CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Biodiesel is one of the renewable, nontoxic and environmental friendly alternative bio fuels (Lapuerta et.al (2005), Meher. et al (2006)) which can be substituted in the Diesel engine without major alteration in the engine. The latest pollution norms, exhausting sources of petroleum, political reasons that leads to gap between supply and demand are the various reasons behind the aggressive research to find alternate fuels. Biodiesel currently emerged as the strong alternative to petro products in the transport sector and globally all countries are investing on the research of various aspects. Raw oil contains tryglycerides which are made by three long fatty acid chains. Triglycerides being substance with high viscosity can be converted to biodiesel with lower viscosity by transesterification reaction.
Burning of biodiesels inside the combustion chamber of CI engines leads to reduced smoke, carbon monoxide (CO), fine dust or particulate matter and hydrocarbon (HC) pollutants. But nitrogen oxide (NOx) pollutions generally increased. Engine efficiency is more or less remaining the same Nabi et al. (2009), Qi et al. (2009), Aydin et al. (2010). The fuel properties that decide the performance and emissions are the calorific value, density and viscosity Alptekin. et.al. (2008). The major cause of concern for the biodiesel for use in CI engines is the high viscosity. Density also considered as an important factor as factors like Cetane number and calorific value are correlated with this Tate et al (2000). Density values are used for estimation of fuel consumption by volumetric method. Any change in density of fuel has an effect on output and spray characteristics of fuel at the time of injection and combustion in the cylinder.

However properties like viscosity, density, calorific value, oxygen content, auto oxidation heating value influence engine efficiency. To improve efficiency many researchers have proposed different additives such as methanol, ethanol, etc. to improve viscosity and reduce fuel consumption. NO\textsubscript{x} emissions can be reduced by choosing methods like altering properties of the biofuel. In certain cases the use of biodiesels reduces life of the engine due to deposit formation, injector choking, and seizure of the piston and overloading of the filters. Several tribological studies were conducted to study the effect on stationary and field automobiles. Only few reviews on emission in CI engine with bio fuel exist in the literature. Of these, only limited discussion on emission aspects of biodiesel operated CRDI engines are available. Hence there is a need for review of this topic, which will be useful for researchers and practicing engineers working with biodiesel fuelled CI engines, including CRDI engines.
The present review covers about important emissions like carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbon (HC) and particulate matter while using biodiesel as fuel. Influence of various parameters like viscosity, injection pressure, percentage of blending on the emission is discussed based on the results of previous researchers. Durability tests are discussed from emission point of view as this aspect has a profound impact on CO emissions. A separate section is included to discuss the emission from CRDI engines.

2.2. ENGINE PERFORMANCES

The literature illustrating the effect of biodiesel on engine power and/or torque are surveyed. Large number of research work is available to understand the influence of use of 100% biodiesel on engine output. In general majority of the papers agreed that with increase in biodiesel percentage, the engine output will drop due to lower heating values of biodiesel. However there exists wide variation in the results. Many authors estimated that the loss of power was lower than expected (the reduced calorific value of biodiesel compared to mineral diesel).

Utlu and Kocak found that the decrease in the value of torque and power for waste frying oil methyl ester (WFOME) was 4.3% and 4.5%. This is due to higher density, viscosity and lower calorific value (8.8%). Hansen et al. found that the loss of brake torque was 9.1% for pure (B100) biodiesel compared to D2 diesel at a speed of 1900rpm due to the changes in the calorific value (13.3%), viscosity and density.

Murillo et al. tested a submarine Diesel engine at full load and found that the reduction in power was 7.14% for biodiesel compared to mineral
diesel on a normal engine with 3-cylinder. The loss of calorific value of biodiesel was about 13.5% compared to mineral diesel. The same range of values between power loss and the decreased heating value was shown. It is reported that the torque and power were lowered by 3–6% for biodiesel from pure cotton seeds compared to mineral diesel, and they found that the calorific value of biodiesel was 5% lower than that of diesel. The reason mentioned is the difficulties in fuel spray characteristics instead of the reduction in the calorific value. The power produced will decrease with the increase of percentage of biodiesel Aydin et al. (2010), Hazar H. (2009), Ozsezen et al. (2009), Karabektas M. (2009), Murillo et al. (2008), Hansen et al. (2006), Reyes JF and Sepúlveda MA. (2006), Carraretto et al. (2004), Raheman H and Phadatare AG. (2004), Kim H and Choi B. (2010), Meng X, Chen G and Wang Y. (2008), Huir et al. (2006), Usta N. (2005), Usta N. (2005).

Carraretto et al. (2004) reported that, as the percentage of biodiesel increases different blends shows a decrease in power output and torque for a range of speed. The testing is done for a series of blends (From B20 to B100). Aydin et al (2010) tested the diesel engines with biodiesel from cottonseeds and found that the torque is reduced with increase in proportion of biodiesel in a blend (From B5 to B100). The reasons were the higher viscosity and lower calorific value. Murillo et al. (2007) tested a 4stroke, single cylinder direct injection diesel engine and found that, the increase in biodiesel blend caused a decreased in engine power.

Many researchers Da Silva Fernandoet al. (2003), Song J-T and Zhang C-H. (2008), Gumus M and Kasifoglu S. (2010), Usta et al. (2005) reported that all the cases of blending do not have this trend. For example, Gumus and Kasifoglu (2010) tested a 4-stroke single cylinder air cooled direct injection engine and reported that the output increases with increase in
biodiesel blend up to B20. This was followed by a decrease in output (up to B100) below that of Diesel powered systems. Thus B20 was the optimum blending. Usta et al. (2005) found that, the power increased for small additions of biodiesel in Diesel, reached highest value. With further additions of blending percentage, the power decreased.

A realistic comparison of pollution and fuel consumption is possible only if the tests are conducted at identical conditions and modes. Cetinkaya et al. (2005) tested a normal air aspirated direct injection Diesel engine with Diesel and biodiesel blends (viscosity of 6.2 cSt) in four modes of operation, with certain range of engine speed and mean effective pressure (bmep). The bmep was considered in proportion to torque of engine. Lin et al. (2006) studied a single cylinder natural aspirated Diesel system with Diesel and rapeseed biodiesel blends. Three modes were defined for a range of engine speed and bmep.

Different researchers used five different operating modes for a range of torque and engine speed. The test is carried out in DI and CRDI systems. Yücesu et al (2009) used a 1.9l engine using blends of Diesel and rapeseed. The test is done for six modes of operation formed from engine speed and air fuel ratio. The torque is related to the air fuel ratio. The loss of calorific value mostly compensated with a higher addition of fuel for a given mass of air under stochiometric conditions. All cases the effective power was reached. In the studies mentioned above, modes were selected based on standard reference cycles. For heavy duty engines, the modes cover the whole range of load (25%, 50%, 75%, and 100% of maximum torque) Cetinkaya et al. (2005), Lin et al. (2006). For vehicle engines the modes are defined for low to medium load Buyukkaya et al. (2010), Choi et al. (2006), Da Silva Fernando et al. (2003), Yücesu et al (2009).
2.3 BREAK SPECIFIC FUEL CONSUMPTION

The lower heating value of biodiesel caused an increased fuel consumption in the Diesel systems to the tune of 14%. That is the loss of calorific value is compensated by an increased fuel consumption. Oxygen content in the fuel is an indicator for the lower caloric value which caused a higher consumption of fuel. Graboski et al. (1996), tested an engine with pure biodiesel from soybean and in various proportions of 20, 25, 65 percentages. A correlation is developed between oxygen content and BSFC. The reason for the small standard error (approximately 0.8%) for the relation is explained based on the carbon to hydrogen ratio (C/H) which are mostly similar in Diesel and biodiesel.

Rakopoulos et al. (2004) reported that the BSFC is increased due to inherent oxygen in the fuel rather than oxygen in the air intake. Depending on the size of vehicles, there are several reports mentioning identical results. Canakci and Van Gerpen (2001) and Canakci et al. (2005) reported that BSFC increases by 2.5% for blend of 20% and 14% for pure biodiesel. The test is done on a 57KW engine using biodiesels from waste oil and soya bean oil. The results were caused by biodiesel blends and ruled out the role of with original fuel.

A test is done by Senatore et al. (2000) in six operational modes using blends of rapeseed oil. The BSFC increase in proportion with the reduction in calorific value (value close to 36MJ/Kg for fuels derived from biodiesel). Almost same results on testing a research engine (single cylinder) using rapeseed oil were obtained by Tsolakis et al. (2006) The test is conducted in three different modes of the engine operation. Many other
researchers tried to explain the reason for the behaviour of biodiesels. A test was done by Lapuerta et al. (2007) on a 2.2 l Diesel engine. Operations were done in five different modes using biodiesels prepared from waste oils. In all the cases, the increase in BSFC is proportional to the loss of calorific value.

A 4.5l engine was tested by Monyem and Van Gerpen (2001) using soybean based biodiesel prepared from different oxidation reactions. The BSFC was increased by 15.1% for oxidised biodiesel (corresponding peroxide index was 340med/Kg). The BSFC change was 13.8% for non-oxidised biodiesel. The difference was attributed to the different calorific values. Majority of the researchers explained the increase in BSFC was due to lower calorific values. Few like (2005) attributed that to the different densities of biodiesels compared to Diesel. The explanation seems to lack certain clarity since the operating modes were identified based on bmep and engine speed and not by position of the accelerator.

2.4. THERMAL EFFICIENCY

Among the studies already cited, (Tsolakis et al.(2006), Senatore et al. (2000), Canakci et al. (2005), Lapuerta et al. (2007), Monyem and Van Gerpen (2001), Graboski et al. (2003), Rakopoulouset al. (2004), Labeckas G and Slavinskas S. (2006), Agarwal AK and Das LM. (2001) concluded that there are no variations in the thermal efficiency with the use of biodiesel from different sources.

Graboski et al. (1996) tested a heavy duty 40CFR engine using pure esters and methyl esters based on variety of feed stocks. The results show that the parameters like oil origin, length of carbon chain, number of double bonds
in the fuel structure do not have any significant effect on the engine efficiency. Few studies reported marginal improvement or decrease in the thermal efficiency while using biodiesel fuels.

Kaplan et al. (2006) reported the reason as possible improvement in the combustion characteristics without explaining it further. The biodiesel handbook (line/http//www. Cytoculture.com /Biodiesel% 20Handbook.htmS) (1999) explains the thermal efficiency is the best corresponding to 20% blends which compensate for the lower heating values. No references were cited for supporting this argument.

Agarwal AK and Das LM. (2001) conducted test on a 4KW single cylinder engine used for agricultural purposes. The biodiesel were derived from linseed oil. The results show improvement in thermal efficiency corresponding to low loads. Lin et al (2006) tested a 2.8l Diesel engine using biodiesel derived from palm oil and found that the efficiency is decreased (increased energy consumption). Pure biodiesel and 20% blends were used and the variation of efficiency was 2.3% which may not considered as significant. Some authors found negative and positive synergies while blending with biodiesel.

Ramadhas et al. (2005) operated the engines (4.75l) under different modes using blends starting from 5% and up to 35%. The fuel was prepared from blends of rapeseed biodiesel and Diesel. The maximum thermal efficiency occurred for blends in the range of 5-10%. Ramadhas et al. (2005) conducted test on a 5.5KW engine (single cylinder) with range of biodiesel blends prepared form rubber seed oil, ranging from 10% to 75%. The maximum efficiencies occurred for 10% to 20% blends.
The improved efficiencies were explained in terms of increased lubricity compared to Diesel. However a 25% increase in efficiency in case of 10% blends seems to be very high. Many authors reported negative aspects in the performance. For example Shaheed A and Swain E. (1999) tested a conventional CI engines with different blends prepared from biodiesel derived from cooking oil on a natural aspirated marine engine. Blends of 10% to 50% were used. The efficiencies were lower compared to that of Lapuerta et al. (2008) with diesel. Highest efficiencies were observed for pure biodiesel.

