CHAPTER 5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

The use of biodiesel in DI engines is studied extensively in the past. The best blend was reported as B20 in most of the cases. Fuel injection technology in CRDI technology is different due to higher pressures used. So the combustion characteristics may be totally different. In the present study, the CI engine working under CRDI technology is tested with several blends of biodiesel for the emission and performance characteristics and compared with that with Diesel. Fuels used for study are Jatropha animal fat biodiesel and tyre pyrolitic oil. In this results are discussed as follows
5.2 JATROPHA BIODIESEL

Brake specific fuel consumption (BSFC) found to vary with respect to load for different blends of jatropha and diesel. The variation is shown in Figure 5.1. It is clear that for higher blends of B40 and B50 brake specific fuel consumption (BSFC) is relatively high. B50 have maximum BSFC. Further BSFC decreased, in all the cases, as the load increased. This is the trend till 60% of the load. BSFC was minimum for B30 blends. BSFC increased with blending percentage which is accompanied by a decrease in efficiency.

BSFC initially decreased, with the increase in load. However, BSFC increased at higher loads, Lowest BSFC (0.23kg/kWh) is reported for B30. The BSFC was higher for B40 and B50 probably due to the lower calorific value of the fuel blend. Figure 5.2 shows the variation of thermal efficiency for various blends. The thermal efficiency was found to decrease with increasing Biodiesel share. With an increase in load the thermal efficiency increased, reached a maximum, followed by a drop. Maximum thermal efficiency (36.1%) occurred corresponding to 80% of rated load.

It is clear that the lower calorific value of jatropha biodiesel leads to an increase in fuel consumption to keep the same energy input to the engine. The near total combustion of bio diesel due to the presence of inherent oxygen causes lower brake specific fuel consumption up to B30 biodiesel blends. The variation of CO gas in exhaust for different blends is shown in Figure 5.3. CO in the exhaust decreased at higher loads compared to diesel systems.
Figure 5.1 Variation of BSFC with load - Jatropha biodiesel

Figure 5.2 Variation of thermal efficiency with load - Jatropha biodiesel
The results show that with the increase of engine load, CO gas in exhaust decreases for blends. The lowest value of CO gas in exhaust is for the B30 blend. At lower loads, CO gas in exhausts was more or less same for different blends. The major reason for this could be the near total combustion and better flame propagation in the blend of the biodiesel in the common rail direct injection engines. Figure 5.4 shows HC emission for different blends of Jatropha and diesel. It is observed from the Figure that, at part loads, HC emissions are higher. But, at higher loads the same tend to decrease for all blends. This can be attributed to the lack of oxygen, which results, in the engine operation at higher equivalence ratio.

Figure 5.4 shows variation of HC with load. The increase in percentage of jatropha oil in the blends up to B30 causes the HC emissions to increase. HC emission for B50 was less compared with B30. Results shows that the jatropha based biodiesel blended with diesel at30% exhibits better emission and engine performance characteristics than with the diesel. The thermal efficiency of 30% and lower blends was higher than that of diesel. The main reason for this is the presence of oxygen in the hydro carbon chain, which improves the burning features. Two conflicting parameters that control burning characteristics are oxygen content in fuel atomic chain and calorific value of blends.

It can be concluded that the dominating effect of increased oxygen content over the decrease in calorific value is the reason for superior performance while using B30. The variation of the exhaust gas temperature of the engine for various blends is shown in Figure 5.5. The comparison with diesel is also shown at various loads. In general, the temperature varies from 140°C to 300°C for various loads for B30. While the B30 shows highest temperature, use of diesel leads to lowest temperature.
Figure 5.3 Variation of CO emission with load - Jatropha biodiesel

Figure 5.4 Variation of HC with load - Jatropha biodiesel
Thermal efficiency depends on different parameters like calorific value of fuel blends, presence of oxygen inside the biofuel chain and the penetration of oxygen from air. Besides the residence time of fuel blends inside the combustion chamber also have a role in combustion characteristics. Depending on the quantity of blending the required residence time can vary. Thus the variation of thermal efficiency and quantity of CO\(_2\) in the exhaust cannot be correlated for varying blends. Uncertainty in the temperature measurement was ±0.15%. Figure 5.3 shows that, the lowest CO gas in exhausts was observed for B30 blend. The CO gas in exhaust varies from 5.72 to 16.98 gm/KWh with B30 having the lowest value (33% lower while compared with diesel of emissions at higher loads.

