 3 holes and 0.3 mm orifice size. The readings recorded only after engine attained stable condition. Further experiments were conducted to optimize IOP and number of holes respectively keeping that IT which yielded better BTE. Various IOP selected were 205, 220, 230, 240 and 260 bar and different injector selected for the study had 3, 4 and 5-holes. Specifications of CI engine used for the experimental study are shown in Table 2. Engine cooling was achieved by applying jacket circulating water. A piezoelectric transducer (Make: PCB Piezotronics, Model: HSM 111A22, Resolution: 0.145 mV/kPa) fitted to the cylinder head was utilized to measure the in cylinder gas pressure. Exhaust gas composition during the steady-state operation was measured by employing a Hartridge smoke meter and five-gas analyzers (A DELTA 1600 S-non-dispersive infrared analyzer).

2.3 Uncertainty Analysis

The uncertainties in the calculated parameters are provided in the Table 3.
Table 2: Specifications of the CI Engine

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Parameter</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type</td>
<td>TV1 (Kirlosker make)</td>
</tr>
<tr>
<td>2</td>
<td>Software used</td>
<td>Engine soft</td>
</tr>
<tr>
<td>3</td>
<td>Nozzle opening pressure</td>
<td>200 – 225 bar</td>
</tr>
<tr>
<td>4</td>
<td>Governor type</td>
<td>Mechanical centrifugal type</td>
</tr>
<tr>
<td>5</td>
<td>No. of Cylinders</td>
<td>Single cylinder</td>
</tr>
<tr>
<td>6</td>
<td>No. of strokes</td>
<td>Four stroke</td>
</tr>
<tr>
<td>7</td>
<td>Fuel</td>
<td>H. S. Diesel</td>
</tr>
<tr>
<td>8</td>
<td>Rated power</td>
<td>5.2kW(7 HP at 1500 RPM)</td>
</tr>
<tr>
<td>9</td>
<td>Cylinder diameter (Bore)</td>
<td>0.0875m</td>
</tr>
<tr>
<td>10</td>
<td>Stroke length</td>
<td>0.11m</td>
</tr>
<tr>
<td>11</td>
<td>Compression ration</td>
<td>17.5:1</td>
</tr>
<tr>
<td></td>
<td>Air measurement manometer</td>
<td>MX 201</td>
</tr>
<tr>
<td></td>
<td>Type</td>
<td>U-Type</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>100-0-100mm</td>
</tr>
<tr>
<td></td>
<td>Eddy current dynamometer</td>
<td>AG-10</td>
</tr>
<tr>
<td></td>
<td>Model</td>
<td>AG-10</td>
</tr>
<tr>
<td></td>
<td>Type</td>
<td>Eddy current</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>7.5 (kW at 1500-3000RPM)</td>
</tr>
<tr>
<td></td>
<td>Flow</td>
<td>Water must flow through Dynamometer during the use</td>
</tr>
<tr>
<td></td>
<td>Dynamometer arm length</td>
<td>0.180 m</td>
</tr>
<tr>
<td></td>
<td>Fuel measuring unit – Range</td>
<td>0-50 ml</td>
</tr>
</tbody>
</table>
Table 3: The Accuracies of the Measurements and the Uncertainties in the Calculated Parameters

<table>
<thead>
<tr>
<th>Measured variable</th>
<th>Accuracy (±)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (N)</td>
<td>0.1</td>
</tr>
<tr>
<td>Engine speed (rpm)</td>
<td>1</td>
</tr>
<tr>
<td>Temperature, (°C)</td>
<td>1</td>
</tr>
<tr>
<td>Fuel consumption (g)</td>
<td>0.1</td>
</tr>
<tr>
<td>HC</td>
<td>±1.2</td>
</tr>
<tr>
<td>CO</td>
<td>±2.5</td>
</tr>
<tr>
<td>NOx</td>
<td>±2.3</td>
</tr>
<tr>
<td>Smoke</td>
<td>±2.0</td>
</tr>
<tr>
<td>Calculated parameters</td>
<td></td>
</tr>
<tr>
<td>BTE (%)</td>
<td>±1.2</td>
</tr>
<tr>
<td>HRR (J/°CA)</td>
<td>±1.3</td>
</tr>
</tbody>
</table>

