CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Vegetable oil was one of the first fuels used in the internal combustion engine. Rudolph Diesel first developed the diesel engine in 1904 with the intention of running of variety of fuels. He had demonstrated his engine running with peanut oil at the world exhibition held at Paris in 1900. Since then, the use of vegetable oil as fuel for diesel engine has been reported in the research papers, even though the availability of fossil fuel was plenty and price was cheaper at that time. The use of vegetable oil and its methyl ester in diesel engine has been reviewed and discussed in this chapter.

1. Use of straight vegetable oil (SVO) in diesel engine
2. Use of vegetable oil blends
3. Use of heating of vegetable oil
4. Use of esters of vegetable oil (biodiesel)
5. Use of blends of vegetable oil methyl ester
6. Use of vegetable oil with low heat rejection engine
7. Use of dual fuel with additives
8. Use of vegetable oil at various injection pressures
2.2 USE OF STRAIGHT VEGETABLE OIL (SVO) IN DIESEL ENGINE

Experiments have been conducted with a number of vegetable oil like rapeseed oil, sunflower oil, soybean oil, rice bran oil, neem oil, palm oil, rubber seed oil, Jatropha oil, karanja oil, coconut oil, etc as fuel in diesel engines ad acceptable performance over a short period of time in unmodified diesel engine has been reported. However, studies also indicate that long-term use of vegetable oils results in problems like heavy smoke emissions and carbon deposition in various parts of the engine due to high viscosity and carbon residue. Use of 100% vegetable oils in diesel engine results in almost same engine power with slightly lower thermal efficiency in comparison to diesel engine.

Bruwer et al (1980) have studied the use of sunflower oil as fuels in tractors. It has been reported that, after 1000 hours of operation, the power loss was only 8%. It has been further reported that the power loss was reduced by replacing the injectors and injection pump. It has been concluded that the carbon deposit in the engine after 1300 hours of operation was equivalent to that of diesel operation. However, the carbon deposit in injectors was higher. It has been concluded that the sunflower oil could be an alternative fuel for diesel and also that it developed severe carbon deposit.

Barsic and Humke (1981) investigated the performance and emission characteristics of a single cylinder naturally aspirated direct injection diesel engine with 100 % sunflower or 100% peanut and their blends (50% by volume) and the results were compared with diesel. They have reported similar performance and higher emissions with vegetable oils. Carbon monoxide and hydro carbon emissions were higher for 50 percent vegetable oil diesel fuel blends than 100 percent vegetable oil or 100percent
diesel fuel for some engine speeds and loads. These higher emissions are due to high fuel viscosity and fuel spray characteristics of vegetable oil.

**Bacon et al (1981)** have evaluated the use of several vegetable oils as potential fuel for diesel engine. It has been stated that the vegetable oils developed acceptable power, but these oils caused high carbon build up in the combustion chamber. It has been concluded that the continuous running of an engine with vegetable oil at part-load and at mid-speed caused rapid carbon deposit on the injector tips. It has been further concluded that long-term engine testing has to be carried out to determine the overall effects of using vegetable oils in a diesel engine.

**Yarbrough et al (1981)** have studied the performance of a diesel engine with six variants of sunflower oil as fuel. It has been reported that the refined sunflower oil gave satisfactory results. It has been further reported that degumming and dewaxing the vegetable oil prevented engine failure. It has been concluded that raw sunflower oil could not be a fuel but modified sunflower oil could be used as a better fuel.

**Pyror et al (1983)** have also conducted short and long term engine performance tests using 100% soy bean oil in a small diesel engine. It has been reported that the short-term test with soy bean oil indicated performance similar to that of diesel fuel and long-term engine testing could not be carried out due to power loss and carbon build up on the injectors. It has been concluded that the soy been oil could be considered for short term operation.

**Seppo et al (1997)** have tested a turbo charged four cylinder direct injection diesel engine using mustard oil. It has been reported that the engine developed power equal to that of diesel. It has been further stated that the
smoke and NOx emissions were lower than diesel. It has been concluded that long term tests be carried out.

Yu et al (2002) have tested the use of waste cooking oil as alternative fuel for diesel engine. It has been further reported that the combustion characteristics were similar to that of diesel fuel. It has also been reported that the peak pressure was little higher and it occurred earlier by 1.1°-3.8° CA than diesel. It has also been stated that the engine performance deteriorates for long term use, because, heavy carbon deposition on the piston crown is higher than diesel. It has been concluded that the waste cooking oil developed similar engine performance but deteriorated after long use.

Pugazvadivu and Jayachandran (2003) have tested a single cylinder direct injection diesel engine with waste frying oil as fuel. It has been stated that the specific fuel consumption and smoke emission was marginally higher than diesel, but NOx emissions were lower than diesel which were due to low solubility of waste frying oil.

Laxminarayana Rao et al (2004) have investigated the use of unrefined rice bran oil, coconut oil and neem oil on a direct injection diesel engine. It has been reported that the brake thermal efficiency was lower for vegetable oil than diesel, due to lower calorific value. It has also been reported that the carbon dioxide and hydrocarbon emissions were slightly higher than diesel, but NOx emissions were lower than diesel. It has been conducted that the sluggish combustion and increased fuel consumption are due to lower caloric value and atomization.