The main reason that can be attributed to this is the total combustion. CO\(_2\) gas in exhausts for lower blend concentrations are low as shown in Figure 5.7 (CO\(_2\) gas in exhaust for different blends of jatropha and diesel). CO\(_2\) gas in exhaust varies from 1.13 to 2.33 kg/KWh. B30 has highest CO\(_2\) gas in exhaust. Figure 5.6 shows the O\(_2\) gas in exhaust for different blends of jatropha and diesel. O\(_2\) gas in exhaust decreases with increase in load. O\(_2\) gas in exhaust varies from 6.69 to 2.77 kg/KWh.
Figure 5.5. Variation of temperature with load - Jatropha biodiesel

Figure 5.6. Variation of $O_2$ emission with load - Jatropha biodiesel
Figure 5.7 Variation of CO$_2$ emission with load - Jatropha biodiesel

Figure 5.8 Variation of NOx emission with load - Jatropha biodiesel
Lowest Oxygen in exhausts corresponds to highest loading condition with the blend B30. As the loading increases, the O$_2$ gas in exhaust decreases in all cases as shown in Figure 5.6. Perfect oxidation takes place in the case of B30 mixture so the O$_2$ content in the exhaust is less compared with other blending percentage. Further, the exhaust temperature is also high, as was shown in Figure 5.5. Figure 5.8 shows the NO$_X$ gas in exhaust for different blends of jatropha and diesel. In the present study, the NOx gas in exhaust is high while using bio diesel blends. For lower loads, up to 60%, the NOx value is the highest for B50. It changes from 100ppm to 354ppm. At higher loads, B20 is found to have an increased nitrogen oxide emissions and the value reached highest of 354ppm at 100 % load. The reason can be attributed to the temperature rise which reached 291°C at 100 % load.

Although most of the studies reported an increase of nitrogen oxide (NOx) gas in exhaust with biodiesels (Kenneth.Proc et.al (2006), Fraer. R et.al (2005), Monyem. et.al (2001), Lin. Y et.al (2008), Altiparmak et.al (2007), Utlu et.al (2008), few also reported a decrease of NOx gas in exhaust (Basha.S.A et.al (2009), Canakci.et.al (2007), Haas et.al (2001), Kegl. B et.al (2008), Arregle et al. (1991)). Different methods are used to reduce NOx gas in exhaust. Some researchers hydrogenated the original Jatropha-oil prior to trans-esterification. The reductions in NOx gas in exhausts were noticed mainly during low engine speed. Knothe et al. (2008) compared diesel with oleic methyl ester (C181), palmitic methyl ester (C160) and lauric methyl ester (C120) in a six cylinder engine under transient conditions. They observed that for the saturated palmitic and lauric esters NOx gas in exhausts reduced respectively by 4% and 5%, whereas for the oleic ester a 6% increase was noticed (Nabi et.al (2009)). At elevated temperatures, oxidation of biodiesel is accelerated and thereby influencing the emission and
performance. Figure 5.5 and Figure 5.8 show that with the increase of biodiesel blend the temperature of exhaust gas and NOx gas in exhaust rises. The percentage of oxygen in the fuel is high at higher blending causing an increase in the oxidation of the fuel. This leads to a rise in the exhaust temperature which causes an increase of nitrogen oxides in the exhaust.

Monyemand Van Gerpen (2001) found that exhaust emissions were reduced considerably with biodiesel undergone oxidation, while nature of engine performance was similar for both oxidized and un-oxidized biodiesel. They also observed that out of, un-oxidized biodiesel and diesel fuels, oxidized biodiesel had less CO and HC emissions, but higher NOx gas in exhaust. It is concluded that the rise in cetane number from 51.1 (un-oxidized) to 72.7 (oxidized) was the reason for reduction in emission. In a recent study, a slightly different behaviour of oxidation was observed, where the reason was stated to be the use of an antioxidant. Its main purpose was however to minimize the BSFC by reducing oxidation.

