AN INVESTIGATION INTO BIODIESEL PRODUCTION FROM NEEM OIL AND EVALUATION OF PERFORMANCE AND EMISSION PARAMETERS OF DIESEL ENGINE USING DIFFERENT BIODIESEL BLENDS

A
Thesis

submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering (M.E.)
In
Thermal Engineering

Submitted by
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UNDER THE GUIDANCE OF
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JULY 2015

CERTIFICATION

I, Farun Garg, declare that this thesis report entitled "***An investigation into biodiesel production from Neem oil and evaluation of performance and emission parameters of diesel engine using different biodiesel blends***", submitted towards fulfillment of the requirements for the award of Master's Degree in Thermal Engineering, in Mechanical Engineering Department of Thapar University, Patiala, is entirely my own work. This document has not been submitted for any degree in any other institution.

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ABSTRACT

Biodiesel now a days is emerging as an alternative fuel which is a good replacement to the petroleum diesel. Biodiesel is mainly derived from fats and oils by different methods such as dilution, pyrolysis, micro emulsification and transesterification but these days most commercial method used for biodiesel production is transesterification. Neem oil biodiesel was prepared using transesterification process by optimizing the production parameters such as alcohol to oil molar ratio, catalyst concentration etc. Engine design also plays an important role as if it is improved it reduces fuel consumption and give better performance parameters. In this thesis the main emphasis has been laid on optimum production of biodiesel from neem oil and then using the biodiesel blends with diesel studying the comparative exhaust emission characteristics and engine performance and also optimizing the compression ratio and the blends made from the biodiesel with diesel. A four stroke variable compression ratio single cylinder compression ignition engine was used to measure performance and emission parameters. Biodiesel (fire point and calorific value) added to the diesel (fire point and calorific value) at four different volume concentrations i.e. 10, 20, 30 and 40% of biodiesel. Based on the analysis of performance and emission parameters the biodiesel blend B10 was found optimum for the most efficient operation of the engine. The CR 14 was found optimum by comparing the performance parameters such as BTHeff, BSFC, and EGT etc. for all the compression ratios.

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NOMENCLATURE

BP	Brake Power [kW]
BMEP	Brake Mean Effective Pressure [bar]
BTE	Brake Thermal Efficiency [%]
EGT	Exhaust Gas Temperature [^oC]
BSFC	Brake Specific Fuel Consumption [kg/kWhr]
Mech.Eff	Mechanical Efficiency
Vol.Eff	Volumetric Efficiency
BThEff	Brake Thermal Efficiency
NO, NO_2, NOx	Oxides of Nitrogen [ppm]
CO_2	Carbon Dioxide [%]
CO	Carbon Monoxide [ppm]
ASTM	American Society of Testing and Petroleum
US	United States
ISO	International standard organization
EU	European Union
PPM	Parts Per Million
H_2SO_4	Sulphuric Acid
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
IC	Internal Combustion
DI	Direct Injection
CI	Compression Ignition
CR	Compression Ratio
TAG	Triacylglycerols
FA	Fatty Acids
FFA	Free Fatty Acids
FAME	Fatty Acid Methyl Ester

B10	10% Neem Oil Methyl Ester by Volume, 90% Petroleum Diesel
B20	20% Neem Oil Methyl Ester by Volume, 80% Petroleum Diesel
B30	30% Neem Oil Methyl Ester by Volume, 70% Petroleum Diesel
B40	40% Neem Oil Methyl Ester by Volume, 60% Petroleum Diesel

CHAPTER 1

INTRODUCTION AND OBJECTIVES

The use of vegetable oils and its derivatives has been used as alternative diesel fuels. From the times of petroleum crisis in 1970 as the demands and prices has been increased day by day more interests are seen towards substitution of fossil fuels with biodiesel. Also biodiesel production has been in great interests because of concern seen towards world growing environment problems in the last few decades (Balat et al. 2008). Now a days biodiesel is emerging as an alternative fuel as viable alternative to petroleum diesel. So many methods are used for production of biodiesel conventionally such as pyrolysis, micro emulsification, dilution, transesterification etc. (Khandelwal et al. 2012).

1.1 Biodiesel

The technical definition of biodiesel is: “The mono alkyl esters of long fatty acids derived from renewable lipid feedstock such as vegetable oils or animal fats, for use in compression ignition (diesel) engines” (National Biodiesel Board, 1996). The vegetable oils and animal fats used to produce biodiesel mainly have triacylglycerol’s TAGs Chemically, TAG are classified as esters of fatty acids (FA) with glycerol (1, 2, 3-propanetriol). Now these TAG constitute of different FA (fatty acids) further each fatty acid attached to a glycerol. These FA present in TAG have different profiles or structures which further have an important role in deciding the physical and chemical properties of the FA which further influence the properties of corresponding animal fats and vegetable oils. The biodiesel can be produced from a large variety of vegetable oils such as, cottonseed, coconut, peanut, soybean, rapeseed/canola, sunflower, palm safflower non-edible oils such as soapnut, mahua, jatropha, karanja, neem, etc and animal fats as tallow. Due to the complete miscibility of biodiesel in petro diesel in many countries it is used as blends with the petro diesel and these blends are often denoted as for example B10 which is actually 10% of biodiesel and 90% of petro diesel and must not be misinterpreted with biodiesel only (Knothe et al. 2005).

1.2 Biodiesel from Non-Edible Oils (Khandelwal et al. 2012)

With increasing petroleum prices biofuel production has been of great interests these days. Therefore feedstock with low cost are needed as it is not so economical to produce biofuels from food grade oils. Hence for the production of biofuels non-edible oils are found to give the good crude oils for production and also in addition they are economical in nature. Also the feedstock depends mainly on availability and price and the non-edible oils are available in large amounts in world like jatropha oil, mahua oil, linseed oil, cotton seed oil, olive oil, neem oil, and rice bran oil and at very economical prices as compared to edible oils. The major difficulty in commercialization of biodiesel is its cost of feedstock which can be reduced by using non edibles instead of edibles and also it sort the issues of food verses fuel which arise due to use if edible oil for biodiesel production.

Table 1.1: Annual production of non-edible oil seeds in India: (Khandelwal et al. 2012)

Type	**Production (MT)**	**Oil%**
Neem	500	30
Karanja	200	27-29
Kusum	80	34
Pilu	50	33
Ratanjot	-	30-40
Jaoba	-	50
Bhikal	-	37

Wild Walnut	-	60-70
Undi	04	50-73
Thumba	100	21

Different factors that affect the production of biodiesel from nonedible oils are mixing intensity, reaction temperature, ratio of alcohol to oil, catalyst type, concentration, effect of free fatty acids, handling and storage of biodiesel and bio degradability (K**nothe et al.** . Reaction is performed nearly at the boiling point of alcohol, it also controls the reaction rate, whereas with increase in ratio of alcohol to oil, conversion rate increases but recovery is decreased due to poor effective catalysts for transesterification than acidic catalyst. More biodiesel yields are obtained with methanol as compared to butanol and ethanol. Ethanol gave least biodiesel yields. Presence of moisture imposes more negative effects on biodiesel production than presence of free fatty acids. FFA content should be less than 2% after acid esterification, otherwise there is significant drop in ester conversion.

1.3 Methods used for Biodiesel processing

As the vegetable oils and animal fats i.e. triglycerides and their derivatives i.e. alkyl esters are good alternative for petroleum diesel but there are some problems with the substitution for petro diesel fuel because of having high viscosities, unsaturated structure and as volatilities are low. These are the problems that are handled by developing derivatives triglycerides which make them approximated to the properties and with hydrocarbon based diesel fuels by following methods:

1.3.1 Pyrolysis (Khadelwal et al. 2012) (Fangrui maa et al. 1999)

Pyrolysis is a technique in which with the help of thermal energy and a catalyst a chemical change is brought in the absence of air. In the absence of air the chemical bond chains break in to small molecules. These small molecules in liquid fractions approach near to the diesel configuration. These pyrolyzates have lower viscosity pour point and flash point but comparatively equal calorific values. These pyrolyzates have optimum amount of water, sediments, sulphur but lower cetane number. Also the ash content, pour point and carbon residue are unacceptable.

1.3.2 Micro-Emulsification (Khadelwal et al. 2012) (Fangrui maa et al. 1999)

The micro emulsions can be defined as thermodynamically stable transparent colloidal equilibrium dispersions whose droplet diameter ranges from 1±150 nm. The micro emulsions formed with vegetable oils reduce the viscosity thus solving the problem. A micro emulsion can be formed with an ester and dispersant in vegetable oil or an alcohol and surfactant with vegetable oil both by mixing and non-mixing of diesel fuels in it. Water tolerance can be increased of micro emulsion with presence of water by using lower proof ethanol.

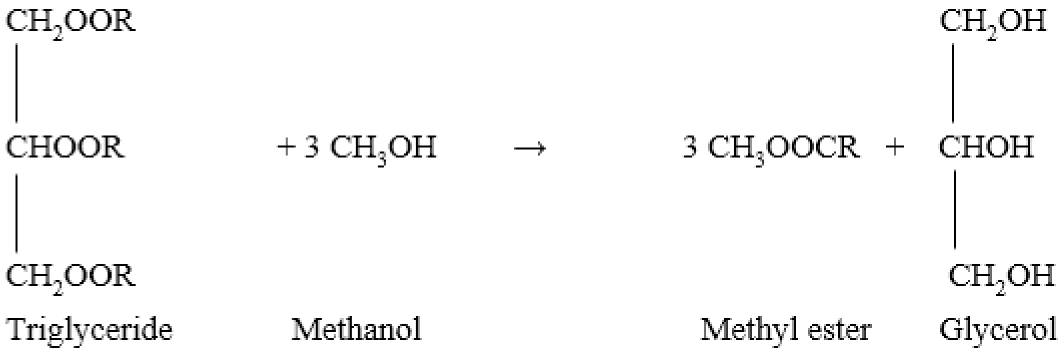
1.3.3 Dilution (Khadelwal et al. 2012)

In dilution it can be achieved with materials such as ethanol, diesel fuels and solvent. This can be done by diluting vegetable oil with petroleum diesel to run the engine.

1.3.4 Transesterification (Schuchardta et al. 1998) (Knothe et al. 2005)

The most common method for biodiesel production is transesterification. It is also called alcoholysis which as the name suggests is the displacement of an alcohol from an ester by another alcohol i.e. basically conversion of one ester into other. In the process the equilibrium reaction takes place by mixing the reactants. It can be enhanced by raising temperature up to certain limits, adding catalyst to it and further by using excess of alcohol to achieve high yields of esters.

Figure describing the basic transesterification reaction:



$$\begin{array}{l} CH_2OOR \\ | \\ CHOOR \\ | \\ CH_2OOR \end{array} + 3\ CH_3OH \rightarrow 3\ CH_3OOCR + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

Figure 1.1: Shows the transesterification reaction taking place for producing biodiesel.

Here in above reaction R is the mixed fatty acid chains and methyl part is CH_3. If methanol is used in the above reaction then it is called methanolysis. Generally the process is base or acid catalyzed but with base catalyst (sodium or potassium hydroxide) the process goes comparatively faster than acid catalyzed reaction.

Parameters effecting transesterification process (Khandelwal et al. 2012) (Fangrui maa et al. 1999)

The most influencing parameters in the transesterification process:

1. Oil temperature
2. Reaction temperature
3. Catalyst and concentration
4. Alcohol to oil ratio

5. Mixing intensity
6. Purity of reactants
7. Stirring effect
8. Moisture and water content effect

1. Oil temperature

The oil temperature which is to be mixed with catalyst and methanol is pre heated up to certain temperature as it affects the reaction. As it is observed that by pre heating the oil the oil to biodiesel conversion and recovery increases to an extent. Also the tests were conducted by pre heating the oil to 60^0C as above it process may result in methanol losses due to low boiling temperature of methanol.

2. Reaction temperature

The reaction temperature has a significant effect on rate of reaction if done on room temperature given enough time it can proceed to completion whereas by attaining a certain reaction temperature it increases the rate of reaction. Generally the reaction is conducted at atmospheric pressure near the boiling point of methanol (60 to 70^0 C). On further increase in temperature a negative effect is seen on conversions. Studies shows that by giving enough time at ambient temperatures the reaction goes satisfactorily using alkaline catalyst. Also it was observed that at low temperatures conversion was unaffected but bio diesel recovery was significantly affected.

3. Catalyst type and concentrations

In transesterification reaction as compared to acidic catalyst the alkaline catalyst are more efficient. Sodium alkoxides are most effectively used for the purpose also potassium alkoxides can be used either. The transesterification reaction rate increases a several times in presence of alkaline catalyst than the reaction taking place in same amount of acidic catalyst. Alkaline catalyst also have an advantage over the acidic as they are less corrosive to equipment used hence mostly the reactions are carried out with alkaline catalyst instead of acidic catalyst. The optimum alkaline catalyst %age by weight is taken 0.5 to 1 % as after increasing the catalyst concentration it will not increase conversion but it will only add to the cost of reaction as the catalyst has to be removed at the end of process from reaction at the time of recovery. Also if high concentration of catalyst is used then the conversions are reduced due to generation of more glycerol during recovery. It was seen that for high FFA content oils high amount of catalyst was required to have efficient conversions.

4.Alcohol to oil ratio

Ratio of alcohol to oil is another important factor affecting the ester yield. As according to stoichiometry of transesterification reaction the molar ratio of 3:1 of alcohol to triglycerides is required to give 3:1 molar ratio of fatty ester to glycerol. Also by increasing the molar ratio of alcohol to triglycerides i.e. by increasing alcohol amount the yield and reaction rate can be increased but up to some limits of molar ratio after that with further increase in alcohol the conversion is increased but there is hindrance in the separation of glycerol. So studies seen that optimum molar ratios are required and that depends on the quality and type of oil used.

5. Mixing intensity

Mixing intensity is a significant tool if applied during correct stage of transesterification reaction because as the single phase is established mixing becomes in significant. So it can be used as a wise tool to scale up the process. So in the studies it is seen that after adding alcohol and catalyst to the oil if the stirring is done for 5 to 10 mins then it results in high rate of conversions and recovery of ester.

6. Purity of reactants

Purity of reactants in a considerable factor that affect the conversion levels in the transesterification reaction. The free fatty acids in oils with impurities have difficulty in conversion to esters but can be overcome at high temperatures and pressure. It is seen that 67% to 84% conversions are there in esters using crude oils whereas in refined oils it 94 to 97% under same operating conditions. Also it is observed that refined and crude oils shows equally good conversions of esters as if the oils are filtered. Quality of oil is also important in this aspect. Also the recovery of biodiesel is less from the oil settled down having impurities in it like wax etc.

7. Stirring effect

It is also an important tool in yield of biodiesel. An optimum rate of stirring is required to have a good yield of esters i.e. if it is less than a certain limit then the reaction can be incomplete while by increasing it more can lead to no changes in yield from a certain speed. The mode of stirring also has a role in stirring i.e. whether it is mechanical stirring or the magnetic stirrer is used.

8. Moisture and water content effect

With the presence of water in the oil it put a great negative effect on the yield of esters. The effect of presence of water in oil has much worse effects than having FFA in it. As a very small amount of water can reduce the ester yield. Due to the presence of water and FFA there is much reduction in alkyl ester yields because they form soap, consume catalyst and make catalyst ineffective. The removal of moisture content from oil is done by heating it on 383K.

1.4 Raw materials used for production of biodiesel

1.4.1 Vegetable oils

The oil used should be free from moisture because with the moisture present in it the catalyst can be consumed by it which then reduce catalyst concentration. It should be free of impurities and sediments as they get collected at bottom of vessel in which reaction is taking place and then hinder in the separation of phases of glycerol during the biodiesel recovery. FFA content of oils should be less than 1% although high FFA oils are also used but the yield depends on the catalyst and oil type.

1.4.2 Alcohol

Methanol and ethanol are used in near to absolute purity. Methanol is used more in reactions as compared to ethanol because of simple structure hence easy transesterification reaction.

1.4.3 Catalyst

Mostly used catalyst in the reactions are sodium and potassium hydroxides but also the alkalides of the both can be used instead. It is seen that the best grades of potassium hydroxides have 14-15% water in it that can’t be removed. As the carbonates cause cloudiness in final ester so the catalyst should be low in carbonates. Also it is seen that sodium hydroxide pallets give good results when used. As the catalyst amount used is less in the reaction so good quality of catalyst can be used.

1.4.4 Animal fats

The animal fats that are presently used in biodiesel production are lard, tallow, beef, guang-pi. The most commonly used animal fat is tallow as it has high saturated fats which cause its melting point more than ambient temperatures.

1.4.5 Waste vegetable oils

Throughout the world millions of tonnes of waste cooking oil is stored every year and is considered as a never ending source of energy. These oils constitute degraded products of vegetable oils and other materials. Also by testing these oils it is seen that there is very less difference in used and unused oils and also with the simple heating and solid waste removal from the oils make them ready for the use in biodiesel production. The cetane number of the esters produced from these frying oils is seen to be close to the esters of the vegetable oils.

