CHAPTER 5

STUDIES ON FUEL PROPERTIES OF NEEM, RICE BRAN, PONGAMIA PINNATA, COTTON, RUBBER SEED OIL METHYL ESTER AND THEIR CONVENTIONAL DIESEL OIL BLENDS

5.1 Introduction

Considerable research work has done on investigation of fuel properties of methyl ester and their blends with conventional diesel oil. It is reported that blend of B20 of unrefined rice bran oil methyl ester has the properties close to that of conventional diesel oil. It is also reported that properties of methyl ester deviates more from conventional diesel oil with increase in the percentage of methyl ester in the blend [1]. Some researchers have studied the fuel properties of mixture of jatropha and pongamia pinnata methyl ester and their blends with diesel to assess their usefulness as CI engine fuel [2]. If 20 % blend of biodiesel is achieved by 2017, it will avoid the amount of 83.87 million tonnes of CO$_2$ equivalent per year. Significant carbon revenue can be earned from blending of bio fuels [3]. The properties of neem oil methyl ester blends with domestic kerosene and conventional diesel oil was studied by some researchers and they found that properties like viscosity, specific gravity, heating value and flash points varies with variation of methyl ester in the blends [4].

In this work fuel properties of unrefined neem, unrefined rice bran, unrefined pongamia pinnata, unrefined cotton, unrefined rubber seed oil methyl ester and their blends with conventional diesel oil in the proportions of 20:80 (B20), 40:60 (B40), 60:40 (B60), 80:20 (B80), have studied.

The relative density of all test samples were determined in accordance with IS: 1448[P: 32]:1992. Redwood viscometer No 1 was used for measurement of kinematic viscosity in cSt was calculated from time units as per IS No.1448 [P: 25]:1976. Heating value was determined as per IS No 1448[P: 6]:1984 by using isothermal bomb calorimeter. Pour point was determined as per IS No, 1448 [P: 10]: 1970. (Pensky –Martens closed cup) was used to find flash and fire point of test samples as per IS No 1448 [P: 21]: 1992.
5.2 Study of fuel properties of neem oil and its blends with conventional diesel

5.2.1 Introduction

In this section characteristic fuel properties such as density, specific gravity, viscosity, flash point, and heating values of neem oil, neem oil methyl ester, B20, B40, B60, B80 were determined experimentally and compared with conventional diesel oil.

Table 5.1 shows the fuel properties of neem oil, neem oil methyl ester (B100), and diesel oil, B20, B40, B60, B80. Table 5.1 also indicates that density, viscosity, specific gravity and flash point of neem oil is greater than neem oil methyl ester and diesel oil.

5.2.2 Results and discussion

5.2.2.1 Effect of specific gravity

The density of fuel is correlated with particulate emission. Figure 5.1 shows the specific gravity of neem oil, B20, B40, B60, B80 and B100. Neem oil has highest specific gravity (0.910) which is reduced to 0.870 after transesterification. Specific gravity of B20 is very close to that of conventional diesel which is 1.032 times higher than conventional diesel oil. B100 has specific gravity of 0.870 which is 1.0661 times higher than the conventional diesel oil. Figure 5.1 indicates that specific gravity increases with the increase in percentage of methyl ester in the blend.

Table 5.1 Properties of neem oil, neem oil methyl ester, diesel oil and blends (B20, B40, B60, B80).

<table>
<thead>
<tr>
<th>Property</th>
<th>Neem oil</th>
<th>Diesel</th>
<th>B20</th>
<th>B40</th>
<th>B60</th>
<th>B80</th>
<th>B100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density in kg/m³</td>
<td>910</td>
<td>816</td>
<td>826.8</td>
<td>837.6</td>
<td>848.4</td>
<td>859.2</td>
<td>870</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.91</td>
<td>0.816</td>
<td>0.8268</td>
<td>0.8376</td>
<td>0.8484</td>
<td>0.8592</td>
<td>0.87</td>
</tr>
<tr>
<td>Viscosity at 40 °C in cSt</td>
<td>40.75</td>
<td>4.3</td>
<td>4.34</td>
<td>4.38</td>
<td>4.42</td>
<td>4.46</td>
<td>4.5</td>
</tr>
<tr>
<td>Flash point in °C</td>
<td>250</td>
<td>53</td>
<td>77.4</td>
<td>101.8</td>
<td>126.2</td>
<td>150.6</td>
<td>175</td>
</tr>
<tr>
<td>Pour point in °C</td>
<td>7</td>
<td>8</td>
<td>-4.4</td>
<td>-0.8</td>
<td>2.8</td>
<td>6.4</td>
<td>10</td>
</tr>
<tr>
<td>Heating value MJ/kg</td>
<td>39.82</td>
<td>45.7</td>
<td>44.86</td>
<td>44.02</td>
<td>43.17</td>
<td>42.34</td>
<td>41.5</td>
</tr>
</tbody>
</table>
5.2.2.2 Effect of viscosity

Viscosity of fuel is an important fluid property because it determines flow characteristic when a liquid fuel flows through flow line, injector nozzle and orifices. Figure 5.2 shows the kinematic viscosity of unrefined neem oil, diesel oil, B20, B40, B60, and B80. Viscosity of B20 was observed 4.34 cSt which is 1.009 times higher than conventional diesel oil, unrefined neem oil has highest viscosity (40.75 cSt at 40°C) which is 9.477 times higher than conventional diesel oil. After transesterification viscosity has decrease from 40.75 to 4.5 cSt which is 1.0465 times higher than diesel oil.

