CHAPTER-4

EXPERIMENTAL INVESTIGATIONS
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of the Sub-Title</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Introduction</td>
<td>121</td>
</tr>
<tr>
<td>4.2</td>
<td>First stage investigations</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td>4.2.1 Performance and emission characteristics of Cotton seed biodiesel blends with diesel as fuel in CI engine</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td>4.2.1.1 Brake thermal potency</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>4.2.1.2 Brake specific Fuel consumption</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>4.2.1.3 Exhaust Gas Temperature</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>4.2.1.4 Smoke Density</td>
<td>123</td>
</tr>
<tr>
<td></td>
<td>4.2.1.5 Hydrocarbon emissions (HC emissions)</td>
<td>124</td>
</tr>
<tr>
<td></td>
<td>Carbon monoxide Emissions (CO emissions)</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>4.2.1.6 Nitrogen oxide Emissions (NOx emission)</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>4.2.2 Performance and emission characteristics of Karanja biodiesel blended with diesel as fuel in CI engine</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>4.2.2.1 Brake thermal potency</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>4.2.2.2 Brake specific Fuel consumption</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>4.2.2.3 Exhaust Gas Temperature</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>4.2.2.4 Smoke Density</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>4.2.2.5 Hydrocarbon emissions (HC emissions)</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Carbon monoxide Emissions (CO</td>
<td>129</td>
</tr>
</tbody>
</table>
4.2.2.7 Nitrogen oxide Emissions (NOx emission)

4.2.3 Performance and emission characteristics of Mahua biodiesel blended with diesel as fuel in CI engine

4.2.3.1 Brake thermal potency
4.2.3.2 Brake specific Fuel consumption
4.2.3.3 Exhaust Gas Temperature
4.2.3.4 Smoke Density
4.2.3.5 Hydrocarbon emissions (HC emissions)
4.2.3.6 Carbon monoxide Emissions (CO emissions)
4.2.3.7 Nitrogen oxide Emissions (NOx emission)

4.2.4 Performance and emission characteristics of Neem biodiesel blends with diesel as fuel in CI engine

4.2.4.1 Brake thermal potency
4.2.4.2 Brake specific Fuel consumption
4.2.4.3 Exhaust Gas Temperature
4.2.4.4 Smoke Density
4.2.4.5 Hydrocarbon emissions (HC emissions)
4.2.4.6 Carbon monoxide Emissions (CO emissions)
4.2.4.7 Nitrogen oxide Emissions (NOx emission)

4.2.5 Performance and emission characteristics of Jatropha biodiesel blended with diesel as fuel in CI engine
4.2.5.1 Brake thermal potency
4.2.5.2 Brake specific Fuel consumption
4.2.5.3 Exhaust Gas Temperature
4.2.5.4 Smoke Density
4.2.5.5 Hydrocarbon emissions (HC emissions)
4.2.5.6 Carbon monoxide Emissions (CO emissions)
4.2.5.7 Nitrogen oxide Emissions (NOx emission)
4.2.6 Optimization of biodiesel blend
4.2.7 Best Biodiesel among the various fuels tested
4.2.8 Conclusions of 1st stage investigations

4.3 Second stage investigations

4.3.1 Performance and emission characteristics of Cotton seed biodiesel blend (B20) as fuel in air gap insulated piston engine

4.3.1.1 Brake thermal potency
4.3.1.2 Brake specific Fuel consumption
4.3.1.3 Exhaust Gas Temperature
4.3.1.4 Smoke Density
4.3.1.5 Hydrocarbon emissions (HC emissions)
4.3.1.6 Carbon monoxide Emissions (CO emissions)
4.3.1.7 Nitrogen oxide Emissions (NOx emission)
4.3.2 Best air gap for the piston 174

4.3.3 Conclusions of second stage investigations 174

4.4 Third stage investigations 179

4.4.1 Performance and emission characteristics of Cotton seed biodiesel blend (B20) as fuel in air gap (2mm) insulated piston engine with thermal barrier piston crown 180

4.4.1.1 Brake thermal potency 180

4.4.1.2 Brake specific Fuel consumption 181

4.4.1.3 Exhaust Gas Temperature 181

4.4.1.4 Smoke Density 182

4.4.1.5 Hydrocarbon emissions (HC emissions) 182

4.4.1.6 Carbon monoxide Emissions (CO emissions) 183

4.4.1.7 Nitrogen oxide Emissions (NOx emission) 184

4.4.2 Choice of Best piston crown 184

4.4.3 Conclusions of third stage investigations 184
4. EXPERIMENTAL INVESTIGATIONS

4.1 Introductions

The biodiesels (Methyl Esters of Cotton seed oil, Mahua Oil, Neem oil, Jatropha oil, Karanja oil) are mingling (mixed) with typical diesel one by one in varied proportions is employed as fuel to gauge (evaluate) the performance and emission characteristics of single cylinder, 5 hp, four-stroke, constant speed water cooled stationary diesel engine at varied engine load. Engine tests are conducted in three stages for analyzing varied parameters like brake thermal potency, brake specific fuel consumption (BSFC), Exhaust gas temperature and emissions of CO, HC, NOx. All the results are made compared at 3/4th of rated load of the engine.

4.2 First stage investigations

In the 1st stage of investigation experiments were conducted at rated engine speed of 1500 revolutions per minute with the blends of above mentioned biodiesels.

4.2.1 Performance and emission characteristics of Cotton seed biodiesel blends with diesel as fuel in CI engine

Engine tests are conducted on a diesel engine with diesel and Cotton seed biodiesel blends [B5, B10, B15, B20, and B25] for analyzing varied parameters like brake thermal potency, brake specific fuel consumption (BSFC), exhaust gas temperature, emissions of CO, HC, NOx and smoke density.
4.2.1.1 Brake thermal potency

The Figure 4.1 shows the variation of brake thermal potency for diesel and Cotton seed biodiesel blends with brake power output. Normally the thermal potency depends on the combustion method that could be a complicated phenomenon that is influenced by many factors like design of combustion chamber, type of injector, injection pressure, spray characteristics and fuel characteristics like cetane range, volatility, viscosity, consistent mixture formation, heat of transformation (latent heat) of vaporization, hot worth (calorific value) etc. It is evident that diesel fuel has the higher brake thermal potency compared to Cotton seed biodiesel blends. This is due to its high hot worth and low viscousness of diesel as compared with Cotton seed biodiesel. With the higher hot worth of the diesel fuel the heat produced within the combustion chamber is more and the combustion is better due to the low viscousness. The thermal potency of diesel is 29.18%, where as for Cotton seed biodiesel blends B5, B10, B15, B20 and B25 are 29%, 28.75%, 28.62%, 28.45% and 27.47% respectively.

4.2.1.2. Brake specific Fuel Consumption

The variation of brake specific fuel consumption (BSFC) for diesel and Cotton seed biodiesel blends with brake power is shown in Figure 4.2. The BSFC is reduced with the load for all fuel blends. it's found that the BSFC of the engine with Cotton seed biodiesel blends is higher than that of diesel fuel at all loads. This is often due to the combined effects of lower heating worth and the higher fuel flow rate due to high density of the Cotton seed biodiesel. Higher proportions of
Cotton seed biodiesel within the blends will increase the viscousness which in turn causes to poor atomization of the fuel and thus the BSFC of the engine is increased with Cotton seed biodiesel blends. The oxygenated biodiesels might cause the leaner combustion, leading to higher BSFC. The BSFC of diesel is 0.284 kg/kW-hr, where as for Cotton seed biodiesel blends B5, B10, B15, B20 and B25 are 0.305 kg/kW-hr, 0.309 kg/kW-hr, 0.311 kg/kW-hr, 0.3115kg/kW-hr, and 0.332 kg/kW-hr respectively.