Nazar et al (2004) have studied the use of coconut oil as an alternative fuel in direct injection diesel engine. It has been reported that the peak thermal efficiency for coconut oil was 28.67% and for diesel, it was 32.51%. It has also been concluded that the smoke, CO, HC and NOx
emissions were lower than diesel emissions while the exhaust gas temperature was higher than diesel.

**Wang et al (2006)** have studied the use of vegetable oil on a direct injection diesel engine. It has been reported that the CO and HC emissions were lower at full load and it was higher at lower loads. It has also been reported that the NOx emissions were lower at all blends.

**Narayana Reddy and Ramesh (2006)** have tested a diesel engine with neat Jatropha oil with various parameters like injection timing injector opening pressure, injection rate and swirl level. It has been reported that the marginal improvement in brake thermal efficiency and reduction in HC and smoke emissions while advancing the injection timing by 3°CA. It has also been reported that by increasing the injector opening pressure, the marginal improvement in brake thermal efficiency and all emissions are reduced, due to better spray atomization.

**Deshmukh and Bhuyar (2009)** have tested a single cylinder direct injection diesel engine with the use of Hingan oil as fuel. It has been reported that slight power loss and higher specific fuel consumption occur with Hingan oil. This may be due to lower heating value of the Vegetable oil. It has also been reported that the CO and HC emissions were reduced and the NOx emissions are same for Vegetable oil compared to diesel fuel.

**Rakopoulos et al (2009)** have investigated the use of Vegetable oil like, Cotton seed, Soybean oil, Sunflower oil, Rapeseed oil, Palm oil, Corn oil and Olive oil on a diesel engine. It has been reported that the smoke, CO emissions are increased with increase in vegetable oil blends. It has also been reported that the brake thermal efficiencies were nearly same and the brake specific fuel consumptions are higher due to lower calorific value of the vegetable oil.
2.3 USE OF HEATING OF VEGETABLE OIL

Use of raw vegetable oil as fuel for diesel engine has an important drawback due to its high viscosity. This affects the spray formation and leads to poor combustion. Preheating the vegetable oil would reduce viscosity. During heating, the heavy fatty components of the vegetable oil are broken or cracked into lighter components and thereby viscosity is also reduced. In this section, the available literature on preheating are grouped and presented.

Barsic and Humke (1981) have investigated the use of peanut oil as fuel in a single cylinder direct injection diesel engine. It has been reported that the preheating of vegetable oil to 70-90°C dissolved the wax contents of the oil. It has been further reported that the preheating prevented the clogging of fuel filters and fuel lines. It has been concluded that the preheating of vegetable oil resulted in reduced viscosity leading to smooth flow and better fuel spray formation.

Ryan et al (1983) have studied the effect of preheating the vegetable oil in direct injection diesel engine. It has been reported that the preheating of vegetable oil to 140°C reduced the viscosity of the vegetable oil to that of diesel. It has been further reported that the preheated fuel improved the performance of the engine due to the improvement in spray pattern, atomization and cetane rating. It has been concluded that there was improvement in performance and reduction in smoke emission.

Murayama et al (1984) have studied the effect of rapeseed oil preheated at 200°C in naturally aspirated direct injection diesel engine. An empirical relation has been found to determine the different preheating temperatures at which the viscosity of vegetable oil becomes equal to the viscosity of diesel. It has been reported that the preheating was effective in reducing carbon build up and ring sticking. It has been further reported that
the brake specific fuel consumption decreased with the use of preheated oil than that of raw rapeseed oil at ambient conditions.

**Rajasekaran et al (1997)** have tested the IDI diesel engine with preheated diesel as fuel at different speeds. It has been reported that the temperature was maintained from 60 to 75°C in steps of 5°C. It has been further reported that the soot reduction was nearly 50% for preheated diesel emission and that there was no remarkable change in brake thermal efficiency. It has been reported that the smoke density showed reduction for preheated diesel. It has been concluded that the preheated fuel in IDI engine showed reduction in soot emission.

**Bose et al (2001)** have investigated the effect of preheated Karanja oil and its methyl esters in a direct injection diesel engine. It has been reported that the karanja oil methyl ester gave higher thermal efficiency than diesel. It has also been reported that at higher injection pressure the performance was improved. It has been concluded that by 4° advancing the injection timing the CO and CO₂ emission levels were little higher.

**Bari et al (2002)** have investigated the effect of preheated palm oil on a diesel engine. Preheating of oil results in lower viscosity and provided smooth fuel flow and it has not affected the injection systems. It has been reported that the cylinder pressure was increased by 6% and shorter ignition delay by 2.6° CA. It has also been reported that the CO and NOx emissions were increased by 9.2% and 29.3% respectively compared to diesel fuel.