2.5. COMBUSTION


Recent refinements in the technology of diesel engines like employment of use of increased fuel injection pressures; super-charging etc. has resulted in tremendous reduction in the quantum of emissions of particulates. Various technological interventions have made diesel engines significantly cleaner in last couple of decades however tiny sized nucleation mode particles has not reduced considerably Abdul-Khalek et al. (1999), Kittelson.D.B and Abdul-Khalek.I. (1999), Maricq.M.M. (2007).

Many studies have reported increase in nuclei mode particles from diesel engines with advanced technologies (Kittelson et al. (200), Bagley et al.
New emission legislations implemented worldwide also consider a strong correlation between number concentration and harmful impact of nanoparticles on human health thereby they put a limit on particulate numbers. EURO-V (September 2011) and EURO-VI emission legislations put a limit of $6.0 \times 10^{11}$ (/km) in addition to the limit on mass emission of particulates (http://www.dieselnet.com/standards/_eu/ld.php accessed on 01.10.2012). Formation of particulates depend on chemical and physical nature of fuels, process of fuel-air mixing and condition of the cylinder charge during combustion in rich premixed reaction zones, where particulate precursors are formed Flynn et al. (1999).

Due to complex dependency of particulate size-number distribution on these factors, several researchers have carried experimental evaluation of the effect of these factors on particulate number-size distribution Tanet al. (2009), Zhu et al. (2011), Agarwalet al. (2011), Kawanoet al. (2006), Zhu et al. (2010), Zhu. L., Cheung C.S. and Zhang W.G. (2010), Desantes et al. (2005), Tanet et al. (2006). Noticed that, as the biodiesel concentration increased in the fuel, there is an increase of the population of particles of nucleation mode group and the size of the particle at peak concentration becomes larger, however the quantum of particles of accumulation mode group decreases at most of the operating range Tanet al. (2009). Zhu et al. (2011) reported that with increase in oxygen content of the fuel, soluble organic fraction of the particles increases and mean diameter of the particles becomes smaller. Agarwal et al. (2011) reported increase in particle number concentration at lower engine loads and vice versa with 20% biodiesel blend.

Kawano et al.(2009) reported that the size number populations of particles of accumulation mode of biodiesel shifts to tiny sizes vis-à-vis diesel, and maxima of particle size-number distribution was almost constant with the
variation of the load on the engine. On increasing the load on the engine, peak number concentration of particulate increases for the diesel and peak concentration of the particulates decreases for RME. Zhu et al. (2011) reported that for various loads on the engine, the total number concentration of particulates while using biodiesel increased than with the use of diesel. Mixing with the ethanol methanol with the biodiesel reduces the total number concentration of the particulates to very low values than with the use of mineral diesel.

Desantes et al. (2005) reported that increasing the fuel injection pressure reduces the accumulation mode particle numbers and favoured the creation of particles of nuclei mode. They also reported that advanced start of injection (SOI) could reduce the accumulation mode particle concentration without changing the location of the peak number concentration. Puzun et al. (2011) observed that size of vast majority of particulates emitted from high-pressure common rail diesel engine were lower than 300 nm for biodiesel as well as for diesel. They also found that at medium and low load on the engine, as the biodiesel proportion is increased in the test fuel, the distribution of particle size modified from single peak to distributions having double peaks; the number of particles in nucleation mode increase; concentration of particles larger than 50 nm diameter in accumulation mode decrease and the peak concentration position shifts towards smaller particle sizes Puzun et al. (2011).

Majority of the diesel engines used today employ common rail direct injection (CRDI) technology. This technology uses very high injection pressures, up to 1600 bars and is the most efficient in ensuring timely quantity and fineness of fuel injection. Multiple injections are possible along with the flexibility of changing start of injection for main and pilot injections, in response to the changing load and speed conditions. However few cases on
understanding the effect of varying timing/method of injection of fuel and pilot injections on the distribution of size-number of diesel and biodiesel fuelled engines.

2.6. EMISSIONS

Table 2.1 summarizes details of previous research of emission in CI engine, while using biodiesel. Use of biodiesel can reduce HC, CO and PM emissions, but NOx emission may increase (Nabi et al. 2009, Qi et al. 2009, Raheman H and Ghadge S.V. 2007, Mc Cromick et al. 2004, Graboski M.S and McCromick R.L. 1998, and Basha S.A et al. 2009). Limited literature has also reported the reductions of NOx (Qi et al. 2009, Aydin H and Ilkilic C. 2010, Utlu Z and Kocak M.S. 2008), and Kegl B. 2008). Additionally, findings of various researchers regarding the change in exhaust emissions for biodiesel compared to Diesel varies for different experiments. The motives explained by various authors differ from each other. The wide changes in the observations and reasoning must be due to sources of biodiesel that is used for testing the engine. Most of the researchers agreed that there is sharp reduction in the pollutants as compared that with the use of Diesel (Aydin H and Ilkilic C. 2010, Utlu Z and Kocak M.S. 2008).

The most accepted factors in the reduction of pollutants, particularly, CO2, CO, sulphur di oxide (SO2), hydrocarbons, smoke and particulates, can be attributed to the existence of inherent oxygen in biodiesel (Kegl B. 2008). Efficient combustion can change CO into carbon dioxide (CO2). It can be concluded from Table 2.1 that the emission of carbon monoxide, hydrocarbon, nitrogen oxides and smoke decreased an average by 27%, 27%, 5%, and 52%, respectively under speed characteristic at maximum load (Nabi et al. 2009).
Justin E. Ketterer et al. (2014), examined pollution of nitrogen oxides, remains of hydrocarbons and PM from a Diesel engine. The techniques used for classification and estimation of emissions of PM were elemental carbon analysis, gravimetric analysis, and the TES (transmission electron microscopy). Testing was done on a system that used B20 blends derived from animal fat, which is then compared with the use of Diesel and B20 blend prepared form soy based biodiesel. The gas emissions were more or less same for these cases. Considerable differences were noticed between the fuels for the case of PM emissions. But PM emissions remains almost same between both the B20 blends (Soy and animal fat). As the exhaust emissions were mostly same and comparable, it is concluded that the soy and animal fat biodiesel blends are compatible with the exhaust treatment systems of Diesel engines and the existing Diesel engines can be substituted with biodiesels.
Table 2.1 Emission comparison biodiesel and diesel engine

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Reference</th>
<th>Fuel type</th>
<th>NO&lt;sub&gt;x&lt;/sub&gt;</th>
<th>CO</th>
<th>CO&lt;sub&gt;2&lt;/sub&gt;</th>
<th>HC</th>
<th>PM</th>
<th>SMOKE</th>
<th>SO&lt;sub&gt;2&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nabi et al. (2009)</td>
<td>B0, B10, B20, B30 (Cottonseed)</td>
<td>10↑</td>
<td>24↓</td>
<td></td>
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<td>2</td>
<td>Qi et al. (2009)</td>
<td>B0, B100 (Soybean-oil)</td>
<td>5↑</td>
<td>27↓</td>
<td></td>
<td>27↓</td>
<td>50↓</td>
<td></td>
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<td>3</td>
<td>Aydin and Ilkilic (2010)</td>
<td>B0, B20 (Sunflower oil)</td>
<td>15↓</td>
<td>33↓</td>
<td>67↓</td>
<td></td>
<td></td>
<td></td>
<td>44↓</td>
</tr>
<tr>
<td>4</td>
<td>Raheman and Ghadge (2007)</td>
<td>B0, B20, B40, B60, B80, B100</td>
<td>6↑</td>
<td>81↓</td>
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<td>5</td>
<td>Murillo et al. (2007)</td>
<td>B0, B10, B30, B50, B100</td>
<td>16↑</td>
<td>10↓</td>
<td></td>
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<td>6</td>
<td>Cheng et al. (2008)</td>
<td>B0, B100 (Waste cooking oil)</td>
<td>4.1↑</td>
<td>9.2↓</td>
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<td></td>
<td></td>
<td>B0, BM10 (10% methanol in B100)</td>
<td>6.2↓</td>
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<td>2.5↓</td>
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<td></td>
<td></td>
<td>B0,</td>
<td>8.2↓</td>
<td></td>
<td>2.5↓</td>
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<td>7</td>
<td>Muhammed et al (2013)</td>
<td>B0, B10, B20, B30 (Tyre-oil)</td>
<td>0.5↓</td>
<td>0.7↓</td>
<td>0.2↓</td>
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<td>8</td>
<td>Altiparmaket al (2007)</td>
<td>B0, B50, B60, B70 (Tallow oil)</td>
<td>30↑</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td>52↓</td>
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<td>9</td>
<td>Utlu and Kocak (2008)</td>
<td>B0, B100 (Waste frying oil)</td>
<td>1.5↓</td>
<td>17↓</td>
<td>8.1↓</td>
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<td>10</td>
<td>Canakci (2007)</td>
<td>B0, B100 (Soybean-oil)</td>
<td>11↑</td>
<td>18↓</td>
<td>0.5↑</td>
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<td></td>
<td>43↓</td>
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<td>11</td>
<td>Deepak et al (2007)</td>
<td>B0, B100 (Jatropha)</td>
<td>0.6↑</td>
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<td>0.4↑</td>
<td></td>
<td></td>
<td>0.6↑</td>
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<td>12</td>
<td>Keigl (2008)</td>
<td>B0, B100 (Rapseed oil)</td>
<td>25↓</td>
<td>25↓</td>
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<td>52↓</td>
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<td></td>
<td></td>
<td>B0, BE20 (20% Ethanol)</td>
<td>12↓</td>
<td>17↓</td>
<td>19↓</td>
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<tr>
<td>13</td>
<td>Metin guru et al. (2010)</td>
<td>B10, B20 (Chicken fat)</td>
<td>5↑</td>
<td>9↓</td>
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<td>13↓</td>
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<td>14</td>
<td>Shaoyangliu et al. (2011)</td>
<td>Beef tallow</td>
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<td>15</td>
<td>Cengizoner (2009)</td>
<td>Animal tallow</td>
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<td>17</td>
<td>Shubham Sharma et al (2014)</td>
<td>Fish oil (urea SCR with Cu-ZSM5)</td>
<td>44↓</td>
<td></td>
<td>12.5↓</td>
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<tr>
<td>18</td>
<td>Sahigupta et al. (2013)</td>
<td>Fish oil</td>
<td>30↑</td>
<td>15↓</td>
<td>16↑</td>
<td>14↑</td>
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</table>
Shubham Sharma et al. (2014) conducted experiments on fish oil biodiesel and mahua oil biodiesel, the use of biodiesels on the exhaust systems. Urea-SCR over Cu-ZSM5 catalysts is good options due to its ability to change the nitrogen oxides to water and nitrogen. Policy makers expressed their concerns that biodiesel feedstock can harm the food supply and affect the people of developing countries in the future. Majority of the systems used fuels of B20 blend, since it is identified as the best blend for enhancing properties and increased performance, optimising pollution and economic aspects.

Another reason is that these blend (B20) can be used with major alteration in the existing Diesel systems. This research is concentrated a comparative performance and emission characteristics of a system that uses mahua oil biodiesel blend, fish oil biodiesel and the Diesel .The effect of Urea-SCR on the exhaust treatment is also studied. The distance between the SCR catalyst injection point and engine exhaust is varied to study the influence on nitrogen oxide emissions. The urea injection points are varied for this. From the results, it is concluded that the use of fish oil based biodiesel leads to lower NOx emissions and increased brake thermal efficiency.