1.5 Storability and Handling (Khandelwal et al. 2012)

Biodiesel and its blends should not be treated as petro diesel. Biodiesel cannot give rise to poisonous fumes as there are no volatile organic compounds present in it also no traces of lead and sulphur are present so as to produce harmful or corrosive gases. On eye contact to biodiesel it can cause eye irritation. As per fire hazard is concerned then the firefighting measures should be taken as classified. Also for the storage of biodiesel it is recommended according to experience that it should not be kept more than 6 months or else some anti-oxidant additives must be added for long term storage. It is recommended that as biodiesel being a mild solvent it creates sediments in the tanks it is stored so the tanks used for storage must be made of steel, aluminum etc. so as to avoid it. It is also seen that the viscosity and FFA increases in some cases in the biodiesel storage.

1.6 Stability of biodiesel

As compared to fossil fuel diesel the maturity in biodiesel comes faster due to the chemical structure formation of the esters contained in it. Three stability criteria are generally seen its stability i.e. oxidation stability, storage stability and thermal stability.

Table 1.2: US and Indian standards for biodiesel

Source: http://www.svlele.com/biodiesel_std.htm

Standards for Biodiesel	**ASTM D-6751**	**IS 15607 : 2005**
Density	Not Mentioned	860 - 900 Kg / m^3
Ester Content	Not Mentioned	96.5 %
Flash point (closed cup)	130°C min. (150°C average)	120°C
Water and sediment	0.050% by vol., max.	500 mg / Kg, max
Kinematic viscosity at 40°C	1.9-6.0 mm^2/s	2.5-6.0 mm^2/s
Oxidation Stability	Not Mentioned	6 hours min, at 110°C
Ramsbottom carbon residue, % mass	0.10	
Sulfated ash	0.020% by mass, max.	

Sulfur	0.05% by mass, max.	50 mg / Kg max
Copper strip corrosion 3 hrs. 50°C	No. 3 max	Class 1
Cetane Number	47 min.	51 min.
Carbon residue	0.050% by mass, max.	
Acid number, mg KOH/g	0.80 max.	0.50 max.
Methanol or Ethanol	Not Mentioned	0.2 % m/m, max
Free glycerin	0.020 % mass	0.020 % mass
Total glycerine (free glycerine and unconverted glycerides combined)	0.24% by mass, max.	0.25% by mass, max.
Group I Metal (Na+K)	5 mg/Kg, max	5 mg/Kg, max
Group II Metal (Ca+Mg)	Not Mentioned	5 mg/Kg, max
Phosphorus content	0.001 max. % mass	10 mg/Kg, max
Distillation	90% @ 360°C	Not Mentioned

1.7 **Objectives**

- Preparing the neem oil biodiesel using transesterification process by optimizing the production parameters.
- Investigation of performance and exhaust emission characteristics of biodiesel blends on variable compression ratio compression ignition engine.

- Optimizing and finding out the best compression ratio and biodiesel blend considering the performance and exhaust emission parameters.

CHAPTER 2

LITERATURE REVIEW

Mustafa Balat and Havva Balat 2008 described that the problems with substituting triglycerides for diesel fuels were mostly associated with their high viscosities, low volatilities and polyunsaturated character. The viscosity of vegetable oils, when used as diesel fuel, can be reduced in at least four different ways: (1) dilution with hydrocarbons (blending), (2) emulsification, (3) pyrolysis (thermal cracking), and (4) transesterification (alcoholysis). Transesterification was the most common method and leads to monoalkyl esters of vegetable oils and fats, now called bio-diesel when used for fuel purposes. The main factors affecting transesterification were molar ratio of glycerides to alcohol, catalyst, reaction temperature and pressure, reaction time and the contents of free fatty acids and water in oils. The commonly accepted molar ratios of alcohol to glycerides are 6:1–30:1. Bio-diesel is a cleaner-burning diesel replacement fuel made from natural, renewable sources such as new and used vegetable oils and animal fats. Just like petroleum diesel, bio-diesel operates in compression-ignition engines or Diesel engines. The bio-diesel was characterized by determining its density, viscosity, high heating value, cetane index, cloud and pour points, characteristics of distillation, and flash and combustion points according to ISO norms. Viscosity is the most important property of bio - diesel since it affects the operation of the fuel injection equipment, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel.

Knothe 2005 discussed that the fuel properties of biodiesel are strongly influenced by the properties of the individual fatty esters in biodiesel. Both moieties, the fatty acid and alcohol, can have considerable influence on fuel properties such as cetane number with relation to combustion and exhaust emissions, cold flow, oxidative stability, viscosity, and lubricity. Generally, cetane number, heat of combustion, melting point, and viscosity of neat fatty compounds increase with increasing chain length and decrease with increasing unsaturation. It therefore appeared reasonable to enrich (a) certain fatty ester(s) with desirable properties in the fuel in order to improve the properties of the whole fuel. For example, from the available data it appeared that iso-propyl esters had better fuel properties than methyl esters. The major disadvantage was the higher price of iso-propanol in comparison to methanol, besides modifications needed for the transesterification reaction. Similar observations likely hold for the fatty acid moiety.

M. Canakci and J. Van Gerpen 2001 investigated the use of low–cost, high FFA feedstock to produce fuel–quality biodiesel. It was determined that feedstock with high FFAs could not be transesterified with the traditional alkaline catalysts that have been used with good success for vegetable oils. Alkaline catalysts form soap when they react with the FFAs. Soap removes the catalyst from the reaction and prevents the separation of the glycerin and the ester. A process was developed to use acid catalysts to pretreat the high FFA feedstock until their FFA level was below 1%, allowing the subsequent use of alkaline catalysts to convert the triglycerides. The effects of the methanol molar ratio, acid catalyst amount, and reaction time on the reduction of FFA level were studied with a simulated high FFA feedstock consisting of 20% palmitic acid in soybean oil. This part of the study showed that the FFA level of the feedstock could be reduced to less than 1% with a 2–step process of acid–catalyzed pretreatment. Extension of the process to yellow and brown grease showed that higher levels of acid catalyst and methanol were required.

M.Mathiyazhagan et al. 2011 researched on the non-edible oils as feed stocks for biodiesel production to reduce the cost of biodiesel. Normally alkali catalyzed method was followed for biodiesel production process. However the non-edible oils having high FFA content which is not suitable for normal transesterification process. Hence a two-step catalyzed method was used to prepare the biodiesel. High FFA content of non-edible oils were efficiently converted into biodiesel fuel. Figure 2.1 shows the flow diagram of biodiesel production from non-edible oils.

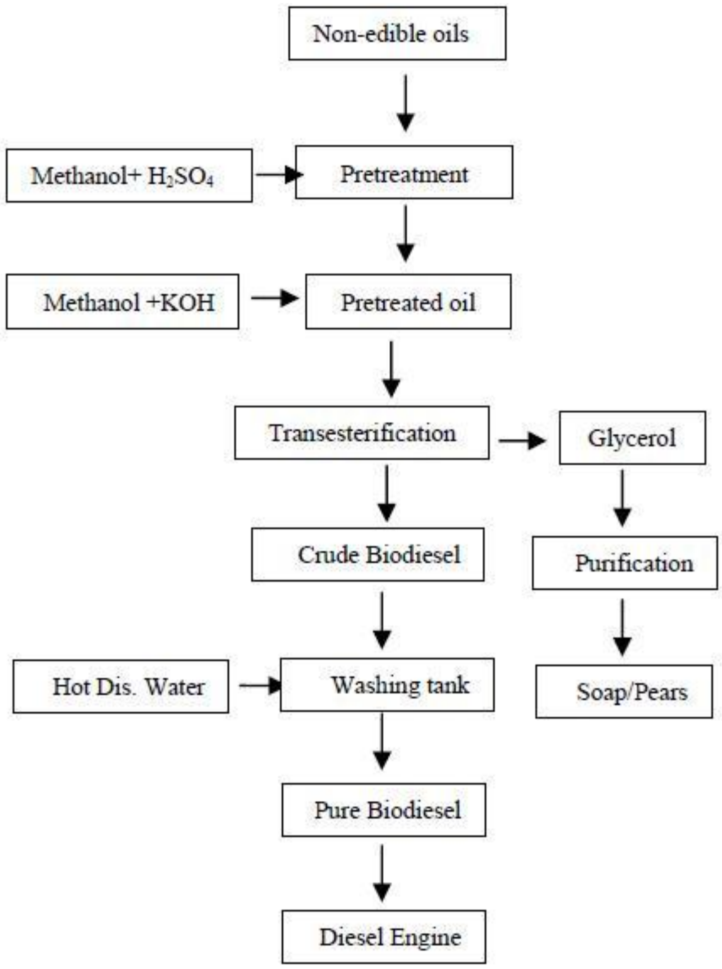


Figure-2.1 Flow chart of Biodiesel production from non-edible oils

Fangrui Ma et al. 1999 produced biodiesel with the help of used cooking oils as raw material and by adapting of continuous transesterification process, leads to recovery of high quality glycerol from biodiesel by-product (glycerol). In this method glycerol were primary options to be considered, in order to lower the cost of biodiesel. There were four primary ways to make biodiesel, direct use and blending, micro emulsions, thermal cracking (pyrolysis) and transesterification. The most commonly used method is transesterification of vegetable oils and animal fats. The transesterification reaction is affected by molar ratio of glycerides to alcohol, catalysts, reaction temperature, reaction time and free fatty acids and water content of oils or fats. The mechanism and kinetics of the transesterification show how the reaction occurs and progresses. The processes of transesterification and its downstream operations are also addressed.

Schuchardta et al. 2008 investigated the process of transesterification of vegetable oils with methanol as well as the main uses of the fatty acid methyl esters. The general aspects of this process and the applicability of different types of catalysts (acids, alkaline metal hydroxides, alkoxides and carbonates, enzymes and non-ionic bases, such as amines, amidines, guanidines and triamino(imino)phosphoranes) were described. Special attention was given to guanidine's, which can be easily heterogenized on organic polymers. However, the anchored catalysts show leaching problems. New strategies to obtain non-leaching guanidine-containing catalysts are proposed. Finally, several applications of fatty acid esters, obtained by transesterification of vegetable oils, are described.

Dhar et al. 2012 focused on the development of environmental friendly alternate source of energy, to compensate growing demand of fuel for various purposes. They produced biodiesel with the help of neem oil. The biodiesel yield and quality depends upon the moisture content and the free fatty acid content (FFA). The neem oil used in this study was highly fatty acid free (FFA 20%). They used two step process i.e. esterification and transesterification to produce biodiesel. In esterification step, the alcohol to oil molar ratio was taken as 6:1 in the presence of 4.5% catalyst at 45^0C and stirring was performed at 1300rpm. In the next step, transesterification process was followed, in which, alcohol to oil molar ratio was 6:1 in the presence of 1% NaOH catalyst at 60^0C and stirring speed was set to 1300rpm. The properties of prepared were characterized and compared with mineral diesel through baseline data in a DI diesel engine. The results showed that the brake specific fuel consumption for biodiesel and its blend was more and the brake thermal efficiency of all biodiesel blends was lower than that of mineral diesel. It was also observed that the brake specific CO and HC emissions were lower for engine fuelled with biodiesel but NO emissions were higher as compared to mineral diesel. The combustion characterization of biodiesel showed that combustion begins earlier for higher blends biodiesel. Further, heat release rate for all prepared biodiesel blend was found similar to mineral diesel. The duration of combustion for biodiesel blends was lower than that of mineral diesel. This study indicated that the Biodiesel produced from highly free fatty acid neem oil was slightly inferior to mineral diesel.

Hasimoglu et al. 2008 suggested that vegetable oils are potential substitute for alternative biodiesel fuel. These oils may cause some long term usage problems in diesel engine viz. injector coking, severe engine deposits, filter gumming, and piston ring sticking and thickening of lubrication oil. This may be due to various characteristics that vegetable oils exhibit (high viscosity, poor volatility and cold flow). In order to eliminate these problems, biodiesel of the vegetable oils can be formed, through transesterification process. The biodiesel have numerous positive aspects such as biodiesel are biodegradable, renewable and emits low exhaust gas as compare to commercial diesel fuel. They applied low heat rejection engine, to improve efficiency of the engine fueled with biodiesel. It was observed that the specific fuel consumption and the brake thermal efficiency improved. The results also showed that the temperature of exhaust gas before the turbine inlet increases for all the fuels studied in the present scenario.

Balaji et al. 2015 investigated the impact of A-tocopherol acetate on the oxidation stability and emission of NOx in a DI diesel engine fueled with methyl ester of neem oil. They examined oxidation stability through Rancimat apparatus and emissions were tested in a four-stroke water cooled computerized model of DI engine. It was observed that the A-tocopherol acetate addition increased the oxidation stability and lowers the NOx emissions. This addition of A-tocopherol, increased the HC, CO, smoke emission and specific brake energy consumption. They reported that the oxidation stability improved upto 57.05 % for MENO + AT mixtures.

Shah et al. 2014 studied the methonalysis of jojoba oil in the occurrence of different catalysts of tin such as powdered tin, dibutyltin diacetate, dioctyltin diacetate, dibutyltin oxide, dioctyltin oxide, diphenyltin oxide, dibutyltin chloride dihydroxide, butyltinhydroxide hydrate, Ni nanoparticles and Pd nanoparticles. They observed maximum conversion in the case of 1% dibutyltin diacetate. They also investigated impact ot of 1% dibutyltin diacetate on the methanolysis of different oils (sunflower oil, neem oil, rocket seed oil and linseed oil) into methyl ester and compared percentage conversions. The results showed the conversion yield of jojoba oil into methyl esters was increased upto 96% with the increase of reaction time, without formation of emulsion. It was observed that same catalyst showed equal efficiency for sunflower oil, neem oil, rocket seed oil and linseed oil, under same experimental conditions. Also, NMR and FTIR characterization techniques were employed to confirm, the formation of jojoba seed oil biodiesel (JSOB), soybean oil biodiesel (SOB), neem oil biodiesel (NOB), rocket seed oil biodiesel (RSOB). GC-MS analysis was used to determine the fatty acid methyl esters of jojoba seed oil biodiesel.

Ramning et al. 2013 examined the impact of various parameters (oil to alcohol molar ratio, reaction time, acid concentration and base catalysts) during the preparation of neem oil methyl ester. They employed oscillatory baffled reactor 1-2% H_2SO_4. The experimentally determined optimum conditions for the production of neem oil methyl ester were 1:9 oil to alcohol molar ratio, reaction time 10 to 15 minutes and temperature was set in the range of 25-30^{0}C. It was observed that the viscosity decreases with the increase of molar ratio. They also suggested that adequate production of biodiesel form neem oil require more oil to alcohol molar ratio. They conducted transesterification reaction in the series of operation in a long reaction that involved immiscible liquid phases, due to which the yield of final product becomes significantly depends upon mixing and agitation.

Thangaraj et al. 2013 used a two-step reaction system for the production of biodiesel from neem seeds (Azardirachta indica). In this reaction system acid and alkaline esterification was done, with the help of short chain alcohol. They determined various important parameters of biodiesel produced from neem oil such as kinematic viscosity 5.81 cSt (40ºC), density 0.898 g/m^3 (15ºC), flash point 175ºC, pour point 8ºC, total sulfur content 0.03%, ash 0.00 %, carbon residue 2% by mass (0.08), copper strip corrosion for 3 hour at 100ºC, sediment 0.00%, water content 0.00%. Also, comparison was made with other methyl esters. The HPLC analysis was conducted to quantify the methyl esters. In the case of two step reaction process, by using 1:8 oil to alcohol molar ratio, biodiesel yield was found to be maximum i.e. 85%, when the acid catalyst was 0.08% and NaOH catalyst was 1%, at 60 ^{0}C temperature.

Muthu et al. 2010 synthesized sulfated zirconia catalyst and characterized by gas chromatography, XRD, SEM and Nicolet (AVATAR 360) techniques. They prepared biodiesel from neem oil with methanol in the presence of catalyst, by using two-step process that includes esterification and transesterification. They observed optimal Free Fatty Acid (FFA) conversion in the case of 9:1 oil to methanol ratio, in the presence of 1 % sulfated zirconia catalyst at 65 ^{0}C temperature and the reaction time was 2 hours. The result showed that the acid content reduced by 94% in the raw oil, which confirmed the conversion. Efficiency of conversion was determined and it was found that efficiency increased up to 95% within ASTM standards, when pretreated oil was reacted in the presence on potassium hydroxide with methanol.

Heroor et al. 2013 focused on the production of biodiesel from neem oil, by using transesterification process. Biodiesel obtained from neem oil exhibit high lubricity, clean burning fuel and can be employed as alternative fuel in existing diesel engines. They determined various fuel properties including flash point and fire point. The emissions of pollutant and different properties of engine fuel with prepared biodiesel was investigated. The results indicated that emission of carbon monoxide and smoke were significantly reduced. It was also observed that the nitrogen oxide gas emission was not changed much. When the injection pressure was at 200 and 220, then the neem blends showed almost same amount of BSFC as compared to conventional diesel. They also seen that the highest peak pressure of diesel as at 200 bar injection pressure, followed by B30, B20 and B10 and this increment remain similar as load was further increased. The blends B20 and B30 were almost similar as that of diesel, for all values of applied loads. No variation was observed in peak pressures for blends of neem oil and neem biodiesel. However, the peak pressure was highest at 200 bar, in the case of blends of neem oil.

