CHAPTER -II
REVIEW OF LITERATURE

2.1. INTRODUCTION

This chapter presents the detailed literature review on the vegetable oils and their derivatives as alternate fuel for compression ignition engines. A brief historical background is followed by the properties of vegetable oils and its blends are determined. Performance and exhaust emission parameters of neat vegetable oil and its blends with diesel are explained. Then the properties of biodiesel and its blends are determined. Performance and emission parameters of bio diesel and its blends are described. Finally, this chapter concludes with the scope of the present work.

2.2. HISTORICAL BACKGROUND:

The idea of using vegetable oil as fuel for diesel engines is not a new one. Rudolph Diesel used peanut oil as fuel in his engine at Paris Exposition of 1900. Inspite of the technical feasibility, vegetable oil as fuel could not get acceptance, as it was more expensive than petroleum fuels. Later various factors as stated earlier, renewed the interests of researchers in using vegetable oil as substitute fuel for diesel engines. In recent years, systematic efforts have been made by several researchers to use vegetable oils of Sunflower, Peanut, Soyabean, Rapeseed, Olive, Cottonseed, Jatropha, Pongamia, Rubber seed, Jojoba etc as alternate fuel for diesel. Many types of vegetable oils are edible in nature. Continuous use of them causes shortage of food
supply and proves far expensive to be used as fuel at present. So far few types of non-edible vegetable oils have been tried on diesel engine leaving a lot of scope in this area. Testing of diesel engines with preheating, blending with diesel and blending with preheating improves the performance and reduces the emissions compared to neat vegetable oil. It also reduces the filter clogging and ensures smooth flow of oil.

2.3. INTRODUCTION TO VEGETABLE OILS:

Vegetable oils have become more attractive recently because of its environmental benefits and the fact that it is made from renewable resources. More than 100 years ago, Rudolph Diesel tested vegetable oil as fuel for his engine. Vegetable oil has the potential to replace a fraction of the petroleum distillates and petroleum-based petrochemicals in the near future. Vegetable oil fuels presently do not compete with petroleum-based fuels, because they are more expensive. However, with the recent increase in petroleum prices and uncertainties surrounding petroleum availability, vegetable oil is used in diesel engines as an alternate fuel.

Chemically speaking, vegetable oils and animal fats are triglyceride molecules, in which three fatty acid groups (or) esters attached to one glycerol molecule [38]. Fats and oils are primarily water-insoluble, hydrophobic substances in the plant and animal kingdoms that are made up of one mole of glycerol and three moles of fatty acids are commonly referred to as triglycerides [39].
Triglycerides are derived from many different carboxylic acids. Triglyceride molecules differ in the nature of the alkyl chain bond to glycerol. Triglyceride vegetable oils and fats include not only edible but also non-edible vegetable oils and fats such as linseed oil, castor oil, and Tung oils are used in lubricants, paints, cosmetics, pharmaceuticals, and for other industrial purposes.

More than 350 oil-bearing crops have been identified, of which only soyabean, palm, sunflower, safflower, cottonseed, rapeseed, and peanut oils are considered potential alternative fuels for diesel engines [40][9]. Vegetable-oil fuels have not been acceptable because they are more expensive than petroleum fuels. However, with recent increase in petroleum prices and uncertainties surrounding petroleum availability, vegetable oils have become more attractive because of its environmental benefits and the fact that it is made from renewable resources [40].

The experimental work [86] was conducted on C.I. Engine using Methyl Ester of Rice Bran oil and results were found satisfactory by reducing the emissions and increasing the performance compared to diesel.

The first use of vegetable oil as fuel was in 1900. The advantages of vegetable oils compared to diesel fuel are liquidity, ready availability, renewability, lower sulphur and aromatic content, bio-degradability. Main disadvantages of vegetable oils compared to diesel are higher viscosity, lower volatility, and the reactivity of unsaturated hydrocarbon chains. The problems met in long-term engine tests, according to results obtained by earlier researchers may be classified as follows: choking on injectors, more
carbon deposits, oil ring sticking, thickening and gelling of the engine lubricant oil. All vegetable oils are extremely viscous, with viscosities ranging from 10 to 17 times greater than D2 fuel (D2 fuel is a diesel engine fuel with 10 to 20 carbon number hydrocarbons).

Soybeans are commonly used in the United States, as food products, Soyabean oil turned out to be a primary source for biodiesel in that country. In Malaysia and Indonesia, palm oil is the source of biodiesel. In Europe, rapeseed is the source of biodiesel. In India and Southeast Asia, jatropha tree is the source of biodiesel.

Major exporters of vegetable oil are Malaysia, Argentina, Indonesia, Philippines, and Brazil. Major importers of vegetable oils are China, Pakistan, Italy, and the United Kingdom. A few countries such as the Netherlands, Germany, the United States, and Singapore are both major exporters as well as importers of vegetable oils [59].

The non-edible oils such as jatropha, microalgae, neem, karanja, rubber seed, mahua, silk cotton tree etc. are easily available in developing countries and are very economical compared to edible oils. The oil from neem (Azadirachta indica) and rubber (Hevea brasiliensis) is free fatty acid (FFA) content. FFAs easily react with alkaline catalysts to form soap that prohibits separation of biodiesel and glycerol. The soaps of FFAs also cause foaming in aqueous media. The resulting soaps also cause an increase in viscosity. Formation of gels, and foams and make the separation of glycerol difficult [41].
Vegetable oil has the potential to substitute a fraction of petroleum-based engine fuels in the near future [42]. Possible acceptable processes for converting vegetable oils into reusable products such as gasoline and diesel fuel are solvent extraction, cracking, and pyrolysis [53]. Vegetable oil fuels are not cost competitive with petroleum-based fuels.

The advantages of biodiesels are portability, ready availability, renewability, higher combustion efficiency, lower sulphur and aromatic content, higher cetane number, and higher biodegradability.

Main advantages of biodiesel given in the literature include its domestic origin, which would reduce dependency on imported petroleum, high flash point, and inherent lubricity in the neat form [60].

Main commodity sources for biodiesel production from non-edible oils are from plant species such as Atrophy or ratanjyote (or) seemaikattamankku (Jatropha curcas), Karanja (or) Honge (Pongamia pinnata), Nagchampa (Calophyllum inophyllum), Rubber seed tree (Hevca brasiliensis), Neem (Azadirachta indica), Mahua (Madhuca indica and Madhuca longifolia), Silk cotton tree (Ceiba pentandra), Jojoba (Simmondsia chinensis), Babassu tree, Euphorbia tirucalli, Microalgae, etc. Non edible oils are cheap compared to edible oil in India [61].

Soyabean oil is of primary interest as biodiesel source in USA, while many European countries use rapeseed oil, and countries with tropical climate prefer to use coconut oil or palm oil.

Rapeseed oil has been grown in Canada since 1936. Hundreds of years ago, Asians and Europeans used rapeseed oil in lamps. Cottonseed oil
is used almost entirely as food material. Sesame, olive, and peanut oil can be used to add flavor to foodstuff. Walnut oil is high-quality edible oil refined by purely physical means from quality walnuts. Poppy seeds are tiny seeds contained within the bulb of the poppy flower, also known as opium plant (*Papaver somniferum*).

Dry oils such as Walnut, sunflower, safflower, dammar, linseed, poppy seed, stillingia, tang, and vernonia oils are used for paint and wood-finishing applications.

The solution to avoid twin problems of environmental pollution and energy shortage should be carefully planned gradual shift of our energy economy from fossil fuels to renewable sources of energy. The production of vegetable oil from seeds is quite simple. Obviously only non-edible vegetable oils can be seriously considered as fuel for engines as the edible oil is in great demand and is far too expensive as fuel. Therefore, it is the right time to search for alternative fuels. Vegetable oils are renewable and are produced easily in rural areas. Its usage has been studied ever since the advent of internal combustion engine. However, it is only in the recent years, systematic efforts have been made to utilize this oil as fuel in engines. Since it has the properties compared to diesel, it can be used to run compression ignition engines with little (or) no modifications. Engines using vegetable oils can produce the same power output, however, with reduced thermal efficiency and increased emissions (particularly smoke).
Vegetable oil does not harm environment as it does not contain sulphur and therefore problems associated with sulphurous acid aerosols would be reduced.

2.4. VEGETABLE OIL AND ITS BLENDS

Several researchers [10], [13], [14], [18] have carried out experimental investigations to improve the performance of engines fuelled by vegetable oils.

Gerhard Vellguth [15] has conducted tests on some types of vegetable oils and reported the following points.

a) Viscosities were significantly higher and densities were marginally higher compared to diesel.

b) Vegetable oil has lower calorific values.

c) The presence of molecular oxygen in vegetable oil raises the stoichiometric A/F ratio.

Both vegetable oils and alcohols such as Methanol, Ethanol are biomass derived renewable sources, but vegetable oils have properties more suitable to compression ignition engines compared to Alcohols [35] [42]. More than 30 different types of non edible oils are used in compression ignition engines since 1900’s [1]. Blending of vegetable oils with some percentage of diesel fuel was a suitable method to reduce choking and for extended engine life.
2.4.1. Performance parameters:

Engine performance is influenced by basic difference between diesel fuels in viscosity, density and molecular oxygen content.

2.4.1.1 Neat vegetable oil:

A.SIVA KUMAR et.al [87] conducted the performance test using Fish oil & Jatropha oil as fuels in a diesel engine and reported that Air-fuel ratio; Volumetric efficiency, Mechanical efficiency, Brake thermal efficiency and Indicated thermal efficiency are increasing indicating that bio-diesel is better than diesel. However there are a few drawbacks like higher flash and fire points, viscosity and the percentage of carbon residue for bio-diesel are more when compared to diesel.

