IMPROVEMENT OF PALM OIL BIODIESEL PROPERTIES USING ETHANOL AS AN ADDITIVE AND ITS EFFECT ON DIESEL ENGINE PERFORMANCE, COMBUSTION AND EMISSIONS

S. Madiwale¹, A. Karthikeyan², V. Bhojwani³ and M. Dombale⁴

¹Sathyabama University, Chennai, Tamil Nadu, India
²Department of Automobile Engineering, Sathyabama University, Chennai, Tamil Nadu, India
³Department of Mechanical Engineering, JSPM’s, College of Engg., Hadapsar, Pune, Maharashtra, India
⁴JSPM’s, College of Engineering., Hadapsar,Pune, Maharashtra, India
E-Mail: shrikantmadiwale@gmail.com

ABSTRACT

As we need an alternating fuel that will replace diesel fuel in order to reduce the harmful emissions coming out of engine as exhaust by products, which necessitates the improvement in engine performance and increase in combustion characteristics of fuels in the combustion chamber. As biodiesels are having high viscosity and higher flashpoint than diesel, it will be difficult to use biodiesel as a fuel alone in present diesel engines. Hence it is preferred to blend biodiesel with diesel to get required properties of blend that will suit the present diesel engines. But higher kinematic viscosity of biodiesel/diesel blends as compared to diesel affects the atomization of fuel in the combustion chamber which further reduces the combustion pressure and temperature and reduces the power output of the engine. This necessitates the addition of ethanol as an additive in the blends which further enhances the hot flow, cold flow and thermo-physical properties of the biodiesel/diesel blends. Therefore in this study feedstock of palm oil biodiesel is used as fuel with 5% ethanol by volume as an additive in the blends of palm oil biodiesel/diesel blends. Hot flow and cold flow properties of blends of palm oil biodiesel/ethanol/diesel blends are experimentally investigated as per IS 1448 standards. Investigation outcome shows that ethanol as an additive improves the kinematic viscosity of blends of palm oil biodiesel/diesel by 4% lesser than biodiesel/diesel blend without ethanol and 12% higher than diesel. But on the other hand calorific value of the blends with the addition of ethanol decreases calorific value by 6.27% than biodiesel/diesel blend without ethanol and 6.87 % than diesel. Most importantly the cold flow properties are enhanced by the addition of ethanol in the blend such as cloud point increases by 13 % than biodiesel/diesel blend without ethanol and pour point increases by 14% than biodiesel/diesel blend without ethanol. The combustion and performance analysis are improved with the addition of ethanol and decreases the harmful emissions from the exhaust manifold of the engine. The effect of ethanol as an additive in the blends of palm oil biodiesel/diesel blend on properties, performance, and combustion and on emissions are studied in this paper.

Keywords: palm oil biodiesel, ethanol, combustion, performance, diesel engine.

INTRODUCTION

Generally biodiesel derived from vegetable oils (triglycerides) have high viscosity, high pour point high density and low calorific value than a diesel fuel. This makes it difficult to use biodiesel oil as a fuel in conventional diesel engines. Biodiesel can be derived from vegetable oil or animal fats (triglycerides). Vegetable oils have high viscosity, pour point and density. Hence vegetable oil only not used as a fuel in conventional diesel engines. The properties of vegetable oil can be brought to certain required level by transestrification process [14]. The transestrified vegetable oil is called as biodiesel.