Ali et al. 2013 considered the aspects that were related to the production of biodiesel from neem oil and examined fuel properties of neem biodiesel blends. The mono alkyl ester obtained from neem oil by using transesterification process. They investigated optimum condition, in order to get maximum biodiesel yield at different temperature and by varying molar ratio of oil to alcohol. In this study, glycerin layer and soap were included at the molar ratio of 3:1 of neem oil and alcohol at 55 – 60 ^{0}C. They had seen that the properties of prepared biodiesel lied within ASTM 6751-02 standard of kinematic viscosity within the range of 1.9 to 6 centistokes. This study concluded that import of diesel fuel will be reduced, if plantation and collection of neem oil occurs in a systematic manner and that will lead to the production of suitable biodiesel.

Radha and Manikandan 2013 focused on the feasibility of production of biodiesel from neem oil. The process used for the production of biodiesel was transesterifiation and optimum experimental conditions were determined, in order to obtain maximum biodiesel yield. In this study, biodiesel products at different temperatures and by varying molar ratio of oil to alcohol were prepared. It was found that the maximum yield of biodiesel occurred at temperature 55 ^{0}C, when the molar ratio of oil to alcohol was 1:12. Results showed that the prepared biodiesel was within ASTM standards of biodiesel fuel. They also evaluate the value of kinematic viscosity and acid value for all the prepared biodiesel form neem oil. The emission of pollutants such as carbon monoxide and smoke was reduced by using biodiesel as fuel in diesel engine. However, the emission of nitrogen oxide was not much changed. This ester produced from neem oil can be used as alternative fuel in diesel engine system.

Prajapati and Sudan 2012 computed brake thermal efficiency of different blends produce from soya and mustard oils. The computed brake efficiency was compared with commercially available fuel (petrol) at different engine loads in a well-defined computerized variable compression ratio multi-fuel (CVCRM). The result showed that the 15-PRS exhibit lower thermal brake efficiency as compared to 20-PRS having highest value of brake thermal efficiency, at an applied load of 7.5 kg. It was also observed that the computed values of brake thermal efficiency was approximately equivalent to the brake thermal efficiency of commercially available petrol fuel, at different loads.

Sathya and Manivannan 2013 used edible oil for the production of biodiesel with the help of methanol and in the presence of alkaline catalyst. The crude neem oil used in this study had large content of free fatty acids (FFA) i.e. 6 %, which could react with the catalyst to form soaps. These soaps were that main obstacle for the separation of the ester and glycerin. They employed transesterification process in order to produce biodiesel form high FFA content neem oil. The volume of oil used was 100 ml and suitable pretreatment conditions were 45 v/v ratio of methanol to oil, catalyst concentration 0.5 % v/w of H_2SO_4 and reaction time was 45 minutes, at 50 ^{0}C temperature. Further, transesterification process was started on pretreated neem oil. For the process the neem oil to methanol molar ratio was 0.3:1, in the presence of 1% KOH catalyst for one hour, at 55 ^{0}C. The results showed that the maximum average yield determined was 90 ± 2%. They also investigated the impact of molar ratio, catalyst and reaction time in each processing step for the production of biodiesel. This study concluded that production cost increases with the increase of H_2SO_4 content.

Tanwar et al. 2013 reported that the production of biodiesel significantly depends upon the used feedstock. As the increased prices of the edible oil, it became impossible to develop biodiesel from edible oil. So, the use of non-edible oil such as neem oil solved the purpose for the production of biodiesel. This oil can be easily transformed into biodiesel, after refining process because it had higher FFA content and moisture content. This experimental work studied soil to oil level, in order to compensate various problems related to the production biodiesel from neem oil. They evaluated extraction parameters of neem oil, refining of raw oil and to determine ideal conditions for transesterification of neem oil. The results showed that almost complete transformation of neem oil into biodiesel was done. Also, various properties of the prepared biodiesel were in accord with ASTM, IS and ES standards for biodiesel.

Khandelwal et al. 2013 studied that large variety of plants that produce non edible oils can be used for biodiesel production such as Madhuca Indica (Mahua), Jatropha curcas(Ratan Jyot), Melia azadirachta (Neem) etc economical compared to edible oils. Also, they studied and assessed different tree borne oilseeds, their extraction, and biodiesel processing and parameters affection production of biodiesel.

Karabektas et al. 2013 investigate the impact of blends containing different alternative fuels and diesel fuel on the performance and emissions of a diesel engine. The parameters considered were brake power, specific fuel consumption and thermal efficiency as well as carbon monoxide, hydrocarbon and nitrogen oxide emissions. The Blends of biodiesel, ethanol, methanol and vegetable oil with diesel fuel. Biodiesel close to obtained in the use of diesel fuel. Ethanol and methanol blends yielded lower brake power, resulted in higher specific fuel consumption and lower carbon monoxide emissions. Vegetable oil blend yielded lower carbon monoxide emissions. The blends containing alcohols kept for a longtime, a partial phase separation occurred. This problem was not experienced in the blends containing biodiesel and vegetable oil.

Hansen et al. 2005 discussed the properties and specifications of ethanol blended with diesel fuel. The factors included blend properties such as stability, viscosity and lubricity, safety and materials compatibility. The effect of the fuel on engine performance, durability and emissions was also considered. Formulation of additives to correct certain key and maintain blend stability as a critical factor in ensuring fuel compatibility with engines. Maintaining vehicle safety with these blends entailed fuel tank modifications. Further work is required in specifying acceptable fuel characteristics, confirming the long-term effects on engine durability, and ensuring safety in handling and storing ethanol–diesel blends.

Achtnicht et al. 2012 studied the impact of fuel availability on demand for alternative-fuel vehicles, using data from a survey of potential car buyers in Germany. The survey was conducted as a computer- assisted personal interview and included a choice experiment involving cars with various fuel types. Applying a standard logit model, they showed that alternative fuel availability influences choices positively, but its marginal utility diminishes with supply. Furthermore, they derived consumers’ marginal willingness-to-pay for an expanded service station network. The results suggest that a failure to expand the availability of alternative fuel stations represents a significant barrier to the widespread adoption of alternative-fuel vehicles.

Gautam et al. 2015 studied physical, chemical and thermal properties biodiesels procured from four different locally available Indian feedstock. Physical properties of biodiesels such as density, viscosity, speed of sound, bulk modulus of compressibility and surface tension are dependent on fuel temperature. e. Data from previous studies on temperature dependent physical properties was used to determine correlations between fuel temperature and physical properties of these four biodiesels. This study established that these correlations can be used for computing fuel injection and combustion characteristics of biodiesel fuelled locomotive diesel engines.

Solaimuthu et al. 2015 reported the experimental results of a single cylinder diesel engine regarding performance, combustion and emission characteristics using Mahua (Madhuca indica) biodiesel and its blends in different volumetric proportions with petro-diesel. The thermo- physical properties of various blends selected for investigation have been experimentally measured for better evaluation of the performance characteristics. Tests have been carried out on a four stroke tangentially vertical (TV) single cylinder diesel engine at 1500 rpm using an eddy current dynamometer. The static injection timing employed is 20_ bTDC with constant nozzle opening pressure of 250 bar. Selective Catalytic Reduction (SCR) as well as Cold and Hot Exhaust Gas Recirculation (CEGR and HEGR) techniques are employed to study the reduction of NOx. Results are compared at full load under steady state condition with conventional engine where no reduction techniques are applied. The comparison indicates that the SCR gives substantial reduction in oxides of nitrogen (NOx) as compared to other technique in a conventional diesel engine fuelled with biodiesel, B100. For B100 with SCR technique, the percentage reduction in NOx is around 20% as compared to conventional engine.

Tuccar et al. 2014 blended citrus sinensis biodiesel with conventional diesel fuel with volumetric ratios of 5%, 10% and 20%. Fuel properties of blends and pure citrus sinensis biodiesel were found out and performance characteristics and exhaust emissions of the engine fueled with blends were analyzed. The engine performance experiments indicated that citrus sinensis biodiesel because a slight reduction in torque and brake power values. Exhaust emission tests revealed that while CO emission values decrease, NOX emission values increase with citrus sinensis biodiesel usage. To conclude, citrus sinensis biodiesel can be used as a very promising additive to improve CO emissions of conventional diesel fueled engine.

Sakthivel et al. 2014 evaluated the performance, emission and combustion characteristics of a single cylinder, constant speed, direct injection diesel engine using biodiesel–diesel blends, under variable load conditions. It was found that there was a reduction in NOx, HC and CO emission along with a marginal increase of CO_2 and smoke emissions with the increase in biodiesel proportion in the fuel. The brake thermal efficiency was found to be higher compared to diesel for the entire load. An analysis of the cylinder pressure rise, heat release, and other combustion parameters such as peak pressure, rate of pressure rise, combustion duration and ignition delay was carried out. The ignition delay, maximum heat release rate and combustion duration were lower for biodiesel–diesel blends compared to diesel.

Nayak et al. 2014 investigated about the production of biodiesel from neat Mahua oil via base catalyzed transesterification and mixing of the biodiesel with a suitable additive (Dimethyl carbonate) in varying volume proportions in order to prepare a number of test fuels for engine application. The results of investigation show increase in brake power and brake thermal efficiency with load for all prepared test fuels. It is also noticed that brake thermal efficiency increases with the percentage of additive in all the test fuels. The brake specific fuel consumption decreases with increase in additive percentage. Exhaust gas temperature increases almost linearly with load for all test fuels and decreases with increase in additive percentage. It is also seen from the results that both CO and HC emissions tend to decrease with increase in additive percentage in biodiesel. The smoke and NOx emissions also decrease with increase in additive percentage in the biodiesel fuel. The overall performance and emission characteristics of the engine was satisfactory with all the test fuels and improved with repeated experiments.

Al_Dawody et al. 2014 studied the effect of blending on the cylinder pressure, heat release rate, carbon monoxide (CO), unburned hydrocarbon (UHC), nitrogen oxides (NOx), and smoke opacity were measured. The results indicate that the use of biodiesel produces lower smoke opacity up to 48.23% with 14.65% higher brake specific fuel consumption (BSFC) compared to diesel fuel. The measured CO emissions of B20% SME and B100% SME were found to be 11.36% and 41.7% lower than that of diesel fuel respectively. All blends of SME were found to emit significantly lower UHC concentration compared to that of diesel over the entire load. NOx emissions are observed to be higher for all blends of SME. The experimental results are compared with the results of Diesel-rk software and a good agreement between them is noticed.

Ashraful et al. 2014 review the potential sources for the biodiesel productions. They reported that the biodiesel can be obtained through different species such as Pongamia pinnata (karanja), Calophyllum inophyllum (Polanga), Maduca indica (mahua), Hevea brasiliensis (rubber seed), Cotton seed, Simmondsia chinesnsis (Jojoba), Nicotianna tabacum (tobacco), Azadirachta indica (Neem), Linum usitatissimum (Linseed) and Jatropha curcas (Jatropha). This study focused on the numerous aspects of non-edible feedstock viz. biology, distribution and chemistry, physicochemical properties of obtained biodiesel. Also, the effect of prepared biodiesel from different species on engine performance and emission. They found that the fuel properties were significantly depends upon the feedstock. Further, the performance analysis showed that the thermal brake efficiency was enhanced for most of the biodiesel produced from different species. The results revealed that the specific brake fuel consumption was reduced in almost all obtained biodiesel. It was found in the literature that the diesel engine fueled with biodiesel showed superior properties and reveled efficient emission regulation with the application of different biofuels (karanja, mahua, rubber seed, and tobacco) and their blends in a diesel engine.

Agarwal et al. 2007 reported production, characterization, properties and current research on the production of biodiesel from vegetable oils. Numerous properties were studied by various research groups such as greenhouse gas emission, engine performance, and variability of biodiesel, efficiency of a biodiesel, infrastructure, availability and effect of lubricants. They observed that ethanol emerge as a potential substitute for conventional diesel fuel. In addition, ethanol is obtained from renewable resource and can be oxygenated, due to which emission from engine get reduced. They also reported specific details and various characteristics of ethanol blended with gasoline and diesel fuel. This study considered the compatibility of material and performance along with emissions in an engine fueled with conventional diesel and biodiesel. The various sources for the production of biodiesel were methyl or ethyl ester obtained from unused and used vegetable oils and animal fat. Further, the biodiesel obtained from non-edible oils of different plant species viz. Jatropha curcas (Ratanjyot), Pongamia pinnata (Karanj), Calophyllum inophyllum (Nagchampa), Hevca brasiliensis (Rubber) etc.

Tan et al. (2010) suggested that the alkyl esters of fatty acid can be used as alternate environmental friendly fuel. This fuel can be prepared by the transesterification of fats or oil, in the presence of catalyst or biocatalyst. Among all biocatalyst, immobilized lipase has drawn significant attention because it possess a greener process. They also reviewed the present scenario of biodiesel production by using various immobilized lipase, by following different immobilization method, numerous feedstokes, inactivation of lipase due to short chain alcohols and large scale industrialization. It was observed that the adsorption is the most frequently used method for immobilization of lipase. Generally, two kinds of immobilized lipase (Candid antartica and Candida sp. 99–125 lipase) are used for the production of biodiesel in large scale industries. However, there is a great need of novel immobilization technique with higher activity and stability that will reduce the cost of biodiesel production.

Atabani et al. (2012) discussed that the diminution of fossil fuels is crucial due to which the production of alternate fuel becomes priority. The biodiesel emerge as potential substitute for fossil fuels and can be used to fuel industries and motorization. They reported that there are various feedstock for the production biodiesel. Among them the non-edible oils has shown significant potential due to the great demand of edible oils. In addition, the biodiesel produced from non-edible oil is cheaper than the biodiesel produced from edible oils. They suggested that the production of biodiesel from the non-edible oil is an effective method. Therefore, the conversion of non-edible oil into biodiesel should be examined.

They introduced the use of non-edible oils as feedstock for the production of biodiesel. In this paper, various aspects required for the production of biodiesel are also reported. These aspects are the overview on the resources of non-edible oils, rewards of non-edible oils, drawbacks associated with non-edible oils, composition of fatty acid in various non-edible oils, techniques of oil extraction, methods for the production of biodiesel, standards of biodiesel and its characterization, also, the properties and distinguishing parameters of non-edible biodiesel and engine performance and emission production.

Ramadhas et al. (2003) focused on the increasing demand of the fuel in industries and motorization in the whole world. The fuel based on non-renewable resources such as petroleum are very limited and only available at few places in the world. This the reason due to which the countries having no such resources are facing terrible problem of foreign exchange that will effect on their overall economy. So, the production alternate fuel i.e. biodiesel is highly essential. They also reported that biodiesel can be produced from the vegetable oil, which will be environmental friendly. Authors reviewed various production methods of biodiesel and its characterization as well as the experimental research conducted in different countries for the production of biodiesel. They discussed the scope and the challenges faced in this research area.

CHAPTER 3

METHODOLOGY AND MATERIALS

The increasing demands of fuels these days due increasing automobiles on planets has increased the risk of depletion of fossil fuels in the world. Also the increasing health problems around the world due to automobiles and use of fossil fuels as due to increase in pollution has reached to the demands of a clean burning and less polluting fuel so due to these demands as an alternative fuel biodiesel has emerged as a very good fuel in the automobile sector. The biodiesel cannot be used as direct fuel in the currently used engines without modification so it is preferred to be used as blends with petro diesels. So this chapter deals with the methodology opted for biodiesel production and then for evaluation of the exhaust emission and performance on the variable compression ratio engine using the different blends of biodiesel. The biodiesel was produced in the School of Energy and Environment labs at Thapar University Patiala, Punjab (India) and the engine experiments and testing was done in internal Combustion Engine Laboratory, Department of Mechanical Engineering, Thapar University, Patiala, Punjab (India). Further the methodology is divided in to two parts:

1. First part shows the optimum production of biodiesel from non-edible oil i.e. neem (Azadirachta indica) oil.
2. Second part shows the emission and performance of the biodiesel blends tested on an engine.

3.1 Methodology for the production of biodiesel from Neem oil:

Here in this from starting the raw materials used for biodiesel production is discussed and after it with the each step with which the whole production process was undergone. The biodiesel properties are also discussed in this section.

3.1.1 Raw materials

1. Crude neem oil
2. Methanol (methyl alcohol)
3. Potassium hydroxide (KOH) as base catalyst
4. Sulphuric acid (H2SO4) as acid catalyst

Dewaxed and degummed crude neem oil was bought from the local general store. The Methanol (methyl alcohol), Potassium hydroxide (KOH), Sulphuric acid (H2SO4) were available in the School of Energy and Environment laboratories, Thapar University, Patiala. The transesterification was then carried out in the labs on a hot plate magnetic stirrer.

3.1.2 Biodiesel preparation

As the crude neem (Azadirachta indica) oil was used for the preparation of biodiesel therefore due to high Free Fatty Acid FFA content of neem oil i.e. approx. 7% the transesterification process was carried out in two stages. The first stage included an acid catalyzed transesterification reaction and in second the base catalyzed transesterification reaction was carried out.