Figure 5.2 also indicates that viscosity increases with the increase in percentage of methyl ester in the blends. Viscosity of neem oil is higher than all other samples which is 9.056 times higher than B100(4.5cSt). Viscosity of B20(4.34 cSt) is very close to that of conventional diesel oil which is 1.0093 times higher than conventional diesel oil. High viscosity of unrefined neem oil and B100 attributed to the molecular composition and structure, greater carbon chain length and reduced number of double bonds, high viscosity leads to poor atomisation of fuel spray which results in larger droplet size. This in turn leads to poor mixing of fuel and air, finally leads to incomplete combustion that results in loss of power and efficiency.
5.2.2.3 Effect of heating value

Table 5.1 indicates the heating values of unrefined neem oil, diesel, B20, B40, B60, B80 and B100. Figure 5.3 indicates that unrefined neem oil has heating value of 39.82 MJ/kg which is 12.866% lower than that of the diesel oil. B100 has the heating value of 41.5 MJ/kg which is 9.19% lower than that of the diesel fuel. B20 has the heating value of 44.86 MJ/kg which is 1.838% lower than that of the diesel. The lower heating value for all samples could be attributed to the presence of few hydrogen atoms and large number of oxygen atoms in the molecule. The lower heating value of methyl ester and their blends could result in loss of thermal efficiency as compared to conventional diesel oil.

5.2.2.4 Flash point

Table 5.1 shows the flash point of unrefined neem oil, diesel, B20, B40, B60, B80 and B100. The flash point of B20 (77.4°C) is 1.46 times higher than that of the
conventional diesel oil. Figure 5.4 shows that flash point increases with the increase in percentage of methyl ester in the blend.

Figure 5.4 Flash point of neem oil, diesel oil, B20, B40, B60, B80 and B100

5.3 Study of fuel properties of rice bran oil and its blends with conventional diesel.

5.3.1 Introduction

In this section characteristic fuel properties such as density, specific gravity, viscosity, flash point and heating values of unrefined rice bran oil, unrefined rice bran oil methyl ester, B20, B40, B60, B80 were determined experimentally and compared with conventional diesel oil and presented in table 5.2.

Table 5.2 Properties of unrefined rice bran oil, rice bran oil methyl ester, diesel oil and blends (B20, B40, B60, B80)

<table>
<thead>
<tr>
<th>Properties</th>
<th>CRBO</th>
<th>Diesel</th>
<th>B20</th>
<th>B40</th>
<th>B60</th>
<th>B80</th>
<th>B100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density kg/m³</td>
<td>914</td>
<td>816</td>
<td>827.8</td>
<td>839.6</td>
<td>851.4</td>
<td>863.2</td>
<td>875</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.914</td>
<td>0.816</td>
<td>0.8278</td>
<td>0.8396</td>
<td>0.8514</td>
<td>0.8632</td>
<td>0.875</td>
</tr>
<tr>
<td>Viscosity at 40°C in cSt</td>
<td>12.3</td>
<td>4.3</td>
<td>4.612</td>
<td>4.924</td>
<td>5.236</td>
<td>5.548</td>
<td>5.86</td>
</tr>
<tr>
<td>Flash point in °C</td>
<td>260</td>
<td>53</td>
<td>79.4</td>
<td>105.8</td>
<td>132.2</td>
<td>158.6</td>
<td>185</td>
</tr>
<tr>
<td>Pour point in °C</td>
<td>-5</td>
<td>-8</td>
<td>-7.6</td>
<td>-7.2</td>
<td>-6.8</td>
<td>-6.4</td>
<td>-6</td>
</tr>
<tr>
<td>Heating value in MJ/kg</td>
<td>36.16</td>
<td>45.7</td>
<td>44.76</td>
<td>43.82</td>
<td>42.88</td>
<td>41.94</td>
<td>41</td>
</tr>
</tbody>
</table>
5.3.2 Results and discussion

5.3.2.1 Effect of specific gravity

Figure 5.5 shows the specific gravity of unrefined rice bran oil, B20, B40, B60, B80 and B100. Unrefined rice bran oil has highest specific gravity (0.914) which is reduced to 0.875 after transesterification. Specific gravity of B20 is very close to that of conventional diesel which is 1.072 times higher than conventional diesel oil. B100 has specific gravity of 0.875 which is 1.362 times higher than that of the conventional diesel oil Figure 5.5 indicates that specific gravity increases with the increase in percentage of methyl ester in the blends.

![Figure 5.5 Specific gravity of rice bran oil, diesel, B20, B40, B60, B80 and B100](image)

5.3.2.2 Effect of viscosity

Viscosity of fuel is an important fluid property because it determines flow characteristic, when a liquid fuel flows through flow line, injector nozzle and orifices. Figure 5.6 shows the kinematic viscosity of unrefined rice bran oil, diesel oil, B20, B40, B60, B80 and B100. Viscosity of B20 was observed 4.612 cSt which is 1.072 times higher than that of conventional diesel oil. Unrefined rice bran oil has highest viscosity (12.3 cSt at 40°C) which is 2.860 times higher than that of conventional diesel oil. After transesterification, viscosity has decreased from 12.3 cSt to 5.86 cSt which is 2.0989 times higher than that of diesel oil.

