CHAPTER – 6

RESULTS AND DISCUSSION

Detailed experiments have been carried out as discussed in the chapter 4. This chapter presents the analysis of the experimental data obtained to characterize the fuel properties of cotton seed oil and cotton seed oil-diesel blends, Palm oil and Palm oil-diesel blends and Neem oil and Neem oil-diesel blends. The performance of the engine with these fuels is also analyzed.

6.1 Experimental Data Analysis

The Viscosity of the diesel, cotton seed oil and cottonseed oil-diesel blends is measured using Redwood Viscometer No.1 as presented in Appendix Tables A-1 to A-3 which show the viscosity values of diesel, cottonseed oil and cotton seed oil-diesel blends.

From the viscosity measurement experiments, it is found that viscosity of pure Palm oil is around 10 times more than that of pure diesel at room temperature. The viscosity of blends gradually decreases with increase in proportions of diesel. At 50-50 blend the viscosity is 5 times that of pure diesel at room temperature.

6.2 Flash and Fire point

The flash and fire points of Diesel found by Abel’s Apparatus. The flash and fire points of Cottonseed oil, Palm oil and Neem oil are found by using Clevelands’s Apparatus. The Values are shown in Appendix Table A-4.

From the flash and fire point experiments, it is observed that
the flash and fire points of Cotton seed oil and Palm oil are much higher than the corresponding values of diesel.

6.3 Calorific Values

The Calorific values of diesel, Cotton seed oil and Palm oil, Neem oil are measured using Bomb calorimeter. From the calorific value measurement experiment, it is found that the C.V. of Cotton seed oil and Palm oil is 39.47MJ/kg and 37.20MJ/kg, and Neem Oil 39.50MJ/Kg which is slightly less than the C.V. of diesel, 45.52 MJ/kg. This suggests that Palm oil and Cotton seed oil can be used in a diesel engine without much change.

From the performance test of 25% diesel & 75% Cotton seed oil blend it is observed that the brake thermal efficiency is almost identical with that of pure diesel operation throughout the entire range of power output. The exhaust gas temperature and smoke level are near to that of diesel engine operation. It is observed that 225 Kg/cm\(^2\) is the optimum injection pressure for better performance. The value of S.F.C is also nearer to the diesel performance value.

It is observed that at lower power outputs 225 Kg/cm\(^2\) is the optimum injection pressures but at higher outputs, there is no improvement. This is because, preheating is not employed, and Spray characteristics are improved by increasing the injection pressures.

6.4 Performance of the C.I. Engine

The properties of the fuel blends such as 25C75D, 50C50D, 25P75D, 50P50D, 25N75D, 50N50D are obtained from the standard
laboratory facilities of Southern ONLINE Bio-Technologies Limited. The above said company is situated in Narayanpur samsthan, Choutuppal, Nalgonda, Andhra Pradesh. The problem of high viscosity of vegetable oils has been approached in several ways, such as preheating the oils, blending or dilution with other fuels, transesterification and thermal cracking/pyrolysis. In the present work, blending of the vegetable oils with diesel is chosen to be the method to reduce the viscosity of oils.

6.4.1 Engine test

Experiments using pure diesel oil, blends of cottonseed oil and diesel; 25C75D, 50C50D by volume, blends of palm oil and diesel;
25P75P, 50P50D by volume, blends of Neem oil and diesel; 25N75D, 50N50D by volume at different injection pressures have been conducted on constant speed Kirloskar engine whose specifications are shown in Appendix-A-1. A hydraulic dynamometer is used for loading the engine. The experimental set-up diagram is shown in chapter -3.

**Fig: 6.5** Brake thermal efficiency of the engine using different blended fuels under various operating conditions at injection pressure 200 kg/cm²

**Fig: 6.6** Brake specific fuel consumption of the engine using different blended fuels under various operating conditions at injection pressure 200 kg/cm²
Fig: 6.7 Brake thermal efficiency of the engine using different blended fuels under various operating conditions at injection pressure 225 kg/cm$^2$

Fig: 6.8 Brake specific fuel consumption of the engine using different blended fuels under various operating conditions at injection pressure 225 kg/cm$^2$