4.2.1.3. Exhaust Gas Temperature

The variation of exhaust gas temperature for diesel and Cotton seed biodiesel blends with brake power output is shown in Figure 4.3. The exhaust gas temperature was found to extend with increase in both the concentration of biodiesel within the mix and engine load. The exhaust gas temperature rises from 150°C to 350°C from no load to full load severally for varied test fuels. The rise in EGT with engine load is due to the actual fact that a more quantity of fuel is needed within the engine to get additional power required to take up conditional loading. Exhaust gas temperature for B-25 is highest. For the diesel oil the exhaust gas temperature is lowest as compared with the biodiesel blends. The exhaust gas temperature for the diesel is 320°C, where as for Cotton seed biodiesel blends B5, B10, B15, B20 and B25 are 324°C, 326°C, 330°C, 332°C and 340°C respectively.

4.2.1.4. Smoke Density

The variation of the smoke densities for diesel and Cotton seed biodiesel blends with power output is shown in Figure 4.4. The smoke
density will increase with the rise of engine load. For all loads the smoke density of the biodiesel blends was invariably on top of that of diesel oil. The smoke density will increase due to lean combustion and high ignition delay. The biodiesel mix has high viscousness, larger fuel droplet formation and reduces in fuel air combining rate. These are the factors concerned to extend the smoke density of biodiesel blends. The smoke density of the engine with diesel fuel is lower as compared with the Cottonseed biodiesel blends. The fuel mix B25 provides high smoke emission than all the other blends. The smoke density for the diesel is 0.67 Bosch, whereas for Cotton seed biodiesel blends B5, B10, B15, B20 and B25 are 0.675 Bosch, 0.68 Bosch, 0.691 Bosch, 0.7 Bosch and 0.72 Bosch respectively.

4.2.1.5. Hydrocarbon emissions (HC emissions)

The variation of HC (hydrocarbon) emission for diesel and Cotton seed biodiesel blends with brake power output is shown in Figure 4.5. The HC emissions rely on mixture strength i.e. amount of oxygen available. The HC emissions increases with increasing the load on the engine and reduce with increase in quantity of bio diesel in the mix. Lower heating worth of biodiesel leads to inject more quantities of fuel for a similar load condition. Compared to diesel, the oxygen content within the bio diesel is additional. More amount of biodiesel leads to more oxygen either inherent in fuel or present within the charge. This excess oxygen helps for better combustion fuel. So that the HC emissions of Cotton seed biodiesel blends are less than the diesel oil. It is found from the figure 4.5 that the decrease in hydro
carbon emissions with increase in Cotton seed biodiesel within the mix as compared with diesel oil. The HC emission for diesel oil is 76 ppm and for Cotton seed biodiesel blends B5, B10, B15, B20 and B25 are 75 ppm, 73 ppm, 72 ppm, 69 ppm and 68 ppm respectively.

4.2.1.6. Carbon monoxide Emissions (CO emissions)

The variation of CO emission for diesel and Cotton seed biodiesel blends with brake power output is illustrated in Figure 4.6. It has been found that the CO emissions are inflated with increase in engine load and reduce with the rise in amount of biodiesel within the blends. The lower CO emission of biodiesel blends compared to diesel oil is due to the presence of oxygen in biodiesel that helps in complete oxidization of fuel. The increase in the quantity biodiesel will increases the oxygen presence in the fuel, further this rich oxygen causes to reduce CO emission. The CO emission for diesel oil is 0.67% volume and for Cotton seed biodiesel blends B5, B10, B15, B20 and B25 are 0.65% volume, 0.64%, 0.6% volume, 0.615% volume and 0.6% volume.

4.2.1.7. Nitrogen oxide Emissions (NOx emission)

The variation of NOx emission for diesel and Cotton seed biodiesel blends with brake power output is illustrated in Figure 4.7. The NOx emission will increase with increase in load on the engine for each diesel and Cotton seed biodiesel blends. These higher NOx emissions could be due to the higher temperature within the combustion chamber at higher loads. The NOx emissions are slightly higher for Cottonseed biodiesel blends as compared with pure diesel.
The rise of NOx emissions could also be related to the oxygen content of the biodiesel, since the biodiesel fuel provided extra oxygen for NOx formation. This one amongst the most reason for the formation of higher NOx with the biodiesel blends as compared with pure diesel. The NOx emission for diesel oil is 690ppm and for Cotton seed biodiesel blends B5, B10, B15, B20 and B25 are 695 ppm, 695 ppm, 705 ppm, 710 ppm, and 720 ppm respectively.

**4.2.2 Performance and emission characteristics of Karanja biodiesel blended with diesel as fuel in CI engine**

Engine tests are conducted on the same diesel engine with diesel and Karanja biodiesel blends [B5, B10, B15, B20, and B25] for analyzing varied parameters like brake thermal potency, brake specific fuel consumption (BSFC), exhaust gas temperature, emissions of CO, HC, NOx and smoke density.

**4.2.2.1 Brake thermal potency**

The variation of brake thermal potency for diesel and Karanja biodiesel blends with brake power output is shown in figure 4.8. It is observed that the brake thermal potency will increases with increase in load on the engine for all fuel samples. It may be attributed to the reduction in heat loss and increase in power with increase in load on the engine. For all loading conditions diesel oil have higher brake thermal potency as compared with Karanja biodiesel blends. It is also observed that the brake thermal potency decreases with increase in quantity of Karanja biodiesel in blend. This is often due to higher viscousness and lower heat value of Karanja biodiesel. Higher
viscousness of the Karanja biodiesel causes to poor atomization, fuel vaporization and combustion. This might be the possible reason for reduction brake thermal potency. The Karanja biodiesel blend B25 being lowest brake thermal potency for all loads as compared with diesel fuel and Karanja biodiesel blends B5, B10, B15 and B20. The thermal potency of diesel is 29.18%, where as for Karanja biodiesel blends B5, B10, B15, B20 and B25 is 27.82% and for B25 are 28.98%, 28.64%, 28.33%, 27.82% and 26.86% respectively. It is also observed that the brake thermal potency of the engine with Karanja biodiesel blends is lower than the cottonseed biodiesel blends when compared at the same blend proportions.

4.2.2.2. Brake specific Fuel Consumption

The variation of brake specific fuel consumption (BSFC) for diesel and Karanja biodiesel blends with brake power is shown in Figure 4.9. It is found that the BSFC is reduced with increase in power output of the engine for all fuel samples. It’s also found that the brake specific fuel consumption of the engine with diesel oil is less than the Karanja biodiesel for all power outputs. This is often due to the actual fact that the Karanja biodiesel have lower heat worth compared with diesel and thus additional biodiesel is required to take same power output. The BSFC of diesel is 0.284 kg/kW-hr, where as for Karanja biodiesel blends B5, B10, B15, B20 and B25 is 0.31 kg/kW-hr, 0.314 kg/kW-hr, 0.317 kg/kW-hr, 0.323 kg/kW-hr and for 0.335 kg/kW-hr respectively. It is also found that the brake specific fuel consumption of Karanja biodiesel blends is higher than the
cottonseed biodiesel blends when compared at the same blend proportions.

4.2.2.3. Exhaust Gas Temperature

The variation of exhaust gas temperature for diesel and Karanja biodiesel blends with relation to the brake power is shown in Figure 4.10. It’s observed that the exhaust gas temperature is inflated with increase in engine load for all fuel samples tested. This increase in exhaust gas temperature with load is apparent from the easy proven fact that the additional quantity of fuel was needed to the engine to get the additional power required for the extra loading. In case of Karanja biodiesel blends it is found that the exhaust gas temperature increases with increase in concentration of biodiesel within the mix because the heat release might occur in later a part of the power stroke. Thus this might lead to higher exhaust gas temperature. The exhaust gas temperatures for the diesel are 320°C whereas for Karanja biodiesel blends B5, B10, B15, B20 and B25 is 324°C, 328°C, 332°C, 334°C and 346°C respectively. It is also observed that the exhaust gas temperature of Karanja biodiesel blends is higher than the cottonseed biodiesel blends.