Figure 5.6 also indicates that viscosity increases with the increase in percentage of methyl ester in the blends. High viscosity of unrefined rice bran oil and B100 attributed to molecular composition and structure, greater carbon chain length and reduced number of double bonds. High viscosity leads to poor atomisation of fuel
spray which results in larger droplet size. This in turn leads to poor mixing of fuel and air, finally leads to incomplete combustion that results in loss of power and efficiency.

Figure 5.6 Viscosity of rice bran oil, diesel, B20, B40, B60, B80 and B100

5.3.2.3 Effect of heating value

Table 5.2 shows the heating values of unrefined rice bran oil, diesel, B20, B40, B60, B80 and B100. Figure 5.7 indicates that unrefined rice bran oil has heating value of 36.16 MJ/kg which is 20.87% lower than that of the diesel oil. B100 has the heating value of 41.00 MJ/kg which is 10.28% lower than that of the diesel fuel.

B20 has the heating value of 44.76 MJ/kg which is 2.056% lower than that of the diesel. The lower heating value for all samples could be attributed to the presence of few hydrogen atoms and large number of oxygen atoms in the molecule. The lower heating value of methyl ester and their blend could result in loss of thermal efficiency as compared to conventional diesel oil.

Figure 5.7 Heating value of rice bran oil, diesel, B20, B40, B60, B80 and B100

5.3.2.4 Flash point

Table 5.2 shows the flash point of unrefined rice bran oil, diesel, B20, B40, B60, B80 and B100. The flash point of B20 (79.4°C) is 1.49 times higher than that of the conventional diesel oil, the flash point of unrefined rice bran oil (260°C) which
is 4.90 times more than that of the diesel. The flash point of B100 is (185°C) which is 3.49 times more than that of the diesel. Figure 5.8 shows that flash point increases with the increase in percentage of methyl ester in the blend.

![Figure 5.8 Flashpoint of unrefined rice bran oil, diesel, B20, B40, B60, B80 and B100](image)

5.4 Study of fuel properties of pongamia pinnata and its blends with conventional diesel

5.4.1 Introduction

In this section characteristic fuel properties such as density, specific gravity, viscosity, flash point and heating values of unrefined pongamia pinnata oil, pongamia pinnata oil methyl ester (B100), B20, B40, B60, B80 were determined experimentally and compared with conventional diesel oil and presented in table 5.3.

Table 5.3 Properties of unrefined pongamia pinnata oil, pongamia pinnata oil methyl ester, diesel oil and its blends (B20, B40, B60, B80)

<table>
<thead>
<tr>
<th>Property</th>
<th>PPO</th>
<th>Diesel</th>
<th>B20</th>
<th>B40</th>
<th>B60</th>
<th>B80</th>
<th>B100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>912</td>
<td>816</td>
<td>824.8</td>
<td>833.6</td>
<td>842.4</td>
<td>851.2</td>
<td>860</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.912</td>
<td>0.816</td>
<td>0.8248</td>
<td>0.8336</td>
<td>0.8424</td>
<td>0.8512</td>
<td>0.86</td>
</tr>
<tr>
<td>Viscosity at 40 °C in cSt</td>
<td>10.5</td>
<td>4.3</td>
<td>4.4</td>
<td>4.5</td>
<td>4.6</td>
<td>4.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Flash point in °C</td>
<td>210</td>
<td>53</td>
<td>78.4</td>
<td>103.8</td>
<td>129.2</td>
<td>154.6</td>
<td>180</td>
</tr>
<tr>
<td>Pour point in °C</td>
<td>-6</td>
<td>-8</td>
<td>-7.8</td>
<td>-7.6</td>
<td>-7.4</td>
<td>-7.2</td>
<td>-7</td>
</tr>
<tr>
<td>Heating value in MJ/kg</td>
<td>38.5</td>
<td>45.7</td>
<td>44.96</td>
<td>44.22</td>
<td>43.48</td>
<td>42.74</td>
<td>42</td>
</tr>
</tbody>
</table>
5.4.2 Results and discussion

5.4.2.1 Effect of specific gravity

Figure 5.9 shows the specific gravity of unrefined pongamia pinnata oil, B20, B40, B60, B80 and B100. Unrefined pongamia pinnata oil has highest specific gravity 0.912 which is reduced to 0.86 after transesterification. The unrefined pongamia pinnata oil has 1.0906 times more specific gravity than that of the diesel oil. Specific gravity of B20 (0.8168) is very close to that of conventional diesel (0.816) which is 1.0009 times higher than that of conventional diesel oil. B100 has specific gravity of 0.816 which is 1.0049 times higher than that of the conventional diesel oil. Figure 5.9 indicates that specific gravity increases with the increase in percentage of methyl ester in the blends.

![Specific gravity graph](graph.png)

Figure 5.9 Specific gravity of pongamia pinnata oil, B20, B40, B60, B80 and B100

5.4.2.2 Effect of viscosity

Figure 5.10 shows the viscosity of unrefined pongamia pinnata oil, diesel oil, B20, B40, B60, B80 and B100. Viscosity of B20 was 4.34 cSt which is 1.0093 times higher than that of the conventional diesel oil. Unrefined pongamia pinnata oil has highest viscosity (9.5cSt at 40°C) which is 2.209 times higher than that of the conventional diesel oil, after transesterification viscosity has decreased from 9.5 cSt to 4.5 cSt which is 1.0465 times higher than that of the diesel oil.

