ABSTRACT

Vegetable oils are very good alternative fuels and have great potential for use in internal combustion engines because of their abundant availability, renewable nature and lower emissions. Many vegetable oils have been used in compression ignition engines with fuel modification or engine modification. Polanga oil, non edible oil by nature is available in a few states of India. An experimental investigation was made to evaluate the combustion, performance, and emission characteristics of a diesel engine using blends of polanga oil and diesel. Polanga oil of 10%, 30% and 50% on a volume basis was blended with 90%, 70% and 50% respectively, diesel fuel. The experimental results are compared with those of pure diesel fuel operation, and presented in this paper.

INTRODUCTION

Global warming and the poor quality of air are due to the fast growth of industries and urbanization. The combustion of different kinds of hydrocarbon based fuels generates different pollutants and that is one of the reasons for the deterioration in the quality of air. On the other hand, due to the consumption of petroleum products on a large scale, the demand for crude oil has increased immensely. In order to overcome these two issues, i.e., the depletion of petroleum resources and the increase in emissions, a great effort is needed among the public, policy makers, scientists, researchers and users. Years ago, in the mid 20th century, promising research was initiated to trace out various options relating to alternative fuels for transport vehicles. Since then, continuous research has been carried out to find fuels from solid, liquid and gaseous substances. Although fuels such as alcohols, liquefied petroleum gas and compressed natural gas are being used as alternative fuels for transport vehicles, the search for better alternative fuels is still on. Rudolf Diesel was the first person, who introduced vegetable oil as a fuel in his engine. As he had forecasted, the use of vegetable oils as alternative fuels today in internal combustion engines has become an appalling reality. The utilization of vegetable oils in diesel engines has many advantages. Vegetable oils are renewable in nature and may generate opportunities for rural employment when used on large scale [1]. The use of vegetable oil, as a sole fuel or in combination with diesel fuel, in compression ignition engines would prolong the duration of the availability of diesel fuel.

Vegetable oils are found to have properties closer to diesel fuel [2]. The heating value of vegetable oil is lower that of diesel fuel, as the oxygen content is very high. Attempts have been made to use vegetable oils in compression ignition engines. But still there is a wide scope for exploring the natural resources of agricultural products as alternative sources of energy for compression ignition engines. India is one of the largest agriculture based countries that produces several non edible seeds annually. More than 86 species occurring in the wild or in cultivated farms sporadically yield oil in considerable quantities [3]. Among the oil bearing species sal, jatropha, karanja, mahua indica, rubber seed, mustard seed etc., have great potential for commercial exploitation and have been investigated largely by many researchers in India to utilize them as fuels. Earlier experimental investigations were carried out to study the performance and emission characteristics of a diesel engine with linseed oil - diesel fuel blends at different injection
pressures. It was noticed from the results that the brake specific fuel consumption of the linseed oil-diesel fuel blends was comparable to that of diesel fuel [4]. However the carbon monoxide and nitric oxide emissions were found to be less in the case of linseed oil-diesel fuel blends as compared to that of diesel fuel. It was seen that the 20% linseed oil blend showed optimum results in comparison to other linseed oil-diesel fuel blends. It was suggested that the linseed oil blends would be troublesome if used in commercial equipment for extended operating periods [5]. Huguenard [6] investigated the fuel economy and indicator card traces for cottonseed oil-diesel fuel blends at various injection timings in two different laboratory-scale DI diesel engines. It was found that cottonseed oil-diesel fuel blends could be run with greater timing advance than that of diesel fuel fuel. Sunflower oil is available in different varieties having different oil contents. 100 kg of sunflower seeds give 60 to 70 kg of kernels, the average oil content of each kernel being from 45% to 57% [7]. It was reported that a sunflower oil fueled engine was inferior to that under diesel fuel operation, in terms of fuel economy and power [8]. Soya was considered a better choice as an alternative fuel for mixing with diesel fuel, because of its larger production and lower price. But the utilization of pure soya oil and diesel fuel blends cannot be recommended in the long run in diesel engines due to the accumulation of carbon deposits which can lead to problems [9]. The utilization of jatropha oil was also tried in diesel engines [10]. In this investigation jatropha oil was used as the main fuel whereas orange oil was admitted along with the air in the intake of the engine. From the results, it was noticed that the brake thermal efficiency of jatropha oil operation was found to be less compared to that of neat diesel fuel. However, with orange oil admission in dual fuel operation, there was an appreciable increase in the brake thermal efficiency. It was found that the maximum thermal efficiencies were 29% with jatropha oil and 34% of orange oil energy share. Orange oil induction also reduced the smoke to 3 BSU with jatropha oil as the pilot fuel and an orange oil energy share of 35%. But emissions were higher while using jatropha oil with orange oil admission. The performance and emission characteristics of a diesel engine using the three degummed non-edible vegetable oils, namely, kanjana, jatropha, and putranjiva were studied [11], and it was concluded that blends of 20% degummed vegetable oil with diesel fuel could be used in diesel engines without any engine modification for better results. Pure rice bran oil was also used to run the engine without any pilot quantity of diesel fuel. Results indicated that with pure rice bran oil, the brake thermal efficiency increased, but the specific fuel consumption was marginally higher than diesel fuel but it could be lowered by blending diesel fuel with 40% rice bran oil. Moreover, the exhaust gas temperature was seen to be considerably lower for the rice bran oil and diesel fuel blends [12]. From the previous works on vegetable oils indicated that the vegetable oils have larger molecules larger than diesel fuel molecules which results in poor volatility. This develops oil sticking to the injector or cylinder walls. Oils then undergo oxidative and thermal polymerization causing a deposition on the injector, forming a film that continues to trap fuel and interfere with combustion and leads to more deposit formation, carbonization of injector tips, rings sticking, and lubricating oil dilution and degradation. Similarly, polanga oil can also be used as an alternative fuel for diesel fuel engines. In India, polanga oil is found in states like Orissa, Tamil Nadu, Kerala, and Andaman Islands. Polanga seeds give a good yield of oil. The possible utilization of polanga oil has to be explored in a better way. The main advantage is that polanga oil may be produced by the farmers, so that it will also improve the rural employment. The main aim of the present investigation is to assess the performance, emission, and combustion characteristics of a single cylinder, four stroke, air cooled, direct injection, diesel engine by using three different blends of refined crude polanga oil with diesel fuel. The notations used for the three blends are PD10, PD30, and PD50 where 10, 30 and 50 refer to the percentage by volume of polanga in the blends. The data collected were compared with those of diesel fuel operation and are presented in this paper.