4.2.2.4. Smoke Density

The variation of the smoke densities for diesel and Karanja biodiesel blends with power output is shown in Figure 4.11. The smoke density will increase with the rise of engine load for all fuel samples due to lean combustion. The smoke density of the Karanja biodiesel blends were invariably on top of that of diesel oil at all engine
loads. This is often due to the higher viscousness of Karanja biodiesel, the atomization of fuel becomes poor and this ends up in larger fuel droplets consequently sluggish combustion which ends higher smoke emission. The Karanja biodiesel mix B25 provides high smoke emission than all the other used fuel blends. The smoke density for the diesel are 0.67 Bosch where as for Karanja biodiesel blends B5, B10, B15, B20 and B25 is 0.68 Bosch, 0.7 Bosch, 0.71 Bosch, 0.74 Bosch and 0.74 Bosch respectively. It is also observed that the smoke density of Karanja biodiesel blends is higher than the cottonseed biodiesel blends.

4.2.2.5. Hydrocarbon emissions (HC emission)

The variation of HC emissions for diesel and Karanja biodiesel blends with brake power is shown in Figure 4.12. The HC emission of the engine with diesel oil is on top of the Karanja biodiesel blends. The reason for reduction in HC emission with Karanja biodiesel mix is higher oxygen content and high cetane number of biodiesel as compared with diesel. The oxygen present in the biodiesel helps to reduce the HC emission. The HC emission for diesel oil is 76ppm and for Karanja biodiesel blends B5, B10, B15, B20 and B25 is 75 ppm, 73 ppm, 72 ppm, 70 ppm, B20 is 70ppm and 69 ppm respectively. It is observed that the HC emissions of Karanja biodiesel blends are higher than the cottonseed biodiesel blends.

4.2.2.6. Carbon monoxide emissions (CO emissions)

The variation of monoxide emissions for diesel and Karanja biodiesel blends with brake power is illustrated in Figure 4.13. It has
been found that for all fuel samples the engine is emitting lower quantity of CO emission at lighter load levels and is giving additional emission at higher loading conditions. It’s going to be attributed to the actual fact that as engine loading is inflated, the surplus fuel is needed. CO emission decreases with increase in amount of biodiesel within the blends. The lower CO emission of biodiesel compared to diesel oil is due to the presence of additional oxygen in biodiesel that helps in complete oxidization of fuel. The CO emission for diesel oil is 0.67% volume, where as for Karanja biodiesel blends B5, B10, B15, B20 and B25 is 0.67% volume, 0.65% volume, 0.642% volume, 0.627% volume and 0.621% volume respectively. It is also found that the CO emissions of Karanja biodiesel blends are higher than the cottonseed biodiesel blends.

4.2.2.7. Nitrogen oxide Emission (NOx emission)

The variation of NOx emission for diesel and Karanja biodiesel blends with brake power output is illustrated in Figure 4.14. The NOx emission results from the oxidization of nitrogen at higher temperature within the combustion chamber of the engine. The NOx emissions are slightly higher for Karanja biodiesel blends as compared with diesel oil. The rise of NOx within the emissions could also be related to the oxygen content of the biodiesel, since the biodiesel fuel provided extra oxygen for NOx formation. The NOx emission for diesel oil is 690ppm and for Karanja biodiesel blends B5, B10, B15, B20 and B25 are 695 ppm, 705 ppm, 710 ppm, 715 ppm and 725 ppm.
respectively. The NOx emissions of Karanja biodiesel blends are higher than the cottonseed biodiesel blends.

4.2.3 Performance and emission characteristics of Mahua biodiesel blended with diesel as fuel in CI engine

Engine tests are conducted on the same diesel engine with diesel and Mahua biodiesel blends [B5, B10, B15, B20, and B25] for analyzing varied parameters like brake thermal potency, brake specific fuel consumption (BSFC), exhaust gas temperature, emissions of CO, HC, NOx and smoke density.

4.2.3.1 Brake thermal potency

The figure 4.15 shows the brake thermal potency for diesel and Mahua biodiesel blends against brake power output. The brake thermal potency increases with increase in load on the engine for all the fuel samples tested in the present work. It is observed that the sole diesel oil is displaying highest brake thermal potency at all the loads due to its higher hot worth as compared with Mahua biodiesel blends. With the higher hot worth the warmth made within the combustion chamber is additionally high, further the combustion and thermal potency are improved. It is also observed that the brake thermal potency of the engine decrease with increase in amount of Mahua biodiesel in mix. The factors like lower heating worth and higher viscousness of biodiesel might have an effect on the mixture formation and hence it ends up in slower combustion resulting in reduction of brake thermal potency. The thermal potency of diesel is 29.18\%, whereas for Mahua biodiesel blends B5, B10, B15, B20 and
B25 is 28.87%, 28.58%, 28%, 27.58% and 26.86 respectively. It is also observed that the brake thermal potency of the engine with Mahua biodiesel blends are lower than the cottonseed biodiesel blends and Karanja biodiesel blends when compared at the same blend proportions.

4.2.3.2. Brake specific Fuel Consumption

The variation of brake specific fuel consumption (BSFC) for diesel and Mahua biodiesel blends with brake power is shown in Figure 4.16. For all fuel samples it is found that the BSFC is reduced with increase in brake power. The brake specific fuel consumption of the engine with diesel oil is less than the Mahua biodiesel blends due to higher hot worth of the diesel fuel as compared with Mahua biodiesel. It’s additionally found that the brake specific fuel consumption will increases with increase in amount of Mahua biodiesel within the mix. The hot worth of Mahua biodiesel is a lower than the diesel, so that an additional fuel is needed for maintaining constant power output. The BSFC of engine with diesel is 0.284 kg/kW-hr, where as for Mahua biodiesel blends B5, B10, B15, B20 and B25 is 0.314 kg/kW-hr, 0.318 kg/kW-hr, 0.321 kg/kW-hr, 0.33 kg/kW-hr and 0.348 kg/kW-hr respectively. It is also found that the BSFC of Mahua biodiesel blends are higherer than the cottonseed biodiesel blends and Karanja biodiesel blends when compared at the same blend proportions.
4.2.3.3. Exhaust Gas Temperature

The variation of exhaust gas temperature for diesel and Mahua biodiesel blends with brake power is shown in Figure 4.17. The exhaust gas temperature is an indicative of quality of combustion in the combustion chamber. The exhaust gas temperature increases with increase in load on the engine. The exhaust gas temperature of the engine with pure diesel as fuel is less than the Mahua biodiesel blends. This is often due to the slower combustion of biodiesel due to high viscousness and poor volatility. The exhaust gas temperature of the engine with diesel is 320°C, whereas for Mahua biodiesel blends B5, B10, B15, B20 and B25 is 324°C, 328°C, 332°C, 336°C and 344°C respectively. The exhaust gas temperature of Mahua biodiesel blends are slightly higher than the cottonseed biodiesel blends and Karanja biodiesel blends when compared at the same blend proportions.

4.2.3.4. Smoke Density

The variation of the smoke densities for diesel and Mahua biodiesel blends with power output is shown in Figure 4.18. It’s observed that the smoke density will increases with the rise of engine load for diesel oil and mahau biodiesel blends. It is also found that the smoke density of the engine is increases with increase within the amount of Mahua biodiesel within the mix. The biodiesel has high viscousness as compared with diesel. With the high viscousness of biodiesel, fuel atomization poor, larger fuel droplets formation and reduce in fuel air combining rate. This ends up in slow combustion
consequently higher smoke emission at \( \frac{3}{4} \)th of rated load. It is also observed that the smoke density of Mahua biodiesel blends are slightly higher than the cottonseed biodiesel blends and Karanja biodiesel blends when compared at the same blend proportions.

4.2.3.5. Hydrocarbon emissions (HC emission)

The variation of HC emission for diesel and Mahua biodiesel blends with brake power is shown in Figure 4.19. The HC emission increases with increase in load on the engine for all fuel samples. There’s a major decrease in HC emission level with increase in amount Mahua biodiesel within the blends. This reduction indicates that better combustion of the fuel. The HC emission for diesel oil is 76ppm, for Mahua biodiesel B20 is 71ppm and for B25 it is 70ppm are literally severally at \( \frac{3}{4} \)th of rated load. The HC emissions of Mahua biodiesel blends are slightly higher than the cottonseed biodiesel blends and Karanja biodiesel blends when compared at the same blend proportions.