Figure 5.10 also indicates that viscosity increases with increase in percentage of methyl ester in the blends. High viscosity of unrefined pongamia pinnata oil and B100 are attributed to molecular composition and structure,
5.4.2.3 Effect of heating value

Table 5.3 indicates heating values of unrefined pongamia pinnata oil, diesel, B20, B40, B60, B80 and B100. Figure 5.11 indicates that unrefined Pongamia pinnata oil has heating value of 40 MJ/kg which is 12.47% lower than the diesel oil. B100 has the heating value of 43 MJ/kg which is 5.90% lower than the diesel fuel. B20 has the heating value of 45.16 MJ/kg which is 1.18% lower than the diesel. The lower heating value for all samples could be attributed to the presence of few hydrogen atoms and large number of oxygen atoms in the molecule. The lower heating value of methyl ester and their blend could result in loss of thermal efficiency as compared to conventional diesel oil.

5.4.2.4 Flash point

Table 5.3 shows the flash point of unrefined pongamia pinnata oil, diesel, B20, B40, B60, B80 and B100. The flashpoint of B20 (77.4°C) is 1.46 times higher than that of the conventional diesel oil. The flash point of unrefined pongamia pinnata oil is 200°C which is 3.77 times more than that of the diesel. The flash point of B100 is
which is 3.301 times more than that of the diesel. Figure 5.12 shows that flash point increases with the increase in percentage of methyl ester in the blend.

![Graph showing flash point increase](image)

**Figure 5.12 Flash point of pongamia pinnata oil, diesel, B20, B40, B60, B80 and B100**

### 5.5 Study of fuel properties of cotton seed oil and its blends with conventional diesel

#### 5.5.1 Introduction

In this section characteristic fuel properties such as density, specific gravity, viscosity, flash point, and heating values of unrefined cotton seed oil, cotton seed oil methyl ester, B20, B40, B60, B80 were determined experimentally and compared with conventional diesel oil and presented in table 5.4.

#### Table 5.4 Properties of unrefined cotton seed oil, cotton seed oil methyl ester, diesel oil and blends (B20, B40, B60, B80)

<table>
<thead>
<tr>
<th>Property</th>
<th>CSO</th>
<th>Diesel</th>
<th>B20</th>
<th>B40</th>
<th>B60</th>
<th>B80</th>
<th>B100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density in kg/m³</td>
<td>890</td>
<td>816</td>
<td>816.8</td>
<td>817.6</td>
<td>818.4</td>
<td>819.2</td>
<td>820</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.89</td>
<td>0.816</td>
<td>0.8168</td>
<td>0.8176</td>
<td>0.8184</td>
<td>0.8192</td>
<td>0.82</td>
</tr>
<tr>
<td>Viscosity at 40 °C in cSt</td>
<td>9.5</td>
<td>4.3</td>
<td>4.34</td>
<td>4.38</td>
<td>4.42</td>
<td>4.46</td>
<td>4.5</td>
</tr>
<tr>
<td>Flash point in °C</td>
<td>200</td>
<td>53</td>
<td>77.4</td>
<td>101.8</td>
<td>126.2</td>
<td>150.6</td>
<td>175</td>
</tr>
<tr>
<td>Pour point in °C</td>
<td>-6</td>
<td>-8</td>
<td>-7.8</td>
<td>-7.6</td>
<td>-7.4</td>
<td>-7.2</td>
<td>-7</td>
</tr>
<tr>
<td>Heating value in MJ/kg</td>
<td>40</td>
<td>45.7</td>
<td>45.16</td>
<td>44.62</td>
<td>44.08</td>
<td>43.54</td>
<td>43</td>
</tr>
</tbody>
</table>
5.5.2 Results and discussion

5.5.2.1 Effect of specific gravity

Figure 5.13 shows the specific gravity of unrefined cotton seed oil, B20, B40, B60, B80 and B100. Unrefined cotton seed oil has highest specific gravity of 0.890 which is reduced to 0.82 after transesterification. The unrefined cotton seed oil has 1.0906 times more specific gravity than that of diesel. Specific gravity of B20 (0.8168) is very close to that of conventional diesel (0.816) which is 1.0009 times higher than that of the conventional diesel oil. B100 has specific gravity of 0.816 which is 1.0049 times higher than that of the conventional diesel oil.

Figure 5.13 Indicates that specific gravity increases with the increase in percentage of methyl ester in the blend.

Figure 5.13 Specific gravity of cotton seed oil, B20, B40, B60, B80 and B100

5.5.2.2 Effect of viscosity

Figure 5.14 shows the kinematic viscosity of unrefined cotton seed oil, diesel oil, B20, B40, B60, B80 and B100. Viscosity of B20 was observed 4.34 cSt which is 1.0093 times higher than that of conventional diesel oil. Unrefined cotton seed oil has highest viscosity (9.5 cSt at 40°C) which is 2.209 times higher than that of the conventional diesel oil. After transesterification viscosity has decreased from 9.5 cSt to 4.5 cSt which is 1.0465 times higher than that of the diesel oil. Figure 5.14 also indicates that viscosity increases with increase in percentage of methyl ester in the blends. Viscosity of unrefined cotton seed oil is higher than all other samples. High viscosity of unrefined cotton seed oil and B100 attributed to molecular composition and structure, greater carbon chain length and reduced number of double bonds, high viscosity leads to poor atomisation of fuel spray which results in larger droplet size.
This in turn leads to poor mixing of fuel and air, finally leads to incomplete combustion that results in loss of power and efficiency.