Neem oil biodiesel transesterification process (two stage process)

First stage (acid catalyzed transesterification reaction)

1. The known quantity of crude neem oil was taken in a conical flask.
2. Then the oil in the flask was heated on a heating plate up to 65^{0}C temperature.
3. A mixture of a known amount of methanol and sulphuric acid as acid catalyst was added to the flask and mixed with the pre heated crude neem oil in the flask.

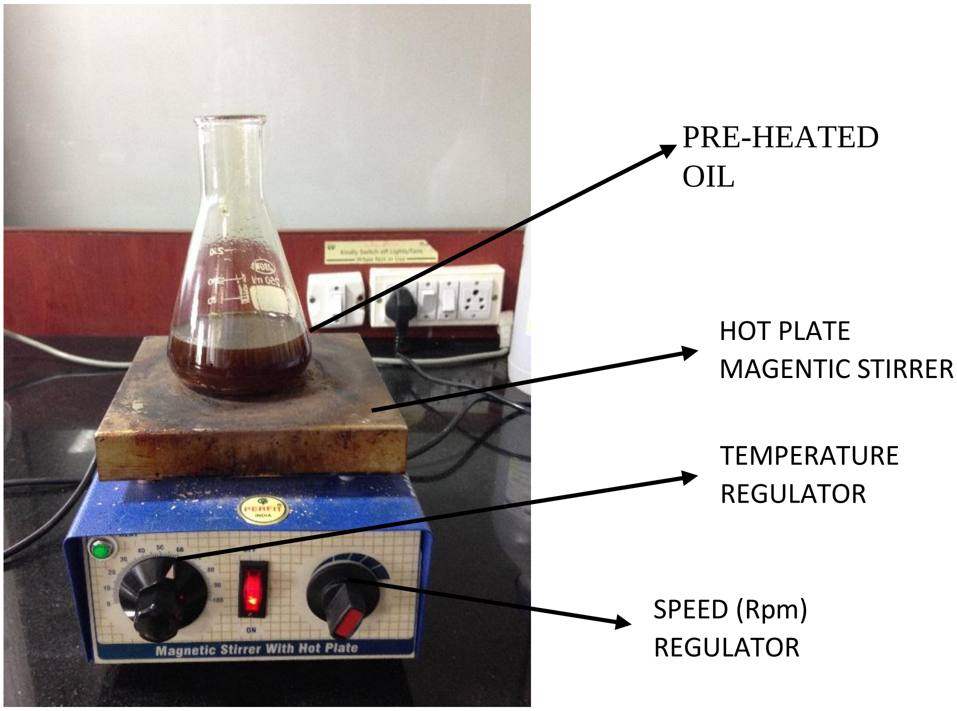


Figure 3.1: Pre heating of neem oil on magnetic stirrer with hot plate.

4. The preheated oil mixture was constantly stirred for 35 min at a constant temperature of 50^{0}C on the magnetic stirrer with hot plate.
5. After the constant stirring of 35mins at constant temperature the mixture as for the impurities to settle down was poured in separating funnel. After 5-6 hours the impurities settled down were separated from the remaining oil.

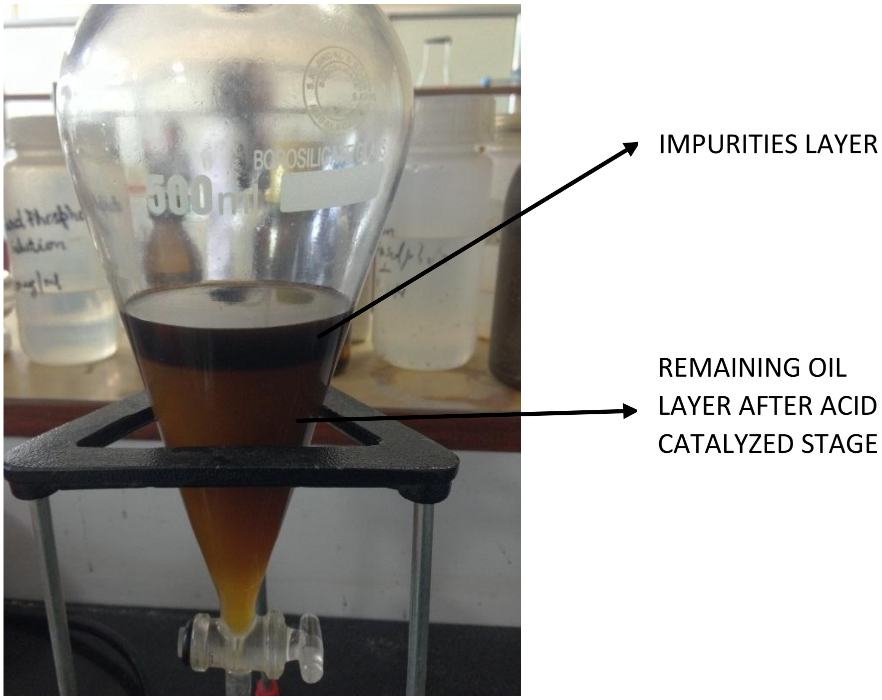


Figure 3.2: Two layers formed after the acid catalyzed stage.

Second stage (base catalyzed transesterification reaction)

1. The oil remained in the separating funnel was again measured and then pre heated up to 65^0C.
2. After that the known amount of methanol and potassium hydroxide mixture was added in the preheated remaining oil.
3. After that a constant stirring of 35 mins was again subjected at a constant temperature of 50^0C on the pre heated remaining oil in the flask on a hot plate magnetic stirrer.
4. After the constant stirring of 35 mins the mixture was poured in separating funnel to glycerol produced to settle down.
5. After 3-4 hours of settling down a layer of glycerol was made on the bottom which was separated and removed.

6. The remaining in the funnel is methyl ester (biodiesel) of neem oil i.e. yield 93% approximately which is further purified by hot water washing and drying to remove the excess of methanol, water, KOH from the oil.

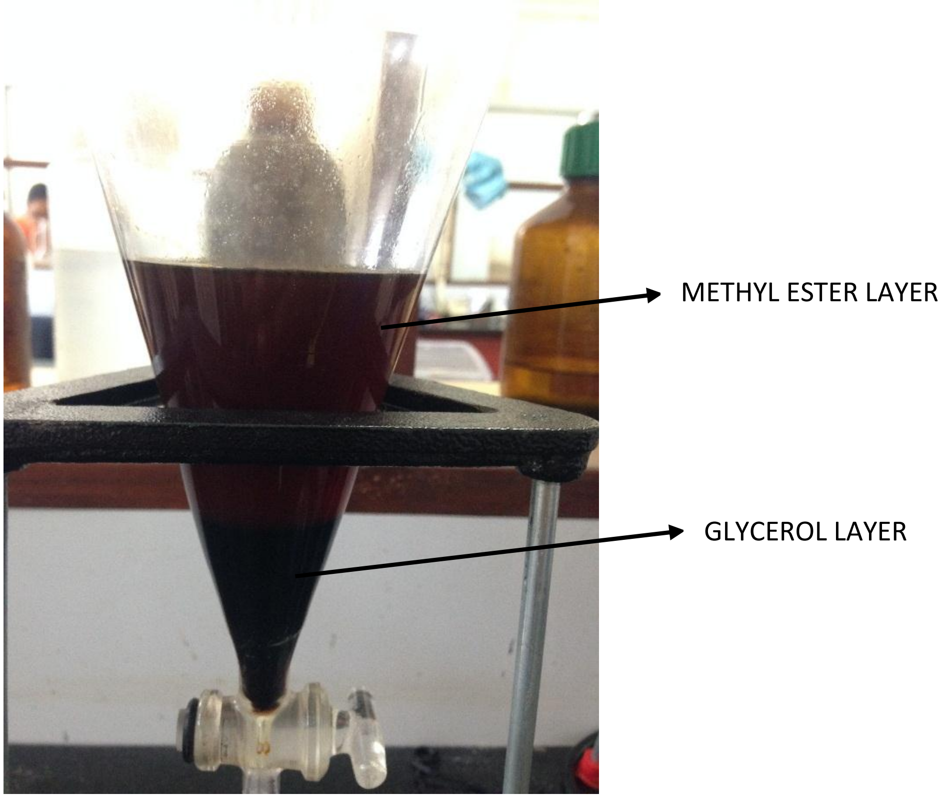


Figure 3.3: Separated layers after base catalyzed stage.

Figure 3.4: Final methyl ester of neem oil formed after the hot water washing.

The various properties of a methyl ester i.e. biodiesel are evaluated with different methods are shown in the table for the neem oil methyl ester (neem oil biodiesel)

Table 3.1: Properties parameters of neem oil methyl ester

PARAMETERS	TEST METHOD	Units	NEEM OIL METHYL ESTER (BIODIESEL)
Calorific value	IS: 1350(PART II), 1970, reaff. Nov. 2010 (Bomb Calorimeter)	kcal/kg	9965
Ash Content	IS:1448 (PART-4)	% by mass	0.02
Flash Point	Pensky Martens Closed Cup Test (PMCC)	ºC	250
Fire Point	Pensky Martens Closed Cup Test (PMCC)	ºC	255
FFA content	Titration with 0.1N NaOH	%	0.311
Cloud Point	Cloud and Pour point apparatus, IS: 1448 [P: 10]: 1970	ºC	6.8
Pour Point	Cloud and Pour point apparatus, IS: 1448 [P: 10]: 1970	ºC	-2
Iodine value	SP:18 (PART 13)-1984	---	58.40
Moisture	Dean-Stark Method	%	Not Detected
Kinematic viscosity @40ºC	Redwood Viscometer, IS : 1448 [P: 25] 1976	cSt	5.88

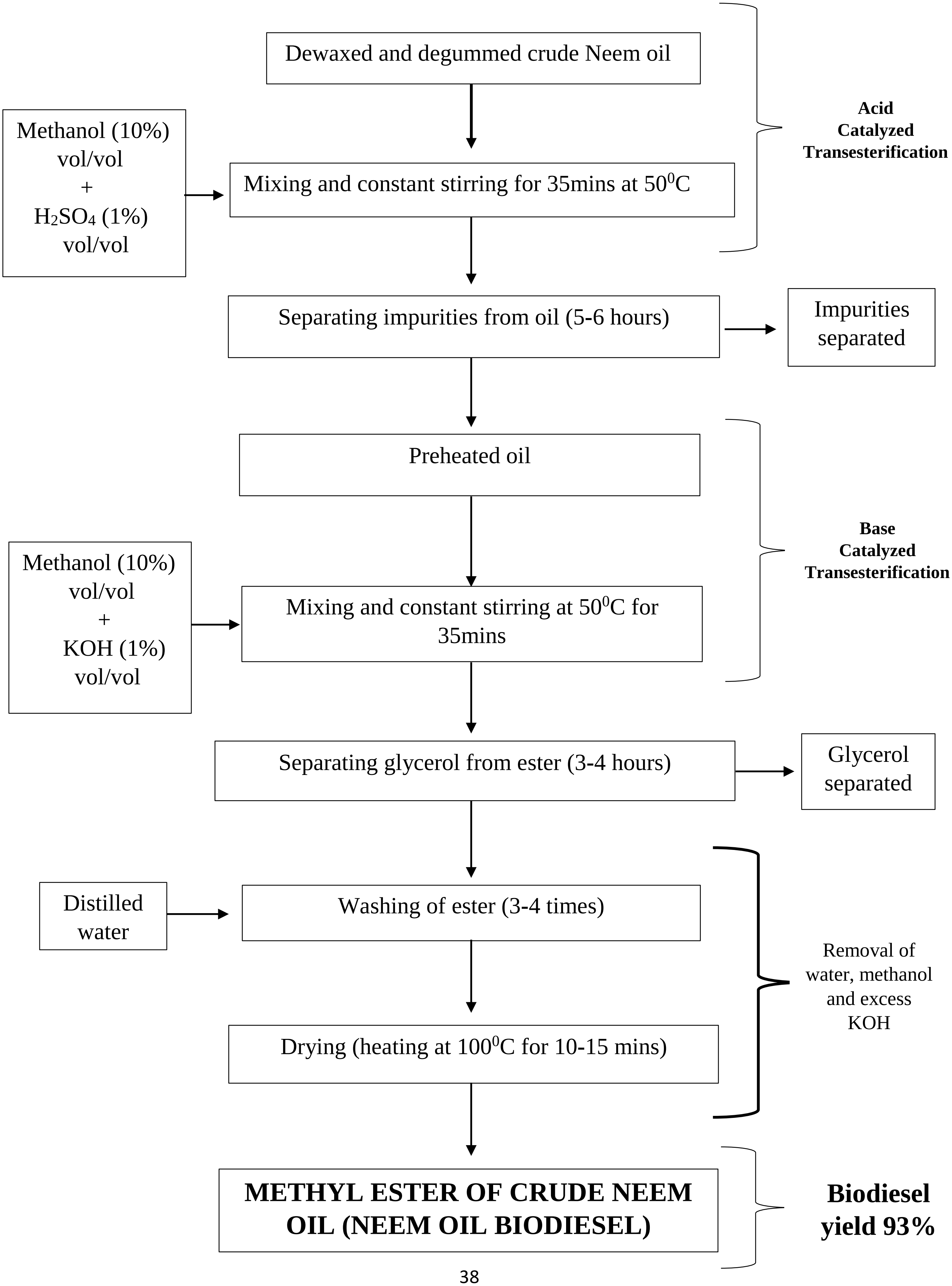


Figure 3.5: Schematic diagram for the procedure of crude neem oil methyl ester (biodiesel) production

Table 3.2: Fatty acid composition of neem oil(Khandelwal)

Fatty Acid	Structure	Amount %
Palmitic acid	16:0	17.8
Stearic acid	18:0	14.4
Oleic acid	18:1	51.3
Linoleic acid	18:2	14.7
Arachidic acid	20:0	1.6
Myristic acid	14:0	0.03

3.2 Methodology for the experimental testing of emission and performance on an engine

The second part of methodology deals with the method used for the experimental testing on the engine using different biodiesel blends. The different apparatus and method used in the process is discussed and also the different performance and exhaust emission parameters are discussed.

3.2.1 Evaluation of engine performance

Evaluation of engine performance is explained as

- Firstly an engine description
- Secondly the method or operation scheme used
- Thirdly the parameters that are evaluated.

Engine description

The picture of the engine on which the experiments are carried out is shown i.e. of the variable compression ratio compression ignition engine along with the online performance evaluation system is shown in figure.

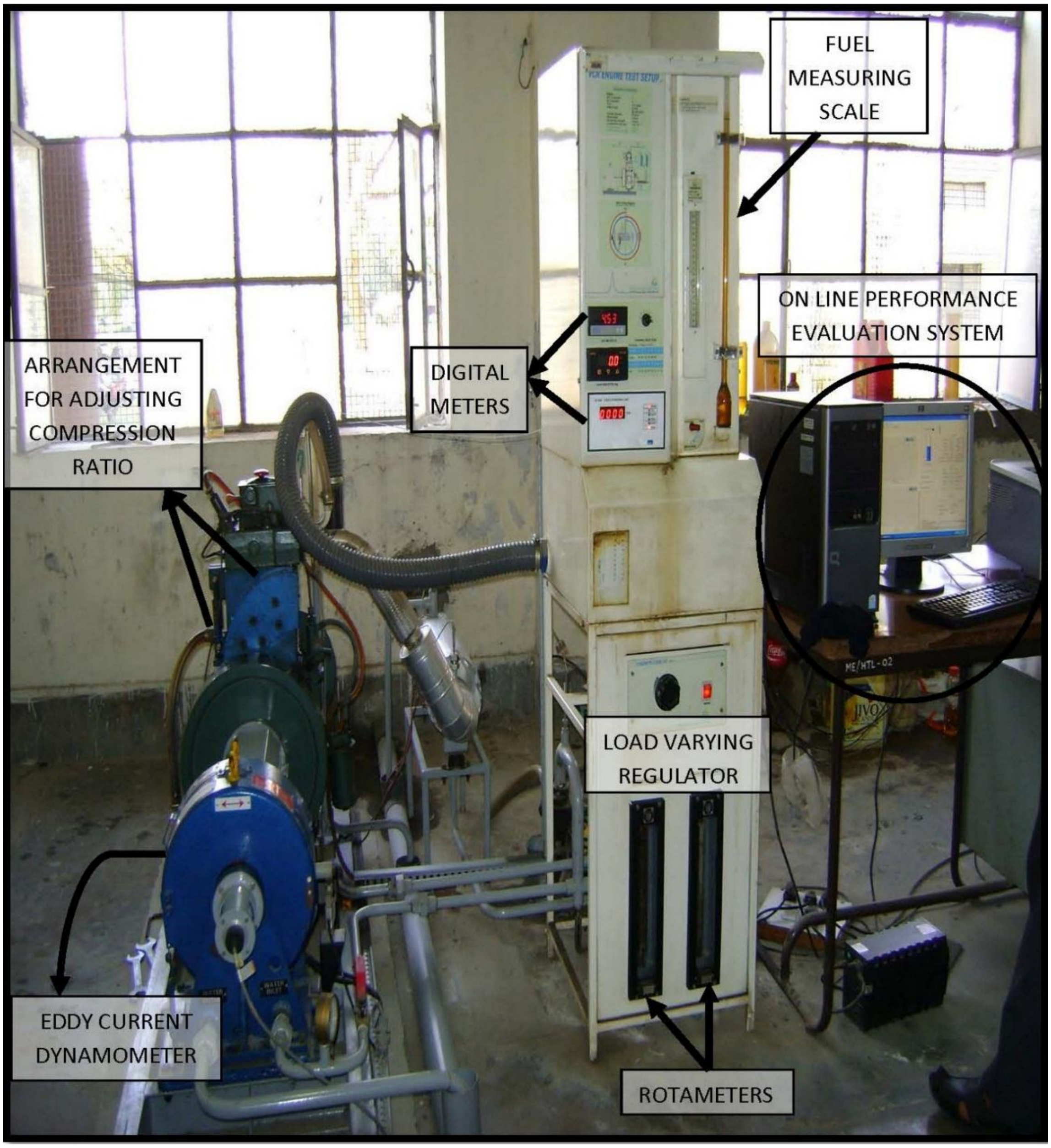


Figure 3.6: Pictorial view of the variable compression ratio compression ignition engine.