P.V.K.Murthy et.al [88] used vegetable oil operation with conventional engine, which showed the deterioration in the performance, while LHR (Low Heat Rejection) engines showed improved performance, when compared to pure diesel operation on conventional engine. LHR-2 engine exhibited improved performance over LHR-1 engine with vegetable oil (Crude Pongamia oil) operation. Increase of Injection pressure, increased efficiency and decreased pollution levels.

S. Naga Sarada et.al [89] used LHR engine with carbureted methanol and crude jatropha oil, which showed improved performance and decreased pollution levels in comparison with conventional engine with pure diesel as fuel. It is reported that LHR engine decreased pollution levels of Smoke and Aldehydes, compared to the conventional engine with alcohol operation.
Conventional engine showed deterioration in the performance with non-edible jatropha oil, while LHR engine showed an improvement in the performance when compared to the conventional engine with pure diesel operation.

Bruwer et al. [2]. Studied the usage of sunflower seed oil as an alternate fuel. The fuel was used in tractors and found that 8% power loss was observed after 1000 hours of operation. After 1300 hours of operation, the carbon deposits were there in the engine except at the injector tips.

Bacon et al. [3]. Evaluated the usage of several types of vegetable oils as alternate fuel sources. These oils caused carbon build up in the combustion chamber of diesel engine. Bacon tested the overall effect using these oils for the long term engine.

Yarbrough et al. [4] Tested six types of sunflower oil as diesel fuel for alternate replacements. He explained that raw sunflower oil was unsuitable as fuel, while refined sunflower oil was found to be satisfactory. Degumming and dewaxing of the vegetable oil was done through blending of raw oil with diesel to prevent engine failure.

Tapir et al. [11] tested and found that sunflower oil viscosity is higher by 14% compared to diesel at 37°C and used as an alternative to diesel in agricultural tractors. The engine performance of sunflower oil was similar to that of diesel fuel, but with a slight decrease in fuel economy. In this case engine failure may occur due to heavy gum and wax deposits on test engine.
Bettis et al. [12] evaluated the performance of sunflower, safflower, and rapeseed oils as an alternate fuels. He found that 94% to 95% additional energy could be obtained and it is 15% more viscous than diesel. The engine may fail due to carbonization of the combustion chamber.

Deere and Company [5] studied the performance of peanut oil and sunflower oil with diesel fuel in a single cylinder engine. He found that the vegetable oil blends increase the amount of carbon deposits in the combustion chamber compared to 100% diesel.

2.4.1.2 Vegetable Oil Fuel Blends:

Vegetable oil can also be used as diesel fuel alternative by supplementing with diesel oil. Significant reductions in viscosity and improved performance were reported by blending vegetable oil with diesel oil. The performance was compared to that of diesel.

The filter clogging problems were not encountered with peanut oil as observed by Basic and Humke [6]. But with the sunflower oil the clogging problems were observed. Heating the sunflower oil to temperature between 70 to 900C eliminated the clogging problems by causing the waxes to dissolve. It was also reported that sunflower oil, peanut oil, and their blends with Diesel fuel exhibited greater nozzle deposits compared to diesel fuel alone. The work has also revealed that exhaust temperature increased as the percentage of vegetable oil in the blends was increased.

F.K. Forson et.al [62] showed that jatropha oil and its blends used as an alternate fuel to diesel in a diesel engine, exhibited increase in brake
thermal efficiency decrease and increase in the specific fuel consumption. The 97.4%/2.6% fuel blend showed highest cetane number and even better engine performance than diesel fuel.

K. Pramanik et.al [43] conducted performance test using blends and jatropha oil was evaluated in a single cylinder C.I. engine and compared with the performance obtained with diesel. He found that the blend up to 50% of Jatropha oil mixed with diesel was proved to be the best suitable oil without modification of engine and without preheating of oil before entering into the combustion chamber.

2.4.1.3. Vegetable Oil Heating:

Vegetable oil heating is one of the techniques to reduce its viscosity. The fuel viscosity at the fuel injector is important for good atomization and combustion. With a high fuel viscosity, fuel spray can impinge upon the walls of the combustion chamber resulting in delayed combustion and burning. If heated to very high temperatures, low viscosity of the fuel can results in poor fuel droplet penetration and poor combustion.

V.Edwin Geo et.al [71] exhibited the experimental results which showed that increase in brake thermal efficiency from 26.56 % to 28.40 % when the fuel was preheated to a temperature of 150°C. The CO and smoke emission of preheated RSO reduced by 29 % and 34 % respectively at 150°C compared to RSO at 30°C. It indicated faster heat release and lead to higher thermal efficiency. It was also concluded that the performance, combustion and
emission parameters were improved for preheated RSO compared to raw RSO at 30°C (without preheating) but it was still inferior to diesel.

GodiganurSharanappa et.al [72] used raw mahua oil and its blend which resulted in inferior performance compared to that of diesel. By heating CMO, the viscosity reduces, at this condition the brake thermal efficiencies are significantly improved and become close to diesel. It is reported that by using CMO, bsfc and Brake thermal efficiency were improved. From the experimental findings, it is concluded that CMO could be used as diesel fuel substituted by reducing its viscosity than that of diesel achieved by preheating it to higher temperatures.

O.M.I. Nwafor et.al [44] conducted the experiments, which shows CO, CO₂ emissions for heated oils are slightly higher and hydrocarbon emissions are reduced compared to diesel fuel. Ignition delay was longer for unheated oils and more fuel consumption is noted. The viscosity is reduced with increase in temperature.

**2.4.2. Exhaust Emission parameters:**

The exhaust emissions of the diesel engine using vegetable oil deal with CO, HC, NOₓ, Soot, Particulate emissions, Aldehydes, Ketones, and aromatic hydrocarbons and particulate bound polycyclic aromatic hydrocarbons. High intensity of exhaust gas smell is also noted. This toxic emission causes health and environmental problems.
2.4.2.1. Neat vegetable oils:

J.F. Reyes et al. [64] used crude and esterified salmon oil in diesel engine to evaluate the performance and emission (PM). It was observed that power loss attained when crude oil was used. 50% of PM emissions were reduced when pure biodiesel was used. There was reduction in the power loss.

V.S. Srinivasa Murthy et al. [73], used a semi-adiabatic or low heat rejection engines to overcome the combustion problems in diesel engines using crude vegetable oil (virgin oil) as fuel. It reported that Hydrocarbon, carbon monoxide and smoke emissions are found to be low in such engines, because of high cylinder temperature and better combustion.

Leon G. Schumacher et al. [65] investigated on a 6V92TA Detroit Diesel Corporation diesel engine fuelled with soya diesel/ diesel fuel, blends of 10, 20, 30, 40% soya- diesel fuel. A 2000 cfm DPF-CVS dilution tunnel was used to collect the particulate emission data. Reports showed efficiency lower by 80.55%, CO is lower by 46%, total particulate matter is lower by 63%, total HC emission is lower by 35%, CO₂ is lower by 15.66%, NOₓ is higher by 9%. for B20. CO is lower by 32%, total particulate matter is lower by 35%, total HC emission is lower by 37%, CO₂ is higher by 78.45%, NOₓ is higher by 13% for B100 when compared to diesel.

Daniel Wiznia et al. [66] studied the feasibility of the use of diesel vehicle for the testing of biofuel performance and exhaust emissions. Results reported low HC, 15% low CO, less particulate matter, high NOₓ, with exhaust gas recirculation 80% NOx reduced along with power loss.
Narayana Reddy et al [48] used Jatropha as an alternate fuel in DI Diesel Engine. It was observed an increase in injector opening pressure, brake thermal efficiency and decrease in HC and Smoke emission at rated load.

2.4.2.2. Vegetable Oil Blends:

Vijaya Kumar Reddy.K [31] tested neem, karanja, simuruba, cottonseed, Jatropha and pongamia oil and their blends with diesel on a 4 stroke, single cylinder diesel engine. He concluded that smoke, CO, and Un-burnt Hydrocarbons are more than those of diesel for blends.

2.4.2.3. Vegetable Oil Heating:

C. Naga Raja et.al [32] conducted the performance of palm oil fuelled engine, which increased with the heating of oil. The exhaust emissions of palm oil were slightly higher than those of diesel. Therefore, palm oil fuel could be considered a better alternative to diesel. Carbon deposits, fuel filtering problems, lubricating oil dilution were still evident even after its heating to 80°C. To find out emission parameters of these types of vegetable oils, 100 hours duration test had to be conducted. A higher injection pressure for better atomization is to be employed.

2.4.3. Summary on the use of Vegetable oil and its blends:

2.4.3.1 Suitability:

Different types of vegetable oils have some properties, which make them suitable to replace diesel.
- Cetane number is to be in close range to that of diesel.

- Heat contents of various types of vegetable oils are nearly 90% of diesel.

- Vegetable oil raises the stoichiometric fuel/air ratio resulting the presence of molecular oxygen.

- Long chain saturated, un-branched hydrocarbons are especially suitable for conventional diesel. The long un-branched hydrocarbons in the fatty acids meet this requirement.

2.4.3.2. Problems:

The problems with vegetable oils can be listed as below.

- Diesel fuel has a chain of 12-13 carbons and fresh vegetable oil has a chain length of around 18. To burn in an engine, the chain needs to be broken to be similar in length to diesel.

- The high viscosity and poly saturated nature of different types of oil.