![Figure 5.14 Viscosity of unrefined cotton seed oil, diesel oil, B20, B40, B60, B80 and B100](image)

**5.5.2.3 Effect of heating value**

Table 5.4 indicates heating values of unrefined cotton seed oil, diesel, B20, B40, B60, and B100. Figure 5.15 indicates that unrefined cotton seed oil has heating value of 40 MJ/kg which is 12.47 % lower than that of the diesel oil, B100 has the heating value of 43 MJ/kg which is 5.90 % lower than the diesel fuel. B20 has the heating value of 45.16 MJ/kg which is 1.18 % lower than the diesel. The lower heating value for all samples could be attributed to the presence of few hydrogen atoms and large number of oxygen atoms in the molecule. The lower heating value of methyl ester and their blend could result in loss of thermal efficiency as compared to conventional diesel oil.

![Figure 5.15 Heating value of unrefined cotton seed oil, diesel, B20, B40, B60, B80 and B100](image)
5.5.2.4 Flash point

Table 5.4 shows the flash point of unrefined cotton seed oil, diesel, B20, B40, B60, B80 and B100. The flashpoint of B20 (77.4°C) is 1.46 times higher than the conventional diesel oil. The flash point of unrefined cotton seed oil is 200°C which is 3.77 times more than the diesel. The flash point of B100 is 175°C which is 3.301 times more than the diesel. Figure 5.16 shows that flash point increases with the increase in percentage of methyl ester in the blend.

![Figure 5.16 Flash point of unrefined cotton seed oil, diesel, B20, B40, B60, B80 and B100](image)

5.6 Study of fuel properties of rubber seed oil and its blends with conventional diesel

5.6.1 Introduction

In this section characteristic fuel properties such as density, specific gravity, viscosity, flash point, and heating values of unrefined rubber seed oil, rubber seed oil methyl ester (B100), B20, B40, B60, B80 were determined experimentally and compared with conventional diesel oil and presented in table 5.4.
Table 5.5 Properties of unrefined rubber seed oil, rubber seed oil methyl ester (B100), diesel oil (B20, B40, B60, B80 B100)

<table>
<thead>
<tr>
<th>Property</th>
<th>Rubber seed oil</th>
<th>Diesel</th>
<th>B20</th>
<th>B40</th>
<th>B60</th>
<th>B80</th>
<th>B100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density in kg/m³</td>
<td>860</td>
<td>816</td>
<td>816.4</td>
<td>816.8</td>
<td>817.2</td>
<td>817.6</td>
<td>818</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.860</td>
<td>0.816</td>
<td>0.8164</td>
<td>0.8168</td>
<td>0.8172</td>
<td>0.8176</td>
<td>0.818</td>
</tr>
<tr>
<td>Viscosity at 40°C in cSt</td>
<td>8.5</td>
<td>4.3</td>
<td>4.32</td>
<td>4.34</td>
<td>4.36</td>
<td>4.38</td>
<td>4.4</td>
</tr>
<tr>
<td>Flash point in °C</td>
<td>190</td>
<td>53</td>
<td>75.4</td>
<td>97.8</td>
<td>120.2</td>
<td>142.6</td>
<td>165</td>
</tr>
<tr>
<td>Pour point in °C</td>
<td>-6</td>
<td>-8</td>
<td>-7.8</td>
<td>-7.6</td>
<td>-7.4</td>
<td>-7.2</td>
<td>-7.4</td>
</tr>
<tr>
<td>Heating value in MJ/kg</td>
<td>40.5</td>
<td>45.7</td>
<td>45.26</td>
<td>44.82</td>
<td>44.38</td>
<td>43.94</td>
<td>43.5</td>
</tr>
</tbody>
</table>

5.6.2 Results and discussion

5.6.2.1 Effect of specific gravity

Figure 5.17 shows the specific gravity of unrefined rubber seed oil, B20, B40, B60, B80 and B100. Unrefined rubber seed oil has highest specific gravity of 0.860 which is reduced to 0.818 after transesterification. The unrefined rubber seed oil has 1.0539 times more specific gravity than that of the diesel. Specific gravity of B20 (0.8164) is very close to that of conventional diesel (0.816) which is 1.0009 times higher than that of the conventional diesel oil. B100 has specific gravity of 0.818 which is 1.00245 times higher than that of the conventional diesel oil.

Figure 5.17 Specific gravity of unrefined rubber seed oil, B20, B40, B60, B80 and B100

Figure 5.17 indicates that specific gravity increases with the increase in percentage of methyl ester in the blend.
5.6.2.2 Effect of viscosity

Figure 5.18 shows the kinematic viscosity of unrefined rubber seed oil, diesel oil, B20, B40, B60, B80 and B100. Viscosity of B20 was observed 4.32 cSt which is 1.0093 times higher than conventional diesel oil. Unrefined rubber seed oil has highest viscosity (8.5 cSt at 40 °C) which is 1.976 times higher than conventional diesel oil. After transesterification viscosity has decreased from 8.5 cSt to 4.4 cSt which is 1.023 times higher than diesel oil. Figure 5.18 also indicates that viscosity increases with increase in percentage of methyl ester in the blends. Viscosity of unrefined rubber seed oil is higher than all other samples. High viscosity of unrefined rubber seed oil and B100 attributed to molecular composition and structure, greater carbon chain length and reduced number of double bonds, high viscosity leads to pour atomisation of fuel spray which results in larger droplet size. This in turn leads to poor mixing of fuel and air, finally leads to incomplete combustion that results in loss of power and efficiency.