2. POTENTIAL AND CHARACTERISTICS OF POLANGA OIL

2.1. NATURE AND AVAILABILITY OF POLANGA OIL

The scientific name of polanga oil is *Calophyllum inophyllum*, commonly known as Alexandrian laurel or beauty leaf or Domba in Sri Lanka, undi or nagachampa in India, planted widely throughout the tropics, growing above the high-tide mark along the sea coasts of northern Australia and extending throughout Southeast Asia and southern India. It has been used by indigenous communities and alternative medicine practitioners for many years. It also has a high demand for its seed oil from cosmetics and pharmaceutical industries.

It usually grows in the areas with 1000-5000mm rain per year at altitudes ranging from 0-200m. It comes under the category of coastal species that usually grow on sandy beaches, and along river margins. Its nature is sensitive towards frost and fire. The size of the tree is medium, around 25m height and diameter up to 150cm. Although the fruits are toxic in nature, are used for human consumption. In India, polanga trees are seen to grow in the states of Tamil Nadu, Kerala, Andaman Islands and Orissa. Studies show that there are two favorable seasons for flowering in Orissa state, i.e., May-June and October-November. The flowers of the polanga tree are pollinated by bees and other insects and fruits are dispersed by sea currents and fruit bats [13]. The seed of Polanga yields 65% oil from its dry weight of 3744 kg/ha from 400 trees (Azam et al. 2005). Non-edible oil seed bearing trees such as
Table 1. Fatty and unsaturated acids in polanga oil

<table>
<thead>
<tr>
<th>Acid</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmitic acid C16:0</td>
<td>12.01</td>
</tr>
<tr>
<td>Stearic acid C18:0</td>
<td>12.95</td>
</tr>
<tr>
<td>Oleic acid C18:1</td>
<td>34.09</td>
</tr>
<tr>
<td>Linoleic acid C18:2</td>
<td>38.26</td>
</tr>
<tr>
<td>Linolenic acid C18:3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 2. Comparison of Polanga Oil with Diesel Fuel