**Nwafor (2003)** have conducted a test on a diesel engine with preheated vegetable oil. It has been reported that there is no significant reduction in brake specific fuel consumption and increase in HC emissions at higher loading conditions. It has also been reported that the preheated oil increase cylinder pressure and it was beneficial at lower load conditions.
Nazar et al (2004) have studied the effect of preheated Karanja oil at 165°C in a 3.67kW direct injection diesel engine. It has been reported that the brake thermal efficiency increased as the fuel temperature increased. It has been reported that CO and HC emissions were decreased for preheated karanja oil. It has been further reported that the smoke level was 3 BSU, while it was 4 BSU for karanja oil without preheating. It has been concluded that there was an improvement in performance, reduction in emissions and also that long term effect has to be tested.

Pugazhvadivu and Jayachandran (2005) have tested the use of waste frying oil preheated to 70-135°C in a direct injection diesel engine. It has been reported that the preheated oil improved the performance of the engine. It has also been reported that the CO and smoke emissions were reduced considerably. It has also been further reported that the NOx emissions were increased with increased fuel inlet temperature. It has also been concluded that the preheated oil at 135°C could be used as diesel fuel for short term engine operation.

Ramadhas et al (2005) have investigated the suitability of rubber seed oil as an alternative for the diesel fuel in compression ignition engine. It has been reported that the brake thermal efficiency were higher and the specific fuel consumptions were also higher in rubber seed oil blends. It has also been reported that the smoke emissions were lower for rubber seed oil blends and it was higher for raw oil. It has been concluded that 20-40 % blends yielded the engine performance closely to diesel fuel and carbon deposits in the combustion chamber of engine was higher in the case of rubber seed oil blends due to incomplete combustion of the fuel.
2.4 USE OF ESTERS OF VEGETABLE OIL

The main drawbacks of vegetable oil are the high viscosity and low volatility, which causes poor combustion in diesel engine. The transesterification is the process of removing the glycosides and combining oil esters of vegetable oil with alcohol. Due to this process the viscosity of the ester is equal to that of diesel and improves the combustion. Available literature related to the use of biodiesel have been grouped and presented in this section.

Yusuf Ali and Hanna (1995) have tested the use of blends of methyl ester of soyate with diesel in a 6 cylinder turbo charged diesel engine. It has been reported that the engine performance was the same up to 70/30 blend. It has been further reported that the CO, HC and smoke were lower and NOx emissions were higher. It has been concluded that the 80/20 methyl ester and diesel blend gave better performance.

Laforgia and Ardito (1995) have studied the methyl esters of Rape seed oil as fuel in an indirect injection diesel engine. It has been reported that there was 10% improvement in engine efficiency 6% increase in CO, a small increase in smoke and 45% reduction in unburned hydro carbon emissions.

Schumacher et al (1996) have investigated the use of soybean methyl ester in a heavy duty diesel engine. It has been reported that the biodiesel blends reduced the particulate matter, total hydrocarbon emissions and increased the NOx emissions. It has been concluded that 3° retarding the injection timing reduced the NOx emissions while maintaining the other emissions.
**Recep Altin et al (2001)** have studied the performance and emissions of diesel engine with various vegetable oils and its methyl esters as fuel. It has been reported that the power developed by methyl esters of all vegetable oils was lower by 7% to 10% less than diesel. It has also been reported that the particulate emissions were higher and NOx emissions were lower for vegetable oil methyl esters compared to diesel. It has been further reported that the CO emissions were higher for raw vegetable oil compared to diesel. It has been concluded that the raw vegetable oil could be used as alternative fuel with little modifications in engine.

**Dorado et al (2003)** have tested the direct injection diesel engine with the use of olive oil methyl ester. It has been reported that the CO, CO₂ and NOx emissions were significantly reduced compared to diesel fuel. It has also been reported that the SO₂ emissions were less because biodiesel contains less sulphur content.

**Nazar et al (2004)** have tested the use of karanja oil as an alternative fuel in direct injection diesel engine. It has been reported that the thermal efficiency for karanja oil ester was 29.6% compared to 31.5% for diesel. It has been reported that the HC and CO emissions for ester were lower than diesel at all loads. It has been further reported that the smoke level was 3.0 BSU for karanja oil methyl ester. It has been concluded that the peak pressure and maximum rate of pressure rise for karanja oil methyl ester were very similar to that of diesel.

**Usta et al (2005)** have tested the use of tobacco seed oil methyl ester as fuel in a turbo charged indirect diesel engine. It has been reported that the performance of the engine running with biodiesel of tobacco seed oil was lower than that of diesel. It has been further reported that the CO emission was lower and NOx emission was higher than diesel. It has also been reported that the exhaust emissions had some traces of SO₂ emission. It has been concluded that the tobacco seed oil methyl ester could be partially substituted for diesel fuel as blend without any modification.
Cetinikaya et al (2005) have investigated the performance and road performance of a heavy duty diesel engine with the use of used cooking oil methyl ester. It has been reported that the power and torque were reduced with biodiesel and the exhaust gas temperature was reduced compared to diesel.

Sukumar puhan et al (2005) produced biodiesel from mahua oil by the Transesterification process and this was tested in a single cylinder, four stroke, direct injection, constant speed, compression ignition engine to evaluate the performance and emissions. There was an increase in specific fuel consumption a slight reduction in brake thermal efficiency. Emissions of CO, HC and oxides of nitrogen were found to be lower for the methyl ester of mahua oil.

