CHAPTER-5

RESULTS AND DISCUSSIONS

In this chapter results of experimental investigations carried out on diesel engine are summarised into two parts, first part is about grape seed biodiesel and second part is related to mango seed biodiesel. Grape seed biodiesel obtained by two production process is divided into four sections. First section of results and discussions is about performance, combustion and emission characteristics of diesel engine fuelled with diesel and blends of methyl esters of grape seed oil obtained by transesterification process of grape seed oil later followed by other three sections about grape seed biodiesel produced by catalytic cracking process with three different catalysts. Graphs are plotted for brake thermal efficiency and specific fuel consumption variations with changes in load, peak cylinder pressure and heat release rate with varying crank angle, various emissions with variation in load based upon engine output data. Results are analysed and discussed with possible reasons for the variations.

5.1 Methyl Esters of Grape Seed Oil (Transesterification Process)

5.1.1 Brake Thermal Efficiency

Fig 5.1.1: Brake thermal efficiency with brake power for different blends of MEGSO & Diesel
Figure 5.1.1 shows the variation of brake thermal efficiency with brake power for methyl esters of grape seed oil (MEGSO) blends B25 (25% biodiesel and 75% diesel) B50, B75, B100 in comparison with diesel. Brake thermal efficiencies of B25, B50, B75 and B100 are 26.25%, 25.93%, 25.71% and 25.52% when compared to diesel brake thermal efficiency 26.89% at 80% engine load. It is observed that brake thermal efficiency of B25 is 26.25% and is very close to that of diesel among all other blends. This is due to better atomization of B25 as compared to other blends of biodiesel. Better atomization leads to better vapourisation of fuel which enhances combustion process ultimately increasing break thermal efficiency. B100 brake thermal efficiency is less due to increased viscous nature of biodiesel.

5.1.2 Specific Fuel Consumption

![Graph showing specific fuel consumption vs brake power for different blends of MEGSO & Diesel](image_url)

Fig 5.1.2: Specific fuel consumption with brake power for different blends of MEGSO & Diesel

Figure 5.1.2 shows the variation of specific fuel consumption with brake power for MEGSO blends in comparison with diesel. Fuel consumption of the engine is decreasing for all test fuels on increasing loads, the combustion is improved due to higher in-cylinder temperature which partially improves fuel air mixing process after successive working of engine. It is observed that the specific fuel consumption of
diesel is 0.2896 kg/kW-h at 80% engine load. The specific fuel consumption of B25, B50, B75 and B100 are 0.3165 kg/kW-h, 0.3226 kg/kW-h, 0.3340 kg/kW-h, 0.3410 kg/kW-h respectively. B25 specific fuel consumption is less compared to biodiesel blends because of complete combustion of injected fuel. B100 specific fuel consumption is more due to injection of more fuel to maintain power output.

5.1.3 Cylinder Pressure

![Cylinder pressure with crank angle for different blends of MEGSO & Diesel](image)

Fig 5.1.3 : Cylinder pressure with crank angle for different blends of MEGSO & Diesel

Figure 5.1.3 depicts the variation of cylinder pressure with brake power for MEGSO blends in comparison with diesel. Peak cylinder pressure at 80% engine load obtained for diesel is 63.26 bar where as peak cylinder pressures for B25, B50, B75 and B100 are 59.01 bar, 58.88 bar, 57.38 bar, 55.53 bar respectively. The peak cylinder pressures for B25 blend is higher to that of other blends at the same operating conditions. The reason for higher peak cylinder pressure of the B25 is high calorific value and proper burning rate when compared to other blends.
5.1.4 Heat Release Rate

The variation of heat release rate with crank angle for MEGSO blends in comparison with diesel is shown in figure 5.1.4. By analysis of figure, it is observed that heat release rate at 80% engine load for diesel, B25, B50, B75 and B100 are 125.34 kJ/ m$^3$ deg, 120.36 kJ/ m$^3$ deg, 118.46 kJ/ m$^3$ deg, 115.82 kJ/ m$^3$ deg, 112.56 kJ/ m$^3$ deg respectively. B25 heat release rate of 120.36 kJ/ m$^3$ deg is highest of all other blends. This is due to more fuel accumulation in the ignition delay period, which releases the maximum heat as it is having calorific value close to diesel value. B100 gives the least heat release rate due to its lower calorific value.

Fig 5.1.4: Heat release rate with crank angle for different blends of MEGSO & Diesel
5.1.5 Nitrogen Oxide Emissions

Figure 5.1.5 exhibits the variation of oxides of Nitrogen emission with brake power for MEGSO blends in comparison with diesel. The NO\textsubscript{x} emission for diesel at 80% engine load is 1135 ppm where as for B25, B50, B75 and B100 are 1074 ppm, 1048 ppm, 996 ppm, 960 ppm respectively. It is noticed that NO\textsubscript{x} emissions are more for diesel compared to biodiesel blends. NO\textsubscript{x} emissions are influenced with cylinder temperatures. Diesel engine with B25 blend fuel emitted less NO\textsubscript{x} emissions due to lesser in cylinder temperatures. NO\textsubscript{x} emissions are decreasing with increasing blend percentage of biodiesel because of their lower heat release rates resulting in lesser cylinder temperatures.
5.1.6 Hydrocarbon Emissions

![Graph showing hydrocarbon emissions with brake power for different blends of MEGSO & Diesel](image)

Fig 5.1.6: Hydrocarbon emissions with brake power for different blends of MEGSO & Diesel

The variation of hydrocarbon emissions with brake power for MEGSO blends in comparison with diesel is demonstrated in figure 5.1.6. It is observed that hydrocarbon (HC) emissions are increasing with increasing load. Hydrocarbon emissions at 80% engine load for diesel, biodiesel blends B25, B50, B75, B100 are 76.4 ppm, 79.4 ppm, 83.2 ppm, 85.6 ppm, 88.4 ppm respectively. B25 has more HC emissions is due to injection of more fuel to develop near similar power output in comparison with diesel or due to some part of fuel entrapped in crevices leaving unburnt because of flame quenching at the cylinder walls. With increasing percentage of biodiesel in diesel there is increment in hydrocarbon emissions.
5.1.7 Carbon Monoxide Emissions

Figure 5.1.7 shows the variation of carbon monoxide (CO) emissions with brake power for biodiesel blends in comparison with diesel. CO emissions are constant at part loads but there is gradual increment towards full load operation. CO emissions at 80% engine load in percentage of volume for diesel, B25, B50, B75 and B100 are 0.16%, 0.15%, 0.14%, 0.12% and 0.12% respectively. Diesel engines are designed to operate on lean side of stoichiometric so CO emissions from diesel engines are less due to very lean air-fuel mixtures and added to this biodiesel blends CO emissions are slightly lesser in comparison to diesel.

5.1.8 Smoke Emissions

Figure 5.1.8 shows the variation of smoke emissions with brake power for MEGSO biodiesel blends in comparison with diesel. Smoke emissions are increasing with increase in load for all test fuels. Diesel smoke emissions at 80% engine load are 64.2 HSU, at the same load MEGSO blends B25, B50, B75 and B100 smoke emissions are 64.5 HSU, 66.8 HSU, 67.4 HSU and 69.4 HSU. For B25 blend smoke emissions are slightly more compared to engine fuelled with diesel, due to injection of
more fuel effecting air fuel ratio resulting in unpleasant black smoke in the exhaust. Smoke emissions are increasing with increase in biodiesel blend percentage in diesel.