Fig: 6.9 Brake thermal efficiency of the engine using different blended fuels under various operating conditions at injection pressure 250 kg/cm$^2$
10 Brake specific fuel consumption of the engine using different blended fuels under various operating conditions at injection pressure 250 kg/cm²

6.4.2 Effect of brake power on brake thermal efficiency

The variation of brake thermal efficiency of the engine between 25N75D, 25C75D, 25P75D & 50N50D, 50C50D, 50P50D blends and diesel at various injection pressures of 200, 225 and 250Kg/cm² is shown in Fig. 6.5, 6.7 and 6.9. From the test results it is observed that initially with increasing brake power, the brake thermal efficiencies of various blends and diesel are increased and the maximum thermal efficiencies are obtained at brake power of 3.0189 kW and then tended to decrease with the further increase in brake power. The brake thermal efficiencies of various blends are lower than that with the diesel fuel throughout the entire range. The maximum values of brake thermal efficiencies with 25N75D, 25C75D, 25P75D are observed as 24.175%, 22.41%, and 22.42% respectively at injection pressure of 225 kg/cm². Corresponding maximum brake thermal efficiencies of 22.74%, 21.95%, and 23.28% are observed with 50N50D, 50C50D, 50P50D at injection pressure of 225 kg/cm².
6.4.3 Effect of brake power on brake specific fuel consumption

The variation of brake specific fuel consumption of the engine between 25N75D, 25C75D, 25P75D & 50N50D, 50C50D, 50P50D blends and diesel at various injection pressures of 200, 225 and 250Kg/cm² is shown in Fig. 6.6, 6.8 and 6.10. From the test results it is observed that initially with increasing brake power, the brake specific fuel consumption of various blends and diesel are decreased and the minimum brake specific fuel consumption is obtained at brake power of 3.0189 kW and then tended to increase with the further increase in brake power. The brake specific fuel consumption of various blends is higher than that with the diesel fuel throughout the entire range. This is mainly due to the combined effects of the relative fuel density, viscosity and calorific value of the blends. However, blends of 25N75D, 25C75D, 25P75D have brake specific fuel consumption very close to that of diesel oil.

![Comparison of Specific fuel consumption Vs Brake power for 25C75D](image)

**Fig. 6.11 Comparison of Specific fuel consumption Vs Brake power for 25C75D**

Figure 6.11 shows the comparison of B.S.F.C. at three different injection pressures of 200 kg/cm², 225 kg/cm² and 250kg/cm². From
the figure, it is observed that the B.S.F.C. is minimum at 225 kg/cm². This is explained in a way that, with increase in the fuel injection pressure, the droplet size, no doubt decreases, but the velocity is so high, that it goes and hits the cylinder walls.

**Fig. 6.12 Comparison of Specific fuel consumption Vs Brake power for 50C50D**

Figure 6.12 shows the comparison of the B.S.F.C for 50C50D blend at 225 kg/cm². This is attributed to the lower value of calorific value of cottonseed oil compared to diesel. Since the viscosity of Cotton seed oil is considerably greater than that of diesel, it is felt that injection pressure which influences the performance. Accordingly, experiments are conducted at different fuel injection pressures.

**Fig. 6.13 Comparison of Specific fuel consumption Vs Brake power**  
**Fig. 6.14 Comparison of Exhaust gas temperature Vs Brake power**
The Fig. 6.13 shows the comparison of B.S.F.C. with blends of Cotton seed oil at 225 kg/cm² injection pressure. This is because of the improved spray characteristics. However, for the 25%-75% Cotton seed oil -diesel blend, the thermal efficiency is 4-5% less as shown in Fig 6.15. The analysis of this experiment deals with performance of single cylinder diesel engine operated at various injection pressures by using different blends of cottonseed oil – diesel. The exhaust gas temperature is also investigated for various blends of cottonseed oil and diesel at optimum injection pressure. The Higher Exhaust gas temperature and Brake Power is shown in Fig. 6.14

**Fig. 6.15 Comparison of Brake thermal efficiency Vs Brake power**

**Fig. 6.16 Comparison of Specific fuel consumption Vs Brake power for 50P50D**
Figure 6.16 shows the comparison of the B.S.F.C for 50P50D at 225 kg/cm². This is attributed to the lower value of calorific value of Palm oil compared to diesel. Since the viscosity of Palm oil is considerably greater than that of diesel.