Transestrification process is also called as alcoholysis, where exchange of alcohol from an ester by another alcohol in a process similar to hydrolysis, except that an alcohol is used instead of water [14]. In order to carry reaction in shorter time the reaction temperature, time, pressure ratio of alcohol to oil, concentration and type of catalyst, mixing intensity, and kind of feedstock, are relevant variables which affect the transestrification process. Addition of methanol to oil or fat gives the biodiesel. Biodiesel is a mixture of mono-alkyl ester of saturated and unsaturated long chain fatty acids. Whereas diesel is nothing but the mixture of paraffinic, naphthenic and aromatic hydrocarbons [20]. As biodiesel fuel has technical, environmental and strategic advantages it can be accepted as an alternative fuel for diesel in diesel engines [11]. Biodiesel has biodegradability, less toxicity and good lubricity. Biodiesel is also miscible with petroleum diesel thus blending of biodiesel can be possible in any proportion. Biodiesel/diesel fuel blend does not require any significant changes in present diesel engines. There is difference in chemical nature of biodiesel and diesel, which altered basic properties of blend and thus affects emissions and performance of diesel engine. Biodiesel generally has high density, high viscosity, high pour point, high cloud point and high cetane number and lower heating value and volatility [1-9]. In order to find out the specifications of blending mixture whether it fits with diesel engine, properties of a blend composition must be investigated. Higher kinematic viscosity of biodiesel/diesel blends as compared to diesel affects the atomization of fuel in the combustion chamber which further reduces the combustion pressure and temperature and reduces the power output of the engine [10]. This necessitates the addition of ethanol as an additive in the
blends which further enhances the hot flow, cold flow and thermo-physical properties of the biodiesel/diesel blends. Ethanol \([\text{CH}_3\text{CH}_2\text{OH}]\) is a colourless liquid, it is also known as ethyl alcohol. Ethanol has higher octane number. Ethanol is low cost oxygenated fuel containing 34% higher oxygen by weight [15]. Ethanol can be made by fermentation process biologically from variety of biomass resources like Sugarcane, Corn, Sugar beet etc. It is produced through catalytic hydration of ethylene using sulphuric acid as catalyst [16]. Table 1 shows the properties of 99.99% pure ethanol which are investigated as per IS 1448 standards in the NABL accredited laboratory.

Table-1. Properties of 99.99% pure ethanol [16, 17, 18].

<table>
<thead>
<tr>
<th>Properties</th>
<th>Ethanol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>790</td>
</tr>
<tr>
<td>Viscosity (Cst)</td>
<td>1.4</td>
</tr>
<tr>
<td>Cetane number</td>
<td>8</td>
</tr>
<tr>
<td>Calorific value (MJ/Kg)</td>
<td>26.95</td>
</tr>
<tr>
<td>Flash point °C</td>
<td>13</td>
</tr>
<tr>
<td>Cloud point °C</td>
<td>&lt; -26</td>
</tr>
</tbody>
</table>

**PALM OIL BIODIESEL**

Since last 100 years palm oil became world’s major agricultural commodity from minor crop in west and central Africa. Whereas Palm oil has been cultivated in Africa for centuries, but it has dramatically increased in Southeast Asia, Africa and Latin America and Malaysia. Palm oil production is driven by producers responding to consumer demand much of which is from India and China. Palm oil is not only an industrial crop but it is also a smallholder crop too increasing rural development in humid tropics [12]. Three important things regarding palm oils are as follows:

a) Demand for palm oil will continue to increase in response to growing population as it is edible one.

b) Palm oil plantation stores more carbon than other alternatives.

c) Oxidation stability of palm oil is due to presence of higher concentration of saturated fatty acids i.e. palm oil is stable for more time when stored as compared to other feedstock of vegetable oil.

The feedstock of palm oil biodiesel was collected from SVM Agro Industries, Nagpur. Table-2 shows the properties of palm oil biodiesel (B100-100% biodiesel), which are investigated as per IS 1448 standards in the NABL accredited laboratory.

Table-2. Properties of Palm oil biodiesel (B100).