Lin et al. suggested using biodiesel-water emulsions to decrease NOx gas in exhausts, but no experimental confirmation was provided in that study. The CO gas in exhaust decreased in the case of rapeseed oil methyl ester blends. NOx and smoke also decreased while increasing the inlet temperature. EGR is the one of the best method to reduce NOx gas in exhaust. Methods to reduce NOx gas in exhausts are adding additives, methanol or fumigated methanol, increasing air inlet temperature and by using Exhaust Gas Recirculation (EGR). Other ways to reduce the NOx

Urea solution may be sprayed and Cu-zeolite based SCR unit is fixed downstream. In case of the short distance between spray and zeolite a very uneven distribution of reducing agent was achieved over the cross-section of
the catalyst entrance. The mixing of urea spray and exhaust gas could be enhanced by the modification of the nozzle geometry to produce a broader spray cone. This causes variation of the injection angle which in turn induces turbulence. It is also possible to increase the injection pressure, which reduces the droplet size and results in a homogeneous SCR performance. NOx gas in exhausts is the most detrimental of all the gases produced by the exhaust of a diesel engine.

Various legislations exists which aim at decreasing NOx. Such legislations can be branched into two categories viz. thermal NOx and NOx. Thermal NOx, the primary source of NOx formation, occurs at temperatures above 1500 °C, and as the temperature rise, the rate of formation rises rapidly. The major reactions producing thermal NOx are described in Zeldovich Mechanism. The use of Cu-ZSM5, urea injection leads to a remarkable fall in the NOx levels for biodiesels. Several studies have been done to investigate the effect of the biodiesel on exhaust emissions as compared to those of diesel (Liam Brennan and Philip Owende. (2010).

Previous research concluded that the best blend for DI engines is B20. The present work reports results from a CRDI engine. The optimum blend for CRDI engine is 30% blend (B30) which differs from the value for a DI engine (B20). The main reason for the variation of results related to best blend between DI and CRDI engines is due to different fuel injection pressure and finer sprays that leads to finer mixing in the CRDI engines and consequent modification of the combustion features.
5.3 ANIMAL FAT BIODIESEL

Figure 5.9 shows that BSFC is high for higher blends of B40 and B50 with B50 having maximum BSFC. It shows that increase in load results in decreased BSFC till 60% load. Higher blends of B40 and B50 having high BSFC with B50 having maximum BSFC. BSFC initially decreases with increase of load. But, at higher loads again the BSFC increases. Lowest BSFC (0.23 kg/kWh) was found at B30.

Thermal efficiency was found to decrease with increasing blending percentage for higher blends of B40 and B50. Lower BSFC was observed while the engine is running with B30 blend. This is due to the lower calorific value of animal fat biodiesel which leads to increased volumetric fuel consumption in order to maintain similar energy input to the engine.

Perfect oxidation due to higher oxygen content in the bio diesel leads to lower BSFC up to B30. BSFC is high for B40 and B50 compared with B30 because of lower calorific value of the fuel blend. The thermal efficiency increases with load Figure 5.10 reaches maximum followed by a decrease. It is clear from Figure 5.10 that maximum efficiency is for B30.

However for higher blending, the efficiency decreases. Maximum value of thermal efficiency (35.4%) was found at 80% of rated load. Figure 5.11 shows that biodiesel blends shows decrease in CO emission at higher rated loads compared to that of diesel. Further as the engine load increases, CO emission decreases for biodiesel blends and CO$_2$ increases (Figure 5.12)
Figure 5.9 Variation of BSFC with load – Animal fat biodiesel

Figure 5.10 Variation of thermal efficiency with load – Animal fat biodiesel
Figure 5.11 Variation of CO emission with load – Animal fat biodiesel

Figure 5.12 Variation of CO₂ emission with load – Animal fat biodiesel
CO emission is the least for the B30 blend. While running at low loads, CO emissions were nearly similar for these fuels, but at higher loads, CO emissions were lower for the biodiesel blends compared to that of diesel. This can be attributed to the better burning characteristics and uniform flame propagation in the mixture of biodiesel in the CRDI engines. Figure 8 shows that HC emissions are higher at part loads, but tend to decrease at higher loads for all blends.