![Smoke emissions with brake power for different blends of MEGSO & Diesel](image)

Fig 5.1.8: Smoke emissions with brake power for different blends of MEGSO & Diesel

Biodiesel produced by transesterification of grape seed vegetable oil when fuelled to diesel engine with different blends, B25 blend is giving closer engine performance, combustion characteristics, reduced NO\(_X\), CO emissions with a slight increase in HC and smoke emissions compared to diesel fuel. It shows methyl esters of grape seed oil can be used in small proportions blended with diesel to operate diesel engines.

5.2 Grape Seed Biodiesel (Catalytic Cracked Grape Seed Oil with Alumina as Catalyst)

Results and discussions about the characteristics of diesel engine, fuelled with diesel and blends of grape seed biodiesel obtained by catalytic cracking process of grape seed oil with alumina as catalyst are detailed. Alumina catalyst with both
Bronsted and lewis acid sites along with its porous structure is good at cracking vegetable oil, giving a better yield of biodiesel. Enriched with oxygen content and with reduced viscosity biodiesel thus obtained is having properties that are close to diesel fuel properties. Graphs for engine performance characteristics like brake thermal efficiency and specific fuel consumption, combustion characteristics like peak cylinder pressure and heat release rate, emission parameters like NOx, HC, CO and smoke density are plotted, probable reasons are discussed for varying curve nature with changing parameters with an overall summary briefing.

5.2.1 Brake Thermal Efficiency

![Graph of Brake Thermal Efficiency](image)

Fig 5.2.1: Brake thermal efficiency with brake power for different blends of Grape Seed Biodiesel & Diesel

Figure 5.2.1 shows the variation of brake thermal efficiency with brake power for grape seed biodiesel (obtained by catalytic cracking of grape seed oil with alumina catalyst) blends B25 (25% biodiesel and 75% diesel), B50, B75, B100 in comparison with diesel. Brake thermal efficiencies of B25, B50, B75 and B100 are 26.54%, 26.19%, 25.96% and 25.88% when compared to diesel brake thermal efficiency of 26.89% at 80% engine load. It is observed that brake thermal efficiency of B25 is 26.54% which is next to that of diesel compared to other biodiesel blends.
This is due to B25 fuel atomisation with very near viscosity value in comparison to viscosity value of diesel. It is also noticed that as blend percentage of biodiesel increases there is decrease in brake thermal efficiency. This is due to the increase in viscosity effecting fuel vaporization and combustion process compared to diesel.

### 5.2.2 Specific Fuel Consumption

The variation of specific fuel consumption with brake power for grape seed biodiesel blends and diesel in comparison with diesel is indicated in figure 5.2.2. It is observed that at 80% engine load specific fuel consumption of diesel is 0.2896 kg/kW-h, for blends of B25, B50, B75, B100 specific fuel consumption is 0.3001 kg/kW-h, 0.3075 kg/kW-h, 0.3157 kg/kW-h and 0.3321 kg/kW-h respectively.

![Specific fuel consumption with brake power for different blends of Grape Seed Biodiesel & Diesel](image)

Fig 5.2.2: Specific fuel consumption with brake power for different blends of Grape Seed Biodiesel & Diesel

B25 fuel consumption is closer to diesel due to a very little variation in fuel atomisation with near viscosity. The fuel consumption of B100 is more when compared to diesel because of its lower calorific value leading to injection of more fuel to maintain same power output in comparison with diesel.
5.2.3 Cylinder Pressure

Figure 5.2.3 shows the variation of cylinder pressure with brake power for grape seed biodiesel blends and diesel in comparison with diesel. Peak cylinder pressure obtained at 80% engine load for diesel is 63.26 bar where as peak cylinder pressures for B25, B50, B75, B100 are 62.56 bar, 61.31 bar, 59.55 bar and 58.20 bar respectively. The peak cylinder pressures for B25 is closer to diesel due to its high energy content, on proper combustion releases high pressure. The reasons for reduced pressure of the other blends is high viscosity, low calorific value and slightly slow burning rate.

Fig 5.2.3: Cylinder pressure with crank angle for different blends of Grape Seed Biodiesel & Diesel
**5.2.4 Heat Release Rate**

![Heat release rate with crank angle](image)

Fig 5.2.4: Heat release rate with crank angle for different blends of Grape Seed Biodiesel & Diesel

Figure 5.2.4 depicts the variation of heat release rate with crank angle for grape seed biodiesel blends and diesel in comparison with diesel. By analysis of figure it is observed that at 80% engine load heat release rate is higher for diesel with 125.34 kJ/m$^3$ deg. B25, B50, B75, B100 blends heat release rate values are 124.40 kJ/m$^3$ deg, 122.35 kJ/m$^3$ deg, 120.86 kJ/m$^3$ deg and 118.69 kJ/m$^3$ deg respectively. B25 gives the next best heat release rate of 124.40 kJ/m$^3$ deg compared to that of diesel. The reason is higher calorific value of fuel and also more fuel accumulation in the delay period releases maximum heat on combustion. B100 gives the least heat release rate value due to lower calorific value.
5.2.5 \( \text{NO}_x \) Emissions

The variation of oxides of Nitrogen emission with brake power for grape seed biodiesel blends and diesel in comparison with diesel is shown in figure 5.2.5. The \( \text{NO}_x \) emission for B25, B50, B75 and B100 blends \( \text{NO}_x \) values are 1183 ppm, 1217 ppm, 1252 ppm, 1275 ppm and for diesel it is 1135 ppm at 80\% engine load. It is noticed that \( \text{NO}_x \) emissions are increasing with increasing blend percentage of biodiesel. Grape seed biodiesel is obtained from unsaturated fatty content of grape seed oil have higher molecular weight, with presence of carbon double bonds in their molecular structure they burn in the late phase of combustion leading to higher exhaust temperatures resulting in increase in \( \text{NO}_x \) emissions.
5.2.6 Hydrocarbon Emissions

Figure 5.2.6 shows the variation of hydrocarbon emissions (HC) with brake power for grape seed biodiesel blends and diesel in comparison with diesel. HC emissions are increasing with increment in engine load. Hydrocarbon emissions for B25, B50, B75 and B100 are 71.6 ppm, 68.4 ppm, 65.4 ppm, 62.2 ppm at 80% engine load. With increase in blend percentage of biodiesel, it is noticed that HC emissions are decreasing. This is due to availability of oxygen in biodiesel decreases quantity of unburnt fuel during combustion process compared to diesel. Hydrocarbon emissions of diesel engine are highest with 76.4 ppm for diesel fuel in comparison with all test fuels.

5.2.7 Carbon Monoxide Emissions

Figure 5.2.7 shows the variation of carbon monoxide (CO) emissions with brake power for grape seed biodiesel blends and diesel in comparison with diesel. CO emissions at 80% engine load in percentage of volume for diesel, B25, B50, B75 and B100 are 0.16%, 0.13%, 0.12%, 0.11% and 0.10% respectively. CO emissions are near constant for all test fuels and found to be decreasing with increasing biodiesel.
blend percentage. This is due to more oxygen content in biodiesel leading to better conversion of CO to CO₂.