Sahil Gupta et al.(146) focused use of two non-edible oils, Mahua oil and fish oil (which is made from the waste of wish processing)The Mahua oil got a higher acid number than Fish oil. The methyl ester from fish oil is produced from a base catalysed trans esterification. The Mahua oil contains high quantity of free fatty acids. Thus it is esterified first and then undergone the transesterification. The test is done on a single cylinder CI engine with air-cooling system. The emission and performance characteristic is studied using B20 blends of Mahua oil biodiesel and fish based oil blend. The brake thermal
efficiency of Mahua oil methyl ester blend was found to be lower than Fish oil methyl ester.

2.6.1 HC, CO and CO₂ emission

Figures 2.1, 2.2, 2.3 show percentage increase or decrease of CO, CO₂ and HC plotted against references at different experimental setup.

Figure 2.1 Percentage variation of CO in the exhaust of a CI engine with biodiesel blends compared to diesel fuelled engine for various researchers

Numbers mentioned in the X axis of the graph is serial number sited in the Table 2.1. Monyem and Van Gerpen (2001) reported that the oxygenated biodiesel caused considerably lower exhaust emission. The performance of the engine remains same for un oxidized biodiesel and oxidized.
Figure 2.2 Percentage variation of CO\textsubscript{2} in the exhaust of a CI engine with biodiesel blends compared to diesel fuelled engine for various researchers

Further, they concluded that the use of biodiesel (oxidized) reduced CO emissions by 15% the biodiesel (unoxidized) and compared to Diesel it is...
28% less (Figure 2.1). Related to HC emissions, the use of Oxidized biodiesel caused emissions significantly lower by 21% and 54% compared to the biodiesel (un oxidised) and diesel.

Lin et al. (2008) concluded that the carbon monoxide emissions reduce with the use of biodiesel. The reason was attributed to the presence of oxygen content and the content of the (lower carbon to hydrogen ratio) in biodiesel fuel while compared to mineral diesel (Table2.2). Engine load, engine speed Cetene number and some other properties have been confirmed to have a substantial control on the carbon monoxide emissions. CO emission from a biodiesel systems decrease with a rise in the speed of the engine. Some of the reported literature (Table2.1) shows that metal based additives can reduce CO emissions of biodiesel. Carbon monoxide emissions are also reduced with the use of ethanol and. With the use of biodiesel HC emissions are significantly lower compared with Diesel Raheman.H and Ghadge. S.V. (2007), Mc Cromick et al. (2004), and Kegl.B. (2008). Figure 2.3 shows HC emission vs number of references. The Figure shows that maximum reduction in HC is 55%. Researchers generally agreed that as the biodiesel content is increased in the blend HC emissions were reduced.

The position of fuel injection and modified features of combustion of biodiesel are the reasons for the emissions of hydrocarbons. With the increase of engine load, there are conflicting reports on HC emissions with the use of biodiesel. The use of additives (metal based found to have lower efficiency in reducing HC emissions for biodiesel compared to their role in reducing other emissions. Addition of trace of methanol and ethanol into biodiesel blends with diesel found to be capable of reducing HC emissions Qi et al. (2009), Raheman. H and Ghadge. S.V. (2007). The parameters like the gas temperature in the exhaust, break thermal efficiency, hydrocarbons, SO, the
emissions of CO$_2$, and the CO increased with brake mean effective pressure. The biodiesel systems shows brake specific fuel consumption higher than that for diesel fuel at the ORG INHN (4 hole nozzles). The reason is attributed to the lower calorific value (LCV) of biodiesel compared system that is fuelled with diesel. At the ORG INHN, when the research engine was fuelled with biodiesel and the blends, the emissions of SO, CO and HC were decreased and CO$_2$ emissions increased due to the modified combustion features (Cenk Sayin et al. (2013). N.R. Banapurmath et.al (2008) carried out dual fuel operation, smoke reduced considerably.

However, CO and HC emissions increased considerably. Maren Bennett et.al (2000) evaluated C and CO levels. As the carbon content is high, there will be a bias in the present two source apportionment method by the EPA in the areas of significant use of biodiesel. As the THC emissions are considerably lower, biodiesel are considered relatively cleaner. With increase in biodiesel in the blend, less EC is emitted out of the system. There is no clear variation in OC emissions. C.H. Cheng et. al (2008) reported that, with the use of bio diesel derived from waste cooking oil, the emissions of HC ,CO and PM concentrations are reduced and the population in the cluster of sub-micron sized particles is lowered (Figure 2.4). The NO$_x$ was increased. Use of ITR leads to lowering of NOx emission.
Figure 2.4 Percentage variation of smoke & SO$_2$ in the exhaust of a CI engine with biodiesel blends compared to diesel fuelled engine for various researchers

Figure 2.5 Summary of United States EPA evaluation of biodiesel impacts on emissions for heavy-duty vehicles
Hoekman et al. (2012) reported that employment of combustion techniques in the exhaust or EAT technologies is advised only for a brief commercial applications. The technique involves more cost and unwanted emissions. Moreover, Rajasekar et al. (2010) reported that the cost of fuel and pollution rises with increase in additives of brake thermal efficiency and generation of smoke. While with the use of ET and WI, the engine components are prone for corrosion. The use of EGR usually leads to lowering of energy efficiency, stability of operation and the rise in PM generation from the engine.

Under these conditions, the LTC mode of combustion is best suited for a biodiesel-fuelled Diesel engine, though there is unwanted rise HC and CO pollution(Northrop et al. (2009), Zheng et al. (2008). With the use of the single pilot injection system along with the LTC mode of combustion leads to better HC emission characteristics. But it is also associated with certain drawback.

The parameters can be varied in the LTC mode of combustion using the complex CFD flow models .This can be used to predict emissions reactions of HC and CO properly (Figure 2.5). In study reports use of (Metin Guru et al. (2010), chicken fat biodiesel added with synthetic Mg additive. A single-cylinder, direct injection (DI) compression ignition engine is used. The influence of additives and its effects on the performance and emissions of the engine were studied. Addition of 10% chicken fat biodiesel, smoke (Figure 2.8) and CO emissions decreased by 9% and 13% respectively. There was an increase of 5% in the NOx emissions.
Figure 2.6 Percentage variation of PM in the exhaust of a CI engine with biodiesel blends compared to diesel fuelled engine for various researchers

Figure 2.7 Percentage variation of NOx in the exhaust of a CI engine with biodiesel blends compared to diesel fuelled engine for various researchers
The results for NO, PM, CO, and HC are illustrated in Figure 2.7, Figure 2.9. The chart shows that, on an average, substantial reduction in PM, CO, and HC can be obtained through the use of biodiesel. From Figure 2.1 and Figure 2.2 it is clear that maximum reduction in CO emission is around 80% and that of CO$_2$ is around 68%.

Emissions such as HC and CO are usually found to significantly decrease with biodiesel. Evangelos G. Giakoumis (2012) reviewed the published research on emission from the biodiesel systems during transient cycles up to 2011 and made an analysis by varying the biodiesel percentage in the biodiesel–Diesel blend. In most of the cases the emissions decreased with increase of biodiesel percentage. CO and HC Emissions decreased for new models over the years.

Shahabuddin et al. (2013) found that use of biodiesel leads to advanced start of ignition and ignition delay involved is shorter. The reasons attributed are higher cetane number (CN), reduced compressibility and composition of biodiesel which contain fatty acids. Further, it is reported that, the rate of heat released (HRR) of biodiesel is lower than diesel owing to the lower heating value, reduced volatility. Use of biodiesel leads to reduction in the exhaust emission such as PM, (Figure 2.6) CO and HC.

Evangelos et al. (2013) reviewed the published literature related to emissions of CI engines while using ethanol or n-butanol/diesel fuel blends under unsteady conditions like acceleration, deceleration and load changes. The major reasons for emissions during unsteady operation were identified and discussed for all the important pollutants from the exhaust.
Figure 2. 8 Effect of EGR rate on smoke emission for tested fuel.

Figure 2. 9 Effect of EGR rate on HC emission for tested fuel
It is reported that many of those mechanisms are related to the inherent instabilities observed during transients, like for example -the turbo lag. Most studies show that with addition of ethanol or n-butanol in the fuel blend, PM and CO emissions decreased and HC emissions increased.

Teresa et al (2010) reviewed viability of microalgae for biodiesel and other purposes. To produce on a large scale factors promoting growth to be controlled and a nurturing factors to be monitored. The economic aspects along with factors like, sequestration of CO$_2$ from flue gas emissions, with wastewater remediation processes, extraction compounds for other is considered. The factors like nutrients, Light, turbulence, temperature, CO$_2$ and O$_2$ levels need to be controlled properly to ensure the best environment for maximum oil content and yield of biomass

2.6.2 PM emission

Figure 2.6 percentage increase or decrease of PM plotted against references at different experimental setup. Numbers mentioned in the X axis of the graph is serial number sited in Table 2.1.

Most of the literatures reported that particular matter emissions of biodiesel were considerably reduced compared to diesel. The reduction of PM emissions in biodiesel is due to the presence of lower sulphur and aromatic compounds higher .Other factors being higher Cetane number for biodiesel. Butthe most important factor is the presence of inherent oxygen in the chain. It is important that with the decreased presence of sulphur in Diesel, this advantage of biodiesel will disappear.
Figure 2.10 Effect of EGR rate on NOx emission for tested fuel.

Figure 2.11 Variation in particulate emission with engine load
With the installation of EGR system, PM emissions will be increased for biodiesel, although PM emissions level remains lower than that with the diesel. NOx emission also decreased (Figure 2.10). But at low temperature conditions PM emissions of biodiesel will change substantially compared to diesel(Michael Bunce et al. (2010). PM emissions with biodiesel can be improved by oxygenates, though it is not useful for power recovery. Certain the metal-based additives exhibit catalyst effect and are very effective in reducing PM emissions of biodiesel N.Kapilan1 and Bayko D Baykov. (2014).

Figure 2.11 shows variation of particulate matter emission with the engine loads for diesel and B20 fuel while running at constant engine speed. it is not worthy that the PM emission have a higher value in diesel exhaust (22 to 59 mg/m3) than B20 exhaust (17–48 mg/m3). At all operating conditions, metals like Mg, Ca, Zn, Fe found in large quantities in biodiesel exhaust whereas metals like Pb, Cu, Cr, Ni, Na were found in excess in the particulate present in the exhaust of mineral diesel.

Sahil Gupta et al. (2013). The technique used to feed forward neural network approach was used successfully to derive models of the emissions and the performance of a CI engine fuelled with biodiesel blends made from castor oil. The derived models were then used in an evolutionary multi-objective Pareto based optimization process, a multi objective process is used with the derived models. This was useful to understand the influence of optimum design aspects along with engine speed and biodiesel percent.

Common NSGA-II algorithm was modified and used to get an even better result. (Mir Majid Etghani et al. (2013). Maren Bennett et.al (2000) evaluated decrease in total PM mass emission rates. C.H. Cheng et al (2008) reported that the mass concentrations of particulates and sub-micron sized
particles were reduced. GayatriAdi et al (2009) conducted tests on a Cummins 2007, 6.7L six cylinder diesel engine with biodiesel fuel and conventional diesel. The research shows the reductions in PM of about 90%. Shaoyang Liu et al (2011) used a radio frequency (RF) heating method for efficient biodiesel production from beef tallow.