- Incomplete combustion, characterized by nozzle choking, engine deposits, lubricating oil dilution, ring sticking, scuffing of the engine cylinder liners, injection nozzle failure and lubricant failure due to polymerization of the vegetable oil.

- Brake thermal efficiency is lower, brake specific fuel consumption are higher compared to diesel.

- Exhaust emissions such as smoke, CO, and Un-burnt hydrocarbons emissions are higher compared to those of diesel. When the engine is
operated for extended periods with vegetable oil, there is a possibility of severe carbon deposit building up and sticking of piston rings. The large droplet size, low volatility, long penetration distances as well as chemical properties of vegetable oils cause such problems.

- Heating of fuel and blending with diesel fuel reduces carbon deposit build up and sticking of piston rings.
- Heating of vegetable oil reduces the problem connected with viscosity and ensures smooth flow of oil.
- Blending of vegetable oil with diesel reduces the viscosity to a great extent, which improves the performance compared to neat vegetable oil.
- Exhaust emissions of the blends are lower compared to diesel. Which run successfully on blends of 20-25% vegetable oil and 80-85% diesel without damage to any parts.

Vegetable oil lacks the low flammability needed for spark ignition engines, but it is similar to diesel in certain rating and heat values. Some of the problems caused by these types of oils include slightly lowered power, poor spray, distorted combustion, wear problem, high smoke during combustion with filter plugging and excessive deposits. Noise, cold start and odour are the other problems associated with them. Due to higher molecular weights, vegetable oil has low volatility. Vegetable oil is UN saturated. So, it is inherently more reactive than diesel fuels. As a result, it is more susceptible
to oxidation and thermal polymerization reactions as reported in the literature. Durability problems appear to be strong function of the engine type, with direct injection engines being more susceptible than indirect injection engines.

High viscosity causes poor atomization, large droplets and high spray jet penetration. As a result, mixing of fuel and air may be improper and affects burning. This may further lead to poor combustion, accompanied by loss of power and economy. In small engines, fuel spray may impinge upon the cylinder walls, washing away the lubricating oil film and causing dilution, of the crank case oil. Many types of oils have kinematic viscosity ranging from of 30 to 50 centi stokes, while it is 1.9 to 4.1 centi stokes for diesel. These problems are overcome by following below mentioned techniques.

(I) Engine Modifications.

- Dual fueling
- Modification of injection system.
- Heated fuel lines.
- Low heat rejection engine.

(II) Fuel modification.

- Blending
- Transesterification.
- Cracking / Pyrolysis
- Hydrogenation to reduce polymerization.
2.5. BIO-DIESEL AND ITS BLENDS:

Fuel Modification by Esterification:

Converting vegetable oils into their esters of methyl and ethyl alcohols is known as Bio-diesel. Ester formation is a possible way to overcome almost all the problems associated with vegetable oils [8]. By the process of esterification the high viscosity of vegetable oils could be brought down to acceptable limits. Esters can be produced from oils and fats by 3 methods. i) Base catalyzed trans-esterification of oil with alcohol. ii) Direct acid catalyzed esterification of oil with methanol. iii) Conversion of oil to fatty acids and then to alkyl esters with acid catalysts.

The first method is preferred because it is economical. The conversion of vegetable oil (Triglyceride Esters) to methyl esters through transesterification process, which reduces the molecular weight to one-third, reducing the viscosity by a factor of 8 and increasing the volatility. Vegetable oil is mixed with alcohol, NaOH as catalyst. The mixture is heated and maintained at 65°C for one hour, while heating, the solution is stirred continuously with stirrer. Two distinct layers are formed, the lower layer is glycerin and the upper layer is ester. The upper layer is separated with moisture and the ester is removed by using calcium chloride. It is observed that 90% of ester is obtained from vegetable oil.
The following are the properties of vegetable oil ester.

i) The density of vegetable oil ester is slightly higher compared to diesel oil and it is about 5%.

ii) The viscosity of vegetable oil ester is slightly higher than that of diesel.

iii) The heating value of vegetable oil ester on a mass basis is lower than that of diesel.

iv) The Cetane number of vegetable oil ester is compared to diesel.

v) Carbon residue is slightly higher.

vi) The high flash point of vegetable oil ester is to make them safer than diesel fuels to handle.

There is an improvement in the engine performance when these types of modified vegetable oils are used instead of base vegetable oils. This improvement in performance can be attributed to good atomization of these modified fuels in the injector nozzle and a significant reduction in the viscosity.

The performance and smoke emission with vegetable oil ester in CI engines are similar to diesel. The low volatility, slightly higher viscosity and high density of vegetable oil ester are the causes for their slightly inferior performance [22] [30].

Fuel properties of vegetable oils and modified hybrid fuels have been studied by many researchers. Compared to diesel, vegetable oil, in general, has acceptable cetane number (35-45), high viscosity (>27 CST). High
carbon residue, high flash point (220-320°C), cloud (17-18°C) and pour points (-6 to 12°C), acceptable calorific value (88-94% diesel), low sulphur content (<0.025) and it contains gumming impurities. The major problem with direct use of vegetable oil as fuel into C. I. Engines is its high viscosity. It interferes with the fuel injection; atomization contributes to incomplete combustion, nozzle clogging, excessive engine deposits, ring sticking, contamination of lubricating oil etc. The problem of higher viscosity of vegetable oil could be overcome to a great extent by various techniques such as heating, dilution, emulsification and esterification.

2.5.1. Performance Parameters:

2.5.1.1. Pure Bio-Diesels:

The vegetable based esterified fuels are popularly known as Bio-Diesels. These are commercially available in the developed world due to their distinct advantage over conventional diesel fuel. Bio- Diesel is an ester based oxygenated fuel derived from renewable sources and can be used easily in compression ignition engines without any modification. Pure bio- diesel is bio-degradable, non toxic, and essentially free from sulphur and aromatics.

Ravi Kadiyala et al [49] studied the performance of pungamia methyl ester by evaluating the combustion properties and engine vibration. A corroborative method was generated to ascertain the engine combustion quality and it was concluded that both viscosity and density were higher compared to diesel.
2.5.1.2. Bio-Diesel Blends:

A.S. Ramadhas et.al [67] conducted the Experimental analysis of the engine with various types of biodiesel and their blends, require much effort and time. In the present investigation, biodiesel is produced using unrefined rubber seed oil. The performance tests are carried out on a C.I. engine using biodiesel and its blends with diesel (B20 and B100) as fuel. The effects of relative air-fuel ratio and compression ratio on the engine performance for different fuels are also analyzed using this model. The comparisons of theoretical and experimental results are presented.

A.S. Ramadhas et.al [50] used the pure rubber seed oil, diesel and biodiesel as fuel in compression ignition engine. The performance and emission characteristics of the engine were analyzed. The lower blends of biodiesel increased the brake thermal efficiency and reduced the fuel consumption. The exhaust gas emissions were reduced with the increase in biodiesel concentration. The experimental results proved that the use of biodiesel (produced from unrefined rubber seed oil) in compression ignition engines is a viable alternative to diesel.

V.S. Hariharan et.al [74] conducted the performance of the cottonseed oil fuelled engine in comparison with diesel fuelled engine. It could be run without any difficulty by using cottonseed oil either in esterified form or in refined form. These blends of cottonseed oil could be recommended for present diesel engines without any modification. Heat loss in the engine was reduced by the usage of cottonseed oil. It was because exhaust gas temperatures were lower, when compared to those of diesel. Hence brake
thermal efficiency of cottonseed oil was high. Thus the above investigations suggested that esterified vegetable oil can be effectively employed in emergency as a suitable alternative fuel in place of existing diesel.

B. Premanand et.al [51] the experiments were conducted on a single cylinder diesel engine. The performance, smoke emissions and combustion parameters of diesel, 100% bio-diesel, 30% and 50% blends are calculated. Performance was increased in lower blends with reduced fuel consumption, but NO\textsubscript{x} was much higher for diesel and blends, and lower for 100% bio-diesel. Particulate matter was higher for neat diesel and lower for 100% biodiesels.

2.5.2. Exhaust Emission Parameters:

2.5.2.1. Pure Bio- Diesel:

N. Usta, [52] conducted an experimental study on the performance and exhaust emissions of a turbocharged indirect injection diesel engine fuelled with tobacco seed oil methyl ester, which was performed at full and partial loads. The results showed that the addition of tobacco seed oil methyl ester to diesel fuel reduced CO and SO\textsubscript{2} emissions while causing slightly higher NO\textsubscript{x} emissions. Meanwhile, it was found that the power and the efficiency increased slightly with the addition of tobacco seed oil methyl ester.

Md. Nurun Nabi et.al [68] used diesel, Bio-diesel mixed with diesel used in diesel engine for the investigation of combustion and emission parameters. It was observed that biodiesel blends with diesel showed lower CO, Smoke and increase NO\textsubscript{x} Emissions. NO\textsubscript{x} emission is to be reduced slightly whenever EGR was applied.
Mustafa Canakci et.al [75] studied the combustion and emissions characteristics of a four-cylinder turbocharged DI diesel engine using soyabean oil and diesel. It was observed that biodiesel reduced PM, CO, and unburned HC emissions and slight increase in NO\textsubscript{x}. The engine does not require any modifications.