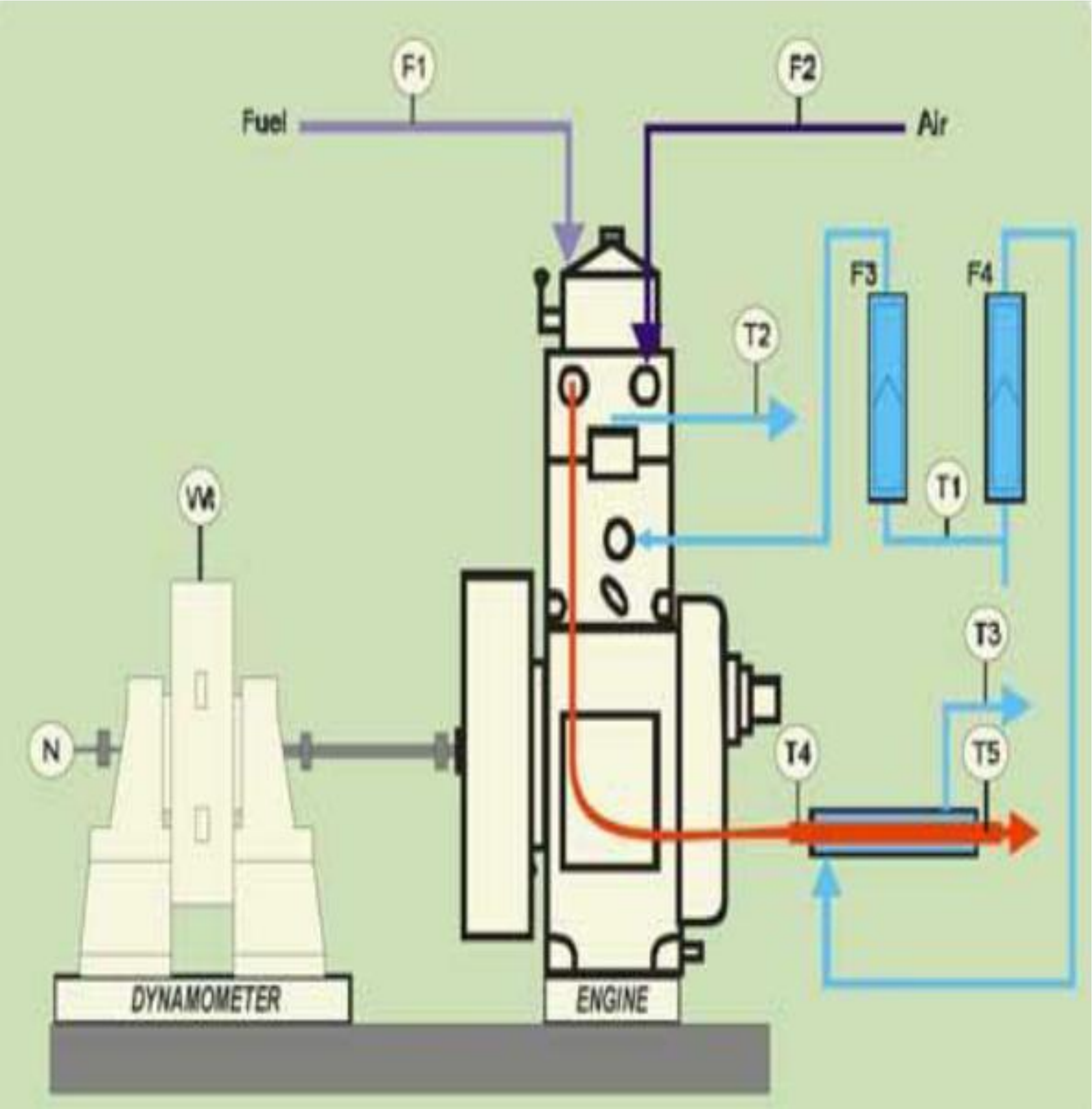


Figure 3.7: Flow line diagram of variable compression ratio compression ignition engine setup

Table 3.3: shows the various points in the flow line diagram of variable compression ratio compression ignition engine.

T1	Inlet temperature of water jacket in calorimeter and engine jacket
T2	Outlet temperature of water from engine jacket
T3	Outlet temperature of water from calorimeter

T4	Inlet temperature of exhaust gases into calorimeter
T5	Outlet temperature of exhaust gases from calorimeter
F1	Fuel supply to engine cylinder
F2	Air flow to engine cylinder
F3	Water flow to the engine jacket
F4	Water flow to calorimeter
N	Non-contact type speed sensor(Engine shaft speed)
W	Load sensor(Eddy current dynamometer)

Specifications of the engine

Make Type: Kirloskar

Engine Type: Single Cylinder 4-Stroke, Water Cooled

Compression ratio: Variable ranging from 12 to 18

Rated power: 3.75 kW@1500 R.P.M

Stroke: 110 mm

Bore: 87.5 mm

Connecting rod length: 234 mm

Loading device: Eddy current dynamometer

Load indicator: Digital, Range 0-50 Kg, and Supply 230V AC

Load sensor: Load cell, type strain gauge, range 0-50 Kg

Speed indicator: Digital with non-contact type speed sensor

Temperature sensor: Thermocouple, Type K

Rotameter: Engine cooling 40-400 LPH; Calorimeter 25-250 LPH

For the varying compression ratio a tilting cylinder block arrangement is used without stopping engine. Necessary instruments are provided in the setup for combustion pressure measurements.

Necessary provisions are made for load, interfacing flow, fuel flow, temperature measurements. A standalone panel box is there in the setup consisting air box, process indicator and engine indicator manometer, fuel measuring unit, transmitters for air and fuel flow measurements, fuel tank. An Engine Performance Analysis software package

Procedure followed in experiments

1. Firstly fill the diesel in fuel tank.
2. Then initially adjust the compression ratio 12:1 of the engine.
3. After that water supply is started. As the cooling water flow for engine is setup at 250 LPH and calorimeter flow at 75 LPH.
4. Ensuring the adequate water flow rate for piezo sensor cooling and dynamometer.
5. Check the electrical connections and then start the power supply to the computer through UPS.
6. The lab view engine performance analysis software package "**Enginesoft**" id opened for the performance evaluation on the screen.
7. By opening the valve at the burette the diesel is supplied to the engine.
8. The value of calorific value and specific gravity is adjusted through the configure option present in the software.
9. After that select the run option on software and start the engine and let it run for few minutes.

10. Then choose the log option in the software. Fuel supply is turned on. After that in 1 minute the display changes to input mode at that time values of water flows in cooling jacket and calorimeter are entered and the file is named (for first reading only) in the software. At that time for no load conditions the first reading gets logged on. Then the fuel knob is turned back to previous (normal) position.
11. Then the experiment is repeated for different loads.
12. The different reading corresponding to the different load will display on the monitor after that which are saved for a particular compression ratio.
13. The compression ratio is then changed by adjusting the screw arrangement.
14. Then the same experiment is repeated for the different compression ratio and the readings are saved for the same.
15. Now for the next fuel blend testing change the fuel in the fuel tank and then accordingly adjust the calorific value and specific gravity of the fuel in the software.
16. Repeat the procedure for different fuel at different compression ratio and record the readings in the computer.
17. After that bring the engine to no load condition and turn off the computer as well as the engine so as to stop the experiment.
18. After that in few minutes also stop the water supply.

Maintenance and precaution instructions

1. Check the oil level in engine before startup and making sure that sufficient oil is present in the engine.
2. Fuel line and fuel tank should be cleaned before starting engine and should be free from foreign particles.

3. The water supply should always be turned on few minutes before starting the engine.

Evaluated parameters

- Brake power (BP)
- Brake thermal efficiency (BTE)
- Brake specific fuel consumption (BSFC)
- Brake mean effective pressure (BMEP)
- Mechanical efficiency (ME)

3.2.2 Exhaust emission evaluation

Apparatus and parameters investigated

Two equipment were used to measure the exhaust emission parameters both having individual sensors attached to them. The figure and figure shows the horiba analyzer and flue gas analyzer

Figure 3.8: Horiba analyzer

Figure 3.9: Flue gas analyzer

Table 3.4: shows the exhaust emission parameters and their respective test methods with unit.

Parameters	Test Methods
Carbon monoxide CO (ppm)	Flue Gas Analyzer (KM19106)
Carbon monoxide CO2 (%)	Flue Gas Analyzer (KM19106)
Nitrogen oxides NO (ppm)	Flue Gas Analyzer (KM19106)
Nitrogen oxides NO2 (ppm)	Flue Gas Analyzer (KM19106)
Nitrogen oxides NOx (ppm)	Flue Gas Analyzer (KM19106)

Operational Procedure followed

1. At a particular load condition sensor is inserted in the exhaust gas outlet.
2. The exhaust gas pass through the sensors of the analyzer attached to it.
3. The readings of the gases passed are then displayed on the screen of the analyzer.
4. After that when the reading is stabilized 3 readings are noted and the mean value is evaluated.

5. Sensors are then removed from the outlet so that the readings settle down to zero.

6. The procedure is repeated for the different fuel and different load conditions.

CHAPTER 4

RESULTS AND DISCUSSION

Result and discussion is divided in to two parts. First objective is to produce the biodiesel from neem oil by optimizing the different parameters that significantly affect the production i.e. molar concentration of methanol to oil, catalyst concentration taken etc. The second objective of results and discussion is to optimize the compression ratio and to obtain a best blend out of all the blends used by considering the performance and emission parameters. Firstly production parameters are discussed with results obtained.

4.1 Production parameters

4.1.1 Molar ratio variation

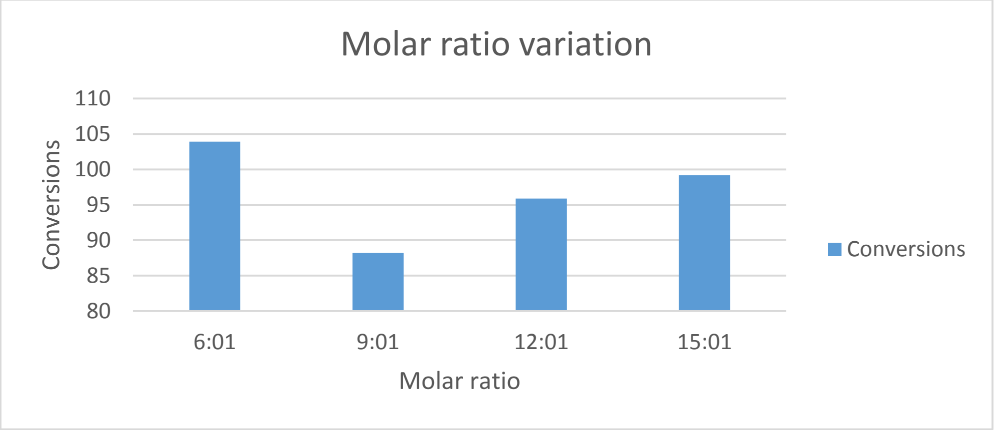


Figure 4.1: shows the variation of conversions with molar ratio of alcohol to oil for acid catalyzed stage.

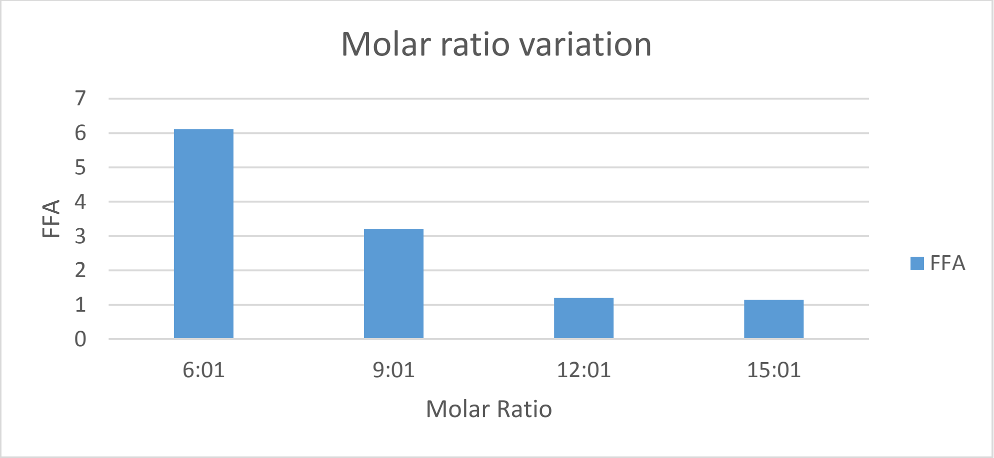


Figure 4.2: shows the variation of FFA with molar ratio of alcohol to oil for acid catalyzed stage.

For the first stage of transesterification process of biodiesel i.e. acid catalyzed stage molar ratio of alcohol to oil is varied at 1% catalyst conc., 50° C temperature for 35mins and the conversions and FFA trends are obtained. As the above figure 4.1 and 4.2 shows that the conversions shows decreasing trend in first from 6:1 to 9:1 molar ratio and then increases with further increase in molar ratio but the increase is slight also it is seen that FFA with increase in molar ratio shows at decreasing trend but is almost similar for the molar ratios 12:1 and 15:1.

4.1.2 Catalyst concentration variation

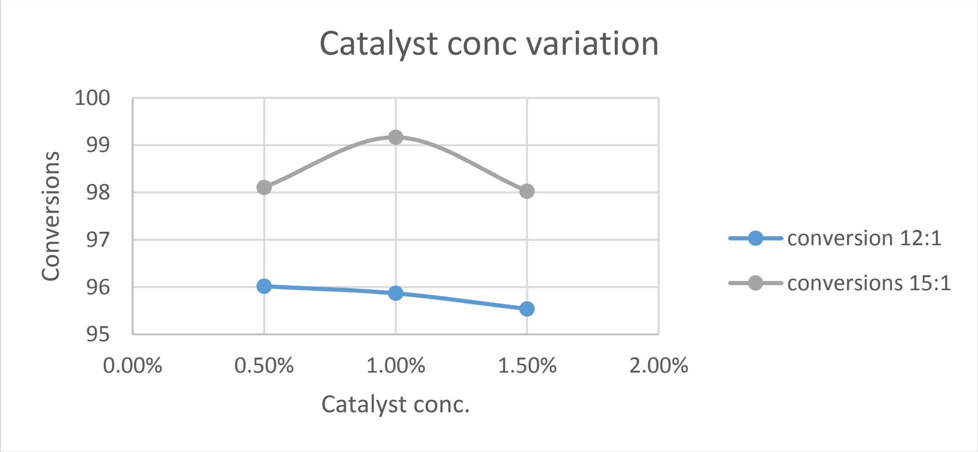


Figure 4.3: shows the variation of conversions with catalyst concentration for acid catalyzed stage.

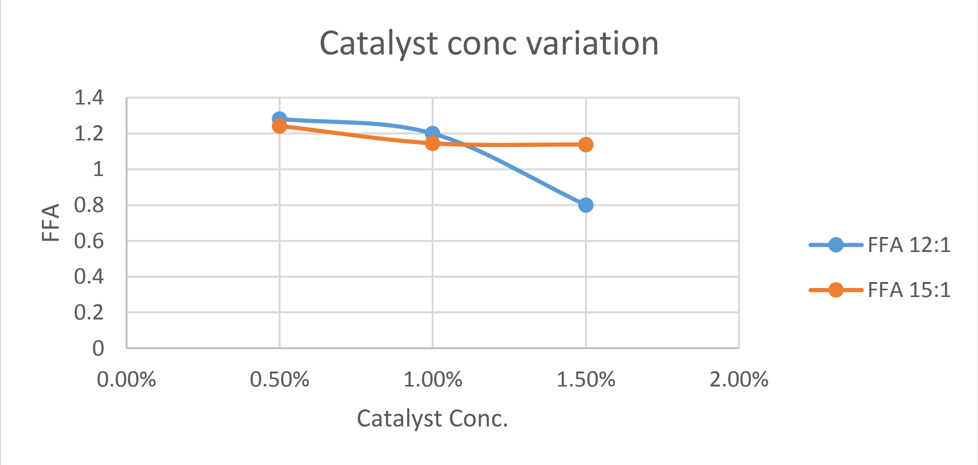


Figure 4.4: shows the variation of FFA with catalyst concentration for acid catalyzed stage.