![Graph showing specific fuel consumption vs brake power]

**Fig. 6.17 Comparison of Specific fuel consumption Vs Brake power for 25P75D**

Figure 6.17 shows the comparison of B.S.F.C. at three different injection pressures of 200 kg/cm², 225 kg/cm² and 250kg/cm². From the figure, it is observed that the B.S.F.C. is minimum at 225 kg/cm². This is explained in a way that, with increase in the fuel injection pressure, the droplet size, no doubt decreases, but the velocity is so high, that it goes and hits the cylinder walls. This represents the layer of air and fuel, unburnt due to wall quenching. The higher exhaust gas temperature and Brake Power as shown in Figures 6.19.
Since the viscosity of Palm oil is considerably higher compared to diesel test is carried out. Fig. 6.18 shows the comparison of B.S.F.C. with Palm oil and at 225 kg/cm² injection pressure. It is observed from the figure there is a 4-6% decrease in the B.S.F.C. The Fig 6.20 shows the comparison of the performance of different blends of Palm oil and diesel. It is observed that for 50%-50% palm oil –diesel blend, the brake thermal efficiency is almost identical with that of pure diesel operating throughout the range of power output. However, for the 75%-25% diesel-palm blend, the thermal efficiency is 5-7% less.
Figure 6.21 shows the comparison of B.S.F.C. at three different injection pressures of 200 kg/cm$^2$, 225 kg/cm$^2$ and 250 kg/cm$^2$. From the figure, it is observed that the B.S.F.C. is minimum at 225 kg/cm$^2$. This is explained in a way that, with increase in the fuel injection pressure, the droplet size, no doubt, decreases, but the velocity is so high, that it goes and hits the cylinder walls.

Figure 6.22 shows the comparison of the B.S.F.C for 50N50D blend at 225 kg/cm$^2$. This is attributed to the lower value of calorific value of cottonseed oil compared to diesel. Since the viscosity of Neem oil
is considerably greater than that of diesel, it is felt that injection pressure is influence the performance. Accordingly, experiments are conducted at different fuel injection pressures.

![Graph showing comparison of specific fuel consumption vs brake power](image1)

**Fig. 6.23 Comparison of Specific fuel consumption Vs Brake power**

![Graph showing comparison of exhaust gas temperature vs brake power](image2)

**Fig. 6.24 Comparison of Exhaust gas temperature Vs Brake power**

![Graph showing comparison of brake thermal efficiency vs brake power](image3)

**Fig. 6.25 Comparison of Brake thermal efficiency Vs Brake power**

The Fig. 6.23 shows the comparison of B.S.F.C. with blends of Neem oil at 225 kg/cm² injection pressure. This is because of the improved spray characteristics. However, for the 25%-75% Neem oil - diesel blend, the thermal efficiency is 4-7% less as shown in Fig 6.25.
The analysis of this experiment deals with performance of single cylinder diesel engine operated at various injection pressures by using different blends of Neem oil – diesel. The exhaust gas temperature is also investigated for various blends of Neem oil and diesel at optimum injection pressure. The Exhaust gas temperature and Brake Power is shown in Fig. 6.24

6.5 Emission Characteristics of Different blends at Various Injection Pressures

6.5.1 Cottonseed Oil Blends

Fig.6.26 shows the variation CO\textsubscript{2} with brake power output for Cottonseed oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm\textsuperscript{2}. CO\textsubscript{2} emission of 50% blends having higher values compared with all other blends and diesel. The highest value of CO\textsubscript{2} at 25% blend of cottonseed oil is 7.54\% in respect to the value of 7.7\% for diesel.

Fig.6.27 shows the variation of CO emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm\textsuperscript{2}. The CO of 50% blend of cottonseed oil has higher values compared with all other blends and is well comparable with diesel. The CO of all blends and diesel increases with increase of brake power.

Fig.6.28 shows the variation of hydrocarbon emission with brake power output for cottonseed oil and its blends with diesel in the test
engine at an injection pressure of 200kg/cm². HC emission of 50% blend of cottonseed oil has higher emission compared with all other blends. While, HC of Diesel and 25% blend of Cottonseed oil are near to pure diesel.