4.2.3.6. Carbon monoxide emissions (CO emissions)

The variation of carbon monoxide emission for diesel and Mahua biodiesel blends with brake power is illustrated in Figure 4.20. It has been observed that the CO emissions are inflated with increase in engine load for all fuel samples. The CO emission of the engine with diesel oil is on top of the biodiesel blends. The lower CO emission of biodiesel compared to diesel oil is due to the presence of oxygen in biodiesel that helps in complete oxidization of fuel. The surplus oxygen offered within the biodiesel converts the some of the
CO into carbon dioxide and thus the CO emission is reduced. The CO emission for diesel oil is 0.67% volume and for Mahua biodiesel blend B20 is 0.623% volume at ¾th of rated load. The CO emissions of Mahua biodiesel blends are slightly higher than the cottonseed biodiesel blends and Karanja biodiesel blends when compared at the same blend proportions.

4.2.3.7. Nitrogen oxide Emission (NOx emission)

The variation of nitrogen oxide emission for diesel and Mahua biodiesel blends with brake power output is illustrated in Figure 4.21. The NOx emissions are higher for Mahua biodiesel mix as compared with diesel oil. The rise of NOx emission could also be related to the oxygen content of the biodiesel, since the biodiesel fuel provided extra oxygen for NOx formation. The NOx emission for diesel oil is 690ppm and for Mahua biodiesel blends B20 is 720ppm at ¾th of rated load. The NOx emissions of Mahua biodiesel blends are slightly higher than the cottonseed biodiesel blends and Karanja biodiesel blends when compared at the same blend proportions.

4.2.4 Performance and emission characteristics of Neem biodiesel blends with diesel as fuel in CI engine

Engine tests are conducted on the same diesel engine with the blends of diesel and Neem biodiesel [B5, B10, B15, B20, and B25] for analyzing varied parameters like brake thermal potency, brake specific fuel consumption (BSFC), exhaust gas temperature, emissions of CO, HC, NOx and smoke density.
4.2.4.1 Brake thermal potency

The Figure 4.22 shows the variation of brake thermal potency for diesel and Neem biodiesel blends with brake power output. The diesel oil has the higher brake thermal potency compared to Neem biodiesel blends due to its high hot worth and low viscousness. A rise of brake thermal potency is found with increase in the engine load for all fuel samples. It is also found that the quantity of diesel within the mix is increased the thermal potency is also increases. The thermal potency of diesel is 29.18%, where as for Neem biodiesel blends B5, B10, B15, B20 and B25 is 28.85%, 28.54%, 28% 27.43% and 26.58% respectively. The thermal potency of the engine with Neem biodiesel blends is lower than the cottonseed biodiesel blends, Karanja biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.4.2. Brake specific Fuel Consumption

The variation of brake specific fuel consumption (BSFC) for diesel and Neem biodiesel blends with brake power for neat diesel and Neem biodiesel blends is shown in Figure 4.23. The BSFC is reduced with the load for all fuel blends. It’s found that the brake specific fuel consumption for the diesel oil is less than the biodiesel blends at all the due to higher hot worth of diesel. Higher proportions of Neem biodiesel within the blends will increases the viscousness of the fuel that successively inflated (increases) the brake specific fuel consumption due to poor atomization of the fuel. The oxygenated biodiesels might cause the lean combustion leading to higher BSFC.
The BSFC of diesel is 0.284 kg/kW-hr, whereas for Neem biodiesel blends B5, B10, B15, B20 and B25 is 0.316 kg/kW-hr, 0.319 kg/kW-hr, 0.322 kg/kW-hr, 0.332 kg/kW-hr and 0.341 kg/kW-hr respectively. The BSFC of the engine with Neem biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.4.3. Exhaust Gas Temperature

The variation of exhaust gas temperature for diesel and Neem biodiesel blends with brake power output is shown in Figure 4.24. The exhaust gas temperature for all fuel samples will increase with increase in load. This is often due to increase in the amount of fuel injected into the combustion chamber to produce additional power to take up increased engine load. So that the burning of more fuel causes to produce more heat in the combustion chamber which in turn the exhaust gas temperature rises. The exhaust gas temperature is also increases with increase in concentration of Neem biodiesel within the mix. The biodiesel contains additional oxygen that takes a part in the combustion. Up to B20 the exhaust gas temperature is lower. It reflects that the effective combustion is happening within the early stage of exhaust stroke and there’s saving in exhaust gas energy loss. Whereas the mix B25 has shown higher exhaust temperature, this is often indicating additional energy loss. The exhaust gas temperature for the diesel at the rated load is 320°C, for Neem biodiesel mix B20 is 338°C and for B25 it is 348°C. The exhaust gas
temperature of the engine with Neem biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.4.4. Smoke Density

The variation of the smoke densities for diesel and Neem biodiesel blends with power output is shown in Figure 4.25. The smoke density will increase with increase in load for all fuel samples. It is observed that the smoke density increases with increase in concentration of biodiesel within the mix. Due to the higher viscousness of Neem biodiesel the atomization of fuel becomes poor and this makes to form the fuel larger droplets in its size consequently sluggish combustion which ends in higher smoke emission. The smoke density of the engine with Neem biodiesel blends is slightly higher than the cottonseed biodiesel blends, Karanja biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.4.5. Hydrocarbon emissions (HC emission)

The variation of HC emission for diesel and Neem biodiesel blends with brake power is shown in Figure 4.26. The HC emission will increases with increase in load on the engine for all fuel samples and reduces with increase in quantity of Neem biodiesel in mix. The oxygen content within the biodiesels is more as compared with diesel. This excess oxygen helps to better combustion biodiesel blends within the combustion. So that the HC emissions are lower for biodiesel blends as compared with diesel fuel. The HC emission for diesel oil is
76 ppm and for Neem biodiesel blends B20 is 72 ppm and for B25 it is 70 ppm. The HC emissions of the engine with Neem biodiesel blends is slightly higher than the cottonseed biodiesel blends, Karanja biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.4.6. Carbon monoxide emissions (CO emissions)

The variation of monoxide emissions for diesel and Neem biodiesel blends with brake power output is illustrated in Figure 4.27. CO emissions are inflated linearly with increase in engine load for all test fuels. It’s found that the decrease of CO emission with the rise in proportion of Neem biodiesel within the blends. The simple reason for this reduction is that the carbon monoxide produced during the combustion of fuel might have converted into carbon dioxide by absorbing the additional oxygen molecule present within the biodiesel. The CO emission for diesel oil is 0.67% volume and for Neem biodiesel blends B20 is 0.62% volume and for blend B25 it is 0.612% volume. The CO emissions of the engine with Neem biodiesel blends is slightly higher than the cottonseed biodiesel blends, Karanja biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.4.7. Nitrogen oxide Emission (NOx emission)

The variation of nitrogen oxide emissions for diesel and Neem biodiesel blends with brake power output is illustrated in Figure 4.28. It’s found that the NOx emission will increase with increase in load for all fuel samples. In general the nitrogen is active at higher
temperatures. It is well known that the exhaust gas temperature increases with increase in load on the engine and thus the increase in temperature causes to emit more NOx. It’s also found that a rise in NOx emission with increase in amount of biodiesel in the blend. The rise of NOx emission could be related to the oxygen content of the biodiesel, since the biodiesel fuel provided extra oxygen for NOx formation. This is one amongst the most reasons for the formation of NOx. The NOx emission of diesel is 690 ppm, B20 is 725 ppm. The NOx emissions of the engine with Neem biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.5 Performance and emission characteristics of Jatropha biodiesel blended with diesel as fuel in CI engine

Engine tests are conducted on a single cylinder internal-combustion diesel engine with diesel and Jatropha biodiesel blends [B5, B10, B15, B20, and B25] for analyzing varied parameters like brake thermal potency, brake specific fuel consumption (BSFC), exhaust gas temperature, emissions of CO, HC, NOx and smoke density.