This is due to lack of oxygen resulting from engine operation at higher equivalence ratio. Biodiesel fuel operation produces lower HC emissions at higher loads. HC emission for animal fat biodiesel is slightly higher than the emission by using animal fat bio diesel. Thus the experimental results suggest that biodiesel produced from the animal fat oil blended with diesel at a percentage of 30 improves engine performance and have better emission characteristics than with the mineral diesel. The thermal efficiency while using of blends up to B30 was higher than that of diesel.

The main reason is the presence of oxygen in the fuel molecules which improves the combustion and oxidation characteristics Therefore, thermal efficiency was found to be higher for higher blend concentrations up to B 30 compared to that of mineral diesel. The better performance of B30 blends may be attributed to the dominating effect of increased oxygen content over decrease in CV.
Figure 5.13 variation of HC emission with load – Animal fat biodiesel

Figure 5.14 Variation of \( \text{O}_2 \) emission with load – Animal fat biodiesel
Figure 5.15 Variation of exhaust temperature with load – Animal fat BD

Figure 5.16 Variation of NOx emission with load – Animal fat biodiesel
Figure 5.15 shows the variation of exhaust gas temperature of the engine while operating with various blends and are compared to that of diesel at various loads. The temperature in general varies from 120°C to 320°C for various loads for B30. The highest and lowest temperatures are observed for B30 and diesel. Uncertainty in the measurement temperature was ±0.15 percentage.

Lowest CO emissions were observed for B30 blend Figure 5.10. The CO emission varies from 0.02% vol to 0.03% vol with B30 having the lowest (32% less comparing with diesel) emissions at higher loads. This is due to the total combustion of the feed. CO₂ emissions for lower blend concentrations were less, Figure 5.12 CO₂ emission varies from 2.4% vol to 7.4% vol. B30 have highest CO₂ emission, O₂ emission decreases with increase in load. O₂ emission varies from 17.32% vol to 10.23% vol.

Lowest O₂ emissions were observed at highest loading condition of the blend B30. HC emissions decreases with the increase in load Figure 5.13 at higher loads HC emissions are lower due to availability of more oxygen. It can be noticed that with the increase in proportion of animal fat in biodiesel up to B30, the HC emissions decreases and coming closer to that of Diesel (Figure 3.13). HC emission for B40 and B50 are higher, compared to that of Diesel.

This is in tune with Figure 5.14 which shows that, O₂ levels are lowest while using B30 especially at higher loads. This indicates that an optimum blending and O₂ availability under these conditions is the reason for lowest HC emissions. As the quantity of biodiesel increases to B40 and B50, O₂ level increases. As seen from Figure, the exhaust temperature is also higher corresponding to B30 Figure 5.15. This further indicates that an optimized
combustion and performance as well as lowest emissions takes place while the engine runs with B30. Similar trend is reported by MagínLapuerta et al (2008) in direct injection engine with biodiesel derived from animal fat. This may be attributed to the presence of better oxygenated biodiesel molecule, higher cetane number of biodiesel and consequent reduction in delay time and lower final distillation points compared to Diesel. Different chain length in chemical structure can be one of the reasons. The results of NOx variation is shown in Figure 5.16.

In the present study NOx emission is high while using bio diesel blends. For lower loads up to 60%, the NOx value is higher for B50. It changes from 56ppm to 313ppm. At higher loads, B20 is found to have an increased NOx and the value shoot to 350ppm. It can be related to the temperature rise which shoots to 291° C. Though a large number of studies have reported the increase of nitrogen oxide NOx emission with biodiesels (Teresa M et. al (2010), Basha. S. A et al. (2009), Raheman. H et. al (2007), Murillo. S et. al, (2007), McCromick et.al. (2005) a few others have reported about the decrease in NOx emission (Utlu et. al (2008), Kegl. B. (2008) the explanations put forward by different researchers are widely varying. Figure 5.15 and Figure 5.16 shows that, with the increase of biodiesel blend, the exhaust gas temperature and NOx emission increases.

At higher blending percentage, the amount of oxygen in the fuel is high so the oxidation of the fuel increases. This causes a rise in the exhaust temperature which leads to increase of NOx emission. Monyem and Van Gerpen et. al (2001) found that exhaust emission considerably reduced with oxidized biodiesel, while both oxidized and unoxidized biodiesel exhibited almost similar engine performance. It is concluded that, compared to
unoxidized biodiesel and diesel fuels, CO emissions is less of about 15% and 28% respectively.