Fig 5.2.7: CO emissions with brake power for different blends of Grape Seed Biodiesel & Diesel

5.2.8 Smoke Emissions

Figure 5.2.8 shows the variation of smoke emission with brake power for grape seed biodiesel blends and diesel in comparison with diesel. Comparatively diesel smoke emissions with 64.2 HSU are higher when compared to biodiesel blends B25, B50, B75 and B100 with the values of 59.4 HSU, 58.3 HSU, 57.0 HSU and 56.1 HSU at 80% engine load. Smoke emissions are higher at high loads as the air fuel ratio decreases with increasing engine loads. For biodiesel blends smoke emissions are decreasing due to presence of fairly good amount of oxygen content enhancing complete combustion of fuel compared to diesel.

From the analysis of results, B25 blend grape seed biodiesel obtained by catalytic cracking of grape seed oil with alumina as catalyst fuelled to a diesel engine gives brake thermal efficiency, specific fuel consumption, peak cylinder pressure and heat release rate that are near similar to diesel and the HC, CO, smoke emissions are lesser with a slight increase in NOₓ emissions.
5.3. **Grape Seed Biodiesel (Catalytic Cracked Grape Seed Oil With Zeolite As Catalyst)**

Tests are conducted on diesel engine first fuelled with diesel and then with grape seed biodiesel obtained by catalytic cracking process of grape seed oil with zeolite as catalyst mixed in different ratios with diesel. Zeolite (ZSM-5) catalyst acts like a molecular sieve, its high acidity and three dimensional pore system is attributed to its alumina and silica content produces biodiesel consisting of shorter hydrocarbon chains and reduced viscosity. Primary engine characteristics that is performance characteristics, combustion characteristics and emission characteristics experimental data are collected. Graphical representation of data and feasible reasons for change in engine characteristics are discussed.

**5.3.1 Brake Thermal Efficiency**

The variation of brake thermal efficiency with brake power for grape seed biodiesel (obtained by catalytic cracking of grape seed oil with zeolite catalyst) blends B25(25% biodiesel and 75% diesel), B50, B75, B100 in comparison with diesel is detailed in figure 5.3.1. Brake thermal efficiencies of B25, B50, B75 and

![Graph showing smoke emissions with brake power for different blends of Grape Seed Biodiesel & Diesel](image)

**Fig 5.2.8:** Smoke emissions with brake power for different blends of Grape Seed Biodiesel & Diesel
B100 are 26.38%, 26.11%, 26.90% and 25.75% when compared to diesel brake thermal efficiency of 26.89% at 80% engine load. It is observed that B25 blend brake thermal efficiency of 26.38% is close to that of diesel among all other blends. This is due to proper atomization of B25 that is comparable to that of diesel. It is also noticed that as blend percentage of biodiesel increases there is decrease in brake thermal efficiency. This is due to increase in viscous nature of fuel affecting fuel atomisation and combustion.

Fig 5.3.1: Brake thermal efficiency with brake power for different blends of Grape Seed Biodiesel & Diesel

5.3.2 Specific Fuel Consumption

Figure 5.3.2 gives the variation of specific fuel consumption with brake power for grape seed biodiesel blends and diesel in comparison with diesel. It is observed specific fuel consumption of diesel is 0.2896 kg/kW-h at 80% load on engine. Specific fuel consumption of B25, B50, B75 and B100 are 0.3105 kg/kW-h, 0.3128 kg/kW-h, 0.3225 kg/kW-h, 0.3362 kg/kW-h respectively. B25 fuel consumption is close to diesel compared to other blends. The fuel consumption of B100 is more
because of its higher density leading to injection of more fuel when compared to diesel to develop same power output.

Fig 5.3.2: Specific fuel consumption with brake power for different blends of Grape Seed Biodiesel & Diesel

5.3.3 Cylinder Pressure

Fig 5.3.3: Cylinder pressure with crank angle for different blends of Grape Seed Biodiesel & Diesel
Figure 5.3.3 details the variation of cylinder pressure with brake power for grape seed biodiesel blends and diesel in comparison with diesel. Peak cylinder pressure obtained for diesel is 63.26 bar where as peak cylinder pressures for B25, B50, B75 and B100 are 61.34 bar, 59.47 bar, 59.32 bar, 57.55 bar respectively at 80% engine load. The peak cylinder pressure for B25 is nearer to that of diesel value. All the other blends peak cylinder pressures are lesser to that of B25 at the same operating conditions. The possible reasons for reduced peak pressure of the biodiesel blends is high viscosity, low calorific value and slightly slow burning rate when compared to diesel.

5.3.4 Heat Release Rate

Fig 5.3.4: Heat release rate with crank angle for different blends of Grape Seed Biodiesel & Diesel

Figure 5.3.4 shows the variation of heat release rate with crank angle for grape seed biodiesel blends and diesel in comparison with diesel. By analysis of figure it is observed that at 80% engine load heat release rate for diesel is 125.34 kJ/ m³ deg. B25, B50, B75 and B100 heat release rate values at same loading are 123.10 kJ/ m³ deg, 121.23 kJ/ m³ deg, 119.24 kJ/ m³ deg, 115.32 kJ/ m³ deg respectively. It is evident that B25 blend is next best heat release rate value to diesel value compared to
other blends. For biodiesel blends heat release rate values are lesser due to lower calorific values compared to diesel. B100 gives the least value of all test fuels.

5.3.5 Nitrogen Oxide Emissions

Figure 5.3.5 shows the variation of oxides of Nitrogen emission with brake power for grape seed biodiesel blends and diesel in comparison with diesel. The NOx emissions for biodiesel blends B25, B50, B75, B100 and diesel are 1189 ppm, 1220 ppm, 1260 ppm, 1283 ppm, 1135 at 80% engine load. NOx emissions are known to increase at high temperatures. It is noticed that NOx emissions are increasing with increasing blend percentage of biodiesel. B25 blend NOx emissions are slightly higher compared to diesel and lesser than other blends. High viscosity of biodiesel leads to an increase in injection line pressure because of which earlier needle opening happens (advanced injection) more fuel gets injected into engine cylinder that leads to early combustion resulting in high temperatures.

5.3.6 Hydrocarbon Emissions

Figure 5.3.6 shows the variation of hydrocarbon emissions with brake power for grape seed biodiesel blends and diesel in comparison with diesel. It is noticed that
for all test fuels hydrocarbon (HC) emissions are increasing with increasing load. Hydrocarbon emissions are more for diesel with 76.4 ppm at 80% engine load. HC emissions of biodiesel blends B25, B50, B75 and B100 are 73.2 ppm, 72.1 ppm, 69.3 ppm, 66.0 ppm respectively which indicates that they are reducing on increasing blend percentage. Reason is maximum amount of injected biodiesel combustion with availability of oxygen in it.