Now the above figures 4.3 and 4.4 shows the variation of catalyst concentration at 50°C temperature and molar ratios of 12:1 and 15:1 for 35 mins in the acid catalyzed stage and the conversions and FFA are obtained. As it can be seen that for molar ratio 12:1 conversions are more than 15:1 for all catalyst concentrations but the increase is not significant in the conversions but for 1% catalyst concentration it can be seen that both the molar ratios have maximum conversions. Also for the FFA it is seen that for molar ratio 12:1 it has decreasing trend but for 15:1 it remains almost same everywhere except a slight decrease at 1% catalyst concentration.

4.1.3 Temperature variation

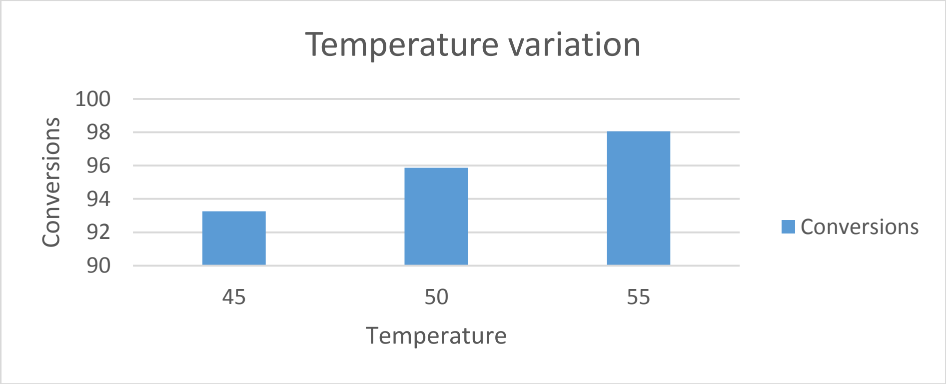


Figure 4.5: variation of conversions temperature for acid catalyzed stage.

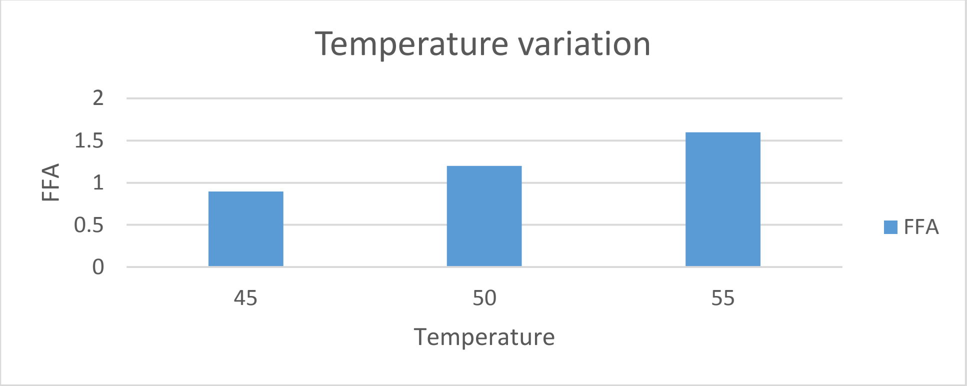


Figure 4.6: variation of FFA temperature for acid catalyzed stage.

The above figures shows the variation of temperature at 1% catalyst concentration , 12:1 molar ratio for 35mins in the acid catalyzed stage obtaining the conversions and FFA for the temperature variations. From the above figures 4.5 and 4.6 it can be seen that with the increase in reaction temperature the conversions show increasing trends though there is not much variation is seen in the temperature 50 and 55 also in case of FFA it again shows an increasing trends but showing much less difference in the former two temperatures then later showing that 50 is the optimum temperature for the process.

4.1.4 Molar ratio variation

Figure 4.7 and Figure 4.8 shows the variation of molar ratio of alcohol to oil for the 6:1 and 9:1 acid catalyzed oil at temperature 50^{o}C and catalyst concentration of 1% for 35mins and conversions and FFA is obtained. It can be seen that for molar ratio 9:1 acid catalyzed oil the conversions are more at each molar ratio then for 6:1 although there is not much variation in the 9:1 molar ratio acid catalyzed oil with the increase in molar ratio in the base catalyzed stage also the trends for 6:1 acid catalyzed oil are mixed with increase in the molar ratio in base catalyzed stage. Also it is seen that the highest conversions are obtained for the 9:1 acid catalyzed oil with 15:1 molar ratio in base catalyzed stage. For FFA it can be seen that the lowest values of FFA are obtained at 12:1 molar ratio of base catalyzed stage for both 6:1 and 9:1 molar ratio of acid catalyzed oil but it also shows that at 12:1 and 15:1 molar ratio of base catalyzed stage for 9:1 acid catalyzed oil have the lowest values of all the values obtained with a slight difference.

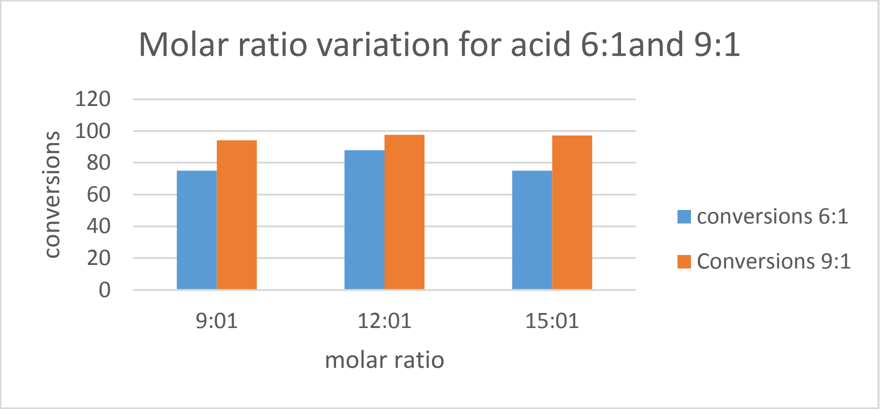


Figure 4.7: variation of conversions with molar ratio of alcohol to oil for the 6:1 and 9:1 molar ratio of acid catalyzed oil for base catalyzed stage

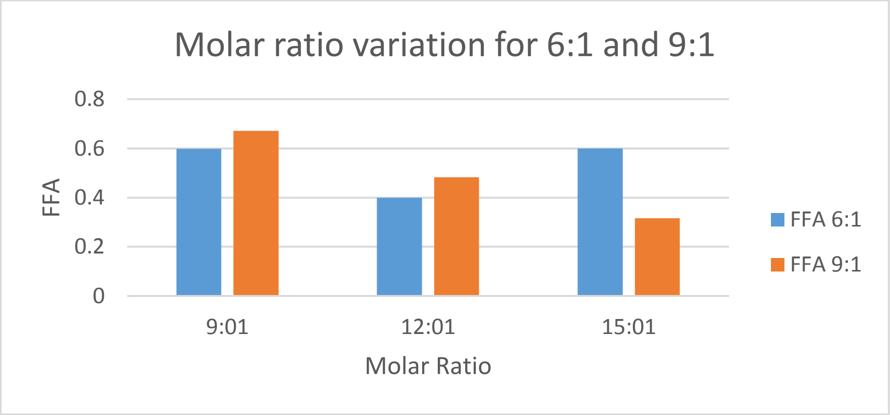


Figure 4.8: variation of FFA with molar ratio of alcohol to oil for the 6:1 and 9:1 molar ratio of acid catalyzed oil for base catalyzed stage

4.1.5 Catalyst concentration variation for 6:1 acid catalyzed oil

The above figures 4.9 and 4.10 shows the variation of catalyst concentrations for 6:1 molar ratio acid catalyzed oil at temperature of 50°C for 35 mins for the molar ratios of 12:1 and 15:1 for base catalyzed stage and conversions and FFA are obtained. From the figures it can be seen that conversions for 12:1 molar ratio of base catalyzed stage has increased with each step although the increase is slight whereas with the molar ratio 15:1 a decreasing trend can be seen. Also for the FFA it can be seen that FFA has a decreasing trend for both the molar ratios i.e. 12:1 and 15:1 but with increase in catalyst concentration the decrease is more in 15:1 molar ratio as compared to 12:1 having very slight changes. Also it is seen that with molar ratio 15:1 in base catalyzed stage and catalyst concentration of 1.5% soap formation was seen.

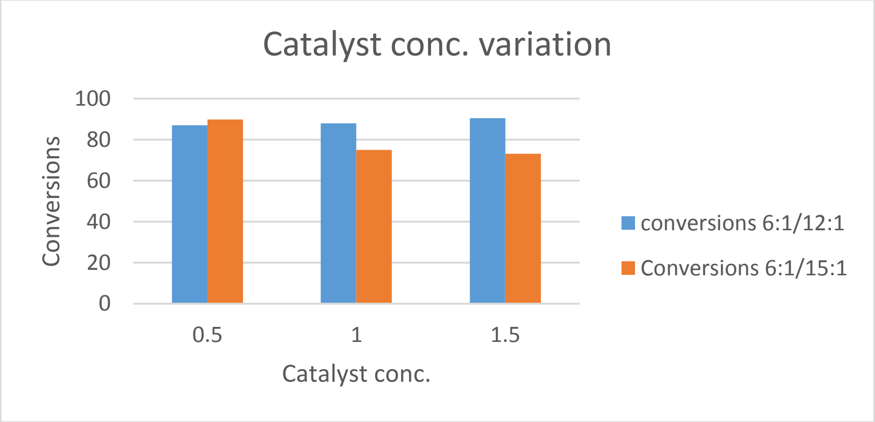


Figure 4.9: variation of conversions with catalyst concentration for the 6:1 molar ratio of acid catalyzed oil for base catalyzed stage of molar ratio 12:1 and 15:1

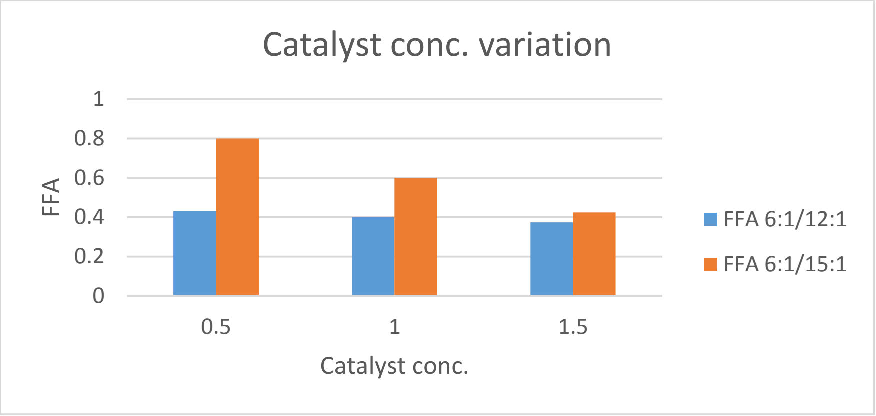


Figure 4.10: variation of FFA with catalyst concentration for the 6:1 molar ratio of acid catalyzed oil for base catalyzed stage of molar ratio 12:1 and 15:1

4.1.6 Catalyst variation for 9:1 acid catalyzed oil

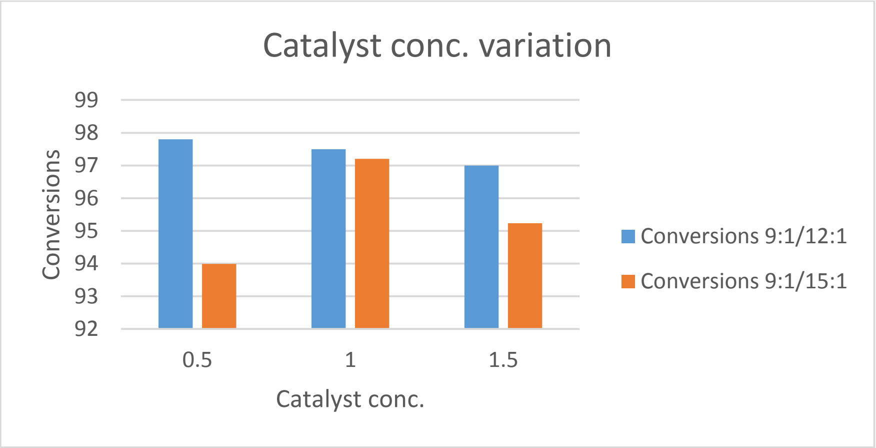


Figure 4.11: variation of conversions with catalyst concentration for the 9:1molar ratio of acid catalyzed oil for base catalyzed stage of molar ratio 12:1 and 15:1

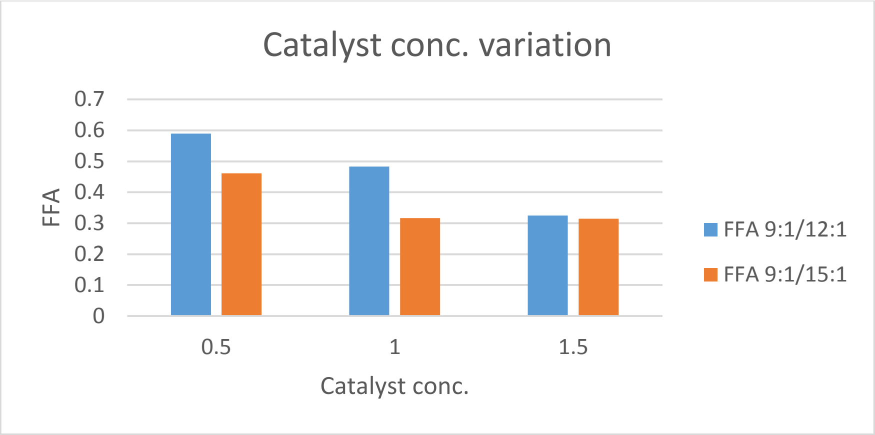


Figure 4.12: variation of conversions with catalyst concentration for the 9:1 molar ratio of acid catalyzed oil for base catalyzed stage of molar ratio 12:1 and 15:1

The above figures 4.11 and 4.12 shows the catalyst concentration variation for molar ratio 9:1 of acid catalyzed oil at temperature 50°C for 35 mins for the molar ratios of 12:1 and 15:1 for base catalyzed stage and conversions and FFA are obtained. From the figures it can be seen that conversions show a mixed trend for the molar ratio 15:1 having highest conversions at 1% catalyst concentration whereas the conversions for 12:1 molar ratio shows a decreasing trend having highest value at 0.5% catalyst concentrations but the same point having the maximum FFA value from all the obtained. It is seen that the trends for both the molar ratios 12:1 and 15:1 have decreasing trend with increase in catalyst concentration. Also it is seen that for FFA the 12:1 molar ratio of base catalyzed stage has decreasing trend with lowest value at 1.5% catalyst concentration but it is also seen that for molar ratio 15:1 of base catalyzed stage has lowest values at both 1% and 1.5% then the 12:1 molar ratio's lowest value.

Hence the best optimized results were found to be for 9:1 molar ratio acid catalyzed stage at 50°C and 1% catalyst concentration for 35mins and then for the base catalyzed stage the best were found at 15:1 molar ratio at 50^{o}C and 1% catalyst concentration for 35mins. After which the production was done at these parameters for the biodiesel production for further engine testing of performance and emission.