Gvidonas and Slavinska (2006) have studied the performance and emission characteristics of a high speed diesel engine with rapeseed oil methyl ester and its diesel blends. It has been reported that the specific fuel consumptions were higher by 23.2% at rated power and exhaust gas temperature also higher for biodiesel blends. It has also been reported that the CO, HC and smoke emissions were lower for RME blends. It has been further reported that the NOx and CO$_2$ emissions were slightly higher for RME blends compared to diesel.

Koyisoglu et al (2006) have studied the effect of sunflower and soy been methyl ester blends in a direct injection diesel engine. It has been reported that the brake specific fuel consumptions and exhaust gas temperature were higher for all biodiesel blends. It has been concluded that the sunflower oil methyl ester blends showed the better performance than soy been methyl ester blends.
Narun Nabi et al (2006) made biodiesel from neem oil by esterification process with methyl alcohol. In the second phase of their investigation, experiments have been conducted with neat diesel fuel and different blends of diesel and biodiesel in a naturally aspirated direct injection diesel engine. They have reported a lower CO and smoke emissions and a higher NOx emission with diesel-biodiesel blends in comparison with conventional diesel.

Deepak Agarwal et al (2007) have investigated the effect of linseed oil, mahua oil, rice bran oil and linseed methyl ester in a diesel engine. It has been reported that brake specific fuel consumptions were higher for vegetable oil compared to diesel fuel. It has been concluded that the 20 % of linseed oil methyl ester blend was optimum that improved the thermal efficiency and reduced the smoke density.

Sudhir et al (2007) have tested the effect of waste cooking oil methyl ester in a diesel engine. It has been reported that the thermal efficiency was decreased by 2 % at higher loads. It has also been reported that the HC emissions were lowered by 35 % compared to diesel fuel. The NOx emissions were same as diesel for waste cooking oil methyl ester due to O_2 content in vegetable oil structure. It has been further reported that the peak pressure and the ignition delay were increased for waste cooking oil methyl ester compared to diesel fuel.

Raheman and Phadatare (2008) have investigated the effect of compression ratio and injection timing on a diesel engine with mahua oil methyl ester. It has been reported that the performance of a diesel engine with biodiesel blends was increased at higher compression ratio and advanced injection timing. It has been concluded that the 20 % biodiesel blend could be used as diesel substitute for diesel engine at higher compression ratio of 20 and 40° injection timing.
Laxminarayana Rao et al (2008) have also investigated the performance of diesel engine with rice bran oil methyl ester and its diesel blends. It has been reported that the ignition delay and the peak heat release rate for RBME were lower for biodiesel and it was increased with increase in RBME blends. It has also been reported that the CO, HC and soot emissions were increased and the NOx emissions were slightly increased with increase in blends compared to diesel fuel operation.

Zafer Utlu et al (2008) have tested the effect of waste frying oil methyl ester in a turbo charged variable speed diesel engine. It has been reported that the brake specific fuel consumption was increased by 14.4%. It has also been reported that the CO, NOx and smoke emissions were decreased by 17.1%, 1.45% and 22.46% respectively and the exhaust gas temperature increased by 6.5% for biodiesel compared to diesel.

Ilker Sugozu et al (2010) have conducted the experiment on a diesel engine to study the performance of a diesel engine with canola oil methyl ester at different speeds. They reported that the power of the engine was less compared to diesel operation. The specific fuel consumptions were increased due to low calorific value of canola oil methyl ester compared with diesel. The CO emissions were decreased and the NOx emissions increased at full load compared to diesel fuel.

Shakila Motamedi et al (2011) have studied the performance of a diesel engine using biodiesel blends. They reported that the brake thermal efficiency is slightly increased for blend. The BSFC, HC, CO and PAH were slightly decreased for B20 blend. The NOx emission was increased for biodiesel and its mixtures.
Arun Balasubramanian (2012) investigated the performance and emission characteristics of various dual biodiesel blends (mixture of Jatropha biodiesel and neem biodiesel) with diesel on a stationary single cylinder, four stroke direct injection compression ignition engine. The blends of BB 10 (combination of Diesel 90% by volume, Jatropha biodiesel 5% by volume and Neem biodiesel 5% by volume) and BB 20 (combination of Diesel 80% by volume, Jatropha biodiesel 10% by volume and Neem biodiesel 10% by volume) gave better brake thermal efficiency and lower brake specific fuel consumption than other dual biodiesel blends (BB 40, BB 80 and BB 100). The blends of BB 10 and BB 20 have superior emission characteristics than other blends and closer to diesel values.

2.5 USE OF BLENDS OF VEGETABLE OIL METHYL ESTER

Vegetable oil is a promising alternative petroleum products. There are many edible and non edible oils being used as fuel in diesel engines. The blends are preferred for several reasons. Alcohols are blended with fossil fuel for better combustion and to reduce the emissions. Vegetable oils cause problems when subjected to prolonged usage in CI engine because of their high viscosity and low volatility. Blending of the vegetable oil with diesel or with solvent is to reduce the viscosity of the vegetable oil. The available literature related to the use of blended fuel in engines have been grouped and presented in this section.