4.2.5.1 Brake thermal potency

The Figure 4.29 shows the variation of brake thermal potency for diesel and Jatropha biodiesel blends with brake power output. The brake thermal potency of an engine mainly depends on the calorific value of the fuel used. The brake thermal potency of the engine will
increase with increase in load on the engine for each diesel and Jatropha biodiesel mix with diesel as fuel. The brake thermal potency obtained with diesel oil is higher than the Jatropha biodiesel blends due to higher hot worth of diesel. As hot worth of Jatropha biodiesel is a smaller amount than the diesel, a rise in amount of biodiesel within the mix causes to decrease the brake thermal potency of the engine. The thermal potency of diesel fuel is 29.18%, where as for Jatropha biodiesel blends B5, B10, B15, B20 and B25 is 28.8%, 28.35%, 27.64% 27% and 26.43% respectively. The thermal potency of the engine with Jatropha biodiesel blends is lower than the cottonseed biodiesel blends, Neem biodiesel blends, Karanja biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.5.2. Brake specific Fuel Consumption

The variation of brake specific fuel consumption (BSFC) for diesel and Jatropha biodiesel blends with brake power is shown in Figure 4.30. The BSFC is reduced with the load for all fuel tested in this experimental work. It’s found that the brake specific fuel consumption of the engine is higher with Jatropha biodiesel blends as compared with diesel as fuel at all power outputs of the test engine. This is often due to poor mixture formation as a result of low volatility, higher viscousness and density of Jatropha biodiesel. The BSFC of diesel is 0.284 kg/kW-hr, where as for Jatropha biodiesel blends B5, B10, B15, B20 and B25 is 0.319 kg/kW-hr, 0.322 kg/kW-hr, 0.325 kg/kW-hr, 0.342 kg/kW-hr and 0.345 kg/kW-hr respectively. The
BSFC of the engine with Jatropha biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends, Neem biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

**4.2.5.3. Exhaust Gas Temperature**

The variation of exhaust gas temperature for diesel and Jatropha biodiesel blends with brake power is shown in Figure 4.31. The exhaust gas temperature was found to extend with increase in concentration of Jatropha biodiesel within the mix as compared with pure diesel. This is often due to the slow combustion of Jatropha biodiesel. The poor volatility and high viscousness of the fuel are the causes for this slow combustion. The exhaust gas temperature is also increases with increase in load on the engine for all fuel samples. An additional fuel is burnt to provide needed power with increase in engine load and so that the exhaust gas temperature will increases at ¾th of rated load. The exhaust gas temperature for the diesel at the rated load is 320°C, for Jatropha biodiesel mix B20 is 340°C and for B25 it is 350°C at ¾th of rated load. The exhaust gas temperature of the engine with Jatropha biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends, Neem biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

**4.2.5.4. Smoke Density**

The variation of the smoke densities for diesel and Jatropha biodiesel blends with power output is shown in Figure 4.32. It's
observed that the density of smoke will increase with the rise of engine load for all fuel samples. This is often principally due to the decrease in air fuel mixture ratio at higher loads, when a larger amount of fuel is injected into the combustion chamber a lot of that fuel emits as unburnt into the exhaust. The smoke density of the engine with Jatropha biodiesel mix will increase with increase in amount biodiesel within the blend. This is often due to heavier molecular structure and high viscousness of biodiesel that ends up in poor atomization of fuel ensuing higher smoke emission at ¾th of rated load. The smoke density of the engine with Jatropha biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends, Neem biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.5.5. Hydrocarbon emissions (HC emission)

The variation of HC emission for diesel and Jatropha biodiesel blends with brake power is shown in Figure 4.33. The HC emission will increases with increase in load on the engine for all fuel samples. The HC emissions with genus Jatropha biodiesel blends were lower as compared with normal diesel. The possible reason for this trend is the presence of excess oxygen within the biodiesel may leads to better combustion of fuel and causing to reduce HC emission. It’s also found from the figure 4.5 that the decrease in hydro carbon emissions with increase in Jatropha biodiesel within the mix as compared with diesel oil. The HC emission for diesel oil is 76ppm and for Jatropha biodiesel blend B20 is 71ppm and for B25 it is 70ppm. The HC emissions of the
engine with Jatropha biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends, Neem biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.5.6. Carbon monoxide emissions (CO emissions)

The variation of CO emission for diesel and Jatropha biodiesel blends with brake power is illustrated in Figure 4.34. It has been identified that the engine emits additional CO with diesel fuel as compared with Jatropha biodiesel blends. The lower CO emission of biodiesel compared to diesel fuel is due to the presence of oxygen in biodiesel that helps in complete oxidization of fuel. The CO emission for diesel oil is 0.67% volume, for Jatropha biodiesel blends B20 is 0.617% volume and for B25 it is 0.6 at ¾th of rated load. The CO emissions of the engine with Jatropha biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends, Neem biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.5.7. Nitrogen oxide Emission (NOx emission)

The variation of oxide emissions for diesel and Jatropha biodiesel blends with brake power output is illustrated in Figure 4.36. The NOx emission increases with increase in load on the engine for all the fuel tested. The NOx emissions are higher for Jatropha biodiesel blends as compared with pure diesel. The NOx emission is directly associated with the engine combustion chamber temperatures, that intern indicated by the prevailing exhaust gas temperature could also
be attributed to the actual fact that the biodiesel had some oxygen content in it that expedited NOx formation. The NOx emission for diesel oil is 690 ppm and for Jatropha biodiesel blend B20 is 730 ppm. The NOx emissions of the engine with Jatropha biodiesel blends is higher than the cottonseed biodiesel blends, Karanja biodiesel blends, Neem biodiesel blends and Mahua biodiesel blends when compared at the same blend proportions.

4.2.6 Optimization of biodiesel blend

Optimum biodiesel mix concentration is determined with the supported parameters like Brake thermal potency, BSFC, smoke density, CO, HC and NOx emissions. Based on above investigations for all biodiesels it’s identified that the biodiesel mix B20 is the optimum mix in terms of fuel economy and emissions that are shown in Figures 4.36 to 4.42.

4.2.7 Best Biodiesel among the various fuels tested

The best biodiesel among the fuels tested in the present experimental work is determined with the parameters like Brake thermal potency, BSFC, smoke density, CO, UBHC and NOx emissions. Based on the above investigations it's found that among all the biodiesels tested the Cotton seed biodiesel is showing better performance and emission characteristics that are shown in Figures 4.36 to 4.42.

4.2.8. Conclusions of 1st stage investigations

The following conclusions are drawn based on above experimental results of the first stage of investigation:
1. The brake thermal potency of the engine depends majorly on the calorific value and viscousness of the fuel. The brake thermal potency of engine with diesel oil is on top of the biodiesel blends. The brake thermal potency of the mix B20 of all biodiesels is nearer to the diesel oil and Cotton seed biodiesel blends are showing better performance among all biodiesels tested.

2. Brake specific fuel consumption of the engine with biodiesel blends is on top of diesel oil. This is often due to lower heating worth and higher fuel flow rate due to high density of biodiesel.

3. The exhaust gas temperature of the engine with biodiesel blends is on top of diesel oil. This is often due to slow combustion and higher fuel flow rate due to high density of biodiesel.

4. The hydrocarbon emissions of all biodiesel blends are less than the diesel fuel.

5. The CO emissions are lower for biodiesel blends due to the presence of gas.

6. The NOx emissions increase with increase in concentration biodiesel in mix due to high exhaust gas temperature.

7. The smoke density increase with increase in concentration biodiesel in mix due to high viscosity of biodiesel.

Finally it is concluded that the bio diesel mix– B20 is the optimum blend for Diesel engines for better performance and emissions. Among all the biodiesels tested the Cotton seed biodiesel is showing better performance and emission characteristics.
Hence the Cotton seed biodiesel mix B20 is employed for further investigations.

Figure 4.1: Variation of Brake thermal Efficiency with power output for diesel and Cotton seed biodiesel blends.

Figure 4.2: Variation of Brake specific fuel consumption with power output for diesel and Cotton seed biodiesel blends.
Figure 4.3: Variation of Exhaust gas temperature with power output for diesel and Cotton seed biodiesel blends.