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Specification</th>
<th>Diesel fuel</th>
<th>Polanga</th>
<th>PD10</th>
<th>PD30</th>
<th>PD50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>D 445</td>
<td>0.86</td>
<td>0.896</td>
<td>0.8636</td>
<td>0.8708</td>
<td>0.8780</td>
</tr>
<tr>
<td>Viscosity (cSt) at 40 °C</td>
<td>D2217</td>
<td>2.87</td>
<td>71.98</td>
<td>11.4</td>
<td>19</td>
<td>40.5</td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>D92</td>
<td>76</td>
<td>221</td>
<td>104</td>
<td>62</td>
<td>56</td>
</tr>
<tr>
<td>Calorific value (MJ/kg)</td>
<td>D4809</td>
<td>44.2</td>
<td>43.705</td>
<td>42.715</td>
<td>41.725</td>
<td></td>
</tr>
<tr>
<td>Acid value (mg KOH/gm)</td>
<td>-</td>
<td>-</td>
<td>44</td>
<td>45.9</td>
<td>35.9</td>
<td>27.1</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>D4737</td>
<td>40-55</td>
<td>57.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud point (°C)</td>
<td>D97</td>
<td>6.5</td>
<td>13.2</td>
<td>-2</td>
<td>-12</td>
<td>-15</td>
</tr>
<tr>
<td>Pour point (°C)</td>
<td>D97</td>
<td>-27</td>
<td>4.3</td>
<td>-9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The physical properties of polanga oil are compared with those of diesel fuel and are given in Table 2.

3. EXPERIMENTAL SETUP

Figure 1 shows the schematic layout of the experimental setup used in this study. The specifications of the test engine are given in Table 3. The engine was coupled to an alternator to provide the load to the engine. A sensor was connected to the flywheel to measure the speed. The air intake was measured by an air flow sensor that fitted to the air box. A burette was used to measure the fuel flow to the engine, via fuel pump. A thermocouple with a temperature indicator measures the exhaust gas temperature. Emissions such as, unburnt hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO₂) and nitric oxide (NO) were measured by an AVL 444 exhaust gas analyzer. A combustion diagnosis was carried out by means of a Kistler-make quartz piezoelectric pressure transducer (Model Type −5395A) mounted on the cylinder head in the standard position. The Kistler pressure transducer has the advantage of a good frequency response and linear operating range. A continuous circulation of air was maintained for cooling the transducer, by using fins to maintain the required temperature. The combustion parameters, such as cylinder peak pressure, ignition delay, maximum rate of heat release and rate of pressure rise were evaluated. All the tests were conducted by starting the engine...
with diesel fuel only. After the engine was warmed up, it was switched over to the polanga oil diesel fuel blends.

4. RESULTS AND DISCUSSION

The combustion, performance and emission parameters of the test engine fueled with polanga oil diesel fuel blends are compared with diesel fuel operation and presented in this section.

4.1. COMBUSTION PARAMETER

4.1.1. Ignition Delay

Figure 2 shows the ignition delay for diesel fuel and polanga oil diesel fuel blends with load. The ignition delay is the time difference in the crank angle between the start of injection and ignition in compression ignition engines. The ignition delay for diesel fuel and the polanga oil diesel fuel blends increases as the load increases. It can be observed from the figure that the ignition delay is the highest for diesel fuel followed by PD10 and PD50. The lower cetane number of PD10 may be the reason for higher ignition delay than that of PD50 and PD30.

The ignition delay of PD30 is found to be the lowest at full load among all the tested fuels. This is because of higher cetane number with comparatively lower viscosity than PD50. The ignition delay of diesel fuel varies from 15.29 °CA at no load to 11.4 °CA at full load. It ranges between 15.32 °CA and 11.07 °CA for PD10, 15.43 °CA and 10.78 °CA for PD30 between no load and full load. In the case of PD50, the ignition delay varies from 15.13 °CA at no load to 11.14 °CA at full load.
4.1.2. Maximum Heat Release Rate

Figure 3 shows the variation of the maximum rate of heat release with load for the tested fuels. It can be seen from the figure that the maximum heat release rate for PD30 is the highest at full load among all the fuels tested.