Fig.6.29 shows the variation of NOₙ emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm². NOₙ of 25% blend of cottonseed oil is less than the diesel. 50% blend has less NOₙ emission compared with all other blends throughout all brake power loads.

Fig.6.30 shows the variation of smoke emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm². Diesel has lower smoke emission compared with all other blends of cottonseed oil.

![Figure 6.26: Comparison of CO₂ Emission Vs Brake Power](image)
Fig. 6.31 shows the variation CO\textsubscript{2} with brake power output for Cottonseed oil and its blends with diesel in the test engine at an injection pressure of 225 kg/cm\textsuperscript{2}. CO\textsubscript{2} emission of 50\% blends having higher values compared with all other blends and diesel.

Fig. 6.32 shows the variation of CO emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 225 kg/cm\textsuperscript{2}. The CO of 50\% blend of cottonseed oil has higher values compared with all other blends and is well
comparable with 25% blend. The CO emission of all blends and diesel increases with increase in brake power load.

Fig.6.33 shows the variation of hydrocarbon emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm². HC emission of 50% blend of cottonseed oil has higher emission compared with all other blends. While, HC of Diesel and 25% blend of Cottonseed oil have more emission than pure diesel.

Fig.6.34 shows the variation of nitrogen oxide emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm². NOx of 25% blend of cottonseed oil is slightly less than that of diesel. 50% blend has less NOx emission compared with all other blends throughout all brake power loads.

Fig.6.35 shows the variation of smoke Emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm². Diesel has lower smoke emission compared with all other blends of cottonseed oil.
Figure 6.31: Comparison of CO\textsubscript{2} Emission Vs Brake Power

Figure 6.32: Comparison of CO Emission Vs Brake Power

Figure 6.33: Comparison of HC Emission Vs Brake Power

Figure 6.34: Comparison of NO\textsubscript{x} Emission Vs Brake Power

Figure 6.35: Comparison of Smoke Level Vs Brake Power
Fig. 6.36 shows the variation CO$_2$ emission with brake power output for Cottonseed oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm$^2$. CO$_2$ emission of 50% blends having higher values compared with all other blends and diesel. The highest value of CO$_2$ at 25% blend of cottonseed oil is 6.71% in respect to the value of 6.34% for diesel.

Fig. 6.37 shows the variation of CO emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm$^2$. The CO of 50% blend of cottonseed oil has higher values compared with all other blends and is well comparable with diesel. The CO of all blends and diesel increases with increase of brake power.

Fig. 6.38 shows the variation of hydrocarbon emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm$^2$. HC emission of 50% blend of cottonseed oil has higher emission compared with all other blends.

Fig. 6.39 shows the variation of nitrogen oxide emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm$^2$. NO$_X$ of 25% blend of cottonseed oil is less than that of diesel. 50% blend has less NO$_X$ emission compared with all other blends throughout all brake power loads.
Fig. 6.40 shows the variation of smoke emission with brake power output for cottonseed oil and its blends with diesel in the test engine at an injection pressure of 250 kg/cm². Diesel has lower smoke emission compared with all other blends of cottonseed oil.

![Comparison of CO₂ Emission Vs Brake Power](image1)

**Figure 6.36: Comparison of CO₂ Emission Vs Brake Power**

![Comparison of CO Emission Vs Brake Power](image2)

**Figure 6.37: Comparison of CO Emission Vs Brake Power**

![Comparison of HC Emission Vs Brake Power](image3)

**Figure 6.38: Comparison of HC Emission Vs Brake Power**

![Comparison of NOₓ Emission Vs Brake Power](image4)

**Figure 6.39: Comparison of NOₓ Emission Vs Brake Power**

![Comparison of Smoke Level Vs Brake Power](image5)

**Figure 6.40: Comparison of Smoke Level Vs Brake Power**
6.5.2 Palm Oil Blends

Fig. 6.41 shows the variation CO$_2$ with brake power output for Palm oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm$^2$. CO$_2$ Emission of 50% blends having higher values compared with all other blends and diesel. The highest value of CO$_2$ at 25% blend of palm oil is 8.1% in respect to the value of 7.72% for diesel.