![Viscosity of rubber seed oil, diesel oil, B20, B40, B60, B80 and B100](image)

5.6.2.3 Effect of heating value

Table 5.5 indicates heating values of rubber seed oil, diesel, B20, B40, B60, B80 and B100. Figure 5.19 indicates that unrefined rubber seed oil has heating value of 40 MJ/kg which is 12.47 % lower than that of the diesel oil, B100 has the heating value of 43 MJ/kg which is 5.90 % lower than that of the diesel fuel. B20 has the heating value of 45.16 MJ/kg which is 1.18 % lower than that of the diesel. The lower heating value for all samples could be attributed to the presence of few hydrogen atoms and large number of oxygen atoms in the molecule. The lower heating value of methyl ester and their blends could result in loss of thermal efficiency as compared to conventional diesel oil.
Figure 5.19 Heating value of rubber seed oil, diesel, B20, B40, B60, B80 and B100

5.6.2.4 Flash point

Table 5.5 shows the flash point of unrefined rubber seed oil, diesel, B20, B40, B60, B80 and B100. The flash point of B20 (75.4 °C) is 1.42 times higher than the conventional diesel oil. The flash point of unrefined rubber seed oil is 190°C which is 3.58 times more than that of the diesel. The flash point of B100 is 165°C which is 3.11 times more than the diesel. Figure 5.20 shows that flash point increases with the increase in percentage of methyl ester in the blend.

Figure 5.20 Flash point of rubber seed oil, diesel, B20, B40, B60, B80 and B100
5.7 Comparison of properties of selected feedstock methyl ester and their blends.

In this section, an effort was made to study the fuel properties of the methyl esters and their blends of the feedstock (oil) that were used in this research work. In the first part, fuel properties such as specific gravity, flash point, viscosity and heating value of B20 of all the feedstock were studied. In the subsequent parts, fuel properties such as specific gravity, flash point, viscosity and heating value study was carried out for B40, B60, B80 and B100 of all the feedstock. Further, specific gravity, flash point, viscosity and heating value of methyl ester (B100) and their blends (B20, B40, B60 and B80) were compared with diesel to study their usefulness as diesel engine fuel.

5.7.1 Effect of specific gravity of B20, B40, B60, B80 and B100 of all selected fuels

Figures 5.21 to 5.25 compares the specific gravity of B20, B40, B60, B80 and B100 of neem, pongamia pinnata, rice bran, cotton seed oil and rubber seed oil with conventional diesel.

Figure 5.21 indicates that the specific gravity of B20 of all fuels were close to that of diesel. B20 of all prepared fuels were found to have their specific gravity 1.00049 to 1.013 times higher than that of the conventional diesel. B20 of rice bran oil has highest specific gravity (0.8278) which is 1.0144 times higher than that of the conventional diesel. B20 of rubber seed oil has lowest specific gravity (0.8164) which is 1.00049 times higher than that of the conventional diesel.

Figure 5.22 indicates that the specific gravity of B40 of all fuels were slightly higher than that of diesel. B40 of fuels were found to have their specific gravity 1.00098 to 1.0264 times higher than that of the conventional diesel. B40 of rice bran oil has highest specific gravity (0.8396) which is 1.0289 times higher than that of the conventional diesel. B40 of rubber seed oil has lowest specific gravity (0.8168) which is 1.00098 times higher than that of the conventional diesel.

Figure 5.23 indicates that the specific gravity of B60 of all fuels were higher than that of diesel and slightly higher than B20 and B40 of all fuels. B60 of fuels were found to have their specific gravity 1.00147 to 1.0433 times higher than that of the conventional diesel. B60 of rice bran oil has highest specific gravity (0.8514) which is 1.0433 times higher than that of the conventional diesel. B60 of rubber seed oil has lowest specific gravity (0.8116) which is 1.00147 times higher than that of the conventional diesel.
oil and cotton seed oil have lower specific gravity 0.8172 and 0.8184 which is 1.00147 and 1.0029 times higher than that of the conventional diesel respectively.

Figure 5.24 indicates that the specific gravity of B80 of all fuels were higher than that of diesel and higher than B20,B40 and B60 of all fuels. B80 of fuels were found to have their specific gravity 1.00196 to 1.0529 times higher than that of the conventional diesel. B80 of rice bran oil has highest specific gravity (0.8632) which 1.057 times higher than that of the conventional diesel. B80 of rubber seed oil has lowest specific gravity 0.8176 which is 1.00196 times higher than that of the conventional diesel.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Specific Gravity</th>
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<tbody>
<tr>
<td>Diesel</td>
<td>0.813</td>
</tr>
<tr>
<td>B20 Neem</td>
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</tr>
<tr>
<td>B20 rice bran</td>
<td>0.826</td>
</tr>
<tr>
<td>B20 Pongamia</td>
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</tr>
<tr>
<td>B20 Cotton</td>
<td>0.814</td>
</tr>
<tr>
<td>B20 Rubber</td>
<td>0.812</td>
</tr>
<tr>
<td>B40 Neem</td>
<td>0.822</td>
</tr>
<tr>
<td>B40 rice bran</td>
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</tr>
<tr>
<td>B40 Pongamia</td>
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</tr>
<tr>
<td>B40 Cotton</td>
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</tr>
<tr>
<td>B40 Rubber</td>
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<tr>
<td>B60 Neem</td>
<td>0.821</td>
</tr>
<tr>
<td>B60 rice bran</td>
<td>0.822</td>
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<tr>
<td>B60 Pongamia</td>
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</tr>
<tr>
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<td>B60 Rubber</td>
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</tr>
<tr>
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<td>B80 Pongamia</td>
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</tr>
<tr>
<td>B80 Cotton</td>
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</tr>
<tr>
<td>B80 Rubber</td>
<td>0.838</td>
</tr>
</tbody>
</table>