PD10 shows the maximum heat release rate, lower than PD30 and diesel fuel but marginally higher than PD50 throughout the load spectrum. This may be due to the lower energy content of PD10 than that of diesel fuel. As already mentioned, due to the higher viscosity and shorter ignition delay of PD50 compared to that of PD10 and PD30, the fuel accumulated in the delay period may be less and hence, it may result in lower heat release rate compared to the other blends and diesel fuel. Polanga oil and diesel fuel blends experience rapid premixed burning followed by diffusion combustion as is typical of naturally aspirated engines. After the ignition delay period, the mixture burns rapidly releasing heat at a very rapid rate, after which diffusion combustion takes place in which the burning rate is controlled by the available combustible mixture [25]. But, as a consequence of the shorter ignition delay at full load, the premix combustion phase for polanga and their blends is less intense. Due to this the fuel release heat slightly lesser as compared to other load. On the other hand, while running with diesel fuel, increased accumulation of fuel during the relatively longer delay period resulted in high rate of pressure rise.

4.1.3. Cylinder Peak Pressure

Figure 4 represents the variation of the cylinder peak pressure with load. The cylinder peak pressure of an engine provides information about the direct utilization of heat for useful work. In a compression ignition engine the peak pressure depends on the combustion rate in the initial stages, which in turn, is influenced by the amount of fuel taking part in the uncontrolled combustion. The uncontrolled phase depends on the delay period and also the mixture preparation during the delay period. From the figure it is noticed that the cylinder peak pressure for PD30 is greater than diesel fuel throughout the load spectrum.
The cylinder peak pressure for PD30 varies from 58 bar at no load to 80.34 bar at full load. This may be due to the more heat released during the uncontrolled combustion. The cylinder peak pressure for diesel fuel ranges between 58 bar and 78.17 bar at no load and full load respectively. In the case of PD10, the values lie between 56 bar and 74.47 bar at no load and full load respectively. The higher cetane is responsible for lower cylinder peak pressure for PD50 for which the value ranges from 54 bars at no load to 72 bar at full load respectively.

4.2. PERFORMANCE PARAMETERS

4.2.1. Brake Thermal Efficiency

Figure 5 shows the variation of the brake thermal efficiency with respect to load for diesel fuel and polanga oil-diesel fuel blends. It can be observed from the figure that, except the PD50 blend, the PD10 and PD30 blends show higher brake thermal efficiencies at full load compared to that of diesel fuel. The brake thermal efficiency for diesel fuel at full load is 28.6% whereas it is 28.96%, 28.73% and 28.28% for PD10, PD30 and PD50 respectively.

The higher thermal efficiencies for PD10 and PD30 may be due to the additional lubricity provided by the fuel blends [17]. In the case of the PD50 blend, the higher viscosity may lead to poor mixture formation that may result in lower thermal efficiency.

4.2.2. Brake Specific Energy Consumption (BSEC)

Figure 6 shows the variation of the brake specific energy consumption with load. When two different fuels of different heating values are blended together, the fuel consumption may not be reliable, since the heating value and density of the two fuels are different. In such cases, the brake specific energy consumption (BSEC) will give more reliable value [18]. The brake specific energy consumption was determined for polanga oil-diesel fuel blends as the product of the specific fuel consumption and the calorific value. It can be observed from the figure that the BSEC for PD10 and PD30 are lower as compared to that of diesel fuel. The availability of the oxygen in the polanga oil-diesel fuel blend may be the reason for the lower BSEC.

In the case of PD50, the heating value of the blend is significantly lower which may require additional fuel air mixture to produce the same power output as that of diesel fuel.

4.2.3. Exhaust Gas Temperature (EGT)

The exhaust gas temperature of an engine is an indication of the conversion of heat into work. Figure 7 shows the variation of the exhaust gas temperature with the load for the tested fuels. The values of the exhaust gas temperature for the PD50 blend is the highest, followed by the PD10 and PD30 blends at full load. For the diesel fuel, the exhaust gas temperature is the lowest among all the tested fuels. The exhaust gas temperature rises from 160 °C at no load to 380 °C at full load for PD50, while for PD30 the exhaust gas temperature rises from 140 °C at no load to 300 °C at full load.

In the case of polanga oil diesel fuel blends, the heat release may occur in the later part of the expansion stroke. This may be reason for the higher exhaust gas temperatures exhibited by the polanga oil diesel fuel blends.
4.3. EMISSION PARAMETERS

The emissions such as oxides of nitrogen, carbon monoxide, carbon dioxide and unburnt hydrocarbon are expressed below.