Ziejewski and Kaufman (1982) have conducted the experiments with 50/50 sunflower oil/diesel blend. It has been reported that severe carbon build up was there on the injectors, intake ports and piston rings leading to engine operating difficulties and eventual catastrophic failure. They have also conducted investigations with 25/75 sunflower oil/diesel blend in turbocharged diesel engine at various injection pressures. It has been reported
that the performance of the engine was same as that of diesel but deteriorated after 200 hrs of operation. It has been further reported that the smoke emission was increased as the test period increased. It has been concluded that the carbon deposit on piston, turbine wheel, nozzle and cylinder head and the tendency of sticking of injector needle was high.

**Yusuf Ali et al (1995)** have studied the use of soy methyl ester/diesel blend in two different turbo charged, 6 cylinder diesel engines. It has been stated that the engine performance did not differ for a blend of 70/30 diesel/soy ester but there was increase in power output for 80/20 blend. It has been reported that the lower HC emissions, increase in NOx emissions were found with increase in soy ester concentration. It has been reported that the CO emissions are same as diesel for all blends but the smoke emissions were lower than that of diesel. It has been concluded that the blends of ester gave better performance and reduction in emissions.

**Masjuki et al (2001)** have investigated the use of coconut oil esters/diesel blends in indirect injection diesel engine. It has been reported that the properties of the blend was comparable with diesel and the power output was higher for 30/70 coconut oil/diesel blend compared to diesel fuel. It has been concluded that all coconut oil blends produced lower exhaust emissions, lower particulate and the lubricating oil contamination level was also very low.

**Suryawanshi (2001)** has studied the use of methyl esters of safflower and maize oil blended with diesel in proportions of 50/50, maize ester ester/diesel 75/25 and safflower ester/diesel 75/25 in a single cylinder direct injection diesel engine. It has been reported that the performance was improved by 26% at higher loads and at 22.5% at part loads for 75/25 maize ester blend than diesel. It has been further reported that the smoke density was reduced by 65% for all blends and 50% reduction in NOx emission for 50/50 blend of safflower and maize esters. It has been concluded that the 75/25 blend could be as an alternative fuel.
Yu et al (2002) have tested the use of waste cooking oil/diesel blend preheated to 70°C in direct injection diesel engine. It has been reported that the engine performance deteriorated after prolonged use due to carbon deposit. It has been reported that the peak pressure was higher than diesel by 1.5 bar and it occurred earlier than diesel at 1.1-3.8 °CA. It has been further reported that the energy released at the late combustion phase was higher due to heavier molecular weight. It has been concluded that the emissions of CO, NO and SO$_2$ were higher for waste cooking oil diesel blend.

Venkatarammmana et al (2003) have tested the use of rice bran oil/diesel blends from 10% to 90% in a 3.5 kW direct injection diesel engine. It has been reported that the specific fuel consumption was marginally higher for neat and pure rice bran oil and the engine performance showed improvement with 40% blend. It has been concluded that 50% blend yielded better brake thermal efficiency than neat diesel operation.

Pramanik (2003) has investigated the use of Jatropha oil blends with diesel fuel in direct injection diesel engine. It has been reported that 50% of Jatropha oil blends can be substituted for diesel fuel in CI engine. It has been reported that the Jatropha oil exhibited higher specific fuel consumption and lower exhaust gas temperatures compared to diesel fuel.

Raheman and Phadate (2004) have used karanja methyl ester and its blends with diesel from 20% to 80% by volume in a single cylinder direct injection diesel engine. It has been reported that the maximum efficiency of 26.8% and 26.19% for B20 and B40 respectively was obtained which was higher than that of diesel. It has been further reported that the CO, smoke and NOx emissions were lower. It has been concluded that the B40 gave better performance and lower emissions.
Suryawanshi (2009) has studied the performance and emissions of a diesel engine with neat palm oil and its diesel blends. It has been reported that the brake thermal efficiency was higher at part and full load and the brake specific energy consumption was lower as compared to diesel at all loads. Exhaust gas temperature was higher with blends of biodiesel as diesel. It has also been reported that the maximum cylinder gas pressure is lower for biodiesel blends and diesel. It has been further reported that there was a significant reduction in smoke emission and unburned hydrocarbon for all blends of biodiesel at part and full loads. Smoke and HC emission was further reduced with an increase in blending of POME. Biodiesel leads to higher NOx levels as compared to diesel.

Gumus (2010) have tested the use of hazelnut biodiesel blends varies from 5%, 20%, 50% and 100% in diesel engine with various injection timing, compression ratio and injection pressure. They have reported that the cylinder gas pressure and rate of pressure rise were decreased with increase in biodiesel blends. The ignition delay and combustion duration were increased with increase in biodiesel diesel blends and varying injection pressure, injection timing and compression ratio. The optimized and concluded that 20% biodiesel blend provides the better performance with the optimum compression ratio 20, injection timing $25^0$ bTDC and injection pressure 200 bar.

