EMISSION STUDIES ON A DIESEL ENGINE OPERATED WITH KARANJA METHYL ESTER BLENDS USING DIETHYL ETHER ADDITIVE

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Abstract:
Growing demand for energy and environmental pollution have led to development and use of alternate fuels for internal combustion engines. In this work, efforts were made to develop an alternate fuel from non-edible Karanja oil for application in a stationary diesel engine. Karanja methyl ester (KME) blends along with diethyl ether (DEE) additive in suitable volume proportions (5%, 10% and 15%) was used in a diesel engine for study of the engine performance and exhaust emissions. Fuel characterization results showed that KME has higher calorific value, greater flash point along with poor cold-flow plugging point compared to diesel. Purpose of using DEE, as an additive to the KME-diesel blends, is to enhance its combustion characteristics as well as emission pattern of the DEE blended biodiesel. The fuel characterization results showed that addition of DEE to KME enhances the calorific value and the cetane number, whereas the cold flow properties are also improved. The engine test results obtained with KME-DEE blends showed higher brake thermal efficiency and lower brake specific energy consumption compared to neat KME and diesel. In addition, the KME-DEE blends exhibited lower CO, HC and smoke emissions along with a little bit increase in NO\textsubscript{x} emissions compared to neat KME and diesel. All the aforementioned emissions tend to decrease with increase in DEE percentage in the blends. However, NO\textsubscript{x} emissions were observed to increase slightly with higher DEE percentage in the blends.

Keywords: Karanja methyl ester, biodiesel, diesel engine, diethyl ether, performance and emission

1. INTRODUCTION
Global rise in population, rapid industrialization, hasty increase in automobiles, machinery etc. have led to excessive demand for energy in the last few decades. Conventional sources of energy, such as coal, petroleum, natural gas etc. are depleting in nature and cause serious damage to the ecosystem in terms of environmental pollution. Incidence of climate change, global warming, increase in greenhouse gas (GHG) percentage in the atmosphere, increase in particulate matter (PM) level in the atmosphere, acid rain are because of the rapid environmental degradation in recent years. In this context, non-conventional and renewable energy sources are regarded as potential solutions to address the aforementioned issues. Development of biofuels from renewable biomass has been an emerging technology to address the increasing fuel prices and their adverse effect on the environment. Many researchers around the globe are working on development of biofuels from various biomass sources for application in internal combustion engines. Straight vegetable oils (SVOs), vegetable oil methyl esters, popularly known, as biodiesel, bioethanol etc. are some of the feasible biofuel options for internal combustion engine applications in recent times.

Misra and Murthy [1] reviewed the status and potential of Jatropha as a major biofuel source in India. They discussed that the Jatropha biodiesel-diesel blends when used as fuel in a compression ignition (CI) engine, resulted in very close values of brake thermal efficiency (BTE), brake specific energy consumption (BSEC) as well as CO, HC and NO\textsubscript{x} emissions compared to neat diesel fuel. Misra and Murthy [2] used soapsnut oil (SO)-diesel blends (10%, 20%, 30%, 40% v/v) in a CI engine and studied the performance and emission behaviorof the engine. They reported that all the SO-diesel blends showed better engine performance in terms of BTE and BSEC along with lower CO, HC and NO\textsubscript{x} emissions compared to diesel. Lapureta et al. [3] reviewed the emissions of a CI engine fueled with various biodiesels and their diesel blends. They concluded that use of biodiesels in a diesel engine results in comparable engine performance and lowers the PM emissions. However, they also reported that using biodiesel enhances the NO\textsubscript{x} emissions of a diesel engine to some extent. Sun et al. [4] presented an excellent review on the use of biodiesel fuel in CI engines and reported that biodiesels can be effective substitute for diesel fuel in CI engines, however NO\textsubscript{x} reduction in biodiesel fueled engines need to be further investigated. Roy et al. [5] used different biodiesel blends with Wintro XC 30 additive in a CI engine and reported improved fuel properties, lower CO, HC and NO\textsubscript{x} emissions with higher BTE compared to diesel fuel. Nayak and Pattanaik [6] studied the use of Mahua biodiesel with dimethyl carbonate as additive in a CI engine and reported higher BTE, lower BSEC as well as lower CO, HC and NO\textsubscript{x} emissions compared to mineral diesel. Similarly, many other researchers have also investigated on the use of biodiesels and their blends using additive in diesel engines and reported improved results in terms of engine performance and exhaust emissions in comparison to mineral diesel fuel. The present work aims to develop biodiesel from non-edible Karanja oil (KO) through base catalyzed transesterification followed by its application in an experimental diesel engine using diethyl ether (DEE) in various proportions as additive. Further, it is also aimed to study the emission characteristics of the diesel engine using the developed test fuels.
II. MATERIALS AND METHODS