3. Results and Discussions
3.1 Effect of IT for Different Fuels Tested

Initially studies on basic performance, emission and combustion characteristics of a single cylinder diesel engine when fueled with diesel, and NOME were carried out. Tests were conducted at four ITs of 19°, 23°, 27° and 31° BTDC keeping IOP constant at 205 bar for different load. Based on the averaged out results from five readings at each of the conditions specified, optimum IT was determined. The impact of IT on BTE for single fuel operation with NOME at four ITs is as shown in Figure 2. NOME showed lower BTE as compared to diesel for all four IT. The decrease in BTE for NOME is due to lower energy content and higher fuel consumption observed for the same power output. As viscosity of NOME is higher than diesel, the poor mixture formation and subsequent poorer combustion could be the reason for the same. The maximum BTE for NOME at 27° BTDC is 24.35 %. However, by advancing the IT by 4° CA decrease in BTE was observed. Based on the magnitudes of BTE, the optimum IT for NOME is selected as 27° BTDC.

3.1.1 Effect of IT on Smoke Opacity

IT effect on smoke for NOME is given in Figure 3. Smoke opacity for renewable fuel NOME increased with increase in load. Higher smoke opacity was observed with NOME as compared to diesel due to heavier molecular structure of NOME, higher viscosity and density. For the same loading engine operation, lower volatility and energy content of the NOME results into varied air-fuel ratio and hence incomplete combustion with higher smoke emissions as compared to diesel operation. Smoke with NOME was minimal at 27° BTDC as shown in Figure 3. It is due to fuel injection occurs at lower temperature and pressure which results in an increase in the ID and led to burning of mixture in premixed mode. The values of smoke emissions for the IT 19°, 23°, 27° and 31° BTDC were 68 Hartridge smoke unit (HSU), 60 HSU, 50 HSU and 54 HSU respectively at 80% load.

Figure 2: Effect of IT on BTE

Figure 3: Effect of IT on Smoke Opacity
3.1.2 Effect of IT on HC and CO Emissions

Unburned Hydrocarbon Emissions

The effect of IT on HC and CO emissions for NOME is as shown in Figure 4 and Figure 5 respectively. HC emissions exhausted from diesel engines are because of incomplete combustion. Lean mixture existing in the engine cylinder during ID and non-uniform mixing of fuel that comes out of injector orifice at reduced velocity could also be responsible for these results. For all four IT, HC and CO emissions were higher for NOME as compared to diesel. Lower BTE with NOME due to poor spray characteristics of NOME could be the reason. HC emission of 61 ppm, 57 ppm, 51 ppm and 63 ppm for 190, 230, 270 and 310 BTDC IT respectively at 80% load. CO is a toxic by-product of the fuel combustion prevailing inside the engine cylinder. The amount of CO observed was lower at part loads and higher at full load at all the IT. NOME showed comparatively higher CO emissions as compared to diesel due to the reasons explained for HC emissions. The amount of CO at 80% load are 0.23%, 0.22%, 0.174% and 0.181% for 190, 230, 270 and 310 BTDC IT respectively. Lowest CO was found at the IT of 270 BTDC. IT of 270 BTDC could be the best to yield lower HC and CO emissions as compared to other IT with NOME.

3.1.3 Effect of IT on NOx Emissions

Figure 6 represents the effect of IT on NOx emissions for NOME. NOx emissions for NOME were lower and increased with load as compared to diesel fuel at all the IT. Higher BTE obtained with fossil diesel and the associated higher premixed combustion phase could be responsible for the observed higher NOx. The main factors responsible for NOx formation are elevated temperatures, oxygen availability and residual time. In general, retarded fuel injection results in lower NOx due to lower peak temperature. NOx levels are higher with NOME operation at advanced IT of 230, 270 and 310 BTDC due to higher premixed heat release on account of longer ID.

3.2 Effect of Injector Opening Pressure (IOP) on the Performance

Studies on performance of the diesel engine were carried out using NOME at different IOP. Engine was operated with IOP varying from 205 bar to 260 bar keeping IT of 270 BTDC. Based on the BTE results, the optimum IOP could be fixed for NOME.
3.2.1 Effect of IOP on BTE

IOP effect on BTE at various loads is given in Figure 7. IOP of 240 bar yielded highest BTE because of better atomization, and enhanced mixing with air. BTE was found to be 25.3% at 80% load at an IOP of 24 MPa.