4.2 Performance parameters

4.2.1 BP vs Load

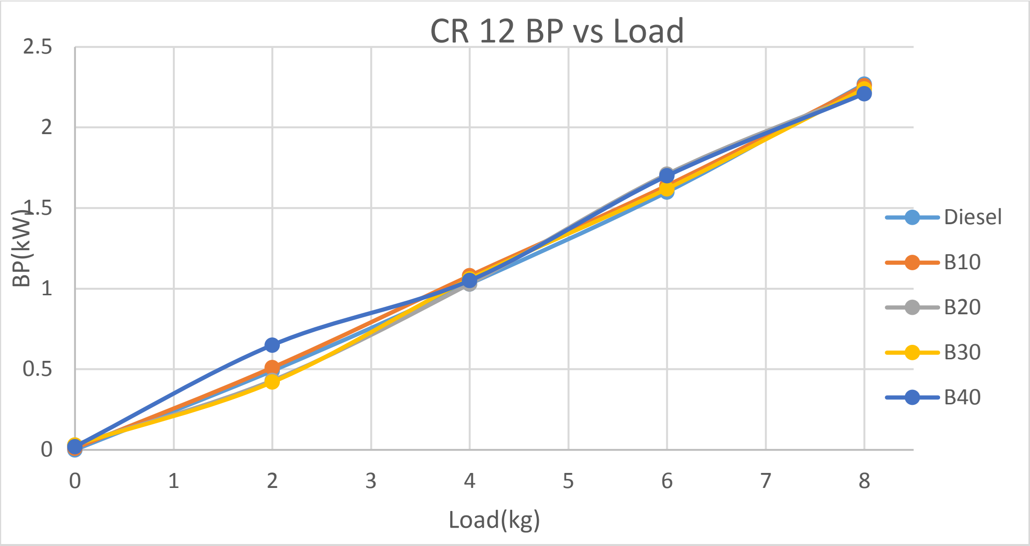


Figure 4.13: variation of BP vs Load for diesel and different biodiesel blends at compression ratio 12:1

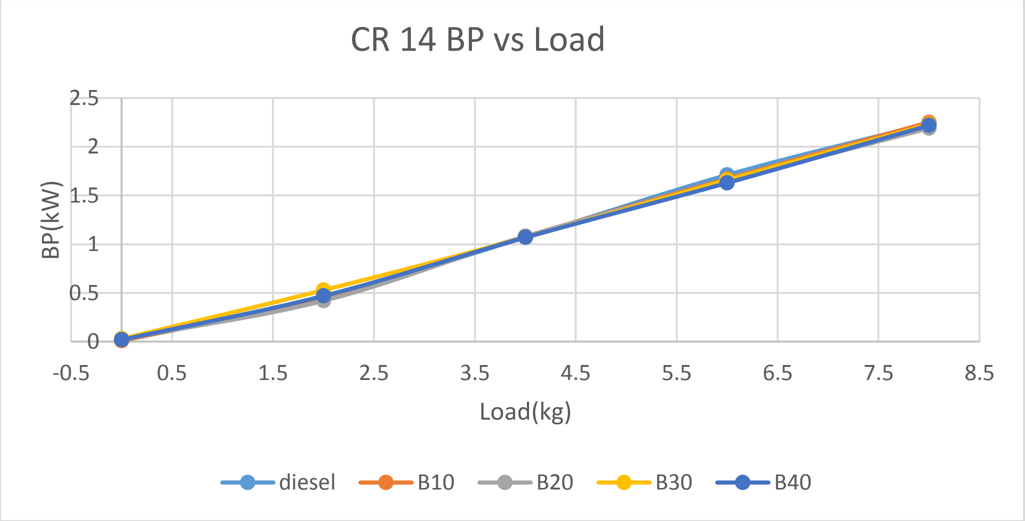


Figure 4.14: variation of BP vs Load for diesel and different biodiesel blends at compression ratio 14:1

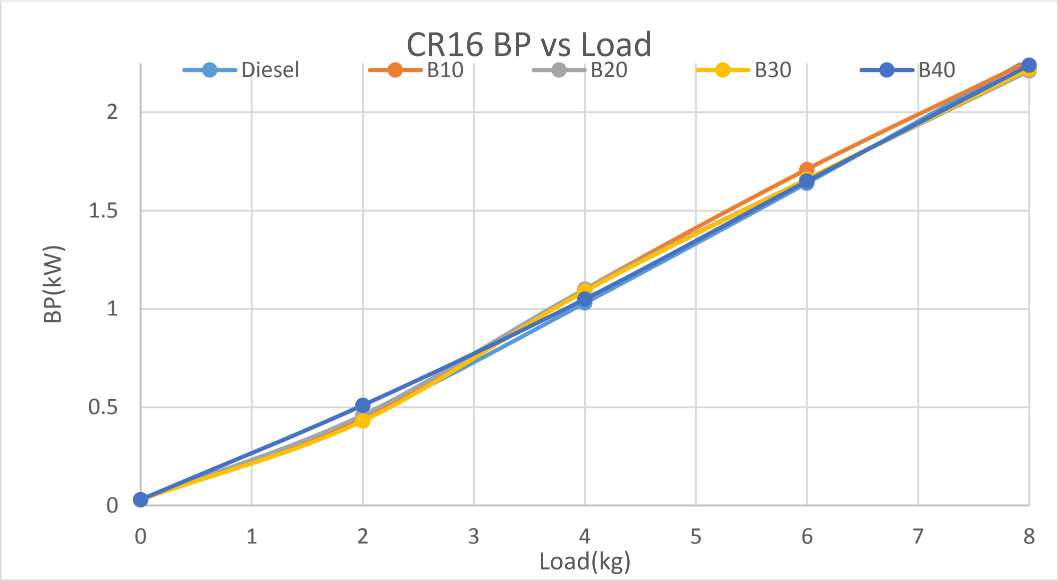


Figure 4.15: variation of BP vs Load for diesel and different biodiesel blends at compression ratio 16:1

The above figures shows the brake power variation at different loads of the diesel and different biodiesel blends. The load vs BP graph shows that at first of all at no load condition the BP is same for all the diesel and biodiesel blends but as the load increases the BP of diesel increases more as compared to others because of having higher heating value than biodiesel blends. At part loads the BP of biodiesel blends decreases than diesel because of having higher viscosity and density but low heating value than diesel and such decrease further on increasing biodiesel amount(%age). Hence maximum BP can be achieved by using diesel other than B10, B20, B30, and B40. An exception in CR12 with B40 has shown more BP all the loads in comparison to BP obtained for all other blends and diesel. Now on increasing the CR there is no much change in trends as shown by above figures with using CR14 and 16 i.e. the diesel heating value is more so the BP produced by diesel in CR14 and 16 is more than biodiesel blends because of the same reason stated above.

4.2.2 Brake specific fuel consumption vs Load

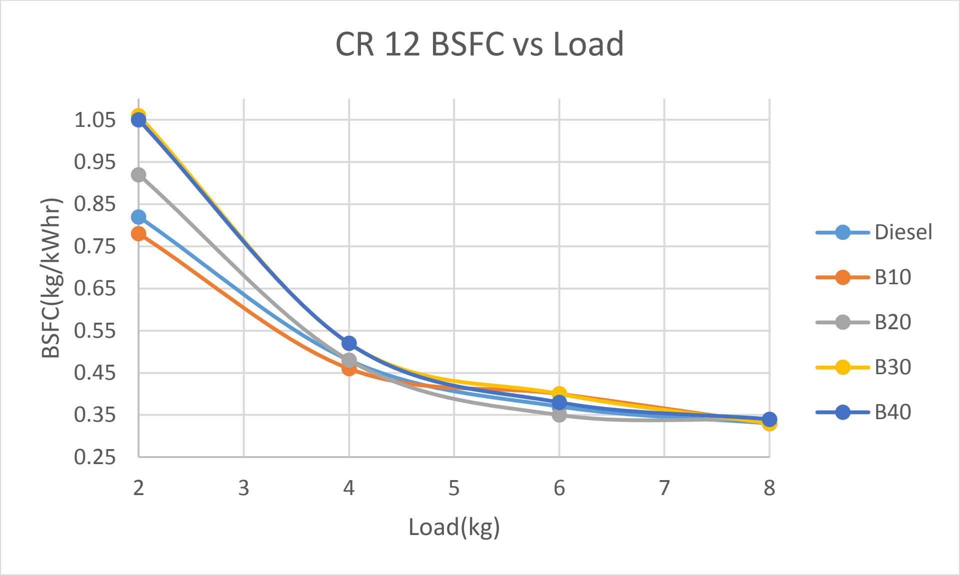


Figure 4.16: variation of BSFC vs Load for diesel and different biodiesel blends at compression ratio 12:1

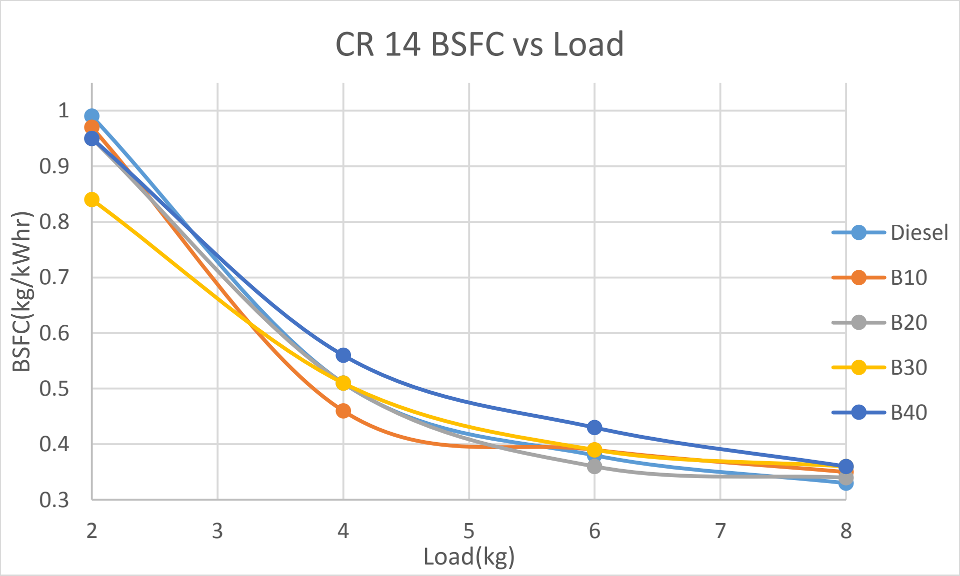


Figure 4.17: variation of BSFC vs Load for diesel and different biodiesel blends at compression ratio 14:1

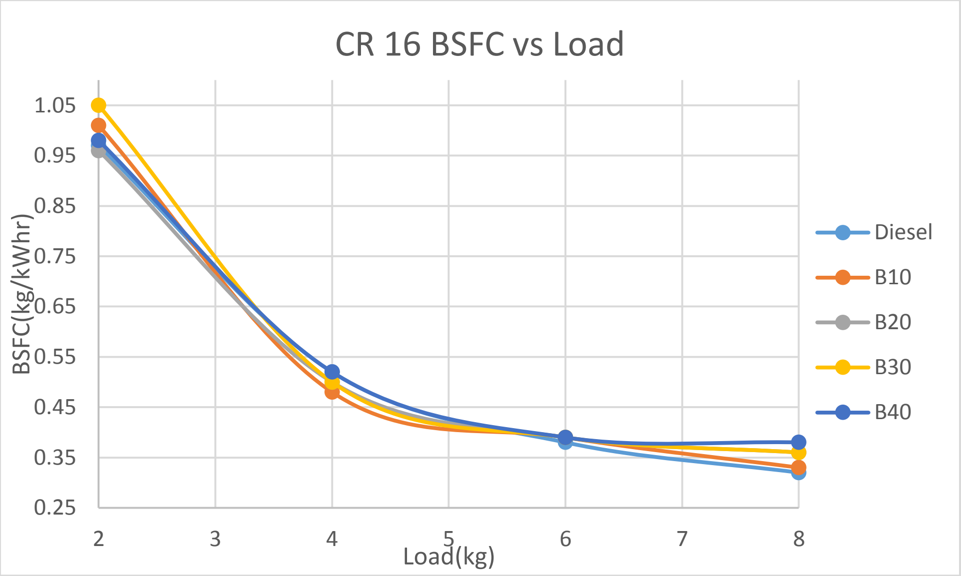


Figure 4.18: variation of BSFC vs Load for diesel and different biodiesel blends at compression ratio 16:1

The above figures shows the variation of BSFC (brake specific fuel consumption) with load of diesel and different biodiesel blends. As the load increases in the above figures the BSFC decreases at lower loads and then it remains almost constant. In the previous work Dhar et al. 2012 using neem oil biodiesel has shown similar trends in the BSFC. Nayak et al. 2014 has also shown similar trends in BSFC using mahua oil biodiesel blends. Ashraful et al. 2014 using neem oil biodiesel has shown trends as slight increase for B20 and for all other biodiesel the BSFC is nearly close to the diesel fuel on engine1-Cylinder DI, CR: 17.5:1, RP: 4.4 kw, 1500 rpm similar to that of above trends. As the load increases firstly the rate of increase of BP compared to fuel consumption is more and as the load moves towards full load conditions the rate of increase of BP and fuel consumption remains same so at these loads BSFC remains almost constant. With increase in the biodiesel %age in the blends the BSFC values increases because the fuel consumption increases due to the lower calorific value of biodiesel. It is also seen that B40 has maximum BSFC at all CR. Further it is recorded that with increase in CR there is not much change in the trends i.e. B40 has maximum BSFC at all loads.

4.2.3 Brake thermal efficiency vs Load

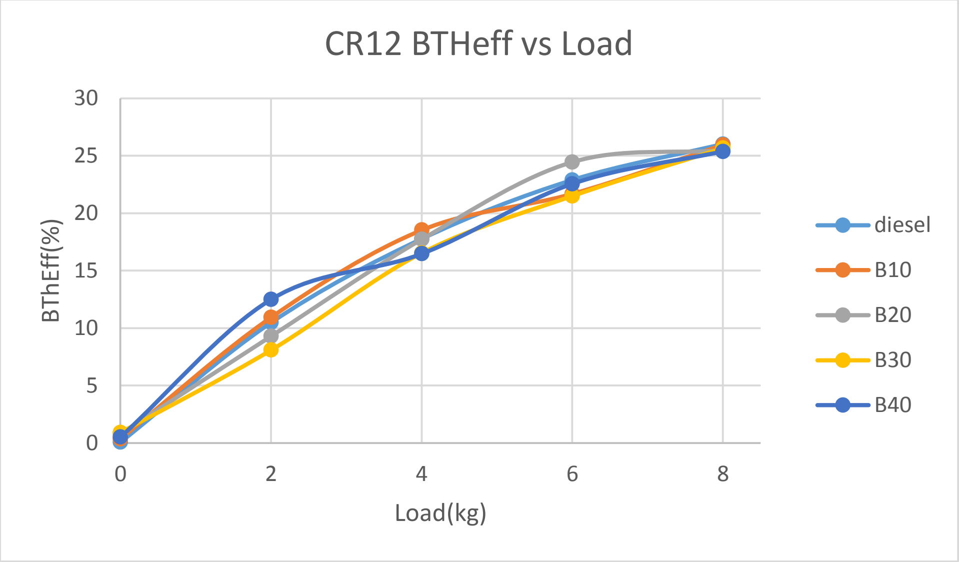


Figure 4.19: variation of BThEff vs Load for diesel and different biodiesel blends at compression ratio 12:1

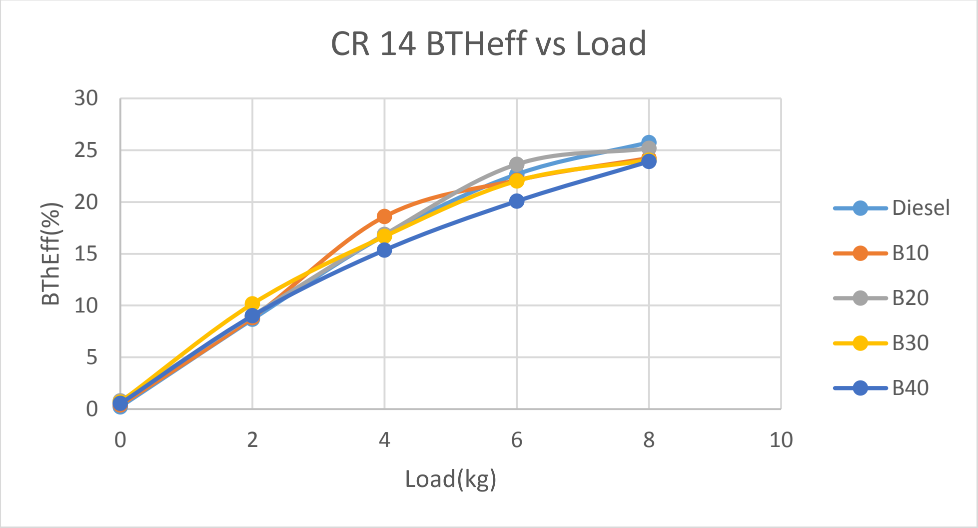


Figure 4.20: variation of BThEff vs Load for diesel and different biodiesel blends at compression ratio 14:1

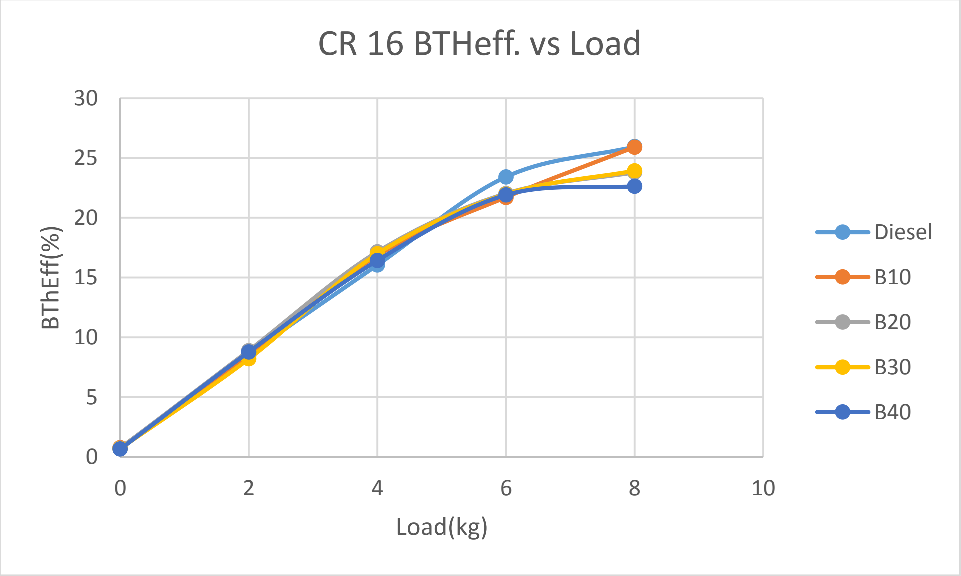


Figure 4.21: variation of BThEff vs Load for diesel and different biodiesel blends at compression ratio 16:1

The above figures shows the variation of brake thermal efficiencies with load. The brake thermal efficiency has increased with increase in the load. The rate of increase was more at lower loads whereas it has decreased with increasing the load further. Dhar et al and Heroor et al. 2013 has also obtained similar trends for brake thermal efficiency using neem oil biodiesel. Nayak et al. 2014 and Sakthivel et al. 2014 also showed similar variations for brake thermal efficiency using mahua oil biodiesel and fish oil biodiesel. Ashraful et al. 2014 has shown increasing trends with increasing biodiesel percentage in fuel blends at all load conditions using neem oil biodiesel which are similar to the above shown trends. At all the CR highest values of brake thermal efficiency was obtained for B20 for all the loads. This trends is because at higher load the rate of increase of BP decreases whereas the rate of increase of fuel consumption remain almost constant. So the decrease in rate of increase of BP at higher loads leads to decrease in the rate of increase of brake thermal efficiency. Variation of brake thermal efficiency has shown that CR negligible influence on the BThEff at different loads for different blends.