Production of biodiesel from corn oil is explained in (183). A study was conducted on the emission characteristics of a CI engine for passenger cars by Gunfeel Moon et al (2010) blending biodiesel (20 and 40 vol%) was carried out with neat diesel and GTL fuels. The trends of PSD showed different patterns with and without introducing the EGR. The normal operating conditions of the engine with EGR, leads to an increase in the PM number concentration in the nucleation mode in the fuels blended with biodiesel.

The increase is due to decrease in PM number concentration of carbonaceous particle agglomerates (accumulation mode particles). Such particles absorb volatile and semi-volatile parts. The engine while operated without EGR, PM number concentrations of both nucleation accumulation mode was decreased.

The existence of high air fuel ratio is responsible for increased oxidation of particles of nuclear mode. Further higher oxygen from oxygenated fuel also contributing to this. The locomotive engine PM emissions were highest for diesel and the value reduced to 60% for B100. Lowest BSHC emissions were attained with B50 (10–40% of maximum) and the diesel produced BSHC emissions were maximum for Diesel.
The emission parameters, BSCO and BSCO₂ were maximum for B100 and the minimum for diesel. B100 showed exhibits lower smoke opacity for mineral diesel at all scales (Anirudh Gautam and Avinash Kumar Agarwal. (2013). The majority of studies have found sharp reductions in particulate emissions (Figure 2.4) with biodiesel as compared to diesel fuel. Most of the researchers reported that, the larger the engine load, the greater the PM emissions of biodiesel and with speed PM emission decreases (Figure 2.4). The variable of injection advance may be used very carefully for biodiesel systems. Such advance is to be applying by considering features of biodiesel and its blends.

2.6.3 NOₓ emission

Figure 2.7 represents percentage increase or decrease of NOx emission reported by different researchers. Numbers mentioned in the X axis of the graph is serial number sited in the Table 2.1. Most researchers agreed on some increase of NOx emissions (Figure 2.5) for biodiesel (Table 2.1). The NOₓ emissions were 13% more for neat oxidized biodiesel than the No. 2 diesel fuel while the value is 14% higher for un oxidized biodiesel. The Cetane number of oxidized biodiesel is increased from 51.1 (un oxidized) to 72.7 (oxidized) is responsible for the reduction in emission (Lin. Y et al. (2008). Refer Figure 2.1 Hess et al. (2005) reported that the addition of butylated hydroxyl anisole (BHA) or butylated hydroxyl toluene (BHT) in biodiesel reduced NOx emissions. As the inlet air inlet temperature increased, carbon monoxide, NOx and smoke emissions were reduced considerably for rapeseed oil methyl ester and diesel blend (Arregle et al. (1991). NOₓ increase is mainly due to the higher oxygen content in biodiesel. NOₓ emissions are more with higher engine speed, which is in line with the mechanism of NOₓ formation.
Metallic additives, oxide additives, emulsifier, seem to be useful to improve NO\textsubscript{x} emissions of biodiesel (Table 2.2). The increase in BMEP caused to increase in the exhaust gas temperature, BTE, NO\textsubscript{x}, and to decrease in BSFC. This is probably due to lower calorific value of biodiesel compared to diesel fuel. As the percentage of biodiesel in the fuel mixture is increased, the peak temperature in the cylinder was higher. The increased NO\textsubscript{x} emissions are due to this (Cenk Sayin et al. (2013)).

N.R. Banapurmath et al. (2008) carried out dual fuel operation, emissions such as smoke and NO\textsubscript{x} reduced considerably. C.H. Cheng et al (2008) in his investigation, there is an increase in NO\textsubscript{x} concentration. Thomas D. Durbin et al (2007) was a joined effort between NFESC, CE-CERT, ATC, and various military buses. The testing encompassed a series of engines of on and off road diesel-powered applications including two trucks with medium power, two Humvees, a -duty diesel truck of high power, a bus, two stationary BUGs, a forklift, and an airport tow vehicle. The experiments were done with a number of test fuels including a CARB ULSD fuel, employed various blend ratios of two different yellow-grease biodiesels and biodiesel (one soy-based), JP-8, and yellow-grease biodiesel blends with two different levels additive for NO\textsubscript{x} reduction.
Table 2.2 Methods to reduce emission from biodiesel engine

<table>
<thead>
<tr>
<th>Sl no</th>
<th>Methods</th>
<th>Influence on Nox</th>
<th>Co</th>
<th>Hc</th>
<th>Smoke</th>
<th>PM</th>
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<tbody>
<tr>
<td>1</td>
<td>Oxidized biodiesel (Altiparmak et al. (2007))</td>
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<td>2</td>
<td>Optimal ECM parameter setting (N. Kapilan et al. (2014))</td>
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<td>3</td>
<td>Metal based additives (Carrie M Hall et al. (2010))</td>
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<td>4</td>
<td>Duel fuel (FangruiMaa et al. (1999))</td>
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<td>5</td>
<td>Use of EGR (S. Kent Hoekman et al. (2012))</td>
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<td>6</td>
<td>BHA BHT (S. M. Palash et al. (2013))</td>
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<td>7</td>
<td>Water biodiesel emulsion (Utlu et al. (2008))</td>
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<td>8</td>
<td>Increase air inlet temperature (Pehan et al. (2012))</td>
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<td>D</td>
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<tr>
<td>9</td>
<td>Use of SCR with Cu-ZSM5 (Jinlin Xue et al. (2011))</td>
<td>D</td>
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D- decrease, I- Increase

GayatriAdiet et al. (2009) found increases of 38% for NOx at one operating point, and BSFC increases by 13%. S.M. Palash et al (2013) investigated the impacts of NO reduction methods on engine performance and the emissions of a biodiesel-fuelled CI engine. LTC technology can be selected as a better NO reduction method compared to other technique, as these techniques could reduce of NO x and PM emissions without affecting the engine performance. In this study (Metin Guru et al. (2010); NOx emission increased by 5%.

The United States Environmental Protection Agency (EPA) published a summary of published biodiesel emission data for heavy duty engines (McCormick RL and Tennant CJ. (2005), the NOx emissions are increased approximately by 2% for B20 blends and increase was 10% for B100. The
model of the engine, year of manufacturing and the technology used has a
great influence on NO\textsubscript{x} emissions. There ported change in NO for B20 ranging
from roughly $+8\%$ to $-6\%$, but average value was $+2\%$. Figure 2.8 and Figure
2.10 shows the influence of EGR rate on NO and smoke emission respectively.
With 15\% EGR rate 65.9\% NO reduction and 5.4\% increase in smoke was
observed for B20 and with 20\% EGR rate it was 69\% and 6.9\% respectively.
For B100 fuel, NO reduction was 74\% and smoke increased by 19.4\% corresponding to 15\% EGR rate. When EGR rate changed to 20\% the changes
for NO and smoke were 75.6\% and 20.6\%. When diesel fuel blends were
oxygenated, the combustion temperature of the blend were reduced due to the
high latent heat of evaporation of ethanol as well as methanol.

The NO\textsubscript{x} emissions were lower compared to biodiesel fuels at 0\% EGR
itself. Compared to B20 and B100, the NO\textsubscript{x} emission reduction obtained for
E15B20 and M15B20 are only marginal with the increased EGR rates. Tri-
compound Further NO\textsubscript{x} reductions in these three-compound oxygenated fuel
blends can be affected by planning fuel injection timing and using right
compression ratio (S. Kent Hoekman and Curtis Robbins. (2012). With SOC
timing fixed, a load-averaged NO\textsubscript{x} increase of $\sim10$ per cent was used for B100
compared to the PRF blend with matched premixed-burn fraction (CN80).

Therefore, there exist factors other than SOC and premixed-burn
fraction that influence NO\textsubscript{x} emissions from biodiesel. A correlation was found
between premixed-burn exhaust emissions heat release and NO\textsubscript{x} emissions for
the three PRF blends. However, NO\textsubscript{x} emissions for B100 were significantly
higher than those that would be predicted based solely upon premixed-burn
differences. Thus, the effect of biodiesel on premixed factor influencing its
tendency to increase NO\textsubscript{x}(121).
The engine for locomotive applications produced the highest BSNOx with B100 at all loads. With the use of B50, BSNOx emissions were 70–80% of corresponding to that of B100; however, value is comparable to diesel at all conditions. The highest NOx emissions (raw) occurred for at the third and fourth loads. PM emissions were maximum for mineral diesel and decreased to 60% for B100. The BSHC emissions were minimum for B50 (10–40% of maximum) and BSHC emissions were maximum for diesel. BSCO and BSCO₂ emissions were maximum for B100 and the minimum for diesel. With B100 smoke opacity was lower compared to mineral diesel at all conditions. In this research, a correlation was established between the NOx, PM emissions and the O/C ratio of the fuel–air mixture as variables. The trends were not clear. For example, for the same O/C ratio, B100 gave a mixed trend of NOx emissions (lower NOx at lower BMEP and higher NOx at higher BMEP) and significantly lower particulates. The peak in-cylinder mean gas temperatures and maximum heat-release rate were calculated along with corresponding timings. The estimations correlate well with NOx emissions Anirudh Gautam and Avinash Kumar Agarwal. (2013).

Carrie et al (2010) studied the impact of a biodiesel blend fraction accommodation scheme to variation in the fatty acid composition of biodiesel. The algorithm of the methodology consists of two controllers The energy calculations by fuel control that causes the reduction in torque and COMF-based method for evaluating increases in NOx emissions observed during optimised burning of biodiesel in CI engines.

The algorithm for NOx control EGR to adjust the in-cylinder COMF constant. As there is a very small change between the mass fractions of fuel oxygen for biodiesel with different fatty acid structures, the NOx controller is also robust to the changes. This factor is verified by experiments for both the fuels with very different compositions of fatty acid formed by separating the
unsaturated and saturated components of biodiesel from soybean. As far as the selection of the biodiesel fuels, most of the researchers conclude that, use of more saturated biodiesel cause decrease in NO\textsubscript{x} formations. While using in a high temperature environment, biodiesel can easily be oxidized which can affect both the emission and performance.

Savita et al. (2012) conducted research using linseed oil in CI engine. The faction of oil content of linseed seeds ranges from 33 to 47%. The emission of carbon-monoxide of Methyl ester of linseed oil is lower compared to 100% linseed oil and Diesel. The reason for lower Carbon monoxide emission of blends is due to the increased oxygen content in the bio-diesel structure that promotes complete combustion of fuel. This factor is also responsible for lower particulate emission. The experimental research with linseed oil- diesel fuel blends at a range of loads shows that NOx level is higher for blends than conventional diesel fuel. The reason may be attributed to the higher exhaust gas temperature with methyl ester of linseed oil compared to diesel and pure linseed oil.

Evangelos G. Giakoumis.(2012) reviewed the available literature on biodiesel emissions during transient/driving cycles up to 2011 and made a statistical analysis with respect to the parameter of biodiesel percentage in the fuel blend. Curve fits were produced for various heavy duties, light duty while using engine/chassis dynamometers. NOx emission increased with respect to increase of biodiesel blend. For models beyond 2005 the increase is not as fast like those models before 2005, showing improved methodologies for reducing NOx emissions. Rakopoulos et al (2011) studied emissions and combustion generated noise for a turbocharged engine for Diesel and biodiesel and n-butanol blends. It is found that turbo lag is the major reason of pollutant
emission. Smoke opacity increased for biodiesel blends and decreased for n-butanol blends.