Figure 4.4: Variation of Smoke density with power output for diesel and Cotton seed biodiesel blends.
Figure 4.5: Variation of HC emission with power output for diesel and Cotton seed biodiesel blends.

Figure 4.6: Variation of CO emission with power output for diesel and Cotton seed biodiesel blends.
Figure 4.7: Variation of NOx emission with power output for diesel and Cotton seed biodiesel blends.

Figure 4.8: Variation of Brake thermal Efficiency with power output for diesel and Karanja biodiesel blends.
Figure 4.9: Variation of Brake specific fuel consumption with power output for diesel and Karanja biodiesel blends.

Figure 4.10: Variation of Exhaust gas temperature with power output for diesel and Karanja biodiesel blends.
Figure 4.11: Variation of Smoke density with power output for diesel and Karanja biodiesel blends.

Figure 4.12: Variation of HC emission with power output for diesel and Karanja biodiesel blends.
Figure 4.13: Variation of CO emission with power output for diesel and Karanja biodiesel blends.

Figure 4.14: Variation of NOx emission with power output for diesel and Karanja biodiesel blends.
Figure 4.15: Variation of Brake thermal Efficiency with power output for diesel and Mahua biodiesel blends.

Figure 4.16: Variation of Brake specific fuel consumption with power output for diesel and Mahua biodiesel blends.
Figure 4.17: Variation of Exhaust gas temperature with power output for diesel and Mahua biodiesel blends.

Figure 4.18: Variation of Smoke density with power output for diesel and Mahua biodiesel blends.
Figure 4.19: Variation of HC emission with power output for diesel and Mahua biodiesel blends.

Figure 4.20: Variation of CO emission with power output for diesel and Mahua biodiesel blends.
Figure 4.21: Variation of NOx emission with power output for diesel and Mahua biodiesel blends.

Figure 4.22: Variation of Brake thermal Efficiency with power output for diesel and Neem biodiesel blends.
Figure 4.23: Variation of Brake specific fuel consumption with power output for diesel and Neem biodiesel blends.

Figure 4.24: Variation of Exhaust gas temperature with power output for diesel and Neem biodiesel blends.
Figure 4.25: Variation of Smoke density with power output for diesel and Neem biodiesel blends.

Figure 4.26: Variation of HC emission with power output for diesel and Neem biodiesel blends.
Figure 4.27: Variation of CO emission with power output for diesel and Neem biodiesel blends.

Figure 4.28: Variation of NOx emission with power output for diesel and Neem biodiesel blends.
Figure 4.29: Variation of Brake thermal Efficiency with power output for diesel and Jatropha biodiesel blends.

Figure 4.30: Variation of Brake specific fuel consumption with power output for diesel and Jatropha biodiesel blends.
Figure 4.31: Variation of Exhaust gas temperature with power output for diesel and Jatropha biodiesel blends.

Figure 4.32: Variation of Smoke density with power output for diesel and Jatropha biodiesel blends.
Figure 4.33: Variation of HC emission with power output for diesel and Jatropha biodiesel blends.

Figure 4.34: Variation of CO emission with power output for diesel and Jatropha biodiesel blends.
Figure 4.35: Variation of NOx emission with power output for diesel and Jatropha biodiesel blends.

Figure 4.36: Variation of Brake thermal Efficiency with power output for diesel and biodiesel blends (B20).
Figure 4.37: Variation of Brake specific fuel consumption with power output for diesel and biodiesel blends (B20).

Figure 4.38: Variation of Exhaust gas temperature with power output for diesel and biodiesel blends (B20).
Figure 4.39: Variation of Smoke density with power output for diesel and biodiesel blends (B20).

Figure 4.40: Variation of HC emission with power output for diesel and biodiesel blends (B20).
Figure 4.41: Variation of CO emission with power output for diesel and biodiesel blends (B20).

Figure 4.42: Variation of NOx emission with power output for diesel and biodiesel blends (B20).
4.3. Second stage investigations

In second stage of investigations air gap insulated piston engine is developed and experiments were conducted by varied the air gap between piston crown and skirt from 1 mm to 2.5 mm. The aim of insulating the piston is to cut back (reduce) the rate of heat transfer from the piston crown to skirt as much as possible. Further, the insulated piston is to be like standard piston with relation to dimensions. Thus in the present work the piston with air-gap insulation is employed.

4.3.1. Performance and emission characteristics of Cotton seed biodiesel blend (B20) as fuel in air gap insulated piston engine

Performance tests are conducted on a air gap insulated piston engine with Cotton seed biodiesel mix [B20] for analyzing varied parameters like brake thermal potency, brake specific fuel consumption (BSFC), exhaust gas temperature, emissions of CO, HC, NOx and smoke density.

4.3.1.1 Brake thermal potency

The variation of brake thermal potency with power output for various air gaps between crown and skirt is illustrated in figure 4.43. The thermal potency depends on the amount of heat produced in the combustion chamber of the engine. It is also depends on the mixture strength and amount of heat given to the fresh charge before combustion. If the fresh charge is preheated before the combustion, it makes the fuel vaporization faster, further the fuel will undergo better combustion and the thermal efficiency can be increased. The air gap
between piston crown and skirt acts as a nonconductor (insulator) to the heat and that heat will be given to the incoming charge for the combustion. This heat transfer to the fresh charge will increases with the air gap up to 2 mm and thereafter it'll decrease. This is often due to reduction within the material thickness between crown center and skirt. It is also observed that the brake thermal efficiency of air gap insulated piston engine will increases with the load for all air gaps. The thermal potency of the engine with Cotton seed biodiesel mix B20 at a 2 mm air gap is 30.6% and for at one mm air gap it's 28.64%. The thermal efficiencies at 1.5 mm and 2.5 mm (29.37% and 29.69%) are in between the efficiencies of one mm and 2mm.

4.3.1.2. Brake specific Fuel Consumption

The figure 4.44 illustrates the variation of the brake specific fuel consumption (BSFC) with power output of air gap insulated piston engine. The BSFC will decreases with increase in load on the engine for all air gaps. The brake specific fuel consumption principally depends upon the consistent mixture formation and complete combustion of the fuel. Due to the high viscousness of Cotton seed biodiesel it needs higher temperatures for the fuel evaporation within the chamber. With the better vaporization of the fuel, the charge becomes homogeneous and the combustion of fuel can be improved. Due to the air insulation between crown and skirt the temperature within the combustion chamber will increase up to 2 mm air gap and afterward it decreases due to the reduction within the piston crown material thickness and that permits the heat to the skirt. The brake
specific fuel consumption for 1 mm, 1.5 mm, 2 mm and 2.5 mm air gaps is 0.316 kg/kW.hr, 0.302 kg/kW.hr, 0.292 kg/kW.hr and 0.3 kg/kW.hr respectively. The BSFC of all other air-gaps are higher than the 2 mm air gap piston engine.

4.3.1.3. Exhaust Gas Temperature

The variation of exhaust gas temperatures with power output of air gap insulated piston engine is illustrated within the figure 4.45. The exhaust gas temperature of the engine depends on the combustion quality and viscousness of the fuel injected. Further the combustion efficiency depends on the evaporation rate of the fuel and mixture strength. Due to the high viscousness the biodiesel the evaporation will increase with increase in the combustion chamber temperature. In the air gap insulated piston the air acts as a nonconductor for the heat transfer and retains the heat. This heat helps for better vaporization of the fuel (Cotton seed biodiesel blend B-20) and improved combustion. Thus the air gap insulated piston engine improves the combustion characteristics with reduced heat losses. Hence the thermal potency of the engine increases and exhaust gas temperature reduces. The exhaust gas temperatures of Cotton seed biodiesel blend B20 as fuel and with 1 mm air gap piston is 332°C and 2 mm air gap it’s 324°C. The exhaust temperatures at the remaining air gaps are in between these two.