![Graph showing Hydrocarbon emissions with brake power for different blends of Grape Seed Biodiesel & Diesel](image)

Fig 5.3.6: Hydrocarbon emissions with brake power for different blends of Grape Seed Biodiesel & Diesel
5.3.7 Carbon Monoxide Emission

Figure 5.3.7 shows the variation of carbon monoxide (CO) emissions with brake power for grape seed biodiesel blends and diesel in comparison with diesel. There is gradual increase in CO emissions towards full load operation. CO emissions in percentage of volume at 80% engine load for B25, B50, B75 and B100 are 0.15%, 0.14%, 0.12% and 0.13% respectively. Diesel CO emissions are 0.16% in volume. CO emissions are decreasing with increasing biodiesel blend percentage, due to availability of oxygen improving conversion process of CO to carbon dioxide gas.
5.3.8 Smoke Emissions

Fig 5.3.8: Smoke emissions with brake power for different blends of Grape seed Biodiesel & Diesel

Figure 5.3.8 shows the variation of smoke emissions with brake power for grape seed biodiesel blends and diesel in comparison with diesel. Biodiesel blends smoke emissions for diesel, B25, B50, B75 and B100 are 64.2, 60.9 HSU, 60.2 HSU, 60 HSU and 59.3 HSU at 80% engine load. Though smoke emissions are increasing with increasing in load for all test fuels the advantage of using biodiesel is that smoke emissions are less compared to diesel, decreasing with increase in blend percentage of biodiesel.

It is observed that biodiesel produced by catalytic cracking of grape seed oil with zeolite catalyst when fuelled to diesel engine is giving closer engine performance, combustion characteristics and reduced HC, CO, smoke emissions with a slight increase in NO\textsubscript{X} emissions compared to diesel fuel. It shows its suitability to fuel diesel engine without any engine modifications.
5.4  Grape Seed Biodiesel (Catalytic Cracked Grape Seed Oil with Zirconia as Catalyst)

Investigations are carried out on diesel engine fuelled with grape seed biodiesel obtained by catalytic cracking process of grape seed oil with zirconia as catalyst mixed in different proportions with diesel and then with conventional diesel. Zirconia with its rich catalytic properties breaks long chain hydrocarbons into short chain hydrocarbons. Silica content in it has high heat retaining capacity because of which cracking of oil occurs at lower temperatures. Graphs for engine performance characteristics parameters like brake thermal efficiency and specific fuel consumption, combustion characteristics parameters like peak cylinder pressure and heat release rate, emission parameters like NOx, HC, CO and smoke density are plotted, probable reasons are discussed for curve variations with changing parameters and results are summarised.

5.4.1  Brake Thermal Efficiency

![Brake thermal efficiency graph](image)

Fig 5.4.1: Brake thermal efficiency with brake power for different blends of Grape Seed Biodiesel & Diesel

Figure 5.4.1 depicts the variation of brake thermal efficiency with brake power for grape seed biodiesel (obtained by catalytic cracking of grape seed oil with
zirconia catalyst) blends B25 (25% biodiesel and 75% diesel), B50, B75, B100 in comparison with diesel. Brake thermal efficiencies of B25, B50, B75 and B100 are 26.34%, 26.05%, 25.86% and 25.62% when compared to diesel brake thermal efficiency of 26.89% at 80% engine load. Brake thermal efficiency of B25 is 26.34% with a very little difference to that of diesel among all other blends. The reason is due to B25 blend close viscosity value to diesel fuel, near similar vaporization and combustion process occurs in engine cylinder.

5.4.2 Specific Fuel Consumption

Fig 5.4.2: Specific fuel consumption with brake power for different blends of Grape Seed Biodiesel & Diesel

Figure 5.4.2 shows the variation of specific fuel consumption with brake power for grape seed biodiesel blends and diesel in comparison with diesel. It is observed that specific fuel consumption of diesel is 0.2896 kg/kW-h at 80% engine load. Specific fuel consumption of B25, B50, B75 and B100 are 0.3138 kg/kW-h, 0.3199 kg/kW-h, 0.3249 kg/kW-h, 0.3492 kg/kW-h respectively. B25 blend specific fuel consumption value is less when compared to other blends and it is next to that of diesel. Consumption of biodiesel fuel is more compared to diesel because of its high
density, more fuel is injected to develop same power output. The fuel consumption of B100 is highest of all other blends to develop same power output.

5.4.3 Cylinder Pressure

![Cylinder pressure with crank angle for different blends of Grape Seed Biodiesel & Diesel](image)

Fig 5.4.3: Cylinder pressure with crank angle for different blends of Grape Seed Biodiesel & Diesel

Figure 5.4.3 shows the variation of cylinder pressure with brake power for grape seed biodiesel blends and diesel in comparison with diesel. Peak cylinder pressure at 80% engine load for diesel is 63.26 bar where as peak cylinder pressures for B25, B50, B75 and B100 are 59.69 bar, 59.10 bar, 58.00 bar, 56.64 bar respectively. The peak cylinder pressures for B25 is closer to diesel value. Other blends are lesser to that of B25 at the same operating conditions. With lowest calorific value and high density B100 peak cylinder pressure is least, out of all test fuels.

5.4.4 Heat Release Rate

The variation of heat release rate with crank angle for grape seed biodiesel blends and diesel in comparison with diesel is shown in figure 5.4.4. Heat release rate values at 80% engine load for diesel, B25, B50, B75 and B100 are 125.34 kJ/ m³ deg, 121.58 kJ/ m³ deg, 119.54 kJ/ m³ deg, 115.69 kJ/ m³ deg and 113.89 kJ/ m³ deg respectively. B25 blend with heat release rate of 121.58 kJ/ m³ deg stands next to that
of diesel heat release rate value. By analysis it is observed that heat release rates are decreasing with increase in biodiesel blend percentage in fuel. B100 gives the least heat release rate value of all test fuels due to its lower calorific value.

Fig 5.4.4: Heat release rate with crank angle for different blends of Grape Seed Biodiesel & Diesel

5.4.5 Nitrogen Oxide Emissions

Fig 5.4.5: Oxides of Nitrogen with brake power for different blends of Grape seed Biodiesel & Diesel
Figure 5.4.5 shows the variation of oxides of Nitrogen emissions with brake power for grape seed biodiesel blends and diesel in comparison with diesel. The NO\textsubscript{x} emissions at 80% engine load for diesel, biodiesel blends B25, B50, B75 and B100 are 1135, 1192 ppm, 1226 ppm, 1265 ppm, 1275 ppm. B25 blend NO\textsubscript{x} emissions are less compared to other biodiesel blends but slightly higher compared to diesel. Due to high viscosity of biodiesel it results in advance injection, earlier combustion of fuel and higher oxygen content enhancing combustion giving out higher heat release rates. With increased inside cylinder temperatures NO\textsubscript{x} emissions tend to increase. It is noticed that NO\textsubscript{x} emissions are increasing with increasing blend percentage of biodiesel.

5.4.6 Hydrocarbon Emissions

![Graph showing hydrocarbon emissions vs brake power for different blends of grape seed biodiesel and diesel.]

Fig 5.4.6: Hydrocarbon emissions with brake power for different blends of Grape Seed Biodiesel & Diesel

Figure 5.4.6 demonstrates the variation of hydrocarbon emissions with brake power for grape seed biodiesel blends and diesel in comparison with diesel. It is seen that hydrocarbon (HC) emissions are increasing with increasing load. Hydrocarbon emissions at 80% engine load for B25, B50, B75, B100 are 73.4ppm, 73.0 ppm, 73.5 ppm, 70.8 ppm which are less compared to diesel HC emissions value of 76.4 ppm.
With increasing blend percentage of biodiesel HC emissions are reducing due to better combustion of injected fuel with less traces of un burnt fuel in the engine cylinder.