Cherng-Yuan Lin et.al [76] conducted an experimental work using biodiesel as an alternate fuel in diesel engine. The experimental results showed that the O/W/O emulsion had the lowest carbon dioxide (CO\textsubscript{2}) emissions, exhaust gas temperature, and heating value, and the largest brake specific fuel consumption, fuel consumption rate, and kinematic viscosity of four tested fuels. The increase of engine speed caused the increase of equivalence ratio, exhaust gas temperature, CO\textsubscript{2} emissions, fuel consumption rate, brake specific fuel consumption, but a decrease of NO\textsubscript{x} emissions. Moreover, the existence of aqueous ammonia in the O/W/O biodiesel emulsion curtailed NO\textsubscript{x} formation, thus resulting in the lowest NO\textsubscript{x} emissions among the four tested fuels in burning the O/W/O biodiesel emulsion that contained aqueous ammonia.

Deepak Agarwal et.al [69] used biodiesel as an alternate fuel and used EGR to reduce all emissions in an air-cooled, two-cylinder, constant speed direct injection diesel engine. All performance characteristics were increased and emissions are decreased except NO\textsubscript{x}. NO\textsubscript{x} increased if EGR is not used. NO\textsubscript{x} decreases if EGR is used, but Particulate Matter increased.
Ch. Satyanarayana et al. [77] reported that HC emissions reduced with the Biodiesel application. Hot MME (Mahua Methyl Ester) injected entailed lesser heat transfer from the compressed air mass after injection resulting in more CO formation. Second reason could be assigned to higher specific gravity of the MME oil. Shorter ignition delay period at full load in the case of MME and MME 55 entailed lower NO emissions. MME 55 possesses lower density because of which the injection distance gets reduced and lesser air entrainment in the premixed combustion period. This may lead to more smoke formation. Lower spectrum average levels in the case of the MME indicated smoother combustion than the baseline oil. MME 55, it may be recommended as a viable non edible oil alternative to the diesel fuel because of low injection problems and low emissions. Preheating of the ester was recommended in the context of several advantages enumerated above.

M. Anandan et al. [78] conducted the performance and emission tests, which were carried out on a Kirloskar single cylinder direct injection diesel engine. The performance of the engine was almost same for palm oil methyl ester and its blend compared to diesel. It was also inferred that Knox emissions were higher for palm oil methyl ester and its blend when compared to those of diesel. To decrease NOx, EGR was adopted. Again the above tests were performed with varying percentage of EGR and it was found that NOx decreased but at the same time the performance of the engine decreased.

Sukumar Puhana et al. [53] used, Maui Oil Ethyl Ester used in diesel engine. Results showed that brake thermal efficiency of Mahua Oil Ethyl Ester (MOEE) was compared to diesel and it was observed as 26.36% for diesel
whereas 26.42% for MOEE. Emissions of carbon monoxide, hydrocarbons, oxides of nitrogen and Bosch smoke number were reduced to around 58%, 63%, 12% and 70%, respectively, in case of MOEE compared to diesel. Based on this study, MOEE could be used a substitute for diesel in diesel engine.

Abdul Monyem et.al [34] used neat Biodiesel in a single cylinder C.I. Engine at speed of 1400 rpm to evaluate the performance and emission characteristics. From this study it was reported that thermal efficiency did not change and fuel consumption increased compared to diesel. The emissions like CO and HC were reduced by 15% and 16% compared to diesel fuel results.

Cherng-Yuan Lin et.al [70] showed that the three biodiesels revealed a higher fuel consumption rate, bsfc, and brake thermal efficiency, and at the same time exhibited lower emission indices of CO and CO$_2$ as well as a lower exhaust gas temperature when compared to ASTM No. 2D diesel. In particular, biodiesel produced with the addition of the per oxidation process had the lowest equivalence ratio and emission indices of CO$_2$, CO and NO$_x$ among all of the four test fuels. Therefore, it was found that per oxidation process could be used to effectively improve the fuel properties and reduce emissions when biodiesel is used.

M.P. Dorado et.al [36] used Neat biodiesel from used olive oil and diesel in Diesel engine to evaluate emission and performance parameters. From this study it was reported that the emissions such as CO, CO$_2$, NO and SO$_2$ were
reduced by 58.9%, 7.4%, 37.5%, 57.7%, but NO\textsubscript{x} increased by 81%
compared to those of diesel fuel. The performance characteristics like fuel consumption increased.

G. Sankaranarayan et al [54], continued his research on the performance and emission characteristics by using hydrogen enriched air, inducted into the engine and injected with raw Madhuca Indica oil. The results showed an increase in brake thermal efficiency from 24 to 40% with hydrogen enrichment, HC reduced by 36%, CO reduced by 40%, NO\textsubscript{x} decreased at full load for 40% of hydrogen enrichment and BSFC was reduced by 39% compared to diesel.

Daniel Wiznia [55]. Studied the feasibility of the use of diesel vehicle for testing bio-fuel performance in the realm of exhaust emissions. Results reported low HC, 15% low CO, less particulate matter, high NO\textsubscript{x}, with exhaust gas recirculation, 80% NO\textsubscript{x} reduced along with power loss.

Sukumar Puhan et.al [37] evaluated the performance and emission test on a direct injection diesel engine with methyl ester of Mahua oil. It was observed that BSFC was 20% higher and brake thermal efficiency was 13% lower than that of diesel. While HC and CO emissions reduced, NO\textsubscript{x} emissions increased.

2.5.2.2. Bio- Diesel Blends:

A.Karthikeyan et.al [56] conducted experiments when the engine was fuelled with pure diesel, pure rice bran oil methyl ester and the blends of
rice bran oil methyl ester diesel in proportions of 20% / 80%, 40% / 60% and 60% / 40% by volume. The bsfc values of the RME / Diesel blends and pure RME were slightly lower than that of diesel. The brake thermal efficiency of the engine with RME / diesel blends was slightly lower than that of diesel. The brake thermal efficiency of the engine with pure RME was higher than that of diesel. The exhaust gas temperatures were reduced when the engine was fuelled with RME / Diesel blends and pure RME. The NO\textsubscript{x} emissions were reduced, when the engine was fuelled with RME / Diesel blends and pure RME. The smoke density increased, when the engine was fuelled with RME / Diesel blends and pure RME. The particulate matter emission increased when the engine was fuelled with RME / Diesel blends and pure RME. The results from the experiments proved that Rice bran oil methyl ester and its blends with diesel are good substitute fuel for diesel engines.

S. Choudhury et.al [79] used single cylinder C.I. Engine to evaluate performance and emission parameters and the comparison was made to suggest better option among the biodiesels under study. The results of physical and chemical properties of all blends showed that blends of up to 20% straight karanja and up to 50% straight jatropha had the value of viscosity and density equivalent to specified range for CI engine fuel. Therefore it was concluded that up to 20% blend for karanja and 50% blend for jatropha could be used to run the stationary CI engine on short term basis. In overall perspective, the B50 jatropha was a better choice as it could partially replace more amounts of diesel in comparison with karanja. Based
on engine emission studies i.e. CO, NO\textsubscript{x} and hydrocarbon, it could be stated that all the parameters are within maximum limits that conclude safer use as an alternate fuel.

K. Purushothaman et.al [80] showed the test results indicating that the performance of 30\% orange oil blends was much better than 10\% and 50\% orange oil blends and diesel. The specific fuel consumption was increased with the increase in orange oil blends due to lower calorific value of orange oil. The emissions of hydrocarbon (HC), carbon monoxide (CO) and smoke were reduced but nitric oxide (NO\textsubscript{x}) increased compared to diesel. It was concluded from the results of the experimental investigation that 30\% orange oil blends could be used as diesel fuel substitute in diesel engine.

SHANKAR K.S.et.al [81] used Coconut oil. The results were compared with diesel fuel baseline data. The effect of injection pressure on the performance and emission characteristics of biodiesel blends of B20, B30 and B100 at four different injection pressures of 180, 200, 220 and 160 bar were studied. From the investigations it was found that 200 bar was the optimum injection pressure with B20 and B30 blends, which resulted in better performance and emission characteristics with biodiesel blends as fuel.

Sudhir C.V, et.al [82] reported the combustion studies on a dual fuel engine fueled with primary fuel as B20 blend of Esterfied Waste Frying Oil (WFO) and petroleum diesel fuel mixture with LPG as secondary fuel. However at higher engine load, operation beyond 75\% of the full load, the combustion performance improved with delay, but with higher rate of heat
release and higher pressure raise due to better auto-ignition of the LPG premixed mixture. As far as pollutant emissions were concerned, the use of gaseous fuel had a positive effect on NO as well as on black smoke emissions.

Aaron Williams et. al [83] experimental work was conducted on Cummins ISB engine (with exhaust gas recirculation) ultra-low sulphur diesel blended with soya-biodiesel at 5% and 20%. It was observed that B20 biodiesel showed better performance and lower emissions, especially soot. NO\textsubscript{x} emission were not changed in the neat and blends of oil compared to diesel.

L. G. Schumacher et.al [25] showed a model 6V92TA Detroit Diesel Corporation diesel engine (9.0 l), which was fueled on blends of 10%, 20%, 30% and 40% soy diesel/diesel fuel. The blends of biodiesel with diesel reduce all the emissions except NO\textsubscript{x}, which has slightly increased. The optimum blend of biodiesel and diesel fuel was a 20/80 biodiesel/diesel fuel blend. If the timing of fuel injection is reduced, it reduced NO\textsubscript{x} emissions, while CO, THC and PM remained essentially constant with a 20/80 biodiesel/diesel fuel blend.

Leon G. Schumacher et al [38] investigated on a 6V92TA Detroit Diesel Corporation diesel engine fuelled with soya diesel/diesel fuel, blends of 10%, 20%, 30%, 40% soya- diesel fuel. Reports showed efficiency lower by 80.55%, CO is lower by 46%, total particulate matter is lower by 63%, total HC emission is lower by 35%, CO\textsubscript{2} is lower by 15.66%, NO\textsubscript{x} is higher by 9% for B20. CO is lower by 32%, total particulate matter is lower by 35%, total
HC emission is lower by 37%, CO$_2$ is higher by 78.45%, NO$_x$ is higher by 13% for B100 when compared to diesel.