The blends of biofuel had a minor effect on the transient performance of the engine (the development of engine speed, response of turbocharger) and the noise produced from overall combustion. Shahabuddin et al. (2013) concluded that use of biodiesel result early start of combustion and relatively shorter ignition delay due to increased value of Cetane number (CN), reduced compressibility and composition of fatty acid in the biodiesel. Further, it is reported that, due to the lower calorific value and lower volatility, the heat release rate (HRR) of biodiesel is slightly lower than diesel. Biodiesel fuel increases the NOx.

Varatharajan and Cheralathan (2012) reviewed influence of fuel properties and composition on NOx formation while using biodiesel. The reasons that are contributed to the increased NOx emissions in biodiesel are advancement of injection timing rise in adiabatic flame temperature, higher heat release rate, burning under stoichiometric conditions and reduction of radiative heat transfer from soots and increased premixed burn fraction.

JinlinXue et al (2011) reviewed emissions from biodiesel blend based CI engines. All emissions were found to reduce except NOx. Emission also depends upon operating/driving conditions. Various studies show inconsistent trends for CO2 emission. In general, it is summarised that small quantities of biodiesel is helpful in reducing emissions.
Syed et al (2009) reported that burning features of biodiesel has similar characteristics as that of diesel and also found that the performance of base catalyst is better than the enzymes and acid catalyst. It is further reported that the performance of the engine was reduced with the use of vegetable oil/diesel blend. This may be due to the high viscosity of oil that caused injector coking that contaminated the lubricating oil. The performance was improved with the use of refined oil blends. The generation of un burnt hydrocarbon from the engine was found to increase with the use of the fuel blends as compared to diesel. The emission nitrogen oxides from the engine were found to be higher for fuel blends as compared to diesel.

Liam Brennan and Philip Owende.(2010) reviewed the literature for the biofuels from microalgae as a green resource and for mitigation of GHG related influence of conventional liquid fuels. High yields for both lipids and biomass, and other co-products are possible which could tremendously enhance economic viability of algae. Net energy balance is the most effective by phototrophic production. The technical viability of a production system depends on the intrinsic properties of the selected algae strain.

2.7 DURABILITY OF ENGINE AND EMISSION

Only a few investigators were committed to the durability tests of biodiesel engine, the main reason being, such tests were more time-consuming and costly. During burning of the fuel in the engine and oxidation of fuel soot is formed from carbon deposits. Biodiesel has lower soot formation, which is consistent to the reduced PM emissions of biodiesel. This factor was agreed by most of the researchers who have conducted this research. Sinha and Agarwal (2010) investigated the influence of B20 (20% rice bran oil methyl ester blend with mineral diesel) biodiesel on wear of engine cylinder and components
during long tests like for a period of 100 hr. It was reported that deposits of carbon on the cylinder head, injector tip, and piston crown of biodiesel engine was considerably lower when compared with mineral diesel engine due to the reduced soot formation during burning of biodiesel. It was concluded that (Agarwal.A.K. (2005), Agarwal.A.K, Bijwe. J, Das. LM. (2003) biodiesel reduced the deposits of carbon in the engine cylinder.

Dorado et al. (2003) conducted experiments on a three-cylinder, WC, direct injection, 2.5 L engine at 8–15kW and 1800–2100rpm for 50 hrs and found that there was no noticeable difference in characteristics of carbon deposits between biodiesel from waste olive oil and No.2 diesel. Pehan et al. (2009) observed similar carbon deposits in combustion chamber between the biodiesel from rapeseed oil and D2 diesel on a 6-cylinder, WC, DI, 11 L engine for 110 h. It is found that addition of even low quantity of biodiesel is effective in reducing friction. The enhanced performance of the biodiesel fuelled system is due to the higher lubricity of biodiesel that result in lower wear of important moving components. Biodiesel thus proves to be a strong candidate for partial replacement of mineral diesel fuel in existing diesel engines.

Kenneth et al. (2006) tested nine identical 40 ft transit buses on B20 blend and diesel for a long period of two years – B20 is used in five buses and the other four were ran with petroleum diesel. The results show that fuel expenses were lower by 1.2% for B20 and this is attributed to the efficient burning of B20 as compared to diesel fuel. The results of the oil analysis indicates that no additional metal wear for B20. Further soot levels in the lubricant were also considerably lower for vehicles with B20. But, one of the tricky issue was the plugging of fuel filter which was the major technical issue
for B20 buses. This seemed to be caused due to the high levels of plant sterols in the biodiesel or other changes in the fuel quality.

In the summary, they have shown that maintenance costs of engine and fuel system were identical for both diesel and biodiesel blend groups until the last phase of the study. But there was a need of component replacements like cylinder head and injector towards the end of the study on one B20 bus. This led to rise of average maintenance costs for the B20 group. An experiment was done by Fraer et al. (2005) on Ford cargo vans and Mack tractors (two of them were on B20 and two on diesel) for four years aimed at investigation in the durability of engine components. Biological contaminants were the reason for filter plugging.

Formation of a deposit were noted around the rocker assemblies in the Mack B20 engines. The sodium levels of the sludge are very high. This is due to the accumulation of soaps in the engine oil from out-of-specification biodiesel. National Biodiesel Board (NBB) conducted durability test for 1000 h duration on 1987 Cummins N14 engine by B20 (soybean methyl ester).

The test was though planned for 1000 h duration; it had to be stopped at 650 h due to damage of the fuel pump. Analysis conducted on the oil sample revealed no major degradation. It was found that the operating issues experienced during this test were due to the instability towards oxidation of the B20 fuel. The fuel filters, fuel lines and fuel transfer pump were replaced during this brief shut-down period at 700 h. At the end of final 250 h, the engine was dismantled and Large deposits were found on most of the engine components. The deposits were mainly come from the lube oil. It is observed
that the fuel atomization is completely stopped due to the cavitation erosion of the injector needle valves.

It is found that the microscopic air bubbles came through the deteriorating fuel pump seals were introduced into the fuel causing major erosion by cavitation. The used lubricant oil found to have elevated content of metal contamination generated from wear. Many cylinders had broken fire and compression rings. Some vehicle owners also complained that nationwide introduction of animal fat and soybean-based fuels lead to fuel filter clogging (PTSA weekly update (2005). There was a decrease in the average emissions of HC and CO with PB20 compared to diesel was studied.

However, the increases in percentages of HC emissions after 250 h compared to 0 h (during the first hour) were 12.12 for diesel and 15.52 for PB20. Similarly, in the case of CO emissions, the increase of percentage was 8.17% with diesel and 10.32% with PB20. Average NO\textsubscript{x} emission increased with PB20 compared to diesel. However, the increase in NO\textsubscript{x} emissions percentage after 250 h compared to 0 h (during the first hour) was 7.89% with diesel and 8.65% with PB20(98).

**2.8. EMISSION FROM CRDI ENGINES**

Michael Bunce et al (2010) tested different blends of soy biodiesel (B5 and B20) with stock and optimal ECM decision making in a modern CI engine with common rail fuel injection, cooled EGR, and a VGT. Experiments with B0 indicates that the stock ECM decision making was indeed optimal for B0 combustion at all three conditions in terms of minimizing BSFC subject to constraints on BSNO\textsubscript{x}, BSPM, and noise. As
expected, combustion of biodiesel blend was accompanied with increases in both BSFC and BSNOx and decreases in BSPM, Optimal ECM parameter settings resulted in the reduction of BSNOx, BSPM, and peak dP/dt to levels comparable to or lower than the corresponding nominal B0 levels.

Kim and Choi (2010) found that BD15E5 mixed fuel (mixture of 15% biodiesel, 5% bio ethanol and 80% diesel) yielded the lower hydrocarbon emissions than that of B20 (20% biodiesel and 80% diesel) on a common rail direct injection (CRDI) engine. Marina Kousoulidou et al. (2010) reported CRDI vehicle emissions, use of the two biodiesel blends led to tailpipe CO2 differences which are within the region of experimental uncertainty for most driving conditions. RME blend is the only one that exhibited a reduction of 4% over a real-world urban cycle. This means that the possible CO2 reduction from biodiesel fuels may only be expected from their generation and not use on an automobile.

The emission range of CO of the car was found much lower than the emission standard over the certification test and at very low absolute level over the actual hot-start cycles. Therefore, use of the biodiesel did not have an influence on its CO performance. HC emissions increased both over the certification tests and over real-world cycles, in particular for the PME derived biodiesel and the maximum difference reached 40%. NOx emissions did not change much with either the PME or the RME biodiesel blends. The PME blend generated 20% higher emissions over the base fuel over the more transient real-world cycles. It is found that the PM emissions were reduced when the vehicle was operated at low load conditions, including the certification test.
The value of the changes was -17% for the PME and -24% for the RME blend. Use of the high speed and motorway cycle of high-load led to much smaller reductions over the PME and a marginal increase with the RME blend. Parametric investigations were carried out by Jitendra Gangwar et al. (2012) on a modern automotive CRDI diesel engine operated at various loads at rated the engine speed of 1800 rpm to study the exhaust particulate emissions of an engine fuelled with biodiesel engine vis-à-vis mineral diesel. The particulates were taken and checked for mass of particulates, benzene soluble organic fraction (BSOF), organic carbon, elemental carbon, particle bound PAHs content of the PM and concentration of metal trace. Biodiesel blend (B20) showed improved engine performance in reducing particulate mass emission at all engine testing conditions compared to diesel.

The organic content in diesel exhaust measured through BSOF decreases with rise in the engine load. It was maximum at idling condition for both biodiesel and diesel. For B20, the BSOF content of particulates was found to be more than that of diesel. Thus CRDI engines with biodiesel in general exhibit reduced CO, HC and PM emission compared to diesel. Moreover level of emissions is lower than DI engines.

Donghui Qi et al (2014) used biodiesel generated from waste cooking oil (WCO) in a common rail direct injection (CRDI) engine. The concentration of soot particle of the biodiesel engine is lower than diesel engine. As the injection pressure rises, CO and HC emissions were reduced marginally, NOx emissions were increased and concentration of the soot particle was decreased. It is found that injection timing do not influences on CO and HC emissions. But the NOx emissions were decreased considerably with the retard of timing of the injection. As the EGR ratio increases, an
increase is noted for the CO and HC emissions, NOx emission were suppressed.

As the engine was operated with biodiesel, use of 30% EGR caused an average reduction in NOx emission up to 75%. However with 30% EGR, a considerable change of up to 78% was achieved by using diesel as the fuel. Compared to that at 25 deg TDC ignition timing, a reduction in NOx emissions by up to 88% is attained for both fuels at injection timing of 5degTDC. The minimum reduction is approximately 65%. NO emissions slightly increased with increasing injection pressure. The average increase in the HC emissions for diesel and biodiesel when compared, for 0%EGR and 30% EGR is about 80% at injection timing of 5 deg TDC. The minimum increase in HC emission is 20% at injection timing of 5 deg TDC. The average increase in CO emissions for diesel and biodiesel when compared for 0% EGR and 30% EGR was about 65%. With the recirculation of exhaust gases into the cylinder the NOx emissions reduces effectively. HC and CO emissions are higher resulting in lower combustion efficiency.