Fig. 6.42 shows the variation of CO emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm$^2$. The CO of 50% blend of palm oil has higher values compared with all other blends. The CO of all blends and diesel increases with increase of brake power.

Fig. 6.43 shows the variation of hydrocarbon emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm$^2$. HC emission of 50% blend of palm oil has higher emission compared with all other blends. While, HC of Diesel and 25% blend of Palm oil are much less compared to 50% blend.

Fig. 6.44 shows the variation of nitrogen oxide emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm$^2$. NO$_X$ of 25% blend of palm oil is less than that of diesel. 50% blend has less NO$_X$ emission compared with all other blends throughout all brake power loads.

Fig. 6.45 shows the variation of smoke emission with brake power output for palm oil and its blends with diesel in the test engine at an
injection pressure of 200kg/cm². Diesel has lower smoke emission compared with all other blends of palm oil. 25% blend of the palm oil smoke level is well comparable with diesel.

Figure 6.41: Comparison of CO₂ Emission Vs Brake Power

Figure 6.42: Comparison of CO Emission Vs Brake Power

Figure 6.43: Comparison of HC Emission Vs Brake Power
Fig. 6.46 shows the variation CO$_2$ with brake power output for Palm oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm$^2$. CO$_2$ emission of 50% blends having higher values compared with all other blends and diesel.

Fig. 6.47 shows the variation of CO emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm$^2$. The CO of 50% blend of palm oil has higher values compared with all other blends. Diesel CO emission is has comparable with 25% blend. The CO emission of all blends and diesel increases with increase in brake power load.

Fig. 6.48 shows the variation of hydrocarbon emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm$^2$. HC emission of 50% blend of palm
oil has higher emission compared with all other blends and is well comparable with 25% blends.

Fig.6.49 shows the variation of nitrogen oxide emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm$^2$. NO$_X$ of 25% blend of palm oil is less than that of diesel. 50% blend has less NO$_X$ emission compared with all other blends throughout all brake power loads.

Fig.6.50 shows the variation of smoke emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm$^2$. Diesel has lower smoke emission compared with all other blends of palm oil.

![Figure 6.46: Comparison of CO$_2$ Emission Vs Brake Power](image)
Fig. 6.51 shows the variation CO$_2$ with brake power output for Palm oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm$^2$. CO$_2$ emission of 50% blends having higher values compared with all other blends and diesel. The highest value of CO$_2$ at 25% blend of palm oil is 6.54% in respect to the value of 6.34% for diesel.

Fig.6.52 shows the variation of CO emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm$^2$. The CO of 50% blend of palm oil has
comparable values with all other blends and is well comparable with 25% blend. The CO of all blends and diesel increases with increase of brake power.

Fig.6.53 shows the variation of hydrocarbon emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm². HC emission of 50% blend of palm oil has higher emission compared with all other blends.

Fig.6.54 shows the variation of nitrogen oxide emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm². NOₓ of 25% blend of palm oil is less than that of diesel. 50% blend has less NOₓ emission compared with all other blends throughout all brake power loads.

Fig.6.55 shows the variation of smoke emission with brake power output for palm oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm².

![Figure 6.51: Comparison of CO₂ Emission Vs Brake Power](image)
6.5.3 Neem Oil Blends

Fig. 6.56 shows the variation CO$_2$ with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm$^2$. CO$_2$ emission of 50% blends having higher values compared with all other blends and diesel. The highest value of CO$_2$ at 25% blend of Neem oil is 9.22% in respect to the value of 7.2% for diesel.
Fig.6.57 shows the variation of CO emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm². The CO of 50% blend of Neem oil has higher values compared with all other blends. The CO of all blends and diesel increases with increase of brake power.

Fig.6.58 shows the variation of hydrocarbon emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm². HC emission of 50% blend of Neem oil has higher emission compared with all other blends.

Fig.6.59 shows the variation of nitrogen oxide emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm². NOₓ of 25% blend of Neem oil is less than that of diesel. 50% blend has less NOₓ emission compared with all other blends throughout all brake power loads.