<table>
<thead>
<tr>
<th>Test parameter</th>
<th>Units</th>
<th>Value</th>
<th>IS 1448 Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gross calorific value</td>
<td>kJ/kg</td>
<td>41173</td>
<td>Bomb Calorimeter</td>
</tr>
<tr>
<td>2 Kinematic viscosity at 40°C</td>
<td>cSt</td>
<td>5.6</td>
<td>IS 1448 Part I (P-25)</td>
</tr>
<tr>
<td>3 Cloud point</td>
<td>°C</td>
<td>18</td>
<td>IS 1448 Part I (P-10)</td>
</tr>
<tr>
<td>4 Pour Point</td>
<td>°C</td>
<td>15</td>
<td>IS 1448 Part I (P-10)</td>
</tr>
<tr>
<td>5 Density @ 15 °C</td>
<td>kg/m³</td>
<td>896.3</td>
<td>IS 1448 Part I (P-16)</td>
</tr>
<tr>
<td>6 Flash point</td>
<td>°C</td>
<td>70</td>
<td>IS 1448 (P20)</td>
</tr>
<tr>
<td>7 Fire point</td>
<td>°C</td>
<td>130</td>
<td>IS 1448 (P-69)</td>
</tr>
</tbody>
</table>

**FUEL BLENDS PREPARATION**

The palm oil biodiesel /diesel blends were prepared in blending concentration of 20%, 40%, 60% and 80% palm oil biodiesel with diesel fuel but without ethanol and 25%, 45%, 65% and 85% palm oil biodiesel with 5% ethanol by volume in diesel fuel. All the blends with and without ethanol were prepared on the volumetric analysis. The thermo physical properties or hot and cold flow properties such as, calorific value, density, viscosity, pour point, cloud point, fire point and flash point were experimentally investigated as per IS: 1448 standards for all blends of palm oil biodiesel/diesel with and without ethanol.

**PROPERTIES INVESTIGATION AND DISCUSSIONS**

Fuel properties plays very important role in complete combustion of the fuel in compression ignition engines. Addition of ethanol as an additive changed the fuel blends properties [19]. Table-3 shows properties of blends of palm oil biodiesel with and without ethanol and these properties are compared with conventional diesel fuel.
Table-3. Properties of Palm oil biodiesel/diesel blends with and without ethanol.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>CV kJ/kg</th>
<th>Kinematic viscosity cSt</th>
<th>Cloud point °C</th>
<th>Pour point °C</th>
<th>Density Kg/m³</th>
<th>Flash point °C</th>
<th>Fire point °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>43851</td>
<td>2.5</td>
<td>-23</td>
<td>-21</td>
<td>817.4</td>
<td>40</td>
<td>42</td>
</tr>
<tr>
<td>P20</td>
<td>43593</td>
<td>2.9</td>
<td>-5</td>
<td>-7</td>
<td>855.2</td>
<td>28</td>
<td>44</td>
</tr>
<tr>
<td>P20 E5</td>
<td>40840</td>
<td>2.8</td>
<td>-8</td>
<td>-10</td>
<td>846.4</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>P40</td>
<td>43483</td>
<td>3.4</td>
<td>1</td>
<td>-5</td>
<td>857.3</td>
<td>30</td>
<td>48</td>
</tr>
<tr>
<td>P40 E5</td>
<td>40229</td>
<td>3.2</td>
<td>-3</td>
<td>-6</td>
<td>850.2</td>
<td>20</td>
<td>32</td>
</tr>
<tr>
<td>P60</td>
<td>42590</td>
<td>3.9</td>
<td>6</td>
<td>1</td>
<td>860.2</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td>P60 E5</td>
<td>39229</td>
<td>3.6</td>
<td>5</td>
<td>1</td>
<td>854</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>P80</td>
<td>41706</td>
<td>4.8</td>
<td>12</td>
<td>10</td>
<td>887.3</td>
<td>42</td>
<td>98</td>
</tr>
<tr>
<td>P80 E5</td>
<td>37025</td>
<td>4.4</td>
<td>8</td>
<td>3</td>
<td>876.2</td>
<td>26</td>
<td>40</td>
</tr>
</tbody>
</table>

Figure-1. Variation of Calorific value of Palm oil biodiesel with and without ethanol for different blend ratio.

Figure-1 shows the variation of Calorific value of blends of palm oil biodiesel with and without ethanol for different blend ratio. Calorific value is the important property of fuel which decides the heat release capacity of the fuel. Lower heating value or calorific value of biodiesel and ethanol, decreases the overall calorific value of all the blends. For P20E5 the calorific value is 7% less than diesel for P80E5 it is 15% less than diesel. So as the percentage of biodiesel increases in the blend, the calorific value of the overall blend decreases.