5.4.7 Carbon Monoxide Emission

Fig 5.4.7: CO emissions with brake power for different blends of Grape Seed Biodiesel & Diesel

Figure 5.4.7 shows the variation of carbon monoxide (CO) emissions with brake power for grape seed biodiesel blends and diesel in comparison with diesel. CO emissions are constant for all test fuels upto half load on engine but gradually increasing towards full load operation of engine. CO emissions at 80% engine load in percentage of volume for diesel, B25, B50, B75 and B100 are 0.16%, 0.13%, 0.12%, 0.11% and 0.10% respectively. B25 blend CO emissions are less compared to diesel due to less carbon compounds and more of oxygen in biodiesel gives more carbon dioxide gas rather than CO emissions.

5.4.8 Smoke Emissions

Figure 5.4.8 shows the variation of smoke emission with brake power for grape seed biodiesel blends and diesel in comparison with diesel. Diesel smoke emissions at 80% engine load is 64.2 HSU and for B25, B50, B75 and B100 grape
seed biodiesel blends smoke emissions are 61.1 HSU, 59.6 HSU, 60.1 HSU and 58.8 HSU. Biodiesel is derived from plant material so they are rich in oxygen content their by enhancing combustion ultimately reducing smoke emissions compared to diesel.

Fig 5.4.8: Smoke emissions with brake power for different blends of Grape Seed Biodiesel & Diesel

From the graphs and results it is noticed that B25 blend of grape seed biodiesel (obtained by catalytic cracking of grape seed oil with zirconia as catalyst) fuelled to a diesel engine gives better performance, combustion characteristics and reduced emissions compared to other blends. So catalytic cracking process proves to be faster process of producing biodiesel compared to transesterification with better engine performance except a slight increase in nitrogen oxide emissions.

The second part of this chapter is all about mango seed biodiesel which is also divided into four sections, first section is about results and discussion of performance, combustion and emission characteristics of diesel engine fuelled with diesel and blends of methyl esters of mango seed oil obtained by transesterification process of mango seed oil later followed by other three sections of mango seed biodiesel produced by catalytic cracking process with three different catalysts. Graphs are plotted for brake thermal efficiency and specific fuel consumption variations with
changes in load, peak cylinder pressure and heat release rate with varying crank angle, various emissions with variation in load based upon engine output data. Results are analysed and discussed with possible reasons for the variations.

5.5 Methyl Esters of Mango Seed Oil (Transesterification Process)

5.5.1 Brake Thermal Efficiency

![Brake thermal efficiency graph]

**Figure 5.5.1:** Brake thermal efficiency with brake power for different blends of MEMSO & Diesel

Figure 5.5.1 shows the variation of brake thermal efficiency with brake power for methyl esters of mango seed oil (MEMSO) blends B25 (25% biodiesel and 75% diesel) B50, B75, B100 in comparison with diesel. Brake thermal efficiencies of B25, B50, B75 and B100 are 25.25%, 24.52%, 23.41% and 22.54% when compared to diesel brake thermal efficiency 26.89% at 80% engine load. It is observed that brake thermal efficiency of B25 is 25.25% and is close to that of diesel among all other blends. This is due to better atomization of B25 as compared to other blends of biodiesel. Better atomization leads to better vapourisation of fuel which enhances combustion process ultimately increasing break thermal efficiency. B100 brake thermal efficiency is less due to increased viscous nature of biodiesel.
5.5.2 Specific Fuel Consumption

The variation of specific fuel consumption with brake power for MEMSO blends in comparison with diesel is shown in figure 5.5.2. Fuel consumption of the engine is decreasing for all test fuels on increasing loads, the combustion is improved due to higher in-cylinder temperature which partially improves fuel air mixing process after successive working of engine. It is observed that the specific fuel consumption of diesel is 0.2896 kg/kW-h at 80% engine load. The specific fuel consumption of B25, B50, B75 and B100 are 0.3518 kg/kW-h, 0.3522 kg/kW-h, 0.3651 kg/kW-h, 0.3785 kg/kW-h respectively. Specific fuel consumption of all biodiesel blends is slightly more because more fuel is injected due to its high density. B100 specific fuel consumption is more due to injection of more fuel to maintain power output.

Fig 5.5.2: Specific fuel consumption with brake power for different blends of MEMSO & Diesel
5.5.3 Cylinder Pressure

![Cylinder Pressure Diagram]

Figure 5.5.3 shows the variation of cylinder pressure with brake power for MEMSO blends in comparison with diesel. Peak cylinder pressure at 80% engine load obtained for diesel is 63.26 bar where as peak cylinder pressures for B25, B50, B75 and B100 are 55.85 bar, 54.87 bar, 53.68 bar, 52.74 bar respectively. The peak cylinder pressures for B25 blend is higher to that of other blends at the same operating conditions. The reason for higher peak pressure of the B25 is high calorific value and proper burning rate when compared to other blends. Lower calorific value of B100 blend is the reason for its lowest peak cylinder pressure.
### 5.5.4 Heat Release Rate

![Graph showing heat release rate with crank angle for different blends of MEMSO & Diesel](image)

Figure 5.5.4 shows the variation of heat release rate with crank angle for MEMSO blends in comparison with diesel. By analysis of figure, at 80% engine load it is observed that heat release rate for diesel, B25, B50, B75 and B100 are 125.34 kJ/ m³ deg, 112.58 kJ/ m³ deg, 111.98 kJ/ m³ deg, 110.53 kJ/ m³ deg, 108.35 kJ/ m³ deg respectively. B25 heat release rate of 112.58 kJ/ m³ deg is highest of all other blends. This is due to more fuel accumulation in the ignition delay period, which releases the maximum heat as it is having calorific value close to diesel value. B100 gives the least heat release rate due to its lower calorific value.
5.5.5 Nitrogen Oxide Emissions

![Graph showing oxides of nitrogen emissions for different blends of MEMSO & Diesel]

Figure 5.5.5 shows the variation of oxides of Nitrogen emission with brake power for MEMSO blends and diesel in comparison with diesel. The NO\textsubscript{x} emission for diesel at 80% engine load is 1135 ppm where as for B25, B50, B75 and B100 are 1065 ppm, 1045 ppm, 995 ppm, 958 ppm respectively. It is noticed that NO\textsubscript{x} emissions are more for diesel compared to biodiesel blends. NO\textsubscript{x} emissions are influenced with cylinder temperatures. Diesel engine with B25 blend fuel emitted less NO\textsubscript{x} emissions due to lesser in cylinder temperatures. NO\textsubscript{x} emissions are decreasing with increasing blend percentage of biodiesel because of their lower heat release rates compared to diesel and also biodiesel helps in proper lubrication of moving engine parts of cylinder reducing friction resulting in lesser cylinder temperatures.

5.5.6 Hydrocarbon Emissions

Figure 5.5.6 shows the variation of hydrocarbon emissions with brake power for MEMSO blends and diesel in comparison with diesel. It is observed that hydrocarbon (HC) emissions are increasing with increasing load. Hydrocarbon emissions at 80% engine load for diesel, biodiesel blends B25, B50, B75, B100 are
76.4 ppm, 80.0 ppm, 83.6 ppm, 85.9 ppm, 90.1 ppm respectively. B25 has more HC emissions due to injection of more fuel to develop near similar power output in comparison with diesel or due to more density some part of fuel escaping unburnt because of flame quenching at the cylinder walls. With increasing percentage of biodiesel in diesel there is increment in hydrocarbons emissions.