Fig.6.60 shows the variation of smoke emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm². Diesel has higher smoke emission compared with all other blends of Neem oil.
Figure 6.56: Comparison of CO$_2$ Emission Vs Brake Power

Figure 6.57: Comparison of CO Emission Vs Brake Power

Figure 6.58: Comparison of HC Emission Vs Brake Power

Figure 6.59: Comparison of NO$_x$ Emission Vs Brake Power

Figure 6.60: Comparison of Smoke Level Vs Brake Power
Fig.6.61 shows the variation CO\textsubscript{2} with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm\textsuperscript{2}. CO\textsubscript{2} emission of 50\% blends having higher values compared with all other blends and diesel.

Fig.6.62 shows the variation of CO emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm\textsuperscript{2}. The CO of 50\% blend of Neem oil has higher values compared with all other blends.

Fig.6.63 shows the variation of hydrocarbon emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm\textsuperscript{2}. HC emission of 50\% blend of Neem oil has higher emission compared with all other blends and is well comparable with 25\% blends.

Fig.6.64 shows the variation of nitrogen oxide emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm\textsuperscript{2}. NO\textsubscript{X} of 25\% blend of Neem oil is slightly higher than that of diesel. 50\% blend has higher NO\textsubscript{X} emission compared with all other blends throughout all brake power loads.

Fig.6.65 shows the variation of smoke emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 225kg/cm\textsuperscript{2}. Diesel has lower smoke emission compared with all other blends of Neem oil.
Figure 6.61: Comparison of CO₂ Emission Vs Brake Power

Figure 6.62: Comparison of CO Emission Vs Brake Power

Figure 6.63: Comparison of HC Emission Vs Brake Power

Figure 6.64: Comparison of NOₓ Emission Vs Brake Power

Figure 6.65: Comparison of Smoke Level Vs Brake Power
Fig. 6.66 shows the variation CO₂ with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm². CO₂ emission of 50% blends having higher values compared with all other blends and diesel. The highest value of CO₂ at 25% blend of Neem oil is 6.54% in respect to the value of 6.4% for diesel.

Fig. 6.67 shows the variation of CO emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm². The CO of 50% blend of Neem oil has comparable values with all other blends and is well comparable with 25% blend. The CO of all blends and diesel increases with increase of brake power.

Fig. 6.68 shows the variation of hydrocarbon emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 200kg/cm². HC emission of 50% blend of Neem oil has higher emissions compared with all other blends.

Fig. 6.69 shows the variation of nitrogen oxide emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm². NOₓ of 25% blend of Neem oil is less than that of diesel. 50% blend has less NOₓ emission compared with all other blends throughout all brake power loads.
Fig. 6.70 shows the variation of smoke emission with brake power output for Neem oil and its blends with diesel in the test engine at an injection pressure of 250kg/cm².

**Figure 6.66: Comparison of CO₂ Emission Vs Brake Power**

**Figure 6.67: Comparison of CO Emission Vs Brake Power**

**Figure 6.68: Comparison of HC Emission Vs Brake Power**
6.6 Emission Characteristics of different blends by using CFD at injection pressure of 225kg/cm²

The temperature distributions plotted for different crank angles on a vertical plane. From 340° – 450° of cranks angle (CA) the global parameters (peak pressures, internal energy, turbulent kinetic energy) the influence of different parameters on the formation of oxides of nitrogen, carbon monoxide, unburned hydro carbons and soot. The local parameters (flow field, spray distribution and temperature contours) plotted for different blends at different injection pressures. The spray and flame reaches the edge of the piston bowl with in short period 7⁰-10⁰ CA. The concentration of oxygen in the high temperature zone is very high resulting in a high NOₓ rate of formation.

The NOₓ from emission test is 1100 ppm at 1500 rpm. The detailed time history of spray, fuel mass fraction and temperature distributions provided by the CFD simulation are valuable towards gaining a better
understanding of the features of combustion for given engine configurations. The temperature distribution inside the cylinder for different crank angles and NOx emissions are given above. NOx formation is highly sensitive to temperature and also effected by species concentration. In-fact the flame in the hemi-spherical bowl is not sufficient to burn a complete combustion because of the bowl shape.