HC emissions were reduced by 21% and 54% with oxidised biodiesel compared with unoxidised biodiesel and diesel. It is reported that the NOx emissions with oxidised biodiesel is 13% higher than that with diesel fuel. Unoxidised biodiesel had about 14% higher NOx compared with diesel. They explained that the reduction in emission of oxidized biodiesel compared to unoxidized was associated with increase of cetane number from 51.1 (unoxidized) to 72.7 (oxidized) In general, most investigations reported an optimum blend of B20 for DI engine (Jilin Xuea et.al (2011) .In the present investigation on CRDI engine, the optimum blend is found to be B30. The reason for the deviation may be due to finer injection systems present in the CRDI technology and consequent improvement in combustion characteristics. Thus it is clear that the engines with CRDI technology can run with higher percentages of biodiesel (B30) while maintaining better performance and emission characteristics.

The CRDI engine is tested with several blends of biodiesel produced from animal fats, for the performance and emission characteristics and compared with that with Diesel. Animal fat based on biodiesel blend (30%) was found even better than that of diesel.

The test is done at different loads and under constant speed (2800 rpm). Results shows that, for compression ignition engines with CRDI technology, animal fat biodiesel is found to be an assuring alternative fuel. Hence without major modification in the engine, it can be considered as a direct substitute for replacement of diesel fuel. For the blend with more than
30% animal fat biodiesel content BSFC and exhaust gas temperatures was found to be higher compared to diesel as fuel.

Thermal efficiency was higher for animal fat biodiesel up to 30 percentage blending compared to diesel. CO and O$_2$ were lower for B 30 compared to that of diesel. Emission parameters such as CO$_2$, NO$_x$, and HC were found to increase with increasing percentage of animal fat biodiesel in the fuel blends compared to diesel. Therefore, for an optimum performance of a CRDI engine blending animal fat biodiesel can be used in CRDI engines at 30 percentages. However to regulate carbon deposits formed during long term usage of biodiesel blends, modified maintenance schedule may be followed. The findings from the present study can be used for optimising the performance of new generation engines with the CRDI technology. The large scale use of animal fat based biodiesel will be helpful in solving the pollution generated from meat waste.

5.4 TYRE PYROLYTIC OIL

The change of brake specific fuel consumption (BSFC) with change of load for various blends of tyre oil and diesel is shown in Figure. 5.17 It can be seen that for higher blends of B40 and B50, B50 having maximum BSFC. Further, in all the cases, as the load increases, BSFC decreases, till 60% load. BSFC is minimum for B30 blends. The increase of blending percentage associated with the increase of BSFC and decrease of efficiency.

BSFC initially decreases with raising the load. However, further increase in load causes BSFC to rise. BSFC (0.24 kg/kWh) is lowest at B 30. Lower BSFC was observed when the engine is operated with the blend of
B30. The lower heating value of the fuel blend causes increase of BSFC for B40 and B50 compared to that of B30.

For the higher blends, the thermal efficiency was found to decrease with increasing Biodiesel share, as shown in Figure 5.18. However, an increase in load shows an increase in thermal efficiency, which reaches a maximum then decreases. From the graph. The maximum value of efficiency is obtained with B 30 blends. Maximum thermal efficiency (35.9%) occurred corresponding to 80% of rated load. Lower heating value of Tyre oil biodiesel causes an increase in fuel consumption, so that same energy input is supplied to the engine.

The reason for better performance for B30 blend is due to the complete combustion due to increased oxygen content in the bio diesel. This resulted in lower brake specific fuel consumption. Figure 5.19 shows CO gas in exhaust for different blends. It shows a decrease in CO gas in exhaust at higher loads compared to diesel systems. The results shows that, with the increase of engine load, CO gas in exhaust decreases for blends. The CO gas in exhaust is the lowest for the case of B30 blend. At lower loads, CO gas in exhausts was more or less same for different blends.
Figure 5.17 Variation of BSFC with load – Tyre pyrolytic oil

Figure 5.18 Variation of thermal efficiency with load – Tyre pyrolytic oil
The main reason for this is the superior combustion features and better conditions for flame movement in the blend of the bio fuels in the common rail direct injection engines. Figure 5.20 shows HC emission for various mixes of tyre oil and diesel. From the Figure it is clear that, at part loads, emissions of HC are higher. But at higher loads the value of HC tends to decrease for all mixes. The main reason for this is due to lower content of oxygen that results, in the operation of engine at an equivalence ratio higher than the usual value. At increased value of loads, use of biodiesel leads to lower HC emissions.