Kandasamy and Marappan (2011) have investigated the reduction of NOx and smoke emission of a diesel engine using thevetia peruviana biodiesel emulsified with water in the ratios of 5, 10, 15, and 20% to investigate the engine performance and emission characteristics. They reported that Emulsified fuels showed an improvement in brake thermal efficiency accompanied by the drastic reduction in NOx. From the detailed study it was found that 15% water emulsified fuel showed the best performance and less emission than the other combinations.
Shakila Motamedi et al (2011) have studied the performance of a diesel engine using biodiesel blends. They reported that the brake thermal efficiency is slightly increased for blend. The BSFC, HC, CO and PAH were slightly decreased for B20 blend. The NOx emission was increased for biodiesel and its mixtures.

2.6 USE OF VEGETABLE OILS WITH LOW HEAT REJECTION ENGINE

The engine incorporating heat conservation is called ‘low heat rejection (LHR) engine’. The LHR engine concept is practiced for obtaining maximum heat recovery by reducing the heat losses through cooling system. Besides, it also improves the combustion and reduces the emission. LHR concept is ideal for diesel engine. It leads to elimination of cooling system, improved fuel economy and reduction in ignition delay period. The available papers on the use of Low Heat Rejection Engine have been grouped in this section.

Kamo et al (1984) have modified a six cylinder direct injection diesel engine into an adiabatic engine by coating zirconia on cylinder liner, cylinder head and piston top face. It has been reported that there was increase in efficiency and an increase in engine temperature. It has been concluded that LHR engine required high temperature lubrication.

Siegla et al (1984) have tested the performance of low heat rejection diesel engine in a passenger car. It has been reported that there was maximum energy conservation and the heat energy escaped only through the exhaust gas. It has been concluded that the addition of super charger in LHR engine compensates the loss of volumetric efficiency.
Gerhard Woschni et al (1987) have tested a single cylinder diesel engine with Nimonic 80A insulated piston. It has been reported that there was no increase in blow by or friction losses, but there was an increase in heat transfer coefficient. It has been further reported that there was an increase in fuel consumption and exhaust gas temperature was higher by 30°C. It has also been stated that the analysis was based on theory and suggested that this method has good fuel economy for the diesel engine. It has been concluded that the ceramic engine was not helpful to decrease the fuel consumption.

Ken Voss (1997) have tested a Zirconia coated 6 cylinder, 2 stroke engine for the durability of coating and reduction of emissions. It has been reported that the combined effect treatment and ceramic coated cylinders helped in reducing the total particulate matter (tpm) to a large extent. It has been concluded that the ceramic coated engine operated at retarded timing and showed 50% reduction in NOx emissions. It has been further stated that the coating even after 1, 10,000 miles was in excellent condition and remained with the same thickness as coated.

Beg and Rahman (2002) have tested linseed oil in a semi adiabatic variable compression single cylinder diesel engine under variable compression ratio. The piston and the cylinder were coated with Yetrix Zirconia and alumino-borosilicate. It has been reported that the brake thermal efficiency was found to be 16.34% and 18.64% for compression ratio of 10 and 20 respectively. It has been further reported that with the esterified linseed oil, there was an increase in exhaust gas temperature, NOx emission and lower smoke emission. It has been concluded that esterified linseed oil showed lower ignition delay in insulated engine due to better combustion.

Hiregouder (2004) have tested the use of vegetable oils and Jatropha ester in a single cylinder low heat rejection engine coated with Superni-90 on the piston crown and on the cylinder liner. It has been reported
that the esterified Jatropha gave smooth engine operation and better performance than vegetable oil and diesel operation. It has been concluded that there was reduction in NOx levels and marginal reduction in smoke density. It has been concluded that in LHR engine, more heat escaped through exhaust gases.

**Sreenivasa Reddy et al (2004)** have used an insulated cylinder head in a 3.67 kW, 4 stroke, single cylinder direct injection diesel engine to study the performance of a semi adiabatic engine. It has been reported that the surface of the cylinder was coated with 0.5mm thick partially stabilized Zirconia coating at 2000°C. It has been concluded that the ceramic coated engine showed improvement in thermal efficiency, increase in friction, and increase in exhaust gas temperature and some loss in volumetric efficiency.

**Adnan Parlak et al (2005)** have studied the performance and emission characteristics of a thermal barrier coated indirect injection diesel engine with the effects of different injection timing at full load in the speed range of 1000, 1400, 1800, and 2200 rpm. The piston crown, cylinder head and valves were coated with 350 µm thickness MgOZrO$_3$ over a 150 µm thickness of NiCrAl bond coat by plasma spray method. It has been reported that injection timing of 34° CA BTDC was optimized for the LHR engine, which is 4° CA less compared with the standard diesel engine. It has also been reported that the power loss is about 3-5% for LHR engine at full load compared to standard diesel engine. It has been further reported that the NOx emission and BSFC are decreased about 40% and 6% respectively for LHR engine with an optimum injection timing of 34°CA compared to those of the standard diesel engine with 38°CA injection timing at full load.