Fig 5.5.6: Hydrocarbon emissions with brake power for different blends of MEMSO & Diesel
5.5.7 Carbon Monoxide Emissions

![Graph showing CO emissions with brake power for different blends of MEMSO & Diesel](image)

Figure 5.5.7: CO emissions with brake power for different blends of MEMSO & Diesel

Figure 5.5.7 shows the variation of carbon monoxide (CO) emissions with brake power for MEMSO blends and diesel in comparison with diesel. CO emissions are constant at part loads but there is gradual increment towards full load operation. CO emissions at 80% engine load in percentage of volume for diesel, B25, B50, B75 and B100 are 0.16%, 0.14%, 0.13%, 0.13% and 0.12% respectively. Diesel engines are designed to operate on lean side of stoichiometric so CO emissions from diesel engines are less due to very lean air-fuel mixtures and added to this biodiesel blends CO emissions are slightly lesser in comparison to diesel.
5.5.8 Smoke Emissions

Figure 5.5.8 shows the variation of smoke emission with brake power for MEMSO blends and diesel in comparison with diesel. Smoke emissions are increasing with increase in load for all test fuels. Diesel smoke emissions at 80\% engine load are 64.2 HSU, at the same load MEMSO blends B25, B50, B75 and B100 smoke emissions are 65.3 HSU, 67.1 HSU, 66.8 HSU and 69.2 HSU. For B25 blend smoke emissions are slightly more compared to engine fuelled with diesel, due to injection of more fuel effecting air fuel ratio resulting in unpleasant black smoke in the exhaust. Smoke emissions are increasing with increase in biodiesel blend percentage in diesel.

Mango seed methyl esters when fuelled to diesel engine with different blends, B25 blend is giving closer engine performance, combustion characteristics, with a reduced NOX, CO, emissions and with a slight increase in HC and smoke emissions compared to diesel fuel. It shows mango seed methyl esters in small proportions can be blended with diesel for operating diesel engines.
5.6 Mango Seed Biodiesel (Catalytic Cracked Mango Seed Oil with Alumina as Catalyst)

5.6.1 Brake Thermal Efficiency

Fig 5.6.1: Brake thermal efficiency with brake power for different blends of Mango Seed Biodiesel & Diesel

Figure 5.6.1 shows the variation of brake thermal efficiency with brake power for mango seed biodiesel (obtained by catalytic cracking of mango seed oil with alumina catalyst) blends B25 (25% biodiesel and 75% diesel), B50, B75, B100 in comparison with diesel. Brake thermal efficiencies of B25, B50, B75 and B100 are 25.61%, 25.34%, 24.99% and 24.54% when compared to diesel brake thermal efficiency of 26.89% at 80% engine load. It is observed that B25 brake thermal efficiency of 25.61% is very close to that of diesel among all other blends. This is due to better atomization of B25 with viscosity value closer to that of diesel value. It is also noticed that as blend percentage of biodiesel increases there is decrease in brake thermal efficiency. This is because of increasing viscosity of biodiesel leading to poorer atomization of biodiesel.
5.6.2 Specific Fuel Consumption

![Specific Fuel Consumption Graph](MSBD(Al2O3))

Fig 5.6.2: Specific fuel consumption with brake power for different blends of Mango Seed Biodiesel & Diesel

Figure 5.6.2 exhibits the variation of specific fuel consumption with brake power for mango seed biodiesel blends and diesel in comparison with diesel. It is observed specific fuel consumption of diesel is 0.2896 kg/kW-h at 80% engine load. Specific fuel consumption of B25, B50, B75 and B100 are 0.3284 kg/kW-h, 0.3359 kg/kW-h, 0.3608 kg/kW-h, 0.3619 kg/kW-h respectively. B25 blend specific fuel consumption value is least compared to other blends and closest value to diesel. Density value of B25 blend is close to diesel value so its combustion is near similar to diesel there by giving closer specific fuel consumption. The consumption of B100 is more compared to all test fuels this is because of its higher density more fuel is injected.

5.6.3 Cylinder Pressure

The variation of cylinder pressure with brake power for mango seed biodiesel blends and diesel in comparison with diesel is shown in figure 5.6.3. Peak cylinder pressure obtained at 80% engine load for diesel is 63.26 bar where as peak cylinder pressures for B25, B50, B75 and B100 are 58.67 bar, 57.29 bar, 56.82 bar, 56.10 bar respectively. The peak cylinder pressures for B25 with 58.67 bar is next to diesel.
B100 is having least peak cylinder pressure at the same operating conditions because of its high viscosity and slow burning rate.

Fig 5.6.3: Cylinder pressure with crank angle for different blends of Mango Seed Biodiesel & Diesel

5.6.4 Heat Release Rate

Fig 5.6.4: Heat release rate with crank angle for different blends of Mango Seed Biodiesel & Diesel
Figure 5.6.4 shows the variation of heat release rate with crank angle for mango seed biodiesel blends and diesel in comparison with diesel. By analysis of figure it is observed that at 80% engine load heat release rate for diesel is 125.34 kJ/ m$^3$ deg, and for B25, B50, B75, B100 heat release rate values are 118.29 kJ/ m$^3$ deg, 116.82 kJ/ m$^3$ deg, 114.28 kJ/ m$^3$ deg, 113.05 kJ/ m$^3$ deg respectively. B25 blend heat release rate on combustion is close to diesel with 118.29 kJ/ m$^3$ due to its closer calorific value to diesel. B100 gives the least heat release rate value of all test fuels.

5.6.5 Nitrogen Oxide Emissions

Fig 5.6.5: Oxides of Nitrogen with brake power for different blends of Mango Seed Biodiesel & Diesel

Figure 5.6.5 shows the variation of oxides of Nitrogen emission with brake power for mango seed biodiesel blends and diesel in comparison with diesel. The NO$_x$ emission for diesel is 1135ppm at 80% engine load and also for B25, B50, B75 and B100 blends NO$_x$ values are 1200 ppm, 1214 ppm, 1246 ppm, 1272 ppm respectively due to higher in cylinder temperatures and higher heat releases. It is noticed that NO$_x$ emissions are increasing with increasing blend percentage of biodiesel. Density increase causes late phase burning of biodiesel increasing exhaust temperatures resulting in increase of NO$_x$ emissions.
5.6.6 Hydrocarbon Emissions

Figure 5.6.6 shows the variation of hydrocarbon emissions with brake power for mango seed biodiesel blends and diesel in comparison with diesel. It is seen that hydrocarbon (HC) emissions are increasing with increasing load because of increase in difference of air-fuel ratio. Hydrocarbon emissions of diesel, biodiesel blends B25, B50, B75 and B100 at 80% engine load are 76.4 ppm, 73.8 ppm, 67.2 ppm, 69.0 ppm, and 71.2 ppm respectively. Diesel is giving higher emissions of hydrocarbons. HC emissions are getting reduced with increase in biodiesel percentage due to availability of oxygen for complete combustion of fuel. B100 is giving less HC emissions in comparison with all test fuels.