The blends of tyre oil exhibit higher emissions of HC while compared with the diesel as shown in Figure 5.20. The increase in percentage of Tyre oil in the mixes up to B30 causes the HC emissions to increase. HC emission for B50 was less compared with B30. From the results of the experiment it is clear that, that the tyre oil based biodiesel blended with diesel at30% exhibits better emission and engine performance features than with the diesel.

The major reason is the inherent oxygen in the hydro carbon chain, which enhances the burning features. Two conflicting parameters that control burning characteristics are oxygen content in fuel atomic chain and calorific value of blends. It can be concluded that the influence of inherent oxygen content over the decrease in heating value is the reason for superior performance while using B30. Figure 6 shows, the exit gas temperature of the system, for the range of blends and that of diesel with change of load. In general, the exhaust gas temperature varies from 130°C to 300°C for range of loads for B30. While the B30 shows maximum temperature, use of diesel leads to lowest temperature.
Figure 5.19 Variation of CO emission with load – Tyre pyrolitic oil

Figure 5.20 Variation of HC with load – Tyre pyrolitic oil
Uncertainty in the temperature measurement was ±0.15%. Lowest CO gas in exhausts were observed for B30 blend as shown in Figure 5.19. The CO gas in exhaust varies from 0.02 to 0.04% vol with the lowest value for B30 (33% lower while compared with diesel) of emissions at higher loads.

The main reason that can be attributed to this is the total combustion. CO\textsubscript{2} gas in exhausts for lower blend concentrations are low as shown in Figure 5.23 (CO\textsubscript{2} gas in exhaust for different blends of tyre oil and diesel). CO\textsubscript{2} gas in exhaust changes from 2.4 % vol to 7.2 % vol. B30 has highest value of CO\textsubscript{2} gas in exhaust. Figure 5.22 shows the O\textsubscript{2} gas in exhaust for different blends of tyre oil and diesel. O\textsubscript{2} gas in exhaust getting lower with increase in load. O\textsubscript{2} gas in exhaust varies from 16.32 % vol to 10.23 % vol. Lowest O\textsubscript{2} gas in exhausts were corresponds to highest loading condition with the blend B30. As the loading increases, the O\textsubscript{2} gas in exhaust decreases in all cases as shown in Figure 5.22.

Perfect oxidation takes place in the case of B 30 mixture so the O\textsubscript{2} content in the exhaust is less compared with other blending percentage. Further, the exhaust temperature is also high, as was shown in Figure 5.21. Figure 5.24 shows the NO\textsubscript{X} gas in exhaust for different blends of tyre oil and diesel. In the current study, the NO\textsubscript{x} gas in exhaust is high with the use of bio diesel mixes. For lower range of loads, up to 60%, the value of nitrogen oxides is the highest for B50. It varies from 100ppm to 280ppm. At higher end loads, maximum nitrogen oxide emissions occurred for B20 and the value reached highest of 350ppm at 100% load.
Figure 5.21 Variation of temperature with load – Tyre pyrolitic oil

Figure 5.22 Variation of O₂ emission with load – Tyre pyrolitic oil
Figure 5.23 Variation of CO$_2$ emission with load – Tyre pyrolitic oil

Figure 5.24 Variation of NOx emission with load – Tyre pyrolitic oil
The reason can be attributed to the increase in temperature rise which rises to 291°C at 100% load. Although most of the studies have reported the rise of nitrogen oxide (NOx) gas in exhaust with bio fuels (Murillo et. al (2007), Canakci et. al (2007), Cheng CH et.al (2008), McCromick RL et al (2005), Altiparmak D et.al (2007), Haas MJ et.al (2001) a few others have reported about decreasing NOx gas in exhaust (Utlu et.al (2008), Qi et.al (2009), Aydin et. al (2010). The different researchers are also different as can be seen below. Different methods are used to reduce NOx gas in exhaust. Some authors hydrogenated (Chapman et. al (2006) the original oil prior to transesterification.