AtulDhar and Avinash Kumar Agarwal (2013) used two fuel injection pressures (500 and 1000 bar) for different injection timings with biofuels (20% and 50% Karanja biodiesel blends) and the results are compared with baseline data of mineral diesel. The size distribution of particulate number-size decreases with increases with injection pressure of the fuel. For a fixed pilot injection timing, particulate number-size distribution increases with retarded main injection for all test fuels. Total particulate number concentration of biodiesel blends is lower than mineral diesel. It is found that 20% blend of Karanja biodiesel results in maximum reduction of particulate number emissions at retarded start of injection timing.
Chien- Hsing Li et al. (2014) summarized that, with the increasing of biodiesel blend, combustion noise has an increasing trend. Each of 20% biodiesel in the blend increased the combustion noise by 0.5 dB. The vibration of engine decreased by 0.25 dB. Regarding emission, for every 20% biodiesel, the NOx emission has decreased by 10.6 ppm approximately. H.G. How et al. (2013) conducted experimental investigation in a high pressure common-rail direct injection diesel engine on the influence of injection timing on the performance of the engine, combustion and emissions characteristics with coconut oil methyl ester (CME). The tests were conducted at rated speed of 2000 rpm and 50% throttle position. The test fuels used were base line diesel fuel and two different fuel blends of CME (B20 and B40). The injection timing was varied from -4 to 8 °ATDC (with two degree crank angle interval) measured from standard main injection timing of 2 °ATDC.

The result indicates that retardation of injection timing resulted in reduced NOx emissions for all the test fuels. With retarded main injection timing, the in-cylinder combustion temperature is reduced because of the larger amount of fuel burned during the later part of the expansion stroke. As a consequence, the gas cylinder volume is expanding rapidly, hence shortening the residence time of the gas burned at high temperature in the combustion chamber.

The lowest NOx emission is achieved with the latest retarded main injection timing of 8 °ATDC for all types of fuel. This finding is verified further by the similar trend of the in-cylinder mean gas temperature. In contrast, the increasing trend in NOx emissions can be observed with the advanced main injection timing for all test fuels. It may be noted that with advance in main injection timing, the mixture ignites and burns earlier and
this results which was resulting in early occurrence of peak pressure near TDC. This causes higher flame temperature and enhances the mechanism of generation of thermal NOx.

The results also show that higher methyl ester content in the fuel blend tends to decrease the NOx emissions across all the main injection timings. This can be attributed to the relatively high value of Cetane number and lower calorific value of the CME B40 compared with CME B20, which reduce the heat release rate at the premix combustion stage and reduce the peak temperature of combustion. Glécia Virgolino da Silva Luz et al. (2013) presented the results about the use of a new fuel additive package containing antioxidant (AS), depressant (D) for pour-point and biocide (Bi) with the aim to increase the quality and amount of biodiesel in the diesel-biodiesel blends. Some of the goals are associated to the degradative effects due to free radicals oxidation, contamination by water and microorganisms.

It is concluded that there is a reduction in opacity and soot in the exhaust gases emitted when adding the additive packages, with best results on adding ASDB in the diesel biodiesel blends. This is possibly connected to the physical and chemical stabilization of the fuel. It can be said that use of the additive package contributed to minimize HC emissions to the environment, especially in mixtures B20RME and B20SME. CO values were lower for the sample B20SME, comparing with the samples and B5RMEB20SME, all without additives. This is possibly due to the chemical characteristics of samples, wherein the presence of oxygen in the mixture contributes to the combustion reactions are complete, reducing CO emissions.

CO concentrations, for all samples, were approximately 2.4 ±0.1% volume. It is found that mixtures B5RME, B20RME and B20SME (with and
without additives) had similar behaviour in CO₂ emissions. Aggarwal et al (2014) studied influence of fuel injection pressures and injection timings on particulate size number distribution and spray characteristics was investigated in a single cylinder, common rail direct injection (CRDI) compression ignition (CI) engine fuelled with Karanja biodiesel blends compared to Diesel.

The results of investigation of spray tip penetration and spray area of biodiesel blends and diesel showed that higher fuel injection pressure result in a longer penetration of spray tip and larger spray area than that at lower injection pressures at same elapsed time after the start of injection. Avinash Kumar Agarwal et al. (2013) used a single cylinder research engine (AVL, 5402) equipped with a modern common rail direct injection system connected to a transient AC dynamometer. Investigations have been done by varying fuel injection pressures to three values (300, 500, 750 bar) and different start of injection timings to four values. The experimental data indicates that the particulate size–number concentration increases with increasing engine load (BMEP) and it reduces with increasing fuel injection pressure.

Particulate size–number, surface area, volume distributions were studied in a single cylinder Diesel operated research engine working at 1500 rpm. The tests were conducted at different engine loads and fuel injection pressures were ranged from 300, 500 and 750 bar at various start of timing of injection. Particulate number concentration in the exhaust increases with increasing load on the engine. As the fuel injection pressure increases, the number concentration of particulates reduce along with mass of particulates at all loads. Increased pressures for fuel injection, advancing the injection timing lowers the concentration of particulate number because advanced
injection timings provide increased residence time for mixing between fuel and air masses before the beginning of combustion.

At low pressures of injection, number concentration increases in the beginning and then lowers as the injection time retards because air–fuel mixing at lower fuel injection pressures is proportional to in-cylinder build-up of pressure, temperature and with time available for mixing before beginning of combustion. Surface area of particulates and volume distribution also increases with rise in engine load and reduces with rise in pressure used for injection.

Pravesh Chandra Shukla et al. (2014) conducted comparative morphological study on the exhaust emissions coming out of a common rail direct injection engine Injection (CRDI) vehicle for sports applications (SUV). The inspection is done in the engine exhaust for aged and primary particulates. The study includes collection of soot particles from the CRDI engine that used diesel and 20% biodiesel mix (B20).

The operation of the engine was done at a rated speed of 1800 rpm at five conditions of load (0%, 25%, 50%, 75%, 100% rated load) for primary and aged particulate collection. In primary emissions, particulate matter collection raised with increase of engine load, which then converted into the form of crystalline format with the increase in engine load, meaning higher EC fraction of the particulate matter. At increased cylinder temperature due to rise in engine load leads to increased oxidation. Under this condition, the contribution of OC to the particulate is reduced. Factors like adsorption of organic compounds and volatile condensation due to low temperature of cylinder resulted in relatively wetter particulate collection of the aged group.
Lower content of sulphur and increase fraction of oxygen content in biodiesel led to better combustion and lower formation of particulates for B20 for both the cases, aged and primary emissions. It was noticed that the collection of particulates on the filter substrates was comparatively lower for aged particulates for B20 at 75% and 100% engine loads (D. Buonoa et al. (2012). It showed heavy reduction of particulates in the photo-chemical chamber itself during photochemical aging and quick hygroscopic growth.

Sumit Roy et al. (2014) investigated the scope of using artificial neural network (ANN) to evaluate the performance and pollution aspects of a single cylinder four-stroke common rail system engine by changing the fraction of EGR. The experimental data available were used to develop an ANN model to predict variation of BSFC, BTE, CO, NOx and PM with the load on the engine. The injection pressure of fuel, EGR and fuel injected per cycle were input data for the ANN system. The study was carried out the following distribution. 70% of total experimental data was used for training the ANN, 15% data used for ANN’s cross-validation and 15% data has been used for evaluating the performance of the trained network. The ANN model thus developed has the capacity for predicting the performance and emissions of the engine for testing with excellent agreement as noted from correlation coefficients within the range of 0.987–0.999, mean absolute percentage deviation in the range of 1.1–4.57% with relatively low root mean square changes. In this study common correlation coefficients were used.

The study also used special statistical error and performance metrics such as mean square relative error. The present study verified the applicability of ANN to simulate the emission performance observations of a CRDI engine under different values of EGR. The ANN model developed in the present study employed one input layer with four hidden neurons, two
hidden layers with ten hidden neurons in each layer and one output layer with five hidden neurons (4-10-10-5). The results of the proposed ANN model has been evaluated on a comprehensive statistical platform of error and performance metrics in comparison to the actual results of the experimental investigation.

The error evaluation shows that the data generated from ANN model matched well with the experimental data with high overall accuracy. Correlation coefficient (R) values ranging from 0.987 to 0.999. The MAPEs were observed to be in the range of 1.1–4.57% with very low RMSE. Jitendra N. Gangwar et al. (2012) carried out, parametric investigations on a modern automotive CRDI diesel engine operated at various loads at two different engine speeds (1800 and 2400 rpm), using diesel and 20% biodiesel mixes (B20) generated from Karanja oil. The particulate were taken and studied for mass, benzene soluble organic fraction (BSOF), EC and OC, particle-bound PAHs content and trace metal contamination.

Biodiesel mix (B20) exhibited increase in the performance of engine. The particulate mass emission reduced at all operating conditions of the engine compared to diesel. This is be due to decrease in sulphur and aromatic fraction of biodiesel. From the results of this study, it is clear that that the PAHs concentration is low at zero load condition which then raises to a maximum value for 60% rated load at 1800 rpm and 20% rated load at 2400 rpm. With further change of engine load, the value reduced. It is concluded that, the mass of particulate matter (PM) is reduced; the BSOF and metal contamination of particulate matter from the engine with biodiesel is comparatively more than that of diesel. This shows chances of potential for higher toxicity of particulates from the biodiesel. There is a need to further test this and verifications and verified by studies involving animal exposure.
Implementation on a large scale for the biodiesel programmes may be done only after such studies.

Tarun Gupta et al. (2011) measured CRDI engine emissions under simulated ambient conditions using a newly developed photochemical chamber. From the experimental data and analysis thereof, several key observations have been made. Exhaust emission ageing was carried out within the temperature range of 35-45°C and RH range of 40-60%. As the engine load raises the emissions of OC, EC and PAHs also increased in the exhaust of the Diesel engine. With increase in engine load, it is observed that the rate of primary EC emission is higher than rate of increase of emissions of OC. The maximum absolute secondary OC forms at 60% engine load, which is the highest loading of the engine for this investigation. However, the relative amount of SOC when normalized with primary OC and EC are highest for 0% and 20% loads respectively. Another important observation is made regarding the particle bound PAHs, which increase by many times after ageing. This means that the toxic value of diesel engine emissions might increase several times even under moderate ageing conditions.
2.9 TALLOW AVAILABILITY FROM MEAT WASTES

The practice of oils or waste tallow as feed for Diesel engines and their by-products for other applications have been suggested for this purpose for the past 100 years, when Rudolf Diesel did their tests using raw petroleum and oil derived from peanut. Though, the scarcity of crude oil stock on the world arcade, produced by equipped clash that started in the 30s, directed to the hunt for practicable methods for substituting conventional fuel. The disposal of greases and waste tallows continues to be a big problem for waste managers. Thus converting them to biodiesel is to be encouraged and subsidizing of biodiesel from these sources is justified. Waste tallows are extremely viscous and ordinarily in solid form at atmospheric temperature because of their large content of saturated fatty acids. The more viscous fuels lead to reduced spraying and result in improper combustion. The penalties are the greater generation of pollutants and particulate matter in the gases flowing out.

Waste tallows are lavishly obtainable because increase in meat consumption are usually well accomplished for product control and handling measures. But, there’s also an element of bio safety issue associated to waste tallows that could come from the diseased animals. The upcoming research to confirm excellence of biodiesel from animal waste (cradle to grave) has been emphasized. Biodiesel prepared by converting waste cooking oil or from waste tallow is less resilient under cold conditions than biodiesel made from pure soybean oil or most other seed oils. As flavours are established specifically for the biodiesel industry, even this dissimilarity could soon vanish.
Most waste tallows are produced in slaughter houses and rendering plants. Yields of rendering industry commonly have poorer market price. Things that for aesthetic or sanitary reasons are not appropriate for human food are proposed as feed stocks for rendering processes (Knothe K. (2008)). The greases generated are normally labelled as follows.

a. Tallow removed from remainders of slaughter of bovines and it may or may not be clean. It has assured that the product encloses least 90% total fatty acids, impurities extreme 1.5% and no FFA or fat deprivation yields; b. Lard removed from swine slaughter deposits, being its requirement and excellence promises the same as for tallow; c. Chicken fat take out from broiler slaughter residues and it can be clean or not since it has certain that the product contains minimum 90% total fatty acids, maximum 3% impurities, without FFA or fat degradation products (Boey, P.L et al. (2011) Distribution of production of animal protein in the world in 1975 and 2008 (http://www.feedipedia.org/node/3255 (last accessed on 9-5-2016)) Waste tallow mix removed from slaughter residues of animals or birds. It can be cleaned or not since it has assured that the produce holds total fatty acids minimum 90%, maximum 2% impurities, without FFA or products of fat deprivation unless the ones produced even with good manufacture performs executed in (Canoira, L et al. (2008)). The animal species for the feed from which the fat creates must be identified. Information on the use of antioxidants must be known in any of these yields. The main variance among waste tallow and vegetable oil is their fatty acid content (Foglia, T.A et al. (1997) fuel as a consequence of increases in combustion chamber temperature via burning of pre-injected fuel.