5.6.7 Carbon Monoxide Emission

Figure 5.6.7 shows the variation of carbon monoxide (CO) emissions with brake power for mango seed biodiesel blends and diesel in comparison with diesel. CO emissions at 80% engine load in percentage of volume for diesel, B25, B50, B75 and B100 are 0.16%, 0.14%, 0.12%, 0.13% and 0.11% respectively. CO emissions
with biodiesel fuel are decreasing due to conversion of CO to CO$_2$ with availability of oxygen molecules in the fuel.

Fig 5.6.7: CO emissions with brake power for different blends of Mango Seed Biodiesel & Diesel
5.6.8 Smoke Emissions

Figure 5.6.8 shows the variation of smoke emission with brake power for mango seed biodiesel blends and diesel in comparison with diesel. Diesel smoke emissions with 64 HSU are higher when compared to biodiesel blends B25, B50, B75 and B100 with the values of 61 HSU, 60 HSU, 60 HSU and 61 HSU at 80% engine load. Smoke emissions are higher at high loads as the air fuel ratio decreases with increasing engine loads. For biodiesel blends smoke emissions are decreasing due to presence of fairly good amount of oxygen content enhancing complete combustion of fuel.

From the analysis of results, B25 blend grape seed biodiesel (obtained by catalytic cracking of mango seed oil with alumina as catalyst) fuelled to a diesel engine gives brake thermal efficiency, specific fuel consumption, peak cylinder pressure and heat release rate that are near similar to diesel and the emissions HC, CO, smoke emissions are lesser with a slight increase in NOx emissions.
5.7 Mango Seed Biodiesel (Catalytic Cracked Mango Seed Oil with Zeolite as Catalyst)

5.7.1 Brake Thermal Efficiency

![Brake thermal efficiency with brake power for different blends of Mango Seed Biodiesel & Diesel](Image)

Fig 5.7.1: Brake thermal efficiency with brake power for different blends of Mango Seed Biodiesel & Diesel

Figure 5.7.1 depicts the variation of brake thermal efficiency with brake power for mango seed biodiesel (obtained by catalytic cracking of mango seed oil with zeolite catalyst) blends B25(25% biodiesel and 75% diesel), B50, B75, B100 in comparison with diesel. Brake thermal efficiencies of B25, B50, B75 and B100 are 25.51%, 25.12%, 24.80% and 24.41% when compared to diesel brake thermal efficiency of 26.89% at 80% load. It is observed that B25 brake thermal efficiency of 25.51% is next to that of diesel among all other blends. Increase of biodiesel percentage in fuel causes reduction in brake thermal efficiency. This is due to increase in viscous nature of biodiesel effecting fuel atomisation and combustion.
5.7.2 Specific Fuel Consumption

![Graph showing specific fuel consumption vs brake power for different blends of Mango Seed Biodiesel & Diesel](image)

Fig 5.7.2: Specific fuel consumption with brake power for different blends of Mango Seed Biodiesel & Diesel

Figure 5.7.2 shows the variation of specific fuel consumption with brake power for mango seed biodiesel blends and diesel in comparison with diesel. It is observed specific fuel consumption of diesel is 0.2896 kg/kW-h at 80% engine load. Specific fuel consumption of B25, B50, B75 and B100 are 0.3315 kg/kW-h, 0.3548 kg/kW-h, 0.3792 kg/kW-h, 0.3741 kg/kW-h respectively. B25 blend fuel consumption is close to diesel. The fuel consumption of B100 is more when compared to diesel to develop the same power output. This is because of lower calorific value of B100 and also due to its high density more fuel is injected in comparison with diesel.
5.7.3 Cylinder Pressure

![Cylinder Pressure Graph]

Fig 5.7.3: Cylinder pressure with crank angle for different blends of Mango Seed Biodiesel & Diesel

Figure 5.7.3 briefs the variation of cylinder pressure with brake power for mango seed biodiesel blends and diesel in comparison with diesel. Peak cylinder pressure obtained at 80% engine load for diesel is 63.26 bar where as peak cylinder pressures for B25, B50, B75 and B100 are 57.35 bar, 56.44 bar, 55.59 bar, 55.25 bar respectively. B25 blend peak cylinder pressure is next to that of diesel pressure. The peak cylinder pressures for all the blends are slightly lesser to that of diesel at the same operating conditions. The possible reasons for reduced pressure of the blends is high viscosity, low calorific value and slightly slow burning rate when compared to diesel.

5.7.4 Heat Release Rate

Figure 5.7.4 indicates the variation of heat release rate with crank angle for mango seed biodiesel blends and diesel in comparison with diesel. By analysis of figure it is observed that at 80% engine load heat release rate for diesel is 125.34 kJ/ m³ deg. B25, B50, B75 and B100 heat release rate values are 114.28 kJ/ m³ deg, 112.56 kJ/ m³ deg, 110.89 kJ/ m³ deg, 106.28 kJ/ m³ deg respectively. It is evident
that B25 blend heat release rate is next best value to diesel value compared to other blends. For biodiesel blends heat release rate values are lesser due to lower calorific values compared to diesel. B100 gives the least value of all test fuels.

Fig 5.7.4: Heat release rate with crank angle for different blends of Mango Seed Biodiesel & Diesel

5.7.5 Nitrogen Oxide Emissions

Figure 5.7.5 shows the variation of oxides of Nitrogen emission with brake power for mango seed biodiesel blends and diesel in comparison with diesel. The NO\textsubscript{x} emissions for biodiesel blends B25, B50, B75, B100 and diesel are 1212 ppm, 1249 ppm, 1269 ppm, 1295 ppm, 1135 at 80% engine load. NO\textsubscript{x} emissions are known to increase with high temperatures. It is noticed that NO\textsubscript{x} emissions are increasing with increasing blend percentage of biodiesel. B25 blend NO\textsubscript{x} emissions are slightly higher compared to diesel and lesser than other blends. Due to higher density of biodiesel more fuel gets injected into engine cylinder and leads to earlier combustion resulting in high temperatures.
Fig 5.7.5: Oxides of Nitrogen with brake power for different blends of Mango Seed Biodiesel & Diesel

5.7.6 Hydrocarbon Emissions

Fig 5.7.6: Hydrocarbon emissions with brake power for different blends of Mango Seed Biodiesel & Diesel
Figure 5.7.6 shows the variation of hydrocarbon emissions with brake power for mango seed biodiesel blends and diesel in comparison with diesel. Complete combustion of injected fuel reduces HC emissions. Hydrocarbon emissions are more for diesel with 76.4 ppm at 80% engine load. HC emissions of biodiesel blends B25, B50, B75 and B100 are 74.2 ppm, 70.5 ppm, 66.9 ppm, 63.9 ppm respectively which indicates that they are reducing on increasing blend percentage. Reason is complete combustion of fuel with availability of oxygen in biodiesel.

5.7.7 Carbon Monoxide Emissions

Fig 5.7.7: CO emissions with brake power for different blends of Mango Seed Biodiesel & Diesel

Figure 5.7.7 shows the variation of carbon monoxide (CO) emissions with brake power for mango seed biodiesel blends and diesel in comparison with diesel. CO emissions in percentage of volume at 80% engine load for B25, B50, B75 and B100 are 0.15%, 0.13%, 0.12% and 0.11% respectively. Diesel CO emissions are 0.16% in volume. CO emissions are decreasing with increasing biodiesel blend percentage, due to availability of oxygen improving conversion process of CO to carbon dioxide gas.
5.7.8 Smoke Emissions

Figure 5.7.8 shows the variation of smoke emission with brake power for mango seed biodiesel blends and diesel in comparison with diesel. Biodiesel blends smoke emissions for diesel, B25, B50, B75 and B100 are 64.2, 61.8 HSU, 59.9 HSU, 59.0 HSU and 58.0 HSU at 80% engine load. Smoke emissions are increasing with increasing in load for all test fuels. Biodiesel blends smoke emissions are decreasing with increase in blend percentage of biodiesel because of improved combustion process compared to diesel.