Figure 7: Effect of IOP on BTE

3.2.2 Effect of IOP on Emissions

Figure 8 illustrates the effect of IOP on smoke with load. Smoke levels were observed to fall at higher IOP on account of better combustion due to well-atomized spray. Smoke level was minimal with 240 bar IOP. At 80% load, the smoke level was 43 HSU with IOP of 240 bar. Figure 9, Figure 10 provides the effect of IOP on HC and CO emission respectively. On the other hand NOx emissions increased with the increase in IOP as shown in Figure 11. Enhanced burning due to lower ID with NOME and higher temperature due to higher HRR could be the reason. HC reduced from 51 to 45 ppm when IOP was increased at 80% load.

Figure 8: Effect of IOP on Smoke Opacity

Figure 9: Effect of IOP on Unburned Hydrocarbon Emissions

Figure 10: Effect of IOP on Unburned Carbon Monoxide Emissions

Figure 11: Effect of IOP on NOx Emissions
3.3 Effect of Different Nozzle Holes on the Performance

Here diesel engine was operated with IOP 240 bar and IT of 27° BTDC. Injector of 3, 4, and 5 holes were used.

3.3.1 Effect of Different Nozzle Holes on BTE

The effect of different nozzle holes on BTE at various loads is shown in Figure 12. Highest BTE was occurred with 5 hole injector as compared to other due to better atomization, mixing with air. BTE was found to be 25.9% at 80% load with 5-hole nozzle and at an IOP of 24 MPa. However, BTE for 3-hole and 4-hole nozzles were found to be 25.3% and 25.6% respectively at 24 MPa. Based on the results, BTE was found to be high with 5-hole injector nozzle holes and IOP of 24 MPa. It is seen that increase in number of holes could increase the fuel-air mixing rate and yield better BTE.

3.3.2 Effect of Different Nozzle Holes on Emission

The effect of different nozzle holes on emissions various loads are shown in Figure 13, Figure 14, Figure 15, Figure 16 amongst all the injectors tested, the lower emissions occurred with 5 hole injector. This is because of better combustion on account of better atomization, spray characteristics and mixing with air. Smoke, HC, CO and NOx were found to be 39 HSU, 40 ppm, 0.13 % volume and 1095 ppm respectively at 80% load with 5-hole nozzle.
3.3.3 Effect of Different Nozzle Holes on Combustion Characteristics

The effect of different nozzle holes on combustion characteristics with load is shown in Figure 17, Figure 18, Figure 19, Figure 20. Amongst all the injectors tested, the lower ID and CD occurred with 5 hole injector. On contrary the PP and HRR were higher with 5 hole injector. This is because of better combustion on account of better atomization, spray characteristics and mixing with air. ID, CD, PP and HRR were found to be 9.8°CA, 29°CA, 71 bar and 74 J/°CA respectively at 80% load with 5-hole nozzle.

Figure 16: Effect of Nozzle Holes on NOx

Figure 17: Effect of Nozzle Geometry on ID

Figure 18: Effect of Nozzle Geometry on CD

Figure 19: Effect of Nozzle Geometry on PP

Figure 20: Effect of Nozzle Geometry on HRR
Conclusions

From the exhaustive experimental tests conducted with NOME powered diesel engine the following conclusions could be drawn:

• When diesel engine was operated with NOME at 205 bar, CR of 17.5 the maximum BTE and lower emissions were obtained at IT of 27° BTDC as compared to other IT.

• When diesel engine was operated with optimized IT of 27°BTDC, maximum BTE and lower emissions were reported at IOP of 240 bar as compared to other IOP and also 5 holes injector yielded better results as compared to other holes injector tested.

On the whole, NOME powered CI engine operation with optimum engine operating parameters like IT of 27° BTDC; IP of 240 bars, and 5 holes injector showed overall better engine performance in terms of higher BTE with reduced emissions. The huge burden on the foreign exchange can be saved by using alternative fuel (NOME) to meet the energy requirement of India and become self sustainable in energy production as well.

References