4.3.1.4. Smoke Density

Figure 4.46 shows the variation of smoke densities with the power output of air gap insulated piston engine. The blending of the
fuel with the air within the compression ignition engine is varied from region to region of the combustion chamber. The smoke emission in the engine is due to the un-burnt liquid particles of fuel or lubricating oil and it creates partial combustion. The smoke and soot formation on the chamber walls is due to the partial burning of the fuel droplets within the chamber. With the rise in the load of the engine the additional quantity of fuel is injected in to the combustion chamber and will increase the unburned fuel droplets on the chamber walls. This is often within the rich regions of the combustion chamber. As the Cotton seed biodiesel consists of inherent oxygen, it's distributed throughout the combustion chamber and enhances the combustion efficiency and reduces the smoke formation. Though the additional oxygen is available at higher loads the time offered for the atomization of fuel is a smaller, further the fuel droplets are larger in size and increases the smoke densities. This smoke formation may be reduced with the enhanced combustion of the fuel by maintaining the higher temperatures within the chamber. With the air gap insulated piston engine the temperatures within the combustion chamber will increase with the air gap and therefore the smoke emissions is reduced. The smoke emission for two mm air gap is 0.68 Bosch. The smoke emissions at the remaining air gaps 1 mm, 1.5 mm and 2.5 mm are slightly higher than 2 mm air gap piston.

4.3.1.5. Hydrocarbon emissions (HC emission)

The variation hydrocarbon emission with power output of air gap insulated piston engine is illustrated in figure 4.47. The
hydrocarbon emission principally depends on the fuel atomization and presence of oxygen for the combustion. Further the improper burning of the fuel and lubricating oil are the other reasons for the emissions. It’s observed that at lesser loads less fuel will be injected and therefore the available oxygen makes the charge rich and it enhances the combustion and reduces the emissions. These emissions can be reduced with the high temperatures within the combustion chamber. In this work the combustion chamber temperature increases with the air insulation between crown and skirt of the piston. Thus the better atomization of the fuel and improved combustion with air gap insulated piston will reduces the HC emission. The HC emission for two mm air gap is 67 ppm. The emissions for the remaining air gaps 1 mm, 1.5 mm and 2.5 mm are slightly higher than two mm air gap piston.

4.3.1.6. Carbon monoxide Emissions (CO emissions)

The figure 4.48 shows the variation of CO emission with power output of air gap insulated piston engine. With the higher temperatures within the Air gap insulated engine the combustion of fuel is improved and further the oxidization of carbon monoxide is additionally improved. Hence the CO emission within the exhaust drops drastically. At the lower loads the quantity of fuel injected into the engine cylinder is also low. The available oxygen in the mixture helps for the combustion and, further it causes to reduce CO emission. As the load is inflated then the fuel injected in to the combustion chamber will be increases and consequently CO
emissions are also inflated. These emissions are reduced with the high temperatures within the chamber due to the air gap insulation in the piston and also the inherent oxygen available within the Cotton seed biodiesel which helps for better oxidation of fuel. Hence the CO is converts into CO$_2$. The CO emission for the two mm air gap is 0.61 % vol. The emissions for 1 mm, 1.5 mm and 2.5 mm air gap are slightly higher than 2 mm air gap piston.

4.3.1.7. Nitrogen oxide emissions (NOx emission)

The variation of nitrogen oxide emission with power output of air gap insulated piston engine is illustrated in figure 4.49. Normally the NOx is inactive at the inferior temperature and is dynamic at the elevated temperatures of the combustion chamber. This is often attentive to the oxygen content within the biodiesel and reacts therewith at higher temperature and forms NOx emissions. At lower loads the NOx emission is lower due to lower exhaust temperature of the engine. However at higher the combustion chamber temperature will increases and therefore the formation of NOx will also increases. This is further increased by the oxygen available within the Cotton seed biodiesel. In case of air gap insulated piston engine due to improved combustion characteristics the increase in NOx emission is very little. The NOx emission for two mm air gap is 712 ppm. The NOx emissions are slightly higher at 1 mm, 1.5 mm and 2.5 mm air gap than 2 mm air gap piston.
4.3.2 Best air gap for the piston

The best air gap between piston crown and skirt is determined with the performance parameters like Brake thermal potency, BSFC, smoke density, CO, HC and NOx emissions. Based on second stage of investigations it’s observed that the 2 mm air gap between piston crown and skirt is showing higher performance and emission characteristics than the other air gaps used. Further it is also observed from the Figures from 4.43 to 4.49.

4.3.3 Conclusions of second stage investigations

The following conclusions are drawn based on the second stage of experimental investigations:

1. With the air insulation between piston crown and skirt the heat loss through the piston will decreases and heat within the combustion chamber will increase. This further enhances the brake thermal potency of the engine.

2. The BSFC of the air gap insulated engine is reduced as compared with normal diesel engine with cotton seed biodiesel blend B20 as fuel.

3. The exhaust gas temperature and smoke density are reduces as compared with normal diesel engine with cotton seed biodiesel blend B20 as fuel.

4. The HC and CO emissions are less with the air gap insulated piston engine due to the entire combustion of the fuel with elevated temperatures within the combustion chamber.
5. With the elevated temperatures within the combustion chamber and presence of inherent oxygen within the Cotton seed oil the NOx emissions is inflated.

It is concluded that out of the various air gaps between piston crown and skirt tested during this work, a 2 mm air gap is best for the Cotton seed biodiesel mix B20 in terms of thermal potency and emissions.

**Hence 2 mm air gap insulated piston and Cotton seed biodiesel mix B20 is employed for next stage of experimental investigations.**
Figure 4.43: Variation of Brake thermal Efficiency with power output for air gap insulated piston engine with Cottonseed biodiesel blend (B20) as fuel.

Figure 4.44: Variation of Brake specific fuel consumption with power output for air gap insulated piston engine with Cottonseed biodiesel blend (B20) as fuel.
Figure 4.45: Variation of Exhaust gas temperature with power output for air gap insulated piston engine with Cottonseed biodiesel blend (B20) as fuel.

Figure 4.46: Variation of Smoke density with power output for air gap insulated piston engine with Cottonseed biodiesel blend (B20) as fuel.
Figure 4.47: Variation of HC emission with power output for air gap insulated piston engine with Cottonseed biodiesel blend (B20) as fuel.

Figure 4.48: Variation of CO emission with power output for air gap insulated piston engine with Cottonseed biodiesel blend (B20) as fuel.
Figure 4.49: Variation of NOx emission with power output for air gap insulated piston engine with Cottonseed biodiesel blend (B20) as fuel.

4.4 Third stage investigations

In the third stage of experimental work three heat barrier piston crowns are designed with whole completely different materials like cast iron, Copper and Brass to cut back the heat losses. The results were compared with the conventional engine. The aim of the current work is to carry the heat of combustion along with the crown and to provides the same heat to the incoming charge throughout the suction and also during compression strokes of consecutive cycle. This preheats the intake air, improves the combustion potency and further the brake thermal potency is enhanced.
4.4.1 Performance and emission characteristics of Cotton seed biodiesel blend (B20) as fuel in air gap (2 mm) insulated piston engine with thermal barrier piston crown

Tests are conducted on a air gap (2 mm) insulated piston engine with completely different crown material and Cotton seed biodiesel mix [B20] as a fuel, for analyzing varied parameters like brake thermal potency, brake specific fuel consumption (BSFC), exhaust gas temperature, emissions of CO, HC, NOx and smoke density.