The deviations from experiment and simulation results of NOx emission are around 3-5 %. It is found that the general agreement between prediction and engine test is good.
6.6.1 Cottonseed oil and Diesel blends (25C75D)

6.71 Counter of CO₂ Emission
6.72 Counter of HC Emission
6.73 Counter of CO Emission
6.74 Counter of NOₓ Emission
6.75 Counter of Smoke Density
6.6.2 Cottonseed oil and Diesel blends (50C50D)

6.76 Counter of CO$_2$ Emission

6.77 Counter of HC Emission

6.78 Counter of CO Emission

6.79 Counter of NO$_x$ Emission

6.80 Counter of Smoke Density
6.6.3 Palm oil and Diesel blends (25P75D)

6.81 Counter of CO₂ Emission

6.82 Counter of HC Emission

6.83 Counter of CO Emission

6.84 Counter of NOₓ Emission

6.85 Counter of Smoke Density
6.6.4 Palm oil and Diesel blends (50P50D)

6.86 Counter of CO$_2$ Emission  
6.87 Counter of HC Emission

6.88 Counter of CO Emission  
6.89 Counter of NO$_x$ Emission

6.90 Counter of Smoke Density
6.6.5 Neem oil and Diesel blends (25N75D)

6.91 Counter of CO\textsubscript{2} Emission

6.92 Counter of HC Emission

6.93 Counter of CO Emission

6.94 Counter of NO\textsubscript{X} Emission

6.95 Counter of Smoke Density
6.6.6 Neem oil and Diesel blends (50N50D)

6.96 Counter of CO₂ Emission

6.97 Counter of HC Emission

6.98 Counter of CO Emission

6.99 Counter of NOₓ Emission

6.100 Counter of Smoke Density
6.6.7 Diesel

6.101 Counter of CO₂ Emission  
6.102 Counter of HC Emission

6.103 Counter of CO Emission  
6.104 Counter of NOₓ Emission

6.105 Counter of Smoke Density
6.7 Analysis of Heat Balance Test Data

Appendix Table A-6 shows the energy distribution of various components (BP, liner, friction, exhaust gases, friction) at different loads (no, 1/4, 1/2, 3/4, full load). From the tabulated values it is observed that as the load on the engine is increased, heat lost through the liner also increased. This is attributed to the increase in the temperature of hot gases inside the cylinder with load.

Similarly it is also observed that miscellaneous losses have increased from no load to full load condition. This is because, as the load increases the temperature of hot gases increase, as a result heat lost by radiation also increases. From the tabulation it is further observed that heat carried away by the exhaust gases has increased from no load to full load. This is due to the fact that, as the load increases, temperature of hot gases at the end of expansion also increases.

![Fig. 6.106 Energy balance at no load](image)

![Fig. 6.107 Energy balance at ¾th load](image)
Figure 6.106, Fig. 6.107 and Fig. 6.108 show the energy balance in the form of a pie diagram. From the diagrams it is observed that, the brake thermal efficiency has increased from no load to ¾ loads. Later it has decreased. This is due to incomplete combustion and increase in miscellaneous losses at full load.

Similarly it is also observed that, the percentage of miscellaneous loses has increased with load. This is because as the load increases the temperature of hot gases increases, as a result radiation losses and heat lost through unaccounted components also increases.

Similarly it is also observed that as the load has increased the corresponding liner temperatures increases as the temperature of hot gases increases with load.

Further it is observed that there is a sudden increase in rate of heat transfer at full load along the cylinder liner. The sudden increase in the temperature gradient due to tremendous increase in the hot gases temperature at full load due to excessive injection is the prime cause for the increase in the rate of heat transfer.
6.8 COMBUSTION ANALYSIS

In spite of the detailed nature of even the most comprehensive CFD codes, they cannot entirely predict the complete details due to complexity in cylinder mechanics. Heywood J.B in his review concludes, “the potential of the three dimensional models for defining flow process with their full details is highly promising. However, these models have to be validated against experiments”. In this context it is important to compare the predicted results with experimental results. Another important aspect in the presentation of the results is to process, organize and present the huge data generated by code. A large amount of spatial information on fluid flow and spatial variables in the cylinder domain are generated with the present computations. So, it is necessary to present this information in easily readable form.

6.8.1 VALIDATION OF RESULTS WITH CFD ANALYSIS

The present work of predicting and analyzing the in-cylinder processes of a diesel engine is carried out in following stages.