Figure-2. Variation of density of Palm oil biodiesel with and without ethanol for different blend ratio.

Figure-2 shows the variation of density of blends of palm oil biodiesel with and without ethanol for different blend ratio. Low density of ethanol is responsible to reduce the overall density of palm oil biodiesel/diesel blend for all blend ratios. Although density of P20E5 is 3% greater than diesel but it is 1% less than P20. So addition of ethanol reduces the density of P20 blend. For all other blends the similar trend was noticed.

Figure-3. Variation of kinematic viscosity of Palm oil biodiesel with and without ethanol for different blend ratio.

Figure-3 shows variation of kinematic viscosity of Palm oil biodiesel with and without ethanol for different blend ratio. Low viscosity of fuel is always preferable for the complete combustion. Addition of the palm oil biodiesel with diesel always increases viscosity of the blend. In order to address this problem, ethanol is added in the blend and addition of ethanol reduces the overall viscosity of the blends. This is because of the low
viscosity of ethanol. Kinematic viscosity of P20E5 reduces by 3.44% than P20. The reduction in the viscosity takes place from 6 to 9% for blend ratios of P40E5 up to P80E5 as compared with P40 to P80 blend ratio of palm oil biodiesel.

Figure-4. Variation of cloud point of Palm oil biodiesel with and without ethanol for different blend ratio.

Figure-5. Variation of pour point of Palm oil biodiesel with and without ethanol for different blend ratio.

Figure-4 and Figure-5 shows the variation of cloud point and pour point of palm oil biodiesel with and without ethanol for different blend ratio. The cloud point and pour point of palm oil biodiesel is higher than the diesel fuel, which limits its application and usability of biodiesel in very cold climatic conditions [13]. But as the cloud point and pour point of ethanol is lower than palm oil biodiesel/diesel blends, so addition of ethanol in the blends of biodiesel reduces the cloud point and pour point of the biodiesel/diesel blends. Cloud point of P20E5 is 13% lower than the P20, and pour point of P20E5 is 14% lower than P20.

Addition of palm oil biodiesel in the diesel increases the flash and fire point of the blends, which is not at all desirable for the combustion. Higher flash point and fire point will increases the ignition delay and affect the combustion temperature and pressure, which will further reduce the power output of the engine. As ethanol having the very low kinematic viscosity than the biodiesel, so addition of ethanol in the blend reduces the flash point and fire point of the blend. For P20E5 flash point is reduces by 25% than P20 and fire point reduces by 47% than P20 respectively. Fig 6 and 7 shows the variation of flash point and fire point of palm oil biodiesel with and without ethanol for different blend ratios.
EXPERIMENTAL TRIAL SET UP AND FUEL

The 20% palm oil biodiesel is mixed with 75% diesel and the 5% ethanol was added as an additive i.e. P20E5. The test fuel was tested for engine performance combustion and for emission in single cylinder variable compression diesel engine. Same engine also tested for the 20 % palm oil biodiesel and 80% diesel blend without ethanol i.e. P20. The results of engine performance combustion and emission of P20E5 and P20 are compared with diesel.

The engine was single cylinder, four stroke, and variable compression ratio diesel engine. Engine was equipped with eddy current dynamometer. The compression ratio of the engine was 18. Engine test rig was installed with pressure transducer and crank angle measurement sensor. With the help of data logger the signals were interface to computer for various P-θ and P-V diagrams. Engine was also equipped with air box, U-tube manometer, and fuel measuring system, air flow and fuel flow measuring instruments. For varying load condition test were carried out on the engine for the load of 3 kg, 6kg, 9kg and 12 kg running at 1500 rpm. Labview based software; engine soft was interface with engine to computer in order to test and record real time data.

RESULTS AND DISCUSSIONS

a) Performance analysis

Figure-8. Variation of brake power with load.