4.4.1.1. Brake thermal potency

The variation of brake thermal potency with brake power output of air gap (2 mm) insulated piston engine with completely different piston crowns is shown figure 4.50. The brake thermal potency of air gap (2 mm) insulated piston engine with brass piston crown is on top of the other two piston crown materials. Due to the lower thermal conductivity phenomenon of brass it retains the heat produced within the combustion chamber and provides it back to incoming fresh air in suction stroke. This hot air helps in higher vaporization of Cotton seed biodiesel mix B20 and combustion is improved. Better vaporization and quicker combustion of the fuel causes to extend the brake thermal potency of the engine. The brake thermal potency of air gap (2 mm) insulated piston engine with Cotton seed biodiesel mix B20 as fuel and brass piston crown is 33.15%, copper piston crown is 31.49%, cast iron piston crown is 30.48%. The thermal potency of air gap (2 mm) insulated piston engine with brass piston crown is higher than the other piston crowns used.
4.4.1.2. Brake specific Fuel Consumption

The variation of brake specific fuel consumption with brake power output of air gap (2 mm) insulated piston engine with completely different piston crown materials is illustrated in figure 4.51. The brake specific fuel consumption of air gap (2 mm) insulated piston engine with brass piston crown is less than the other piston crown materials. As the brass crown piston acts as heat reservoir, the warmth within the combustion chamber will increase and the combustion potency is improved. The rise in combustion potency provides fuel economy. The brake specific fuel consumption of air gap (2 mm) insulated piston engine with Cotton seed biodiesel mix B20 as fuel and brass piston crown is 0.28 kg/kW.hr, copper piston crown is 0.289 kg/kW.hr, and cast iron piston crown is 0.291 kg/kW.hr. The brass crown piston acts as a good heat reservoir, with its better thermal properties. This will increase the temperature of the incoming air and any the combustion potency. Hence it is observed that the brake specific fuel consumption of air gap (2 mm) insulated piston engine with Cotton seed biodiesel mix B20 as fuel and brass piston crown is slightly lower than the other piston crowns used.

4.4.1.3. Exhaust Gas Temperature

The variation of exhaust gas temperature with brake power of air gap (2 mm) insulated piston engine with differing types of piston crown materials is illustrated in figure 4.52. The exhaust gas temperature will increase with increase in load on the engine. It’s found that the exhaust gas temperature of air gap (2 mm) insulated
piston engine with brass piston crown is less than the other piston crown materials. This decrease in exhaust gas temperature is due the reduction in ignition delay within the hot surroundings of combustion chamber with the provision of insulation by the piston crown, which causes the gases to expand within the cylinder giving higher work output and lower heat exhaust. The exhaust gas temperature of air gap (2 mm) insulated piston engine with Cotton seed biodiesel mix B20 as fuel and brass piston crown is 323°C. The EGT of copper and cast iron piston crowns are slightly higher than brass piston crown.

### 4.4.1.4. Smoke Density

The variation of smoke density with brake power output of air gap (2 mm) insulated piston engine with different piston crown materials is illustrated in figure 4.53. It is observed that the smoke density of air gap (2 mm) insulated piston engine with brass piston crown and Cottonseed biodiesel mix B20 as fuel is nearer to the conventional internal-combustion engine with pure diesel and slightly less than the other piston crowns. The decrease in smoke density is due to improved combustion with inflated heat within the chamber. The smoke density of air gap (2 mm) insulated piston engine with Cotton seed biodiesel mix B20 as fuel and brass piston crown is 0.66 Bosch, copper piston crown is 0.672 Bosch and cast iron piston crown is 0.696 Bosch.

### 4.4.1.5. Hydrocarbon emissions (HC emission)

The variation of HC emission with brake power output of air gap (2 mm) insulated piston engine with different piston crown materials
is illustrated in figure 4.54. It's observed that the HC emission will increase with increase in load on the engine for all piston crown materials utilized in the current work. HC emission of air gap (2 mm) insulated piston engine with brass piston crown is less than the other piston crown materials. This decrease in HC emission could be due to increase in heat within the combustion chamber as a result of better insulation by brass due to its low thermal conductivity phenomenon. The HC emission of air gap (2 mm) insulated piston engine with Cotton seed biodiesel mix B20 as fuel and brass piston crown is 65 ppm. The HC emissions of copper and cast iron piston crowns are slightly higher than brass piston crown.

4.4.1.6. Carbon monoxide Emissions (CO emissions)

The variation of CO emission with brake power output of air gap (2 mm) insulated piston engine with different types of piston crown materials is illustrated in figure 4.55. The CO emission of air gap (2 mm) insulated piston engine with brass piston crown is less than the other piston crown materials. It's well known fact that the better fuel combustion ends up in lower CO emission. The rise in heat within the combustion chamber helps in higher evaporation, quicker combustion of fuel injected into the combustion chamber and thereby lower CO emission. The CO emission of air gap (2 mm) insulated piston engine with Cotton seed biodiesel mix B20 as fuel and brass piston crown is 0.59% volume. The CO emissions of copper and cast iron piston crowns are slightly higher than brass piston crown.
4.4.1.7 Nitrogen oxide emissions (NOx emission)

The variation of NOx emission with brake power output of air gap (2 mm) insulated piston engine with completely different piston crown materials is shown in figure 4.56. The formation of NOx depends on the heat available in the combustion chamber. The air gap insulation in the piston as well the brass piston crown reduces the heat losses through the piston and increases the evaporation rate of the fuel. This will improves the combustion process and causes to increase in NOx emission. NOx emission is also increases as a result of the supply of additional oxygen with Cotton seed biodiesel. So the rise in NOx emissions with brass crown piston is extra and with cast iron piston crown it is marginal compared to normal diesel engine. The NOx emission with brass crown piston is 718 ppm. The NOx emissions of copper and cast iron piston crowns are slightly lower than brass piston crown.

4.4.2 Choice of Best piston crown

The best piston crown is determined with the performance parameters like Brake thermal potency, BSFC, smoke density, CO, HC and NOx emissions. Based on third stage of investigations it’s observed that the brass piston crown is showing better performance and emission characteristics than the other piston crowns used. Further it is also observed from the Figures from 4.50 to 4.56.

4.4.3 Conclusions of third stage investigations

The following conclusions are drawn based on the experimental results of the third stage of investigation work:
1. With the lower thermal conductivity phenomenon of brass material compared to other crown materials the brass piston crown acts as a good nonconductor for the heat transfer. This retains the warmth within the chamber and makes the combustion better. The brake thermal potency of brass material is 3.34 % more than the normal diesel engine.

2. The BSFC of an air gap (2mm) insulated piston engine with brass piston crown is lower as compared with other piston crown materials used in this work.

3. The exhaust gas temperature of an air gap (2mm) insulated piston engine with brass crown piston is marginally lower as compared with other piston crowns.

4. Due to the higher prevailing operation temperatures among the air gap insulated combustion chamber with brass piston, the combustion is improved and therefore the smoke density is reduced.

5. At the 3/4th of rated load the HC emission with brass crown piston is lower as compared with other piston crowns.

6. The CO emission for the brass crown piston is found to be reduced as compared to other piston crowns. This is often attributed to the upper temperatures within the chamber with air gap insulation and brass piston crown.

7. The NOx emission with brass crown piston is slightly higher as compared to other piston crowns at the 3/4th of rated load.
Due to brass properties, the brass piston acts as a sensible heat regenerator that may increase the heat transfer between hot gases and piston crown. It’s concluded that out of four completely different piston crowns tested at air gap (2mm) insulation to the piston with Cotton seed biodiesel blend (B20) as fuel, the brass crown piston is a best crown in all aspects.

Figure 4.50: Variation of Brake thermal Efficiency with power output for air gap insulated piston engine with different piston crowns and Cottonseed biodiesel blend (B20) as fuel.
Figure 4.51: Variation of Brake specific fuel consumption with power output for air gap insulated piston engine with different piston crowns and Cottonseed biodiesel blend (B20) as fuel.

Figure 4.52: Variation of Exhaust gas temperature with power output for air gap insulated piston engine with different piston crowns and Cottonseed biodiesel blend (B20) as fuel.
Figure 4.53: Variation of Smoke density with power output for air gap insulated piston engine with different piston crowns and Cottonseed biodiesel blend (B20) as fuel.

Figure 4.54: Variation of HC emission with power output for air gap insulated piston engine with different piston crowns and Cottonseed biodiesel blend (B20) as fuel.
Figure 4.55: Variation of CO emission with power output for air gap insulated piston engine with different piston crowns and Cottonseed biodiesel blend (B20) as fuel.

Figure 4.56: Variation of NOx emission with power output for air gap insulated piston engine with different piston crowns and Cottonseed biodiesel blend (B20) as fuel.