Shahir et al (2015) reported the use of Biodiesel and compared to diesel as a fuel, in ordinary diesel engines without modification. The review
concludes that biodiesel causes lowering of PM, HC and CO emissions, followed by a light power loss, increase in fuel consumption and NOx emission. The comparison is made on both conventional and CRDI engines. The quantum of research published work in CRDI system is limited compared to that of available literature in direct injection engine.

Vishal Mutreja et al (2011) explain the production of biodiesel from mutton tallow advantage of magnesium oxide with potassium hydroxide as catalyst for pre-treatment of mutton tallow with methanol has been experimentally determined. In this reaction, the yield of biodiesel is 98% in 20 min which is achieved with 0.02 % of water vapour and 0.002 % of FFA with methanol fully transformed to biodiesel. Extra 1% of water vapour content produces soap. Magnesium oxide with 20 % potassium hydroxide reagents can accommodate extra 1% of water in the tallow. Cenk Sayin et al. (2008), showed the impact of injection timing on the engine emission of a single cylinder DI engine. Ordinary CI engine has been practically examined using diesel fuel blended with ethanol from 0% to 15% with an addition of 5% increase in steps. The engine has its initial injection timing 270 CA BTDC but the examinations were executed at injection timings 210,240,270,300,330 CA BTDC by altering the depth of advanced shim.

The research outcomes in improved NOx and CO₂ content in exhaust while the CO and HC content were reduced with cumulative quantity of ethanol in the fuel combination. When matched to the evaluations of actual injection timing, at the delayed injection timings (210 and 240 CA BTDC) reasons a growth of NOx and CO₂ content in the engine exhaust. The unburned HC and CO content in the exhaust reduced for all experimental setup. Alternatively, with the progressive injection timings (300 and 330 CA BTDC), HC and CO content in the exhaust decreased, and NOx and CO₂
content in exhaust improved. Venkanna et al. (2009) conducted experiments by using different blend of rice bran oil (0% to 50%) with diesel. Direct injection engine was used for conducting experiments up to 100 % rated load. The result show that for a blend B20, BSFC and exhaust parameters were close to the values of diesel.

2.10 P-Θ DIAGRAM

H.G. How et al. (2011) and Chien- Hsing Liet al. (2014) showed that Combustion pressure of the engine for various fuel blends at standard injection timing condition and constant engine speed was slightly higher than diesel. This reason for this is the higher oxygen content in the fuel of biodiesel blends, which causes better burning efficiency. By using experimental design and analysis method, the transformation of angle domain, frequency domain and emission have been discussed in this study. In term of transformation of angle domain, Figure 2.12 (a) showed the curve of angle domain which was under engine operation conditions including 1500 rpm/ 84 Nm, 2000 rpm/ 170 Nm and 2500 rpm/ 238 Nm, respectively. The crank angle from −10° to 15° has been discussed in this Figure. With the different testing condition, the variation of combustion pressure wave has been observed obviously.

In theory, the curve of combustion pressure wave could be smooth. In fact, the combustion pressure wave of diesel engine showed slight shaking which showed in this Figure. Speaking of phenomenon of combustion pressure wave, engine speed from 1500rpm to 2000rpm, engine torque output at 50% load, the shaking at those operation conditions was almost the same. However, shaking of combustion pressure wave, while engine speedup to 2000rpm;
especially increase the percentage. Figure 2.12 (b) shows the combustion pressure of the engine for various fuel blends at standard injection timing condition and constant engine speed of 2000 rpm and throttle position corresponds to 50%.

As seen in Figure 2.12 (c) the first peak occurring near TDC corresponds to the injection of pilot spray, and the inverted U-shaped curve reflects the main injection period. With a fraction of fuel injected prior to the main injection, reductions of combustion noise and NOx emissions can be achieved compared with an engine operation without pilot injection. Also, the split injection strategy shortens the ignition delay for the main.

(a). 1500 rpm/ 30%/ 84 Nm
(b) 2000 rpm/ 50%/ 170 Nm

(c) 2500 rpm/ 70%/ 238 Nm

Figure 2.12. Transformation of combustion pressure and angle domain at different operating conditions
Figure 2.13 Combustion pressure curves for different fuels (H G How)
It can be observed that when the engine is operated with CME B20, the peak pressure achieved from the pilot injection is slightly decreased, (Figure 2.14) but the following hump-shaped pressure curve which corresponds to the combustion of main fuel remains almost the same with baseline diesel. The decrease of peak pressure on the increase of biodiesel fraction in the blends
may be due to the lower calorific value of the fuel. However, with higher biodiesel fuel blend of CME B40, both the peak pressure and the hump-shaped pressure curve hardly vary. The reason for this may be attributed to the oxygen content in the chains of coconut methyl ester blends, which increases the features of combustion.

Figure 2.13 shows the combustion pressure for baseline diesel, CME B20 and CME B40 under various injection timings (with pilot and main injection timing are varied simultaneously) at constant engine speed of 2000 rpm and 50% throttle position. The general trend for CME B20 and CME B40 is almost the same as for baseline diesel. It can be observed that the peak pressures which occur near TDC are increased with the retarded injection timing, but keep almost the same as standard injection timing with advanced cases. The reason is due to the retarded start of pilot injection timing, the pilot combustion thus occurs late in the compression stroke, which results in an increase of peak pressure near TDC. With the advanced start of pilot injection timing, the pre-injected fuel does not ignite immediately until the in-cylinder pressure and temperature are above the fuel’s ignition point, and thus lengthens the ignition delay and results in insignificant effect on the variation in peak pressure.

The hump-shaped pressure curve after the TDC point reflects the fuel combustion due to main injection. The result indicates that when the start of main injection is retarded, the main combustion event is thus shifted away from TDC in expanding stroke. This causes a reduction in IMEP and some losses in thermal efficiency. For the advanced injection timing, the whole main combustion event move backwards toward TDC in the expanding stroke, thereby resulting in an improvement of IMEP and thermal efficiency. Another interesting observation is that when the main injection timing is shifted to the
most advanced of −4°ATDC, the pressure rise during the combustion of main injection is much sharper for CME B20 and CME B40 than for baseline diesel fuel. This shows that methyl ester content of coconut oil promotes faster burning rate than that of diesel. In fact, the trend of faster combustion of biodiesel can be further observed from the heat release rate data.

2.11 ANIMAL FAT

Significant increase in waste tallow occurs during previous decades. Meat manufacture in the world touched 237.7 million tons in 2010. Eventually higher amount of waste tallow from this industry has been created. To avoid inefficient disposal of waste tallow from meat industry may be used to produce biodiesel as fuel in the Diesel engines.

So many papers are available to compare properties of biodiesel from different sources such as waste tallow, waste oil, and wastage of fish, vegetable oil, and ordinary diesel (Choi S-H, Oh Y. (2006), Metin Guru et al. (2010), Shao yang Liu et al. (2011), Darunde Dhiraj S and Deshmukh Mangesh M. (2012) and Lebedevas S et al. (2006). It is found some properties like density, heat of burning, flash point, acid value and corrosion related to the source of biodiesel (Shao yang Liu et al. (2011). Following properties of biodiesel can be obtained from ester profile of fuel. Oxidative stability kinematic viscosity and low temperature properties. Fuel qualities significantly effects on lino lenate and some contaminants (Shao yang Liu et al. (2011).
2.12 TYRE OIL

It is well known that the requirement of petroleum products exponentially increase due to industrialization. This led to higher living standards and increased use of automobiles. These are the non-renewable resources, their generation and availability is unpredictable in future. This and other political problems cause an uncertainty in the supply and price and have an impact on the developing countries like India which import 80% of the total consumption of the crude oil products. Considerable research has been made by different scientists to find out substitute fuels for Internal Combustion engines.

Many substitute fuels like LPG (Liquefied Petroleum Gas), Biodiesel, Alcohols and CNG (Compressed Natural Gas) are being substituted recently by different vehicles. Tyre pyrolysis oil is obtained by the pyrolysis of waste tyres. Tyre pyrolysis oil is mixed into diesel in different ratios viz. 10, 20, 30, 40 and 50 per cent by volume fraction. The properties of fuel samples are measured by standard methods. The performance characteristics are studied on CRDI engine. Experiments were carried out to estimate the performance characteristics of a CRDI diesel engine that used by 10, 20, 30, 40 and 50 per cent blends of Tyre pyrolysis oil (TPO) with diesel fuel (DF). For this work, Pyrolysis is a technical solution to handle the issue of safe disposal of used tyres.

Pyrolysis is nothing but anaerobic thermal decomposition of organic matter at elevated temperatures. Tyre of which main constituent is rubber is a basically a hydrocarbon. At elevated temperatures the carbon hydrogen bonds present in the structure of rubber is seen to undergo reformation and rubber
contents break down to volatile fumes, 80% of which are condensable and 20% are non-condensable gases. The condensable fumes settle down to make a family of liquid fuels which is commonly termed as Tyre Pyrolytic Oil. From the results it is clear that the brake thermal efficiency of the system that used TPO-DF blends raised with increase in tyre oil content and higher than Diesel fuel.

Several substitute fuels like methanol, biogas, vegetable oils and ethanol have been tested as a partial or total alternative to diesel fuel (Qi et al. (2010), Aral Mozhi Selvan (2009), S. Kalligeros et al. (2003)The vegetable oil can be used directly in CI engine as a feed, as their percentage of energy content is little high and mostly match that of diesel. The methodology of generation, the collection, conversion of vegetable oil from oil seed crop and other trees with oil seeds is well established and relatively simple (Suryanarayanan S et al. (2008), S. Kalligeros et al. (2003), A.A. Zabaniotou and Stavropoulos, (2003), S. Muruganet al. (2007), Benjumea P et al. (2009).

It is also found that TPO has property values near to that of diesel fuel. In reference, Production was carried out in a one ton batch pyrolysis system to generate oil, char and gas from waste vehicle tyres through pyrolysis process (S. Kalligeros et al. (2003), A.A. Zabaniotou and Stavropoulos, (2003), Yoon SH and Lee CS. (2011). Across the word especially in cities, the tire waste remains as one of the important problem creating waste. Increase in the use of automobiles of the developed and developing countries contributed to this (http://www.rma.org/scrap_tires). Estimates shows that the amount of waste tyres of vehicle accumulated each year tires are approximately 1 billion (http:// www. rma .org /publications/ scrap tires/index.cfm Publication ID =11453 (2005). With these huge quantity of
tires as feed, pyrolytic oil can be produced this carries 85.54% C, 11.28% H, 1.92% O, 0.84% S, and 0.42% N (Mastral et al. (2000). The tire pyrolysis oil and plastic pyrolysis oil have been tested and found that they both are able to run in CI engine and the fuel properties of the oils are identical to diesel oil (S. Murugan et al. (2008), M. Mani and G. Nagarajan, (2009). Both oils from pyrolysis are a chemical chain of C5-C20 organic compounds.