Figure-8 shows the variation of brake power with the different load condition. It is observed that the brake power of P20E5 is reduces in the range of 7 to 8% as compared with diesel. This is due to the lower calorific value of P20E5 as compared with P20 and diesel fuel. Figure-9 shows the variation of brake mean effective pressure with load on engine. The BMEP of P20E5 is 3% more than the conventional diesel because of the lower kinematic viscosity of the blend which ensures the maximum combustion in cylinder and build the maximum BMEP.

Figure-9. Variation of brake mean effective pressure with load.

Figure-9 shows the variation of brake mean effective pressure with load. For P20E5 the brake mean effective pressure is increases from 4% to 7% than conventional diesel fuel and 3% to 6% more than P20. Figure-10 shows the variation of brake thermal efficiency with load. It is reported that for P20E5 the fuel consumption is increased from 1% to 4% as compared to diesel. This is due to the lower heating value of the biodiesel and ethanol.

Figure-10. Variation of brake thermal efficiency with load.
**b) Emission analysis**

Figure-12, Figure-13, Figure-14 and Figure-15 shows the variation of CO, HC, CO$_2$ and NO$_x$ emission with varying load respectively. Investigation reported that CO emissions of P20E5 are more than diesel but less than P20 by 30% to 40%. HC emissions of P20E5 blend are more than diesel by 30% but less than P20 by near about 40% to 50%. Carbon dioxide emissions of P20E5 are more only at 12 kg load and are less than diesel by 5% to 10% but on the other hand CO$_2$ emissions are less than P20 blend by 5% to 15%. NO$_x$ emissions of P20E5 reduces as compared with P20. This is because of the more nitrogen is available for the combustion, as in air 70% nitrogen is available. Also biodiesel is a oxygenated fuel which liberate more amount of energy and increases combustion temperature which dissociate nitrogen in to nitrogen oxide.
c) Combustion analysis

Figure-16 shows the variation of pressure build near TDC with crank angle. It is clear from the figure that because of the higher heating value of the diesel; the maximum pressure is build after the TDC in case of diesel fuel as compared with P20E5 and P20 who possesses lower heating value than diesel.

![Figure-16. Variation of pressure with crank angle.](image1)

Figure-17 shows the quantity of fuel consumed for the combustion. Mass fraction of P20E5 is greater than the P20 because of the lower kinematic viscosity, which ensures good atomization and maximum combustion. But mass fraction of P20E5 and P20 is less than diesel fuel.

![Figure-17. Variation of mass fraction burned with crank angle.](image2)

CONCLUSIONS

Palm oil biodiesel/diesel blend should be prepared with the addition of 5% ethanol as an additive only. Addition of ethanol by 5% in volume of blend of P20E5 enhances the hot flow, cold flow and thermo-physical properties of the blend. Kinematic viscosity of P20E5 reduces by 4% than P20, which is beneficial to the process of atomization and combustion. Also cloud point and pour point of P20E5 reduces by 13 % and by 14 % than P20 respectively. Flash point and fire point defines the combustion quality of the fuel. Addition of ethanol enhances the flash point of P20E5 by 25 % than P20 and fire point by 47% than P20.

Because of addition of ethanol as an additive in the fuel i.e P20E5 improves the performance of the engine than the fuel without ethanol i.e. P20. There is improvement in brake thermal efficiency of P20E5 than P20 by 6%. Emission analysis shows that CO emissions of P20E5 are higher than diesel but less than P20 by 30% to 40%. HC emissions of P20E5 blend are more than diesel by 30% but less than P20 by near about 40% to 50%. Carbon dioxide emissions of P20E5 are only more at load of 12 kg and it is less than diesel by 5% to 10% but it is less than P20 blend by 5% to 15%. A NOX emission of P20E5 reduces as compared with P20. Addition of ethanol as an additive in palm oil biodiesel improves the properties of the blends, enhances the performance and reduces the harmful exhaust emission from diesel engine.

REFERENCES