![Graph showing smoke emissions with brake power for different biodiesel blends and diesel](MSBD(ZSM-5)

It is observed that mango seed biodiesel produced by catalytic cracking of mango seed oil with zeolite catalyst when fuelled to diesel engine is giving closer engine performance, combustion characteristics and reduced HC, CO, smoke emissions with a slight increase in NOx emissions compared to diesel fuel. It shows its compatibility to be used as a fuel to diesel engine without any engine modifications.
5.8 Mango Seed Biodiesel (Catalytic Cracked Mango Seed Oil with Zirconia as Catalyst)

5.8.1 Brake Thermal Efficiency

The variation of brake thermal efficiency with brake power for mango seed biodiesel (obtained by catalytic cracking of mango seed oil with Zirconia catalyst) blends B25 (25% biodiesel and 75% diesel), B50, B75, B100 in comparison with diesel is given in figure 5.8.1. Brake thermal efficiencies of B25, B50, B75 and B100 are 25.43%, 24.89%, 24.70% and 24.22% when compared to diesel brake thermal efficiency of 26.89% at 80% engine load. Brake thermal efficiency of B25 is 25.43% which is very near to that of diesel. The reason is B25 blend close viscosity value to diesel fuel, near similar vaporization and combustion process occurs in engine cylinder. B100 brake thermal efficiency is least among all other blends.

Fig 5.8.1: Brake thermal efficiency with brake power for different blends of Mango Seed Biodiesel & Diesel
5.8.2 Specific Fuel Consumption

Figure 5.8.2 shows the variation of specific fuel consumption with brake power for mango seed biodiesel blends and diesel in comparison with diesel. Specific fuel consumption of diesel is 0.2896 kg/kW-h at 80% engine load and that of B25, B50, B75 and B100 blends are 0.3418 kg/kW-h, 0.3611 kg/kW-h, 0.3692 kg/kW-h and 0.3747 kg/kW-h respectively. B25 blend specific fuel consumption value is less when compared to other blends and it is next to that of diesel. Consumption of biodiesel fuel is more compared to diesel because of its high density, more fuel is injected to develop same power output. The fuel consumption of B100 is highest of all other blends to develop same power output.

Fig 5.8.2: Specific fuel consumption with brake power for different blends of Mango Seed Biodiesel & Diesel
5.8.3 Cylinder Pressure

Figure 5.8.3 shows the variation of cylinder pressure with brake power for mango seed biodiesel blends and diesel in comparison with diesel. Peak cylinder pressure for diesel at 80% engine load is 63.26 bar where as peak cylinder pressures for B25, B50, B75 and B100 are 56.28 bar, 55.75 bar, 54.79 bar and 53.88 bar respectively. The peak cylinder pressures for B25 is closer to diesel value. Other blends are lesser to that of B25 at the same operating conditions. Among all test fuels B100 peak cylinder pressure is least due to its high density and lowest calorific value.
5.8.4 Heat Release Rate

Figure 5.8.4 briefs the variation of heat release rate with crank angle for mango seed biodiesel blends and diesel in comparison with diesel. Heat release rate values at 80% engine load for diesel, B25, B50, B75 and B100 are, 125.34 kJ/ m$^3$ deg, 113.62 kJ/ m$^3$ deg, 112.43 kJ/ m$^3$ deg 111.35 kJ/ m$^3$ deg and 110.53 kJ/ m$^3$ deg respectively. B25 blend with heat release rate of 113.62 kJ/ m$^3$ deg is next to that of diesel heat release rate value. By analysis it is observed that heat release rates are decreasing with increase in biodiesel blend percentage in fuel. B100 gives the least heat release rate value of all test fuels due to its lower calorific value.
5.8.5 **Nitrogen Oxide Emissions**

![Graph showing nitrogen oxide emissions vs brake power for different blends of Mango Seed Biodiesel & Diesel]

Fig 5.8.5: Oxides of Nitrogen with brake power for different blends of Mango Seed Biodiesel & Diesel

Figure 5.8.5 shows the variation of oxides of Nitrogen emission with brake power for mango seed biodiesel blends and diesel in comparison with diesel. The NO$_x$ emission at 80% engine for diesel, B25, B50, B75 and B100 are 1135 ppm, 1220 ppm, 1259 ppm, 1268 ppm, 1298 ppm respectively. B25 blend NO$_x$ emissions are lesser compared with other blends but slightly higher than diesel. Higher in cylinder temperatures are cause for higher NO$_x$ emissions. It is noticed that NO$_x$ emissions are increasing with increasing blend percentage of biodiesel.

5.8.6 **Hydrocarbon Emissions**

Figure 5.8.6 shows the variation of hydrocarbon emissions with brake power for mango seed biodiesel blends and diesel in comparison with diesel. It is seen that hydrocarbon emissions are increasing with increasing load. Hydrocarbon emissions at 80% engine load for B25, B50, B75, B100 are 75.6 ppm, 72.3 ppm, 70.8 ppm, 67.5 ppm which are less compared to diesel HC emissions value of 76.4 ppm. With increasing blend percentage of biodiesel HC emissions are reducing due to better
combustion of fuel with availability of more oxygen reducing less un burnt fuel escaping out from the engine cylinder.

**Fig 5.8.6: Hydrocarbon emissions with brake power for different blends of Mango Seed Biodiesel & Diesel**

**5.8.7 Carbon Monoxide Emissions**

Figure 5.8.7 shows the variation of carbon monoxide (CO) emissions with brake power for mango seed biodiesel blended with diesel in comparison with diesel. CO emissions at 80% engine load in percentage of volume for diesel, B25, B50, B75 and B100 are 0.16%, 0.15%, 0.14%, 0.13% and 0.12% respectively. B25 blend CO emissions are less compared to diesel due to less carbon compounds and more of oxygen in biodiesel gives more carbon dioxide gas rather than CO emissions.
Fig 5.8.7: CO emissions with brake power for different blends of Mango Seed Biodiesel & Diesel

5.8.8 Smoke Emissions

Fig 5.8.8: Smoke emissions with brake power for different blends of Mango Seed Biodiesel & Diesel
Figure 5.8.8 shows the variation of smoke emission with brake power for mango seed biodiesel blended with diesel in comparison with diesel. Diesel smoke emissions at 80% engine load is 64.2 HSU and for B25, B50, B75 and B100 grape seed biodiesel blends smoke emissions are 61.9 HSU, 60.6 HSU, 60.8 HSU and 59.1 HSU. Biodiesel is derived from plant material so they are rich in oxygen content their by enhancing combustion ultimately reducing smoke emissions compared to diesel.

From the graphs and results it is noticed that B25 blend of mango seed biodiesel produced by catalytic cracking of mango seed oil with zirconia as a catalyst can be a good alternative to diesel because of its closer engine performance, combustion characteristics and reduced emissions compared to diesel.