Reheman et al [84] investigated the effect of Karanja methyl ester and its blends on a single cylinder direct injection diesel engine. It was found that Karanja methyl ester with diesel up to 40% by volume could replace diesel for running the engine without sacrificing the power output. Reduced CO, smoke, NO$_x$ was 80%, 50%, 26% respectively compared to diesel.

O.D. Hebbal et al [45] investigated on Deccan hemp oil, a non-edible vegetable oil blended with diesel in 25/75%, 50/50%, 75/25%, 100/0% on volume basis. The effect of viscosity on temperature was studied along with performance and emissions at various loads of 0.37, 0.92, 1.48, 2.03, 2.58, 3.13 and 3.68 KW at constant speed of 1500 rpm. A 1.16% decrease in BSFC, 0.05 Kg/Kw-hr in bsec for Deccan hemp oil was observed. CO, HC emissions increased for 50% blends and higher by 51.74%, 71.42%, and 33.3% respectively compared to diesel. Also reported that 25% biodiesel was better without any engine modification.

Magin Lapuerta et.al [90] In this study, waste cooking oil methyl and ethyl esters are used as fuels in diesel engine. This experimentation was conducted to evaluate performance and emissions of the diesel engine. The results shows that slight increase in fuel consumption. Reduction of emissions such as particulate matter, hydrocarbons and smoke, but increase in NO$_x$ emission compared to diesel.
Ali Keskin et.al [91] Used tall oil bio-diesel as fuel in DI diesel engine to evaluate performance and emission parameters. Metal based additives such as MgO and MgO2 are added to biodiesel to improve the properties of the fuel. Engine performance does not change with biodiesel compared to diesel. Emissions such as CO, HC, CO2 are reduced compared to diesel.

Ming Zheng et.al [92] Used soy, Canola and yellow grease derived bio-diesel are used in diesel engine to evaluate the performance and emissions. All the parameters are compared to those of diesel. This results reveals that emission parameters such as CO, HC and soot are reduced, but NOx emission is increased with these bio-diesels compared to those of diesel. NOx emission and soot emissions are reduced when EGR is applied.

Magín Lapuerta et.al [93] The main objective of the work was to study the effect of bio diesel blends on particulate emissions, measured in terms of mass, optical effect (smoke opacity) and size distributions. A sharp decrease was observed in both smoke and particulate matter emissions as the bio diesel concentration was increased. The mean particle size was also reduced with the bio diesel concentration, but no significant increases were found in the range of the smallest particles. No important differences in emissions were found between the two tested bio diesel fuels.

Zafer Utlu et.al [94] In this study, usage of methyl ester obtained from waste frying oil (WFO) is examined as an experimental material. A reactor was designed and installed for production of methyl ester from this kind of oil. Physical and chemical properties of methyl ester were determined in the
laboratory. The methyl ester was tested in a diesel engine with turbocharged, four cylinders and direct injection. Gathered results were compared with No. 2 diesel fuel. Engine tests results obtained with the aim of comparison from the measures of torque, power; specific fuel consumptions are nearly the same. In addition, amount of emission such as CO, CO$_2$, NO$_x$, and smoke darkness of waste frying oils are less than No. 2 diesel fuel.

H. Raheman et.al [95 ] The performance of Ricardo E6 engine using biodiesel obtained from mahua oil (B100) and its blend with high speed diesel (HSD) at varying compression ratio (CR), injection timing (IT) and engine loading (L) has been presented in this paper. The brake specific fuel consumption (bsfc) and exhaust gas temperature (EGT) increased, whereas brake thermal efficiency (BTE) decreased with increase in the proportion of biodiesel in the blends at all compression ratios (18:1–20:1) and injection timings (35–45° before TDC) tested. However, a reverse trend for these parameters was observed with increase in the CR and advancement of IT. The BSFC of B100 and its blends with high speed diesel reduced, whereas BTE and EGT increased with the increase in L for the range of CR and IT tested. The differences of BTEs between HSD and B100 were also not statistically significant at engine settings of ‘CR20IT40’ and ‘CR20IT45’. Thus, even B100 could be used on the Ricardo engine at these settings without affecting the performance obtained using HSD.
Can Haşimoğlu et.al [96] Used sunflower oil methyl esters as fuel in DI diesel engine to evaluate the performance of engine. The aim of this study is to apply LHR engine for improving engine performance when biodiesel is used as an alternative fuel. For this purpose, a turbocharged direct injection (DI) diesel engine was converted to a LHR engine and the effects of biodiesel (produced from sunflower oil) usage in the LHR engine on its performance characteristics have been investigated experimentally. The results showed that specific fuel consumption and the brake thermal efficiency were improved and exhaust gas temperature before the turbine inlet was increased for both fuels in the LHR engine.

Ali Keskin et.al [97] In this study, usability of cotton oil soapstock biodiesel–diesel fuel blends as an alternative fuel for diesel engines were studied. Biodiesel was produced by reacting cotton oil soapstock with methyl alcohol at determined optimum condition. The cotton oil biodiesel–diesel fuel blends were tested in a single cylinder direct injection diesel engine. Engine performances and smoke value were measured at full load condition. Torque and power output of the engine with cotton oil soapstock biodiesel–diesel fuel blends decreased by 5.8% and 6.2%, respectively. Specific fuel consumption of engine with cotton oil soapstock–diesel fuel blends increased up to 10.5%. At maximum torque speeds, smoke level of engine with blend fuels decreased up to 46.6%, depending on the amount of biodiesel. These results were compared with diesel fuel values.
K. Sureshkumar et.al [98] This paper presents the results of performance and emission analyses carried out in an unmodified diesel engine fueled with Pongamia pinnata methyl ester (PPME) and its blends with diesel. The results reveal that blends of PPME with diesel up to 40% by volume (B40) provide better engine performance (bsfc and bsec) and improved emission characteristics.

N.R. Banapurmath et.al [99] This paper presents the results of investigations carried out on a single-cylinder, four-stroke, direct-injection, CI engine operated with methyl esters of Honge oil, Jatropha oil and sesame oil. Biodiesel can be used in its pure form or can be blended with diesel to form different blends. It can be used in CI engines with very little or no engine modifications. Engine performance in terms of higher brake thermal efficiency and lower emissions (HC, CO, NOx) with sesame oil methyl ester operation was observed compared to methyl esters of Honge and Jatropha oil operation.

Deepak Agarwal et.al[100] Fuel crisis because of dramatic increase in vehicular population and environmental concerns have renewed interest of scientific community to look for alternative fuels of bio-origin such as vegetable oils. This study was carried out to investigate the performance and emission characteristics of mahua oil, rice bran oil and linseed oil methyl ester (LOME), in a stationary single cylinder, four-stroke diesel engine and compare it with mineral diesel Economic analysis was also done in this
study and it is found that use of vegetable oil and its derivative as diesel fuel substitutes has almost similar cost as that of mineral diesel.

Makame Mbarawa [101] In this study the performance, emission and economic evaluation of using the clove stem oil (CSO)–diesel blended fuels as alternative fuels for diesel engine have been carried out. Experiments were performed to evaluate the impact of the CSO–diesel blended fuels on the engine performance and emissions. The societal life cycle cost (LCC) was chosen as an important indicator for comparing alternative fuel operating modes. The LCC using the pure diesel fuel, 25% CSO and 50% CSO–diesel blended fuels in diesel engine are analysed. Emissions of CO and HC are low for the CSO–diesel blended fuels. NOx emissions were increased remarkably when the engine was fuelled with the 50% CSO–diesel blended fuel operation mode.

C.D. Rakopoulos et.al [102] An experimental investigation is conducted to evaluate the use of sunflower and cottonseed oil methyl esters (bio-diesels) of Greek origin as supplements in the diesel fuel at blend ratios of 10/90 and 20/80, in a fully instrumented, six-cylinder, turbocharged and after-cooled, direct injection (DI), Mercedes-Benz, mini-bus diesel engine installed at the authors’ laboratory. When working with neat diesel fuel and the two bio-diesels are determined and compared. Theoretical aspects of diesel engine combustion with the differing physical and chemical properties of these blends, aid the correct interpretation of the observed engine behavior.
S. Murugan et.al [103] the properties of the Tyre pyrolysis oil (TPO) derived from waste automobile tyres were analyzed and compared with the petroleum products and found that it can also be used as a fuel for compression ignition engine. This paper presents the studies on the performance, emission and combustion characteristics of a single cylinder four stroke air cooled DI diesel engine running with the Distilled Tyre pyrolysis oil (DTPO).

A.P. Roskilly et.al [104] an experimental investigation of the application of biodiesel (recycled cooking fat and vegetable oil) on small marine craft diesel engines was completed. The tests were performed on Perkins 404C-22 (Marinised) in Boat No. 1 (Fair Countess) and on Nanni Diesel 3.100HE in Boat No. 2 (Aimee 2). The test results show that The NOx emissions were found to be reduced when fuelled with biodiesel. The CO emissions were found to be lower when the engines operated at higher loads using biodiesel.

Md. Nurun Nabi et.al [105] Different parameters for the optimization of biodiesel production were investigated in the first phase of this study, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures were carried out. Cottonseed is non-edible oil, thus food versus fuel conflict will not arise if this is used for biodiesel production. The trans-esterification results showed that with the variation of catalyst, methanol or ethanol, variation of biodiesel production was realized. However, the optimum conditions for biodiesel production are suggested in this paper. A maximum of 77% biodiesel was produced with 20% methanol
in presence of 0.5% sodium hydroxide. The engine experimental results showed that exhaust emissions including carbon monoxide (CO) particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.