It is important to validate the results obtained with the code to ascertain its prediction capabilities. Hence, as a first step, the computed histories of certain global parameters like average cylinder pressure are presented. A single cylinder diesel engine with hemi-spherical bowl shape in the piston is considered for the analysis, because the test engine for which the experimental results available has the same bowl configuration. The other engine details used in the analysis are also
same as that of the test engine. The variations in the global parameters with Crank angle, during compression and expansion processes, are presented in x-y plots. Besides the pressure histories and other global parameters such as mass of the liquid, vapour fuel, total energy and turbulent kinetic energy are also predicted and presented in this section. Further, the global parameters are predicted with standard K-epsilon model.

In the second stage, detailed analysis of spatial information, predicted using CFD code modified with standard K-epsilon model, such as, turbulent kinetic energy, turbulent intensity, fuel variance, residuals and temperature variations with crank angle are presented for Hemispherical bowl in-piston configuration. The local flow field is presented in the form of velocity vectors. Also, spray distribution plots and temperatures contours are provided.
6.8.2 Results Obtained for Diesel with Cottonseed, Palm and Neem Oils are shown below for 25% oil and 75% Diesel Blends at 340 ° CA and at an injection pressure of 225kg/cm²
Total Turbulent Kinetic Energy Variations

Mass Imbalance Variations
6.8.3 Results Obtained for Diesel with Cottonseed, Palm and Neem Oils are shown below for 25% oil and 75% Diesel Blends at 390 °CA and at an injection pressure of 225kg/cm²
Total Turbulent Kinetic Energy Variations

Mass Imbalance Variations

25C75D

25P75D

25N75D

25C75D

25P75D

25N75D
6.8.4 Results Obtained for Diesel with Cottonseed, Palm and Neem Oils are shown below for 25% oil 75% Diesel Blends at 450° CA and at an injection pressure of 225kg/cm²

<table>
<thead>
<tr>
<th>Pressure Variations</th>
<th>Velocity Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="25C75D" /></td>
<td><img src="image" alt="25C75D" /></td>
</tr>
<tr>
<td><img src="image" alt="25P75D" /></td>
<td><img src="image" alt="25P75D" /></td>
</tr>
<tr>
<td><img src="image" alt="25N75D" /></td>
<td><img src="image" alt="25N75D" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature Variations</th>
<th>Total Energy Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="25C75D" /></td>
<td><img src="image" alt="25C75D" /></td>
</tr>
<tr>
<td><img src="image" alt="25P75D" /></td>
<td><img src="image" alt="25P75D" /></td>
</tr>
<tr>
<td><img src="image" alt="25N75D" /></td>
<td><img src="image" alt="25N75D" /></td>
</tr>
</tbody>
</table>
6.8.5 Results Obtained for Diesel with Cottonseed, Palm and Neem Oils are shown below for 50% oil 50% Diesel Blends at 340° CA and at an injection pressure of 225kg/cm²

<table>
<thead>
<tr>
<th>Pressure Variations</th>
<th>Velocity Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>50C50D</strong></td>
<td><strong>50C50D</strong></td>
</tr>
<tr>
<td><strong>50P50D</strong></td>
<td><strong>50P50D</strong></td>
</tr>
<tr>
<td><strong>50N50D</strong></td>
<td><strong>50N50D</strong></td>
</tr>
</tbody>
</table>
Total Turbulent Kinetic Energy Variations

Mass Imbalance Variations

50C50D

50P50D

50N50D

50P50D
6.8.6 Results Obtained for Diesel with Cottonseed, Palm and Neem Oils are shown below for 50% oil 50% Diesel Blends at 390° CA and at an injection pressure of 225kg/cm².
Temperature Variations

Velocity Variations

![50C50D](image1)

![50P50D](image2)

![50N50D](image3)
Total Turbulent Kinetic Energy Variations

Mass Imbalance Variations

50C50D

50P50D

50N50D
6.8.7 Results Obtained for Diesel with Cottonseed, Palm and Neem Oils are shown below for 50% oil 50% Diesel Blends at 450° CA and at an injection pressure of 225kg/cm²
Total Turbulent Kinetic Energy Variations

- **50C50D**

- **50P50D**

- **50N50D**

Mass Imbalance Variations

- **50C50D**

- **50P50D**

- **50N50D**