**Ekrem Buyukkaya et al (2006)** have studied the performance and emission characteristics of a thermal barrier coated turbocharged six cylinder diesel engine at full load in the speed range of 1000, 1200, 1400, 1600, 1800,
2000, 2200 and 2400 rpm different with injection timings. The piston surface was coated with 350 µm thickness MgZrO₃ over a 150 µm thickness of NiCrAl bond coat. CaZrO₃ was employed as the coating material for the cylinder head and valves. It has been reported that the SFC was reduced about 1-8% and the NOx emissions were reduced by 11% for 18° BTDC with LHR engine compared to the uncoated engine. It has also been reported that the particulate emissions decreased by about 40% for LHR engine, while the NOx emissions were increased by about 9% compared to those of the standard engine due to higher exhaust gas temperature for the LHR engine.

Banapurmath and Tewari (2008) have studied the performance and emission characteristics of a thermal barrier coated diesel engine at constant speed with honge oil and its methyl ester at full load. The piston top surface, cylinder head and valves were coated with 400 µm thicknesses Zirconium oxide by plasma spray method. It has been reported that they optimized the injection timing as 19° CA BTDC for vegetable oil and its methyl ester with LHR engine. It has been reported that the CO and HC emissions were reduced for LHR engine with Honge oil methyl ester compared with Honge oil. Heat release rate was better for HOME when compared with Honge oil operation, which resulted in improved brake thermal efficiency.

Hazer (2009) studied performance and emission characteristics of a ceramic coated diesel engine using canola methyl ester blends of 20%, 35% and 100% at full load in the speed range of 1800, 2100, 2400, 2700 and 3000 rpm. Cylinder head, piston surface, exhaust and inlet valves are coated with a ceramic material MgO-ZrO₂ of thickness 0.5 mm by the plasma spray method. It has been reported that the power of the engine is increased about 8.4% for diesel and 3.5% for biodiesel and the SFC decreases about 5% for diesel and 8% for alternative fuels. The CO and smoke emissions decreased about 24%
and 8.2% respectively, while the NOx emissions were increased about 7.3% for alternative fuels. The exhaust gas temperature increased about 11.4% for diesel and 5.4% for alternative fuels compared with the uncoated engine.

2.7 USE OF VEGETABLE OIL WITH DUAL FUEL ADDITIVES

**Edwin Geo et al (2009)** have investigated a diesel engine with rubber seed oil supplemented with diethyl ether (DEE). It has been reported that the brake thermal efficiencies were increased by 7% for raw vegetable oil and the smoke emissions were decreased significantly with DEE operation. It has also been reported that CO and HC emissions were reduced and slight increase in NOx emission. The combustion parameters cylinder pressure was increased by 4.2% and ignition delay was increased by 1° with DEE at the optimum quantity of 200 g/h at the rated power.

**Kandasamy and Marappan (2011)** have investigated the reduction of NOx and smoke emission of a diesel engine using Thevetia peruviana biodiesel emulsified with water in the ratios of 5, 10, 15, and 20% to investigate the engine performance and emission characteristics. They reported that emulsified fuels showed an improvement in brake thermal efficiency accompanied by the drastic reduction in NOx. From the detailed study it was found that 15% water emulsified fuel showed the best performance and less emission than the other combinations.

**Pugazhvadivu and Rajagopan (2009)** have studied the performance and emission characteristics of a single cylinder direct injection diesel engine fuelled with blends of biodiesel and diesel at different proportions with di-ethyl ether (DEE) as fuel additive. The addition of diethyl ether to the blends reduced the NOx emission at low and medium loads; however, at high loads the NOx emission was higher compared to diesel and
lower compared to the corresponding biodiesel blend. The addition of diethyl ether to biodiesel blends reduced the both NOx and smoke emission further.

Venkata Subbaiah et al (2012) investigated the performance and combustion characteristics of a direct injection diesel engine with the effect of Triacetin as an additive with coconut oil methyl ester. They reported that the CO, HC and smoke emissions are decreased, and significant reduction in NOx emissions compared to diesel fuel at full load.

2.8 USE OF VEGETABLE OIL AT VARIOUS INJECTION PRESSURES

Higher injection pressure is used to reduce droplet size of the injected fuel and permits the utilization of intake air for better air entrainment leading to better combustion. The smaller the fuel size, the better will be the combustion. The higher injection pressure also reduces the emission. The available literature on the use of higher injection pressure is presented in this section.

Murari Mohan Roy et al (2000) have reported that high pressure injection in a 7799cc, 6 cylinders, and common rail electronic controlled diesel engine produced low hydrocarbon and aldehydes in exhaust. It has been further reported that the ignition delay was reduced and the odour was minimum when injection pressure of 60-80 MPa was maintained. It has been concluded that higher injection pressure only can meet the latest emission requirements.

Pugazhvadivu and Jayachandran (2004) have tested the waste frying oil in a single cylinder, direct injection diesel engine at various injection pressures of 190,210,210,230 and 250 bar and studied the performance and emissions. It has been stated that when the injection pressure
was increased, the brake specific energy consumption reduced, due to the improvement in the fuel atomization and due to mixing of air and fuel. It has been reported that when injection pressure was increased, there was an improved rate of evaporation and combustion of fuel. It has also been concluded that when the injection pressure was increased, the NOx emission and combustion temperature tend to increase and the smoke emission tends to decrease.