2.1 Preparation of Biodiesel and Blends

In the current work, non-edible Karanja oil was selected for biodiesel production. 10 liters of raw KO was procured from M/s Sajjan Brothers, Karanjia, Baripada, Odisha for the purpose of developing biodiesel. The raw KO was first filtered for separation of impurities. Base catalyzed transesterification of the neat and filtered KO was carried out in a 2 L capacity biodiesel reactor (Make: M/s Gobind Machinery Works, India) using KOH as base catalyst and methanol as reagent. 20% v/v methanol was used along with 10 gm of KOH for one single run of biodiesel production. Transesterification reactions were carried out at 60°C for a period of 1.5 h. After the reaction is over, the reaction products were permitted to settle down overnight. On the next day, glycerol was removed from the bottom layer and Karanja methyl ester (KME) was collected to another container. The collected KME was then water washed three times followed by drying to obtain neat KME. DEE was purchased from M/s Global Agency, Kolkata, West Bengal. 5% and 10% v/v of DEE was suitably mixed with KME for preparation of KME+DEE blends. In this way, the test fuels prepared were neat KME, KME with 5% DEE (KMED5), KME with 10% DEE (KMED10) and KME with 15% DEE (KMED15). All the developed test fuels were characterized for important fuel properties using standard ASTM procedure. The results of the fuel characterization are presented in Table 1.

Table 1. Test fuel properties

<table>
<thead>
<tr>
<th>Fuel Property</th>
<th>Diesel</th>
<th>KME</th>
<th>KMED5</th>
<th>KMED10</th>
<th>KMED15</th>
<th>ASTM Standard</th>
</tr>
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<tbody>
<tr>
<td>Density at 20°C, kg/m³</td>
<td>835</td>
<td>848</td>
<td>844</td>
<td>841</td>
<td>839</td>
<td>D4052</td>
</tr>
<tr>
<td>Kinematic viscosity at 40°C, cSt</td>
<td>2.67</td>
<td>4.92</td>
<td>4.23</td>
<td>4.12</td>
<td>4.02</td>
<td>D445</td>
</tr>
<tr>
<td>Flash point, °C</td>
<td>71</td>
<td>176</td>
<td>162</td>
<td>156</td>
<td>152</td>
<td>D93</td>
</tr>
<tr>
<td>Calorific value, MJ/kg</td>
<td>44.58</td>
<td>41.2</td>
<td>41.9</td>
<td>44.2</td>
<td>44.38</td>
<td>D240</td>
</tr>
<tr>
<td>Cloud point, °C</td>
<td>6.6</td>
<td>11.2</td>
<td>10.8</td>
<td>10.4</td>
<td>10.1</td>
<td>D2500</td>
</tr>
<tr>
<td>Pour point, °C</td>
<td>3.2</td>
<td>5.6</td>
<td>5.2</td>
<td>4.8</td>
<td>4.6</td>
<td>D97</td>
</tr>
<tr>
<td>Cetane index</td>
<td>49</td>
<td>52.3</td>
<td>54.2</td>
<td>55.2</td>
<td>56.7</td>
<td>D4737</td>
</tr>
<tr>
<td>Ash content, %</td>
<td>0.001</td>
<td>0.008</td>
<td>0.006</td>
<td>0.005</td>
<td>0.004</td>
<td>D976</td>
</tr>
</tbody>
</table>

2.2 The Experimental Set up

Engine tests were carried out using all the above-mentioned test fuels in a stationary diesel engine (Make: Kirloskar AV-1). It is a computerized four-stroke water-cooled single-cylinder direct injection diesel engine equipped with an eddy current dynamometer. The rated power of the engine is 5.2 kW at 1500 rpm. The emission measurements were carried out using an AVL Digas 444 emission analyzer and an AVL 437 smokemeter. All the engine tests were performed at 0%, 25%, 50%, 75%, 85%, 90%, 95% and 100% of the rated load. Diesel was used as the base line fuel for all the experimentations. During the tests, the observed data was stored in the attached computer. The main engine parameters investigated were BTE, BSEC along with CO, HC, NOₓ and smoke emissions. A schematic diagram of the test engine is presented in Fig. 1.
III. RESULTS AND DISCUSSION