The tire pyrolysis oil consist of a major fraction of aromatics and up to 1.4% sulfur content whereas the plastic pyrolysis oil is able to occur high presence of chlorine, especially if the plastic is not sorted properly (M. Mani et al. (2009), A. Demirbas, (2004). The steps like chemical procedures, generation and scope of production of pyrolysis oils are done extensively in the past (J. G. Rogers and J. G. Brammer, (2012) R. W. J. Westerhout et al. (1998), M. R. Islam et al. (2011). From the above reported literature it is clear that a CRDI engine is not tested for higher percentage TPO blends for performance characteristics. In the present study a CRDI engine is tested with blends upto B50. Performance characteristics are compared for various blends and compared with that of Diesel.

Tyre of which main constituent is rubber is a basically a hydrocarbon. At elevated temperatures the carbon hydrogen bonds present in the structure of rubber is seen to undergo reformation and rubber contents break down to volatile fumes, 80% of which are condensable and 20% are non-condensable gases. The condensable fumes settle down to make a family of liquid fuels which is commonly termed as Tyre Pyrolytic Oil. The condensate has the following typical specifications. (Table 2.3)
Table 2.3 specification of tyre pyrolitic oil condensation

<table>
<thead>
<tr>
<th>Specification</th>
<th>CST</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic Viscosity At 40°C</td>
<td>CST</td>
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</tr>
<tr>
<td>Acidity, Total</td>
<td>MgKOH/gm</td>
<td>0.01</td>
</tr>
<tr>
<td>Ash</td>
<td>% BY WT</td>
<td>0.005</td>
</tr>
<tr>
<td>Flash point, COC</td>
<td>°C</td>
<td>40</td>
</tr>
<tr>
<td>Water content</td>
<td>% BY WT</td>
<td>NIL</td>
</tr>
<tr>
<td>Pour point</td>
<td>°C</td>
<td>6</td>
</tr>
<tr>
<td>Density at 27°C</td>
<td>gm/cc</td>
<td>0.907</td>
</tr>
<tr>
<td>Sediments</td>
<td>% By mass</td>
<td>0.02</td>
</tr>
<tr>
<td>Total sulphur</td>
<td>% By mass</td>
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</tr>
<tr>
<td>Copper strip corrosion test for 3 Hrs at 100°C</td>
<td>No units</td>
<td>1b</td>
</tr>
<tr>
<td>Gross calorific value</td>
<td>kj/kg</td>
<td>42676.8</td>
</tr>
</tbody>
</table>

It can be seen that the fuel is highly flammable and has calorific value equivalent to that of petroleum derived fuel. The low sulphur content makes it far less polluting than petroleum derived fuels. This fuel can safely be used for heating applications in furnaces and boilers using burners of varied types. For using pyrolytic fuel to be used as fuel for engines it is further distilled in distillation columns. On distillation the pyrolytic oil gives a range of streams at various boiling points. The compounds of light tyre pyrolysis oil are alkenes, alkenes and aromatic compounds.

2.12.1 Tyre Pyrolytic Oil Distillation

Crude oil is a mixture of different hydro carbons. Tyre Pyrolytic Oil is also a mixture of different hydrocarbons. Crude Oil is subjected to fractional distillation for making different petroleum products like naphtha, petrol, Kerosene, diesel etc. Many useful products can be made from these hydrocarbons. The different hydrocarbon components are called fractions. The separation between different fractions is done by a chemical process
called fractional distillation. Each substance have a unique boiling point, is the principle behind such separation. For example, petroleum contains naphtha and kerosene which are useful components (naphtha is converted to petrol for cars, and kerosene is converted into jet fuel.

As the mixture cools, the kerosene condenses first, and the naphtha condenses later. In a similar way, Tyre Pyrolytic Oil can also be subjected to fractional distillation. This is principle behind fractional distillation. The Tyre pyrolytic oil is gradually heated to reach 300°C, which makes most of the oil evaporate. The fractions of oil in vapour form enter the fractionating column as it boils. With the movement of vapour upwards through the fractionator, it cools and condenses. The condensates are collected in separate vessels. The remnant in the boiler is denser with specific gravity of about 0.95 and least volatile.

The general scheme of collecting distillates followed is given below. **Fraction A** All those which has boiling points ranging from 109 up to 160 degree are collected as Fraction A. They are highly volatile with flash point falling close to 30 deg **Fraction B** all those which has boiling points ranging from 160 up to 190 degree are collected as Fraction B. They are less volatile with flash point falling between 35 deg to 40 deg. **Fraction C** All those which has boiling points ranging from 195 up to 240 degree are collected as Fraction C. They are less volatile with flash point falling above 42 deg and are denser. **Fraction D** All those which have boiling points ranging from 240 up to 300 degree are collected as Fraction D. They are less volatile with flash point falling above 45 deg. It can be seen that Fraction A& B has characteristics similar to that of petrol while C&D has characteristics similar to that of diesel.
2.13 INFERENCES FROM LITERATURE REVIEW

The following are the summary that is drawn from the present study

- From the above reported literature it is clear that a CRDI engine is not tested for higher % biodiesel blends for performance and emission characteristics. The current real world requirement is technology for substitution of a higher fraction of the automotive fuel by biodiesel.

- The similar issues identified by the researchers during durability tests are fuel pump failure, plugging of filter, injector coking, sticking of moving parts.

- Studies generally concluded the increase of NO\textsubscript{x} generation with the use of biodiesel blends. The majority of literature concludes that this is due to injection advance in biodiesel systems. Such an advance may be due to the changes in physical properties like density which then causes the electronic unit to respond in a different way. Some researchers suggested delay in injection as a means of effective control of NO\textsubscript{x}. They also caution on the fact that any such step increases the particulate emissions. There are many conflicting information’s in the literature regarding the effects of biodiesel on NO\textsubscript{x} emissions. Majority express their opinion that use of biodiesel or biodiesel blends increases NO\textsubscript{x} emissions in comparison with mineral diesel fuel. The reasons for this inconsistent observation are due to the fact that several factors contribute to the generation of NO\textsubscript{x}. The relative importance of these factors, variations in the engine technology and operating conditions contributed to these differences. It was reported that certain additives act as antioxidant in biodiesel that can reduce the prompt NO (by up to 43.5\%). This led to rise in CO and HC emissions. The LTC mode of combustion in engines with biodiesel reduces NO Redesigned engine or/and its control systems is needed for optimizing ignition and injection with biodiesel as fuel.
• Exhaust gases such as those of HC and CO are usually found to decrease considerably with the use of biodiesel. The main reason pointed out for this is the complete combustion caused by the oxygen content in the fuel chain of the biodiesel molecules. The emission of aromatic and polyaromatic compounds, as well as their toxic and mutagenic effects, has been generally considered to be lowered with the use of biodiesel. Use of ITR technology lowers NO emissions by about 9.77–36.84% while compared to biodiesel and 21–37% while compared to diesel. However this is accompanied by reduced engine performance and increased emissions of CO, smoke and HC. The influence of simultaneous NO control technologies, such as dopes, emulsion and 15–20% EGR on a biodiesel-fuelled engine shows positive impacts on the performance of the engine and NO emissions. However CO, HC, and smoke could not be controlled. PM emissions were higher by about 95% and 98%, respectively, with little changes on engine performance. Though such method increases HC and CO emissions greatly, the impact can be minimized with the help of after burner equipment such as OCC.

• The majority of studies have found sharp reductions in particulate emissions with biodiesel as compared to diesel fuel. The higher oxygen content and lower aromatic compounds have been regarded as the main reasons. Many of the researches agreed that aromatic and polyaromatic compounds emissions for biodiesel are lower compared with the use of diesel. Emissions of carbonyl compounds have varying results for biodiesel, although it is widely accepted that, biodiesel increases these oxidants emissions because of increased oxygen content. This reduction is mainly caused by lower soot formation and enhanced oxidation of soot. The reasons pointed out were the oxygen content and the absence of aromatic content in biodiesel. It is possible that under starting
conditions the mentioned reduction could be stopped or even reversed to result in a certain increase.

- Regarding particulate matter, most of the authors have reported a decrease in the mean diameter of the PSDs with the biodiesel fuels, as compared to Diesel. Such a shift is mainly caused by a decrease in the number of large particles generated. Some of the studies reported uncertain increase in the number of the smallest ones.

- Higher specific fuel consumption is observed for biodiesels, due to low calorific value, high density and high viscosity of these fuels. But this tendency getting weakened as the proportion of biodiesel in the blend is reduced.

- Biodiesel can improve combustion features and hence has higher brake thermal efficiency than crude based diesel. Engine power is lowered slightly or even remains the same, because the consumption of biodiesel increases sufficient to compensate its lower calorific value. In general engine performance with the biodiesel is in the acceptable range and there is a scope for further improvement if viscosity could be lowered.

- The majority of studies have shown that PM emissions for biodiesel are significantly decreased, compared with diesel. The oxygen content and lower aromatic compounds have been held as the main factors.

- During durability test, the common problems identified by the researchers are failure of fuel pump, filter plugging, injector coking, moving parts sticking etc.

- Majority of the literature showed that aromatic and polyaromatic compound formation for biodiesel are lower compared with the use of diesel. Carbonyl compounds emissions have conflicting results for biodiesel, although it is well known that, use of biodiesel causes an
increase of these oxidants emissions because of higher content of oxygen.

- Production of biodiesel should be done in the future to uphold quality of biodiesel. Research and development of various additives is needed in order to increase the consumption of biodiesel so as to ensure a power recovery, economy and emissions especially for NOx generation.

- Recalibrating or redesigning of engine or/and its control systems for biodiesel, particularly for controlling ignition and injection, and EGR control to achieve a more effective combustion

- The performance of biodiesel engine under low temperature condition is noticed because biodiesel presents higher viscosity than diesel. This could affect the emissions due to the different size of droplets and the different primary zone equivalence ratio for biodiesel and diesel without any change in fuel nozzle.

- Latest types of engine like CRDI engine should be tested in biodiesel with different blending proportions up to 100%

- New methods for production of biodiesel also have relevance

- Very latest methods for analyzing engine performance may be considered in the future developments

From the above literature it is clear that a CRDI engine is not tested for higher percentage biodiesel blends for performance and emission characteristics. The literature also shows that the bio fuels from jatropha, animal fat and tyre pyrolitic oil is not studied in the CDRI engine. In the present study a CRDI engine is tested with blends up to B50 using bio fuels derived from jatropha, animal fat and tyre pyrolitic oil. Performance and
emission characteristics are tested for various blends and compared with that of diesel.

**2.14 AIM AND OBJECTIVES**

The aim of the present study is to test a CRDI engine with blends up to B50 using bio-fuels derived from jatropha, animal fat and tyre pyrolitic oil. Performance and emission characteristics are tested for various blends and compared with that of diesel.

The following are the objectives

1. To identify optimum conditions for the production of biodiesel from raw meat oil and Jatropha oil

2. To conduct the performance and emission characteristics of the CRDI engine using biodiesel produced from Jatropha biodiesel and compare with that of pure Diesel.

3. To conduct the performance and emission characteristics of the CRDI engine using biodiesel produced from meat waste and compare with that of pure Diesel

4. To conduct the performance and emission characteristics of the CRDI engine using biofuel produced from tyre oil and compare with that of pure Diesel

5. Conduct a comparative study on performance and emission of the CRDI engine with the different fuels based on the results from the above objectives