Figure 5.21 Specific gravity of B20 of all the selected fuels

Figure 5.22 Specific gravity of B40 of all the selected fuel
Specific gravity of B60 of all the selected fuels

Figure 5.23 indicates that the specific gravity of B100 of all fuels were higher than that of diesel and higher than B20, B40, B60 and B80 of all fuels. B100 of fuels were found to have their specific gravity 1.0024 to 1.072 times higher than that of the conventional diesel. B100 rice bran oil has highest specific gravity (0.875) which is 1.072 times higher than that of the conventional diesel. Rubber seed oil has lowest specific gravity 0.818 which is 1.0024 times higher than that of conventional diesel.

Specific gravity of B80 of all the selected fuels

Figure 5.24 Specific gravity of B80 of all the selected fuel

Specific gravity of B100 of all the selected fuels

Figure 5.25 Specific gravity of B100 of all the selected fuels
5.7.2 Effect of viscosity of B20, B40, B60, B80 and B100 of all selected fuels

Viscosity is the most important property of diesel fuel since it affects operation of fuel injection systems, particularly at low temperatures when an increase in viscosity affects the fluidity of fuel. High viscosity leads to poor atomisation of fuel. Lower the viscosity of the fuel, the easier it is to pump and atomise and achieve finer droplets. The conversion of vegetable oil into methyl or ethyl esters through transesterification reduces the molecular weight which in turn reduces the viscosity of esters.

In this part, viscosity of B20, B40, B60, B80 and B100 of all selected fuels were compared with conventional diesel.

Figure 5.26 to 5.30 compares the viscosity of B20, B40, B60, B80 and B100 of neem, rice bran, pongamia pinnata, cotton seed oil and rubber seed oil with conventional diesel.

Figure 5.26 indicates that the viscosity of B20 of all fuels were close to that of diesel. B20 of fuels were found to have their viscosity 1.0046 to 1.0725 times higher than that of the conventional diesel. B20 of rice bran has slightly higher viscosity (4.612 cSt) which is 1.0725 times higher than that of the conventional diesel. B20 of rubber seed oil has viscosity very close to conventional diesel.

Figure 5.27 indicates that the viscosity of B40 of all fuels were slightly higher than that of diesel. B40 of fuels were found to have their viscosity 1.0093 to 1.145 times higher than conventional diesel. B40 of rice bran oil have highest viscosity (4.924 cSt) which is 1.145 times higher than that of the conventional diesel. B40 of rubber seed oil has lowest viscosity (4.34 cSt) which is 1.0093 times higher than that of the conventional diesel.

Figure 5.28 indicates that the viscosity of B60 of all fuels were higher than that of the diesel and slightly higher than B20 and B40 of all fuels. B60 of fuels were found to have their viscosity 1.0139 to 1.217 times higher than that of the conventional diesel. B60 rubber seed oil have highest viscosity (5.236 cSt) which is 1.217 times higher than that of the conventional diesel. B60 of rubber seed oil has lowest viscosity (4.36 cSt) which is 1.0139 times higher than that of the conventional diesel.
Figure 5.29 indicates that the viscosity of B80 of all fuels were higher than that of diesel and higher than B20, B40 and B60 of all fuels. B80 of fuels were found to have their viscosity 1.0186 to 1.29 times higher than that of the conventional diesel. B80 of rice bran oil have highest viscosity (5.548 cSt) which 1.290 times higher than that of the conventional diesel. B80 of Rubber seed oil has lowest viscosity (4.38 cSt) which is 1.0186 times higher than that of the conventional diesel.

Figure 5.30 indicates that the viscosity of B100 of all fuels were higher than that of diesel and higher than B20, B40, B60 and B80 of all fuels. B100 of fuels were found to have their viscosity 1.023 to 1.362 times higher than that of the conventional diesel. B100 of rice bran oil have highest viscosity (5.86 cSt) which is 1.362 times higher than that of the conventional diesel. B100 of rubber seed oil has lowest viscosity of 4.4 cSt which is 1.023 times higher than that of the conventional diesel.

Figure 5.26 Viscosity of B20 of all the selected fuels

Figure 5.27 Viscosity of B40 of all the selected fuels
Figure 5.28 Viscosity of B60 of all the selected fuels

Figure 5.29 Viscosity of B80 of all the selected fuels

Figure 5.30 Viscosity of B100 of all the selected fuels
5.7.3 Effect of heating values of B20, B40, B60, B80 and B100 of all selected fuel

Heating value is an important property of biodiesel as it is considered as an alternative to diesel fuel. Converting the vegetable oils into esters through transestrification improves the heating value. However, it has been reported that esters contain approximately 10% less energy than that of conventional diesel. The lower value is due to the presence of oxygen in biodiesel. Hence, in this study an attempt was made to find the percentage variation in heating value of methyl esters and their blends with conventional diesel.

Figure 5.31 to 5.35 compares the heating value of B20, B40, B60, B80 and B100 of neem, rice bran, pongamia pinnata, cotton seed, rubber seed oil with conventional diesel.