Şehmus Altun et.al[106] In this study, a blend of 50% sesame oil and 50% diesel fuel was used as an alternative fuel in a direct injection diesel engine. Engine performance and exhaust emissions were investigated and compared with the ordinary diesel fuel in a diesel engine. The experimental results show that the engine power and torque of the mixture of sesame oil–diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel. Hence, it is seen that blend of sesame oil and diesel fuel can be used as an alternative fuel successfully in a diesel engine without any modification and also it is an environmental friendly fuel in terms of emission parameters.

Murat Karabektas et.al [107] In this study, cottonseed oil methyl ester (COME) is use as fuel in diesel engine to evaluate the performance and emission parameters. For this purpose sigle cylinder, four-stroke, direct injection diesel engine. Before supplied to the engine, COME was preheated to four different temperatures, namely 30, 60, 90 and 120 °C. The results revealed that preheating COME up to 90 °C leads to favourable effects on the BTE and CO emissions but causes higher NOx emissions. Moreover, the brake power increases slightly with the preheating temperature up to 90 °C.
When the COME is preheated to 120°C, a considerable decrease in the brake power was observed due to the excessive fuel leakage caused by decreased fuel viscosity. The results suggest that COME preheated up to 90 °C can be used as a substitute for diesel fuel without any significant modification in expense of increased NOx emissions.

**Murugu Mohan et.al [108]** This paper discusses the performance characteristics of a single cylinder diesel engine using rice bran and pungam oil blended with diesel fuel. The experiments were carried out for the various blends i.e., B20, B40, B60, B80 and the results were compared with the neat diesel. The blended fuel is preheated before it is being injected to cylinder. The preheating ensures the enhancement of combustion efficiency and the over all performance of the engine.

**Breda Kegl et.al [109]** This paper discusses the influence of biodiesel on the injection, spray, and engine characteristics with the aim to reduce harmful emissions. The results indicate that, by using biodiesel, harmful emissions (NOx, CO, HC, smoke, and PM) can be reduced to some extent by adjusting the injection pump timing properly while keeping other engine characteristics within acceptable limits. Furthermore, the results indicate better lubrication conditions when biodiesel is used.

**Harish Kumar Gangwar et.al [110]** Experimental investigations have been carried out to examine the combustion characteristics of an indirect injection transportation diesel engine running with diesel, and jatropha oil blends with diesel. Engine tests were performed at different engine loads
ranging from no load to 100% rated load at constant engine speeds (2000 rpm). A careful analysis of cylinder pressure rise, instantaneous heat release and cumulative heat release was carried out. All test fuels exhibited similar combustion stages as diesel; however, jatropha oil blends showed earlier start of combustion and lower heat release during premixed combustion at all engine loads. The crank angle position of peak cylinder pressure for vegetable oil blends shifts towards top dead center compared to baseline diesel. The maximum rate of pressure rise was found to be higher for jatropha oil blends at higher engine loads.

Bhaskar Mazumdar et al. [111] In present experimental investigation, waste cooking oil obtained from restaurant was used to produce biodiesel through transesterification process and the chemical kinetics of biodiesel production was studied. Biodiesel was blended with petroleum diesel in different proportions. The blends were evaluated for the engine performance, emissions and combustion characteristics in a four-stroke, four-cylinder, indirect injection transportation engine via baseline data of petroleum diesel. It is observed that mass emission of various regulated pollutant species from biodiesel blends is not significantly different from baseline petroleum diesel. Oxides of nitrogen (NOx) emissions increased with increasing concentration of biodiesel in blends, while carbon monoxide (CO) emissions decreased. Brake thermal efficiency of biodiesel blends was observed to be higher as compared to petroleum diesel for all blends. Brake specific fuel consumption (bsfc) and brake specific energy consumption of all biodiesel blends was
found to be lower than petroleum diesel and it was found to be lowest for B20.

A Shailendra Sinha et.al [112] Performance, emission and combustion characteristic, a 20% blend of ROME (B20) was selected as optimum biodiesel blend for endurance test. Endurance test of 100 hours was conducted on a medium-duty direct injection transportation diesel engine. Tests were conducted under predetermined loading cycles in two phases: engine operating on mineral diesel and engine fuelled with 20% biodiesel blend. Experimental results exhibited superior performance of biodiesel blends and less deterioration of lubricating oil with usage. This paper discusses the effect of biodiesel on lubricating oil vis-

Shailendra Sinha et.al[113] The most detrimental properties of vegetable oils are its high viscosity and low volatility, and these cause several problems during their long duration usage in compression ignition (CI) engines. The most commonly used method to make vegetable oil suitable for use in CI engines is to convert it into biodiesel, i.e. vegetable oil esters using process of transesterification. Results showed that biodiesel obtained under the optimum conditions has comparable properties to substitute mineral Diesel, hence, rice bran oil methyl ester biodiesel could be recommended as a mineral Diesel fuel substitute for compression ignition (CI) engines in transportation as well as in the agriculture sector.

Harish Kumar Gangwar et.al [114] In the present research, experiments were designed to study the effect of reducing Jatropha oil's viscosity by
blending with mineral diesel, thereby eliminating its effect on combustion characteristics of the engine. In the present experimental research, vegetable oil (Jatropha Curcus) was used as substitute fuel. Experimental investigations have been carried out to examine the emission and combustion characteristics in an indirect injection transportation diesel engine running with mineral diesel and vegetable oil blends with mineral diesel. Engine tests were performed at different engine loads ranging from no load to 100% rated load at constant engine speeds (2000 rpm). A careful analysis of engine emissions, cylinder pressure rise, instantaneous heat release and cumulative heat release was carried out via mineral diesel to find the suitability of Jatropha oil blends in an unmodified IDI medium-duty diesel engine.

Siva Kumar et.al [115] In this study, different parameters for the optimization of biodiesel production were investigated in the first phase, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures was carried out. The engine experimental results showed that exhaust emissions including carbon monoxide (CO), particulate matter (PM) and Smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.

D.H. Qi et.al [116] In this study, soya bean biodiesel is prepared by using alkaline catalyzed trans esterification process. This soybean biodiesel was used as fuel in diesel engine to performance and emissions of the engine.
The important properties of biodiesel were compared to those of diesel. This results reveals that the power output of the biodiesel is almost same to that of diesel. bsfc is higher compared to diesel due to lower heating value of biodiesel. CO, HC, NOx and smoke emissions are reduced at rated load compared to diesel. Soya bean biodiesel is a substitute fuel to diesel.

P.K.Sahoo et al [117] In this study, Jatropha (Jatropha curcas), Karanja (Pongamia pinnata) and polanga (Calophyllum inophyllum) non-edible methyl esters and their blends (B20, B50, B100, Diesel) with diesel were used as fuels in water cooled diesel engine to evaluate the performance and emission characteristics. The results reveals that the maximum increase in power is observed for 50% jatropha biodiesel at rated load. smoke emission is reduced for all biodiesels and their blends compared to diesel at rated load.

Rosca Radu et al [118] In this study, waste vegetable biodiesel is used as fuel in diesel engine. In this 50% biodiesel mixed with 50% diesel used as fuel to evaluate injection pressure, combustion and engine characteristics. Biodiesel blending leads to lower output and torque. It also gives lower auto ignition delay, lower peak combustion pressures. Pressure wave propagation leads to change in pressure and heat release traces.

İsmet Çelikten et al [119] In this study, Rapeseed methyl ester and Soy bean methyl esters are used in diesel engine. all the performance and emissions of engine is compared to diesel. These tests are conducted at different injection pressures such as 200, 300, 350 bar with each of these fuel in order to evaluate the engine performance. Results reveals that performance
and emission values of rapeseed oil (R) and soybean oil (S) methyl esters were found to be nearly the same with those of diesel fuels (D) when injection pressure was increased to 300 bar.

Sharanappa Godiganur et.al [120] In this study Fish oil methyl ester is used as fuel in diesel engine to evaluate the performance and emission characteristics of engine. The properties of fish methyl ester are similar as diesel fuel. The results reveal that engine performance and reduction in emissions of engine is almost same as diesel fuel without any engine modifications. Fish oil showed good combustion properties and environmental benefits.

Bai-Fu Lin et.al [121] In this study, Vegetable oil methyl ester (VOME) is used as fuel in DI diesel engine. The performance, combustion and emissions of engine was evaluated. The results showed that higher BSFC, increase in heat release rate, power production is same as compared to diesel. But with a reduction in the Exhaust gas temperature (EGT), smoke and total hydrocarbon (THC) emissions, with a slight increase in nitrogen oxides (NOx) emissions was observed compared to diesel. Higher combustion rate is obtained near the Top dead centre.

Fujia Wu et.al [122] In this study, five biodiesels such as cottonseed methyl ester (CME), soybean methyl ester (SME), rapeseed methyl ester (RME), palm oil methyl ester (PME) and waste cooking oil methyl ester (WME) are used in diesel engine. It is used to evaluate the performance and emission characteristics of the engine. All the results are compared to those of diesel.
The results reveals that Particulate matters and Dry Soot are reduce from 56% to 69% and 79% to 83% respectively with these oils. All emissions such as CO,HC, Smoke emissions are reduced compared to diesel.