A comparative analysis of the obtained results in terms of the major engine emission parameters, viz. CO, HC, NO\textsubscript{x}, and smoke emissions, was carried out and suitably presented with discussions in the present section. All the previously mentioned emission parameters were studied for the selected test fuels with diesel as the base line fuel under variable loading conditions. The details of the comparative analyses are presented as below.

3.1 CO Emissions

The CO emissions for all the test fuels and diesel under variable load conditions are plotted in Fig. 2. The trend of CO emissions for all the selected fuels is observed to be initially decreasing with increase in load up to 85% followed by an increasing trend until rated load. It is observed that the CO emissions are lowest for KMED15 blend and highest for diesel at all loads. It is also observed that the CO emissions decrease with increased percentage of DEE in the blends. This may be due to better combustion with DEE additive, which is related to the higher cetane number and calorific value of the blends. The same is in accordance with the published literature [10].

![Fig. 2 Variation of CO emissions](image)

3.2 HC Emissions

Figure 3 represents the variation in HC emissions for all the test fuels under variable loads. As can be seen from Fig. 3, the HC emissions for the considered fuels increase with load after 85% loading condition. The HC emissions for KMED15 is found to be lowest and the same is highest for diesel among all the test fuels under all loads. Further, HC emissions tend to decrease with increase in percentage of DEE in the biodiesel blends. This may be attributed to the higher cetane number and calorific value as well as lower viscosity of the additive blends that leads to better combustion and lower HC emissions. On the other hand, highest HC emissions for diesel is because of its higher hydrocarbon content and availability of less oxygen during combustion. These results are in agreement with the work of Yasin et al. [11].

![Fig. 3 Variation of HC emissions](image)

3.3 NO\textsubscript{x} Emissions

The NO\textsubscript{x} gas is regarded as the most dangerous emission among all the exhaust emissions. NO\textsubscript{x} mainly forms inside the engine cylinder due to availability of higher oxygen and a higher in-cylinder temperature [12]. Fig. 4 depicts the variation of NO\textsubscript{x} emissions for all the test fuels under variable loads. It can be noticed that the NO\textsubscript{x} emissions rise with increase in load for all the test fuels. This is attributed to the higher in-cylinder temperature and pressure with increase in load [13]. KMED15 is observed to exhibit highest NO\textsubscript{x} emissions among all the fuels, whereas the same is found to be lowest for diesel at all engine loads. This may be due to the higher cetane number, higher calorific value and lower viscosity of the additive blends in comparison to neat biodiesel and diesel [14].
3.4 Smoke Opacity

Figure 5 shows the variation of smoke opacity with load. It is observed that smoke opacity for all the selected fuels increase with rise in load. Diesel exhibits highest smoke opacity among all the fuels at all loads. On the other hand, the same for the biodiesels and the blends is comparatively lower. This is because of the higher oxygen content in biodiesels and their higher calorific value and higher cetane number that results in better combustion. Further, the higher smoke opacity with diesel can be attributed to less availability of oxygen [15]. The lowest smoke opacity is observed for KMED15 blend, which can be explained in terms of its better combustion characteristics compared to the other test fuels.

IV. CONCLUSIONS

The key findings of the present experimental investigation are enumerated as below.

- Addition of DEE with biodiesel improves the cold flow properties, such as viscosity, cloud and pour point of the blends. Again, the same also enhances the cetane number and calorific value of the resulting biodiesel blend.
- Use of DEE as an additive to biodiesel enhances the combustion quality as well as lowers the CO, HC and smoke emissions. Further, the same also results in higher BTE and lower BSEC of the resulting blend.
- The NO\textsubscript{x} emissions tend to increase marginally with increase in DEE percentage in the biodiesel blend.
- Thus, the present work establishes that DEE can be successfully used as an additive to biodiesel with superior engine performance and lower exhaust emissions. However, further investigation is desirable to limit the NO\textsubscript{x} emissions of the biodiesel-DEE blends.
REFERENCES