4.3.1. Nitric Oxide (NO)

Figure 8 indicates the variation of nitric oxide emission for different blends and diesel fuel with load. Nitric oxide constitutes more than 90% of the oxides of nitrogen in an engine exhaust. The two principal factors that affect the formation of nitric oxide are temperature and oxygen fraction [18, 19]. Nitric oxide is a necessary ingredient of our life cycle. The formation of oxides of nitrogen is due to: (i) thermal root leading to thermal nitric oxide, (ii) hydrocarbon fragment related root leading to prompt nitric oxide(iii) fuel bound nitrogen that result fuel bound nitric oxide. The nitric oxide formation due to thermal root depends on the combustion temperature and the oxygen availability. It can be observed from the figure that the nitric oxide emission increases with increase in engine load for all the tested fuels as expected [20, 21]. The nitric oxide emissions for polanga oil diesel fuel blends are lower than that of diesel fuel except PD30. PD30 shows a higher NO emission followed by PD10 and PD50.

This may be due to presence of oxygen in the fuel better complete combustion that results in higher heat release. This is evident from the maximum heat release rate graph. Higher cetane number and lower heating value are responsible for lower NO emissions for PD10 and PD50. This is because of the presence of oxygen in the blend may result in more complete combustion than PD10.

4.3.2. Carbon Monoxide (CO) Emission

Figure 9 shows the variation of carbon monoxide with load for diesel fuel and polanga diesel fuel blends. The carbon monoxide emission is an indication of the incomplete combustion of the fuel air mixture that takes part in the combustion. The carbon monoxide emission from the engine exhaust is lower in the compression ignition engines compared to that in spark ignition engines, since the
compression ignition engines are always operated with a lean mixture. CO emission is the lowest in the case of diesel fuel and it is the highest for PD50 at full load. Poor mixer formation due to higher viscosity of the blend is the reason for this. It is also seen from the graph that the PD30 blend shows lower value for carbon monoxide emission at full load compared PD10 and PD50 but higher than that of diesel fuel.

The values of CO emission at full load for diesel fuel are 0.015%. The CO emissions for PD10, PD30 and PD50 are 0.023%, 0.019% and 0.028% respectively at full load. However, all the values lie below 0.1% throughout the load conditions.

4.3.3. Hydrocarbon Emissions

Figure 10 shows the variation of hydrocarbon emission for diesel fuel and the three blends of polanga with respect to load. Hydrocarbon emissions are generated in CI engines because of fuel molecules, pyrolysis of fuel compounds and partially oxidized hydrocarbons [23]. The unburnt hydrocarbon is the direct result of incomplete combustion in the combustion chamber. It is seen that there is a sharp decrease in the hydrocarbon emission with the increase in the load.

Diesel fuel emits 3-5 ppm lesser unburned hydrocarbon than the polanga oil diesel fuel blends at full load. Poor mixture formation and local rich regions may be the reason for more incomplete combustion of PD50 blend [24]. Local rich region is the reason for unburnt hydrocarbon emission for PD10. In the case of PD30, more oxygen availability leading to better complete combustion than PD10 and PD50 is the reason for lower unburnt hydrocarbon emission. However, the value is higher than that of diesel fuel at full load owing to higher viscosity that results in comparatively poorer combustion.

CONCLUSIONS

Polanga oil seems to have the potential to be used as alternative fuel in diesel fuel engines. The viscosity of polanga oil reduces substantially after blending with diesel fuel. The conclusion of the experimental study is as follows:
The brake thermal efficiency of the engine fueled with polanga oil-diesel fuel blends is marginally better than that of diesel fueled engine.

The brake specific energy consumption is higher for polanga oil diesel fuel blends operation than for diesel fuel operation because of their high viscosity and low calorific value. PD30 gives a better performance as compared to PD10 and PD50.

The exhaust gas temperature is found to be very high for polanga oil diesel fuel blends as compared to neat diesel fuel due to the heat release in the later part of the combustion.

The NO emission is lower for all the polanga oil diesel fuel blends compared to that of diesel fuel.

The carbon monoxide emission decreases with the increase in load due to the presence of oxygen in the polanga oil-diesel fuel blends, which oxidizes carbon monoxide into carbon dioxide.

The unburned hydrocarbon emission is also lower as compared to that of diesel fuel with an increase in the load. Among all other blends PD50 shows more THC emission.

Because of its high viscosity PD50 shows a higher ignition delay at full load which is 2 to 3 degrees lesser than that of diesel fuel.

The polanga diesel fuel blend (PD30) had higher peak pressure about 6.2% more as compared to diesel fuel due to this the maximum heat release rate of polanga diesel fuel blends is more as compared to diesel fuel. This is because of more accumulation of more fuel inside the engine cylinder.

REFERENCES


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