B. Baiju et.al [123] In this study, Methyl and ethyl esters of Karanja oils are used as alternate to diesel in C.I.Engine. Performance and exhaust emission characteristics of the engine were determined using petrodiesel as the baseline fuel and several blends of diesel and biodiesel as test fuels. Results show that methyl esters produced slightly higher power than ethyl esters. Exhaust emissions of both esters were almost identical. These studies show that both methyl and ethyl esters of Karanja oil can be used as a fuel in compression ignition engine without any engine modification.

Ahmet Necati Ozsezen et.al [124] In this study, waste palm oil(WPOME) and canola oil methyl esters (COME) are used as fuels in DI diesel engine. It is used to evaluate the performance and combustion characteristics of the engine. The engine performance slightly decreased and combustion characteristics slightly changed when compared to petroleum based diesel fuel (PBDF). The biodiesels caused reductions in carbon monoxide (CO), unburned hydrocarbon (HC) emissions and smoke opacity, but they caused to increases in nitrogen oxides (NOx) emissions.

S.K. Haldar et.al [125] This paper investigates non-edible straight vegetable oils of Putranjiva, Jatropha and Karanja to find out the most suitable alternative diesel by a chemical processing. Degumming is an economical chemical process that is done by concentrated phosphoric acid. This process
is applied to the above-mentioned non-edible oils to remove the impurities
for the improvement of viscosity, cetane number and better combustion in
the diesel engine up to certain blend of diesel and non-edible vegetable oils.
Ten percent, 20%, 30% and 40% blends of degummed non-edible oils and
diesel are used in a Ricardo variable compression engine to study and
compare the performance and emission characteristics. It is observed that
the non-edible oil of Jatropha gives the best results related to the
performance and emissions at high loads and 45° bTDC injection timing.

Gvidonas Labeckas et.al [126] This article presents the bench testing
results of a four stroke, four cylinder, direct injection, unmodified, diesel
engine operating on pure rapeseed oil (RO) and its blends with ethanol to
test engine emission characteristics and smoke opacity. The results reveals
that all the emissions such as CO, CO₂, HC and Smoke are reduced
compared to those of diesel.

Avinash Kumar Agarwal et.al [127] In this study, Karanja and its blend with
diesel was used as fuel in C.I. Engine. It is used to evaluate the performance
and emission characteristics of the engine. The results shows that
Significant improvements have been observed in the performance
parameters of the engine as well as exhaust emissions, when lower blends
of Karanja oil were used with preheating and also without preheating. The
results of the experiment in each case were compared with baseline data of
mineral diesel. The gaseous emission of oxide of nitrogen from all blends
with and with out preheating are lower than mineral diesel at all engine
loads. Karanja oil blends with diesel (up to 50% v/v) without preheating as
well as with preheating can replace diesel for operating the CI engines giving lower emissions and improved engine performance.

P.K. Devan et al. [128] Experimental tests have been carried out to evaluate the performance, emission and combustion characteristics of a diesel engine using Neat poon oil and its blends of 20%, 40%, and 60%, and standard diesel fuel separately. It was found that there was a reduction in NO\textsubscript{x} emission for Neat poon oil and its diesel blends along with a marginal increase in HC and CO emissions. Brake thermal efficiency was slightly lower for Neat poon oil and its diesel blends. From the combustion analysis, it was found that poon oil–diesel blends performed better than Neat poon oil.

B. Prem Anand et al. [129] This paper presents the results of experimental work carried out to evaluate the combustion performance and exhaust emission characteristics of turpentine oil fuel (TPOF) blended with conventional diesel fuel (DF) fueled in a diesel engine. Indicated that the engine operating on turpentine oil fuel at manufacture's injection pressure–time setting (20.5 MPa and 23° BTDC) had lower carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NO\textsubscript{x}), smoke level and particulate matter. Further the results showed that the addition of 30% TPOF with DF produced higher brake power and net heat release rate with a net reduction in exhaust emissions such as CO, HC, NO\textsubscript{x}, smoke and particulate matter. Above 30% TPOF blends, such as 40% and 50% TPOF blends, developed lower brake power and net heat release rate were noted.
due to the fuels lower calorific value; nevertheless, reduced emissions were still noted.

S. Saravanan et.al [130] In the present investigation an attempt was made to test the feasibility of crude rice bran oil methyl ester (CRBME) which is derived from high free fatty acid (FFA) crude rice bran oil (CRBO) as a fuel for a heavy-duty automotive compression ignition (CI), i.e. diesel engine in blended form. While running with CRBME blend significant reductions in CO, UHC and particulate emission were observed with a marginal increase in NOx emission than that of diesel. Brake thermal efficiency of the engine reduced marginally for CRBME blend when compared with diesel. Experimental results show that as a fuel for a heavy-duty diesel engine CRBME blend shows better emission characteristics than diesel with a marginal increase in NOx emission. Hence efforts can be taken to utilize it effectively.

Mustafa Canakci et.al [131] used preheated crude sunflower oil (PCSO) was tested for combustion and emission properties against petroleum based diesel fuel (PBDF) in a naturally aspirated, indirect injection (IDI) engine. The brake specific fuel consumption increased by almost 5% more or less in proportion to the difference in calorific value, so that the 1.06% increase in thermal efficiency was again statistically insignificant. The emission test results showed that the decreases in CO$_2$ emission and smoke opacity 2.05% and 4.66%, respectively; however, this was not statistically significant, though in line with the apparent increase in thermal efficiency.
There was a significant 34% improvement in the emissions of un-burnt hydrocarbons. Carbon monoxide increased by 1.77% again the result was not statistically significant given the small number of repeat tests.

N.R. Banapurmath et.al [132] Experiments have been conducted on a single cylinder, four-stroke, direct injection, water-cooled CI engine operated in single fuel mode using Honge, Neem and Rice Bran oils. In dual fuel mode combinations of Producer gas and three oils were used at different injection timings and injection pressures. Dual fuel mode of operation resulted in poor performance at all the loads when compared with single fuel mode at all injection timings tested. However, the brake thermal efficiency is improved marginally when the injection timing was advanced. Decreased smoke, NO\textsubscript{x} emissions and increased CO emissions were observed for dual fuel mode for all the fuel combinations compared to single fuel operation.

M. Mani et.al [133] The present investigation was to study the effect of cooled exhaust gas recirculation (EGR) on four stroke, single cylinder, direct injection (DI) diesel engine using 100% waste plastic oil. Experimental results showed higher oxides of nitrogen emissions when fueled with waste plastic oil without EGR. NO\textsubscript{x} emissions were reduced when the engine was operated with cooled EGR. The EGR level was optimized as 20% based on significant reduction in NO\textsubscript{x} emissions, minimum possible smoke, CO, HC emissions and comparable brake thermal efficiency. Smoke emissions of waste plastic oil were higher at all loads. Combustion parameters were
found to be comparable with and without EGR. Compression ignition engines run on waste plastic oil are found to emit higher oxides of nitrogen.

Yage Di et.al [134] Experiments were conducted on a 4-cylinder direct-injection diesel engine using ultra-low sulfur diesel, biodiesel and their blends, to investigate the regulated and unregulated emissions of the engine under five engine loads at an engine speed of 1800 rev/min. Blended fuels containing 19.6%, 39.4%, 59.4% and 79.6% by volume of biodiesel, corresponding to 2%, 4%, 6% and 8% by mass of oxygen in the blended fuel, were used. Biodiesel used in this study was converted from waste cooking oil. The following results are obtained with an increase of biodiesel in the fuel. The brake specific fuel consumption and the brake thermal efficiency increase. The HC and CO emissions decrease while NOx and NO2 emissions increase. The smoke opacity and particulate mass concentrations reduce significantly at high engine load. In addition, for submicron particles, the geometry mean diameter of the particles becomes smaller while the total number concentration increases. The results indicate that the combination of ultra-low sulfur diesel and biodiesel from waste cooking oil gives similar results to those in the literature using higher sulfur diesel fuels and biodiesel from other sources.

Hanbey Hazar et.al [135] Raw rapeseed oil (RRO) was used as blended with diesel fuel (DF) by 50% oil–50% diesel fuel in volume (O50) also as blended with diesel fuel by 20% oil–80% diesel fuel in volume (O20). The test fuels were used in a single cylinder, four stroke, naturally aspirated, direct
injection compression ignition engine. The effects of fuel preheating to 100 °C on the engine performance and emission characteristics of a CI engine fueled with rapeseed oil diesel blends were clarified. Results showed that preheating of RRO was lowered RRO’s viscosity and provided smooth fuel flow. Heating is necessary for smooth flow and to avoid fuel filter clogging. It can be achieved by heating RRO to 100 °C. It can also be concluded that preheating of the fuel have some positive effects on engine performance and emissions when operating with vegetable oil.

H.E. Saleh [136] Jojoba methyl ester (JME) has been used as a renewable fuel in numerous studies evaluating its potential use in diesel engines. The aim of this study mainly was to quantify the efficiency of exhaust gas recirculation (EGR) when using JME fuel in a fully instrumented, two-cylinder, naturally aspirated, four-stroke direct injection diesel engine. The tests were made in two sections. The results showed that EGR is an effective technique for reducing NO\textsubscript{x} emissions with JME fuel especially in light duty diesel engines. A better trade-off between HC, CO and NO\textsubscript{x} emissions can be attained within a limited EGR rate of 5–15% with very little economy penalty.