Figure 5.31 indicates that the heating value of B20 of all fuels were close to that of diesel. B20 of fuels were found to have their heating value 0.962% to 2.05% lower than conventional diesel. B20 of rice bran oil (44.76 MJ/kg) has lowest heating value which has 2.05% lower heating value than that of the conventional diesel. B20 of rubber seed oil has heating value (45.26 MJ/kg) closer to conventional diesel and 0.962% lower heating value than that of the conventional diesel.

Figure 5.32 indicates that the heating value of B40 of all fuels were slightly higher than that of diesel. B40 of fuels were found to have their heating value 1.925% to 4.114% lower heating value than that of the conventional diesel. B40 of rice bran oil has lowest heating value (43.82 MJ/kg) which is 4.114% lower heating value than that of the conventional diesel. B40 of rubber seed oil has highest heating value (44.82 MJ/kg) which is 1.925% lower than that of the conventional diesel.

![Figure 5.31 Heating value of B20 of all the selected fuels](image)
Figure 5.33 indicates that the heating value of B60 of all fuels were higher than that of the diesel. B60 of fuels were found to have their heating value 2.88 % to 6.17 % lower than that of the conventional diesel. B60 of rice bran oil has lowest heating value (42.88MJ/kg) which is 6.17 % lower than that of the conventional diesel. B60 of rubber seed oil has highest heating value (44.38MJ / kg)) which is 2.88 % lower than that of the conventional diesel.

Figure 5.32 Heating value of B40 of all the selected fuels

Figure 5.33 Heating value of B60 of all the selected fuel

Figure 5.34 indicates that the heating value of B80 of all fuels were higher than that of the diesel. B80 of fuels were found to have their heating value 3.85 % to 8.22 % lower than that of the conventional diesel. B80 of rice bran oil has lowest heating value (41.94 MJ/kg) which is 8.22 % lower than that of the conventional diesel. B80 of rubber seed oil has highest heating value (43.94 MJ /kg) which is 3.85 % lower than conventional diesel.
Figure 5.35 indicates that the heating value of B100 of all fuels were lower than that of diesel. B100 of fuels were found to have their heating value 4.81% to 10.28% lower than conventional diesel. B100 of rice bran oil have lowest heating value (41 MJ/kg) which is 10.28% lower than conventional diesel. B100 of rubber seed oil has highest heating value (43.5 MJ/kg) which is 4.81% lower than conventional diesel.

![Figure 5.34 Heating value of B80 of all the selected fuels](image1)

![Figure 5.35 Heating value of B100 of all the selected fuels](image2)

5.7.4 Effect of flash point of B20, B40, B60, B80 and B100 of all selected fuels

Flash point is an important property to consider in the handling, storage and safety of fuels and flammable materials. High values of flash point reduces the danger of fire which is required for safe transportation of fuels. The various national standards specify flash point of biodiesel above 100°C. Biodiesel generally has flash point above 100°C which is an advantage of biodiesel over conventional diesel. In the
following sections, investigation was carried to study the flash points of all selected fuels.

Figure 5.36 to 5.40 compares the flash point of B20, B40, B60, B80 and B100 of neem, rice bran oil, pongamia pinnata, cotton seed oil and rubber seed oil with conventional diesel.

Figure 5.36 indicates that the flash point of B20 of all fuels were close to that of diesel. B20 of all fuels were found to have their flash point 1.4226 to 1.498 times higher than that of the conventional diesel. B20 of rice bran oil (79.4 °C) has highest flash point which is 1.498 times higher than that of the conventional diesel. B20 of rubber seed oil has flash point 1.4226 times higher than that of the conventional diesel.

Figure 5.37 indicates that the flash point of B40 of all fuels were higher than that of diesel. B40 of all fuels were found to have their flash point 1.845 to 1.996 times higher than that of the conventional diesel. B40 of rice bran oil has highest flash point (105.8 °C) which is 1.996 times higher than that of the conventional diesel. B40 of rubber seed oil has flash point 1.845 times higher flash point than conventional diesel.

![Figure 5.36 Flash point of B20 of all the selected fuels](image-url)
Figure 5.37 Flash point of B40 of all the selected fuels

Figure 5.37 indicates that flash point of B60 of all fuels were higher than that of diesel. B60 of all fuels were found to have their flash point 2.2679 to 2.494 times higher than that of the conventional diesel. B60 of rice bran oil has highest flash point which is 2.494 times higher than that of the conventional diesel. B60 of rubber seed oil has flash point closer to conventional diesel and 2.26 times higher flash point than that of the conventional diesel.

Figure 5.38 Flash point of B60 of all the selected fuels

Figure 5.38 indicates that flash point of B80 of all fuels were higher than that of diesel. B80 of all fuels were found to have their flash point 2.69 to 2.99 times higher than that of the conventional diesel. B80 of rice bran oil have highest flash point which is 2.99 times higher than that of the conventional diesel. B80 of rubber seed oil has lowest flash point which is 2.69 times higher flash point than that of the conventional diesel.

Figure 5.40 indicates that flash point of B100 of all fuels were higher than that of diesel. B100 of all fuels were found to have their flash point 3.113 to 3.49 times higher than that of the conventional diesel.
higher than that of the conventional diesel. B100 of rice bran oil have highest flash point which is 3.49 times higher than that of the conventional diesel. B100 of rubber seed oil has lowest flash point which is 3.113 times higher flash point than that of the conventional diesel.

Figure 5.39 Flash point of B80 of all the selected fuels

Figure 5.40 Flash point of B100 of all the selected fuels
REFERENCES


3] South Asia working paper series Number 8, November 2011.