The reductions in NOx gas in exhausts were noticed mainly during low values of engine speed. Knothe et. al (2006) made a comparison with oleic methyl ester with conventional diesel fuel (C181), palmitic methyl ester (C160) and lauric methyl ester (C120) in a multi cylinder engine under unsteady conditions, They observed that for the lauric esters and saturated palmitic, NOx gas in exhausts reduced respectively by 4% and 5%, whereas for the oleic ester a 6% increase was noticed by Shahir et. al (2015). At elevated temperatures, oxidation of biodiesel is accelerated and thereby the emission and performance levels are influenced. Figures 5.21 and 5.24 show that, with the rise of biodiesel blend, the temperature of exit gas and NOx gas in exhaust rises. The higher percentage of oxygen in the fuel is with higher blending, cause an increase in the burning of the fuel. This leads to an increase in the exhaust temperature which causes an increase of oxides of nitrogen in the exhaust. EGR is the one of the best method to reduce NOx gas in exhaust. Methods to reduce NOx gas in exhausts are mixing additives like, methanol or fumigated methanol, increasing the inlet temperature of air and by using Exhaust Gas Recirculation (EGR). EGR is the one of the best way to reduce
NOx gas in exhaust. Other ways to reduce the NOx Urea solution may be sprayed and Cu-zeolite based Selective Catalytic Reduction (SCR) unit is fixed downstream.

In case of the short distance between spray and zeolite, a very uneven distribution of reducing agent was achieved over the cross-section of the catalyst entrance. The mixing of urea spray and exhaust gas could be enhanced by the modification of the nozzle geometry to produce a broader spray cone. This causes variation of the injection angle which in turn induces turbulence. It is also possible to increase the injection pressure, which reduces the droplet size and results in a homogeneous SCR performance. NOx gas in exhausts is the most detrimental of all the gases produced by the exhaust of a diesel engine. There are increasing engine legislations which aim to decrease NOx which can be branched into thermal NOx and prompt NOx. Thermal NOx, the major source of NOx production, takes at temperatures around 1500 °C, and as the temperature goes up, the rate of formation rises rapidly. Zeldovich Mechanism explains the three major reactions that lead to the production of thermal NOx. The use of Cu-ZSM5, urea injection leads to a remarkable fall in the NOx levels for biodiesels.

In the past, investigations have done to study the effect of the biodiesel on the emissions as compared to those of diesel. In is clear that most of the research shows a best mix of B20 for DI engines Shubham Sharma et al. The present work discussed the results from a CRDI engine. The reason for this deviation between DI and CRDI engines may be due to small orifices and high pressures in the injector that leads to finer injections in the CRDI engines and related changes and modification of the combustion phenomena. The SCR could not reduce the emission much, it mainly depend on fuel
source. The SCR have an impact on activity of catalyst. The urea injection is very effective.

The CI engine with common rail direct injection (CRDI) is tested with a range of combinations of tyre oil for the emission and performance characteristics and the results are compared with that with diesel oil as feed. A mix of 30% Tyre oil with Diesel was found to be superior to that of diesel. The tests were conducted at various engine loads and at a speed of 2800. The results leads to a conclusion that tyre oil while it used at an optimum blend, is an important option as a fuel for Diesel engines based on CRDI technology. Another important conclusion is that the fuel is suitable to use in CI without any major component change in the engine.

The exhaust gas temperatures and BSFC and for the mix of 30% tyre oil was less while compared to that of diesel. For B30 mixes the thermal efficiency was higher compared with the results obtained with diesel as fuel. O₂ and CO were lower for B30 mixes compared to that of diesel. For other combinations like B40 and B50, exhaust gas temperature and BSFC were found higher compared to diesel. The emission parameters like CO₂, NOₓ, and HC were increased with raising the proportion of tyre oil in the blends compared to that with the diesel. Therefore, for the best performance of a CRDI engine, tyre oil can be used in CRDI engines at 30% blend. One of the important issues is the formation of carbon deposits with the long term use of tyre oil blends. A unique maintenance programme may be planned for the continuous use of this blend. The conclusions from the present research will be useful for in further optimization of CRDI engines with tire oil as fuel blend.