S. Jindal et.al [137] Being a fuel of different origin, the standard design parameters of a diesel engine may not be suitable for Jatropha methyl ester (JME). This study targets at finding the effects of the engine design parameters viz. compression ratio (CR) and fuel injection pressure (IP) jointly on the performance with regard to fuel consumption (bsfc), brake thermal
efficiency (BTHE) and emissions of CO, CO$_2$, HC, NO$_x$ and Smoke opacity with JME as fuel. Comparison of performance and emission was done for different values of compression ratio along with injection pressure to find best possible combination for operating engine with JME. It is found that the combined increase of compression ratio and injection pressure increases the BTHE and reduces BSFC while having lower emissions. For small sized direct injection constant speed engines used for agricultural applications (3.5 kW), the optimum combination was found as CR of 18 with IP of 250 bar.

K. Purushothaman et.al [138] In the present work the performance, emission and combustion characteristics of a single cylinder, constant speed, direct injection diesel engine using orange oil as an alternate fuel were studied and the results are compared with the standard diesel fuel operation. Results indicated that the brake thermal efficiency was higher compared to diesel throughout the load spectra. Carbon monoxide (CO) and hydrocarbon (HC) emissions were lower and oxides of nitrogen (NO$_x$) were higher compared to diesel operation. Peak pressure and heat release rate were found to be higher for orange oil compared to diesel fuel operation.

P.K. Devan et.al [139] The significance of this study is the complete replacement of diesel fuel with bio-fuels. For this purpose, bio-fuels, namely, methyl ester of paradise oil and eucalyptus oil were chosen and used as fuel in the form of blends. Various proportions of paradise oil and eucalyptus oil are prepared on a volume basis and used as fuels in a single cylinder, four-
stroke DI diesel engine, to study the performance and emission characteristics of these fuels. In the present investigation a methyl ester derived from paradise oil is considered as an ignition improver. The results show a 49% reduction in smoke, 34.5% reduction in HC emissions and a 37% reduction in CO emission for the Me50–Eu50 blend with a 2.7% increase in NOx emission at rated load. There was a 2.4% increase in brake thermal efficiency for the Me50–Eu50 blend at full load. The combustion characteristics of Me50–Eu50 blend are comparable with those of diesel.

Murat Karabektas et.al [140] The aim of this study is to investigate the suitability of isobutanol–diesel fuel blends as an alternative fuel for the diesel engine. four different isobutanol–diesel fuel blends containing 5, 10, 15 and 20% isobutanol were prepared in volume basis and tested in a naturally aspirated four stroke direct injection diesel engine at full load conditions at the speeds between 1200 and 2800 rpm with intervals of 200 rpm. The test results indicate that the break power slightly decreases with the blends containing up to 10% isobutanol, whereas it significantly decreases with the blends containing 15 and 20% isobutanol. There is an increase in the BSFC in proportional to the isobutanol content in the blends. Although diesel fuel yields the highest BTE, the blend containing 10% isobutanol results in a slight improvement in BTE at high engine speeds. The results also reveal that, compared to diesel fuel, CO and NOx emissions decrease with the use of the blends, while HC emissions increase considerably.
S. Saravanan et.al [141] The objective of the present work is to analyze the combustion characteristics of crude rice bran oil methyl ester (CRBME) blend (20% of CRBME with 80% no.2 diesel on volume basis) as a fuel in a stationary small duty direct injection (DI) compression ignition (CI) engine. It was observed that the delay period and the maximum rate of pressure rise for CRBME blend were lower than those of diesel. CRBME blend requires more crank angle duration to release 50% & 90% of heat when compared with diesel. The brake specific fuel consumption of CRBME blend was found to be only marginally different from that of the diesel and its hourly fuel cost was higher than that of diesel. CRBME blend has lower smoke intensity and higher NOx emission than those of diesel. Since the measured parameters for CRBME blend differs only by a smaller magnitude, when compared with diesel, this investigation ensures the suitability of CRBME blend as fuel for CI engines with higher fuel cost.

M. Gumus et.al [142] In this study, apricot seed kernel methyl ester (Prunus armeniaca) and their blends with diesel were used in diesel engine to evaluate the performance and emission parameters of engine. This study reveals that lower concentration of apricot seed kernel methyl ester in blends gives better performance and lower emissions without modification of the engine.

Hüseyin Aydin et.al [143] In this study, cotton seed methyl ester and its blends(B5,B20,B50,B75, and B100) with diesel was used as fuel in diesel engine. It is used to evaluate performance and emission parameters of the
engine. The experimental results showed that the use of the lower blends (B5) slightly increases the engine torque at medium and higher speeds in compression ignition engines. Also with the increase of the biodiesel in blends, the exhaust emissions were reduced. Lower contents of CSOME in the blends can partially be substituted for the diesel fuel without any modifications in diesel engines.

2.5.3. Summary on the use of Biodiesel and its Blends:

2.5.3.1. Suitability:

The biodiesel has some properties, which make it suitable for replacement of diesel fuel.

- Low content of free glycerin (\(< 0.02 \text{ better } 0.002\<\) )
- High degree of transesterification (\(> 99.8\% \) )
- Low acid number (\(<0.5 \text{ better } < 0.2 \) )
- No polymers, hence very clean.

2.5.3.2 Benefits:

- By using Bio-diesel from renewable sources such as agriculture products, agro industry residues, Re cycled cooking oils; there is a reduction in the disposal costs of government and industry.
- Bio-diesel Reduces emissions.
- Bio-diesel itself composed 11 % of O\(_2\) in mass and almost surplus free. Thus even low concentration added to petroleum diesel makes it burn better and may improve the performance of catalytic converter.
- Bio-diesel is non-toxic, bio degradable.
➢ It reduces the impact of accidental spills substantially.

➢ Blends of Bio-diesel accelerate the combustion process.

➢ Pure Bio-diesel is essentially free of surplus and aromatics.

➢ The exhaust smells better than that of petrol diesel engine. It freezes at lower temperature.

➢ **Bio-diesel has more energy**, it has higher cetane rating.

➢ Bio-diesel gives lower engine wear.

➢ Bio-diesel is a better solvent than standard diesel.

➢ Bio-diesel cleans the engine.

➢ Bio-diesel removes the deposits in the fuel lines.

➢ Bio-diesel is also used as heating fuel in domestic and commercial boilers.

➢ Bio-diesel has high boiling point and low vapor pressure.

➢ Density of Bio-diesel is less than that of water.

➢ The volumetric energy density of Bio-diesel is about 9% lower than that of petrol diesel (i.e. 33 MJ/Liter).

➢ Bio-diesel gives better lubricity and greater engine efficiency.

➢ Bio-diesel releases less green house gases.

➢ It provides a domestic, renewable energy.

➢ Esters have lower viscosities than the parent oils and ensure better atomization of the fuel in the combustion chamber.

➢ Bio diesel has high flash point, which make it safer to transport.

➢ Bio diesel is more lubricating than diesel. So, it increases the life of engine.
2.5.3.3. **Drawbacks:**

- Slight increase in NO\textsubscript{x} emissions.

2.6. **SCOPE OF PRESENT WORK:**

From the above review of literature the following important conclusions are made. The past work reveals that vegetable oils like sunflower, safflower, soyabean, rapeseed oil, rice bran oil and their derivatives as alternate fuels in place of diesel in C.I. Engines were proved useful.

The past studies reveal that vegetable oils and their derivatives is used in place of diesel in C.I. Engine with little or no modifications. The blends of this oil with diesel and neat vegetable oils were tried. Performance and emissions of the engine was reported. In majority of cases the performance was found with some operating problems. The operational problems were engine starting problem, nozzle clogging, increased smoke, engine seizure due to deposit formation, lube oil degradation etc. The high viscosity and low volatility of vegetable oil may be the reason for the above problems. Preheating the vegetable oils and blending with diesel can overcome these problems to some extent. Engine produces the maximum output at a comparable thermal efficiency, but these emit higher smoke, CO, CO\textsubscript{2}, Unburnt Hydro carbons and Nitrogen oxides. Further emissions can be reduced by the use of esterified vegetable oil.

So far a very few types of vegetable oils have been tested on C.I. Engines. Among them many are edible vegetable oil. The use of edible oil in
the engine decreases the production of animal and human food. In India, so far biodiesel is used for limited applications to run few railways and buses. India has great potential for the production of bio fuels from non–edible vegetable oil seeds. Hence there is a need to identify new types of non-edible vegetable oils and examine their suitability as an alternate fuel.

In view of the plight of energy crisis, the author has experimented upon and has used in this work five types of non-edible vegetable oils such as Linseed oil, Castor oil, Palm stearin oil, Mahua oil and Neem oil, which were identified for the investigation in the diesel engine.

The scope of the work undertaken in the report is as follows:

1. Determining the important physical properties, chemical properties and parameters of Linseed oil, Castor oil, Palm Stearin oil, Mahua oil and Neem oil

2. Finding the effect of blending Linseed, Castor, Palm stearin, Mahua and Neem oil with diesel on viscosity.

3. Finding the effect of Temperature on viscosity of Linseed, Castor, Palm stearin, Mahua and Neem oil and diesel blends. Determining temperature at which the viscosity of the blends is equal to that of the diesel at 40⁰C.

4. Suitability of five chosen oils as alternate fuels used in diesel engine are examined by evaluating performance and emission parameters of diesel engine using various blends. The results are compared with those of diesel.
5. Performance and emission parameters of suitable oils are tested and are compared with similar type of works available in the literature for the validation.

6. Preparation for Methyl Esters (Bio-diesel) of suitable vegetable oils.

7. Investigations are carried out on Methyl Ester of suitable oil in the test engine.

8. Emission and Performance parameters are evaluated and compared with those of diesel. Also better performing Methyl Ester among tested esters are determined.

9. Further to ascertain the validity of the results obtained, the performance and emission parameters of Methyl Ester are compared with the results of other bio-diesels available in the literature.