Hyungik Kim (2011) have studied performance and emission characteristics of a turbocharged direct injection diesel engine using two types of bio fuels at different load conditions. They reported that when the injection pressure and duration increased, injection quantity increased linearly and spray penetration was shorter at lower injection pressure and higher ambient pressure. Biodiesel has lower CO₂, PM emissions than diesel. Biodiesel has higher NOx emission level because it contains oxygen.

2.9 CYLINDER PRESSURE AND HEAT RELEASE

In order to analyze the nature of the combustion in an internal combustion engine, the principal diagnostic information is the time history of the cylinder. Cylinder pressure, changes with crank angle mainly due to volume changes and combustion. If the effect of volume change on pressure can be accounted for, the influence of combustion can be seen. The combustion rate information can be obtained only from accurate present data. Cylinder pressure is measured with piezoelectric pressure transducers. With pressure data from the combustion chamber, the energy changes taking place can be calculated by thermodynamic analysis. This type of data reduction is usually called heat release analysis with the help of the first law of thermodynamics. Important combustion parameters like peak pressure, occurrence of peak pressure, maximum and average rates of pressure rise, indicated mean effective pressure, ignition delay, combustion duration and
cyclic variations in pressure can be calculated with the help of pressure crank angle data. Hence, in this section, literature in cylinder pressure data acquisition and heat release analysis are discussed.

Lancaster et al (1975) have indicated a user oriented description of techniques for the measurement and analysis of engine cylinder pressure. They have developed techniques for piezoelectric transducers and for digital systems of data acquisition and analysis. Test cell procedures were described for transducers preparation, calibration and for association of each pressure with appropriate crank angle. Techniques were also described for evaluating the accuracy of pressure data, to identify the possible errors, to show the effect of these errors on the data and to suggest ways of eliminating specific errors. Two uses of pressure data are also discussed, the calculation of heat release rate in DI diesel engines and computation of internal flows in IDI engines. The majority of the pressure transducers used were water cooled. A dead weight tester and digital voltmeter were used to calibrate the transducer. They indicated that a properly coated and cooled transducer when flush mounted on the combustion chamber could give excellent results and service as compared to passage mounting.

Randolph (1990) studied three feasible mounting schemes of piezoelectric pressure transducers namely flush mount, remote mount via a single passage remote mount via multiple slots. This study reviews the theoretical principles dictating the performance of transducers and examines the influence of the mounting scheme on pressure data quality. He also reported that a fourth mounting scheme, namely remote mount via a sintered porous-metal interface proved not possible because of excessive pressure drop across the porous metal. The multiple slot-mounting adopters performed the best. When properly designed, this adopter can maintain data accuracy while considerably reducing transducer-induced variability relative to flush mounting.
**Rocco (1993)** conducted experiments on a single cylinder small DI marine diesel engine to evaluate the influence of wrong TDC setting on cylinder pressure data. The experimental apparatus used to measure pressure data was based on a fast A/D converter with a 12-bit vertical resolution and a sample rate of 1 deg/sample independently of the rpm value. Crank position is detected by means of an optical crank angle encoder. He studied cylinder pressure time history in order to calculate both indicated mean effective pressure and the rate of heat release as quantitative information about the combustion progress. As far as IMEP evaluation is concerned, a wrong adjustment of TDC reference position, leading to incorrect pressure crank angle phasing had been recognized as the major error source. He also reported that an error of 1 degree yields a significant error of up to 10% in estimating the net heat released. He identified that the evaluation of the indicated work can lead to a wide uncertainty even for small TDC setting errors, particularly for D.I engines, where high pressure rises occur in near TDC. He concluded that when the TDC reference position is determined, an expected error of even 0.5 degree might lead to uncertainty while process pressure data.

**Samuel and Arvind (1997)** concluded an experimental analysis of the heat release rate from experimental data obtained on a Detroit, 6-cylinder 12.7 litre turbo charged diesel engine. The overall gross heat release rate and net apparent heat release rate were obtained by two separate concepts. The gross heat release rate was determined by exhaust gas concentration measurements using an exhaust gas analyzer. The net apparent heat release was determined from the in-cylinder pressure measurements for each of the six cylinders, averaged over 80 cycles. They suggested that these techniques could be used to validate steady state heat transfer models and also investigate the steady state effects of insulated ceramic coatings in the cylinder. They concluded that more accurate measurements of the rate and composition of blow by would produce even more precise results.
Micheal et al (1999) studied the effects of common errors on the calculated gross heat release rate data obtained when analyzing simulated and experimental direct injection diesel engine pressure diagrams using a traditional single zone first law heat release model. They revealed that the greatest uncertainty in most cases would be caused by assuming the wrong rate of heat transfer between cylinder charge and combustion chamber walls. To overcome this limitation they proposed an alternative heat release model to give good results over a wide range of operating conditions. This heat release model used a variable polytrophic index to cater for the heat transfer. They reported that the new polytrophic index model was found to produce similar results to the traditional gross first law model in general and was much superior in performance compared to the adiabatic first law model. They concluded that the polytrophic index model is well suited for diesel engine development applications where consistent results are required.