4.2.4 Mechanical efficiency vs load

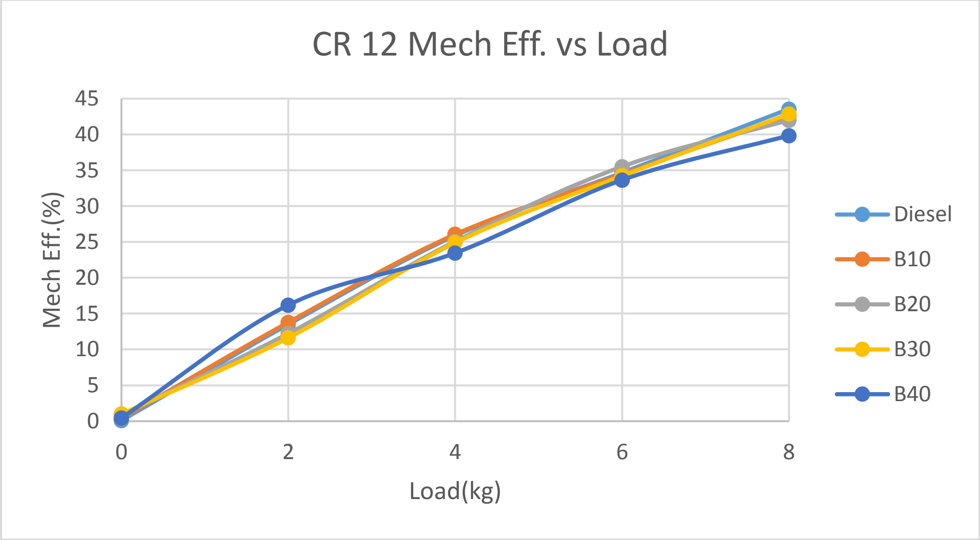


Figure 4.22: variation of Mech Eff vs Load for diesel and different biodiesel blends at compression ratio 12:1

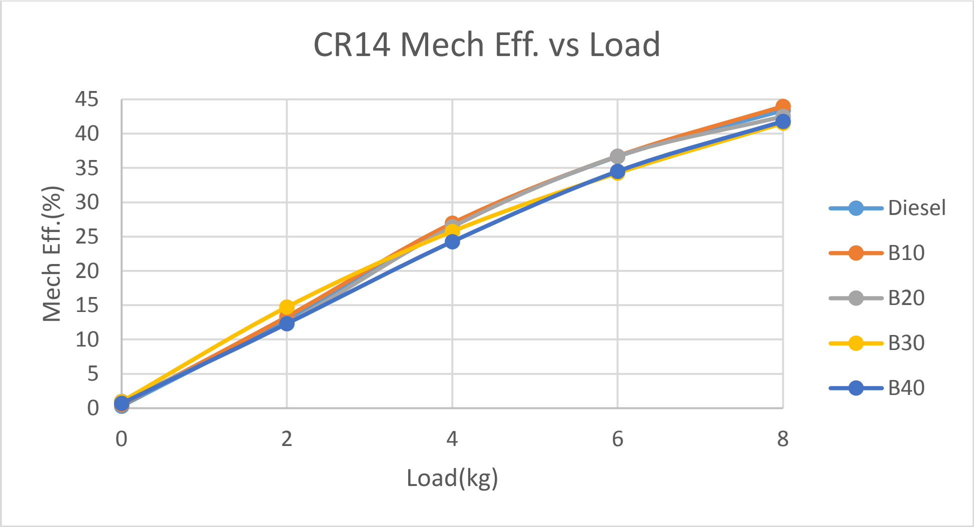


Figure 4.23: variation of Mech Eff vs Load for diesel and different biodiesel blends at compression ratio 14:1

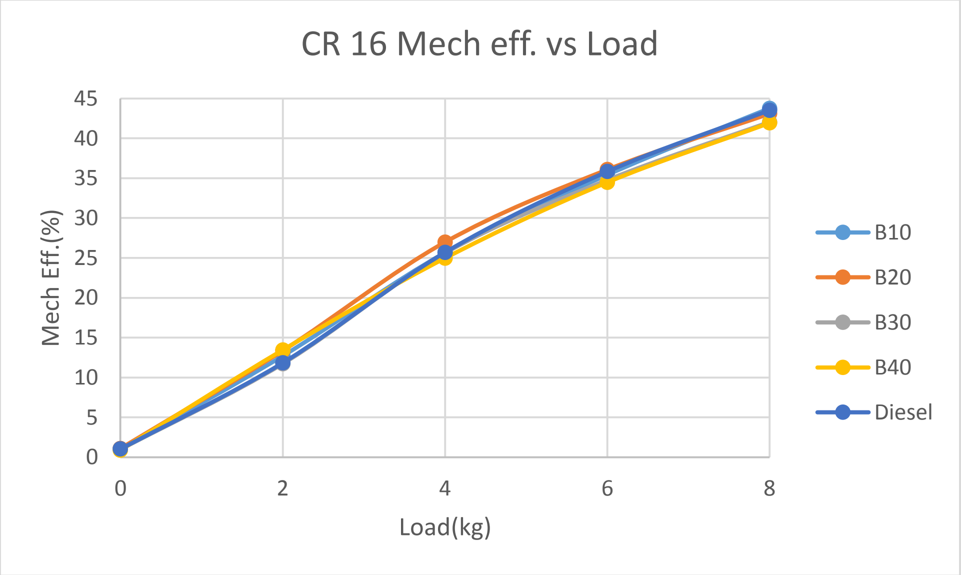


Figure 4.24: variation of Mech Eff vs Load for diesel and different biodiesel blends at compression ratio 16:1

These figures shows the variation of mechanical efficiency with load of diesel and different biodiesel blends. The mechanical efficiency has shown increasing trends with increase in the load at all the CR for all the blends. The rate of increase is more at low loads as compared to the rate of increase at higher values of load. This is due to the fact that at higher loads the increase in BP is less as compared to lower loads whereas IP power increases with the same rate at all loads. At higher loads the temperature of engine increases which leads to decrease in viscosity of the lubricating oil hence frictional power losses increases with more rate at higher loads. From the figures it can be seen that the CR has not much affected the mechanical efficiency. The mechanical efficiency obtained for B10 blend was maximum at higher loads for all CRs.

4.2.5 Volumetric efficiency vs Load

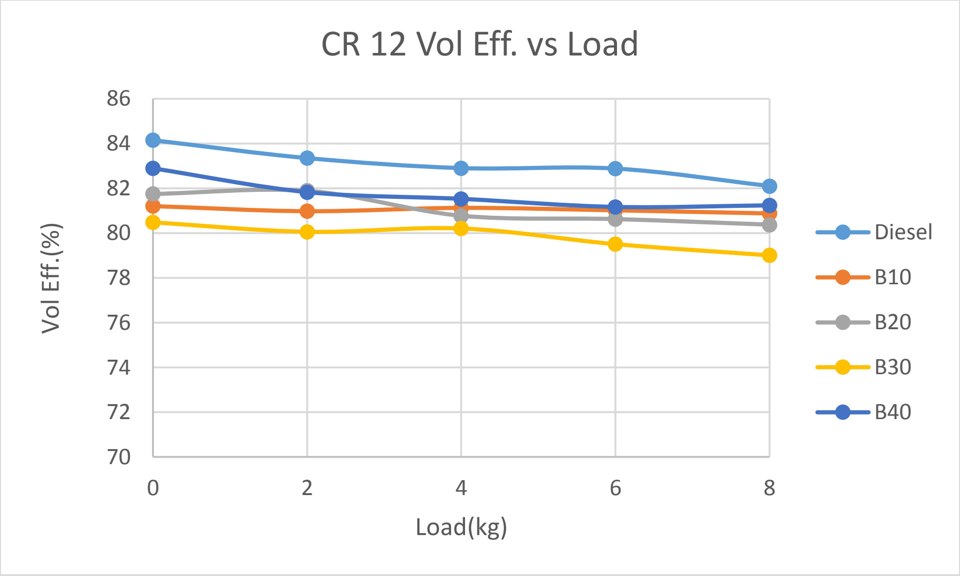


Figure 4.25: variation of Vol Eff vs Load for diesel and different biodiesel blends at compression ratio 12:1

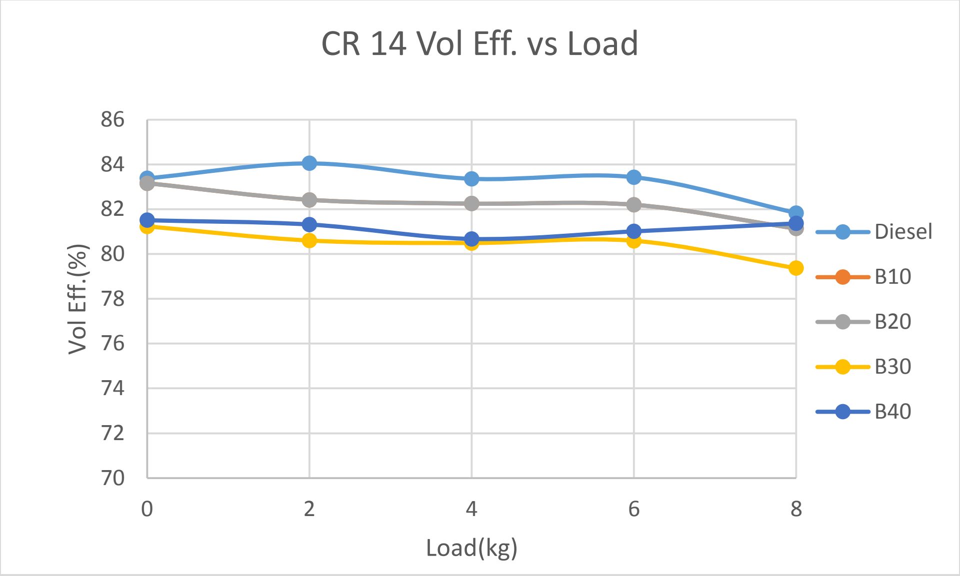


Figure 4.26: variation of Vol Eff vs Load for diesel and different biodiesel blends at compression ratio 14:1

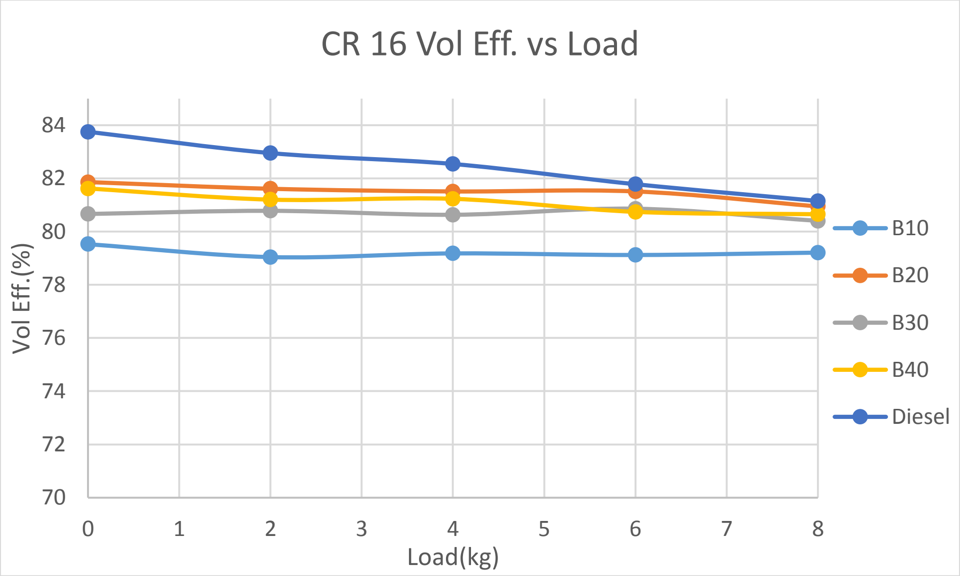


Figure 4.27: variation of Vol Eff vs Load for diesel and different biodiesel blends at compression ratio 16:1

The above figures shows the variation of diesel and biodiesel blends volumetric efficiency with the load. It is seen that with increase in load volumetric efficiency has shown decreasing trend but the amount of decrease is very small when the load was varied from no load to full load conditions. Not much change in trends of volumetric efficiency was seen with the increase in CR. The max volumetric efficiency was obtained with diesel whereas minimum volumetric efficiency was recorded for the B30 blend.

4.2.6 Exhaust gas temperature vs load

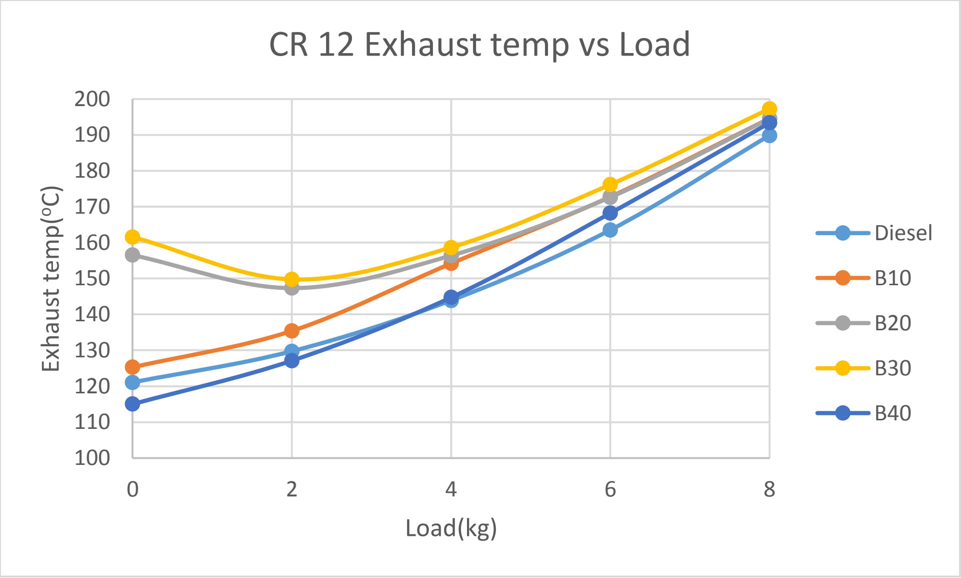


Figure 4.28: variation of EGT vs Load for diesel and different biodiesel blends at compression ratio 12:1

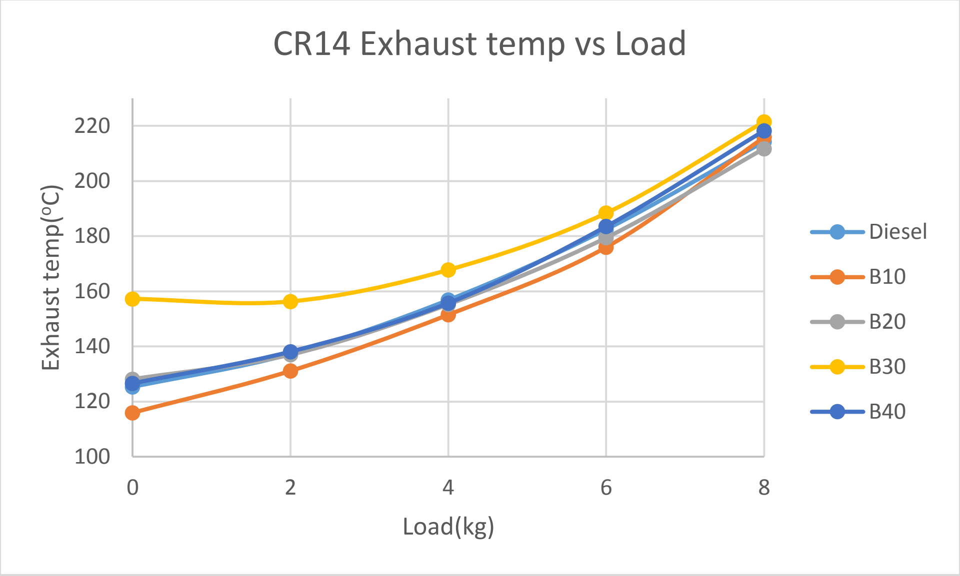


Figure 4.29: variation of EGT vs Load for diesel and different biodiesel blends at compression ratio 14:1

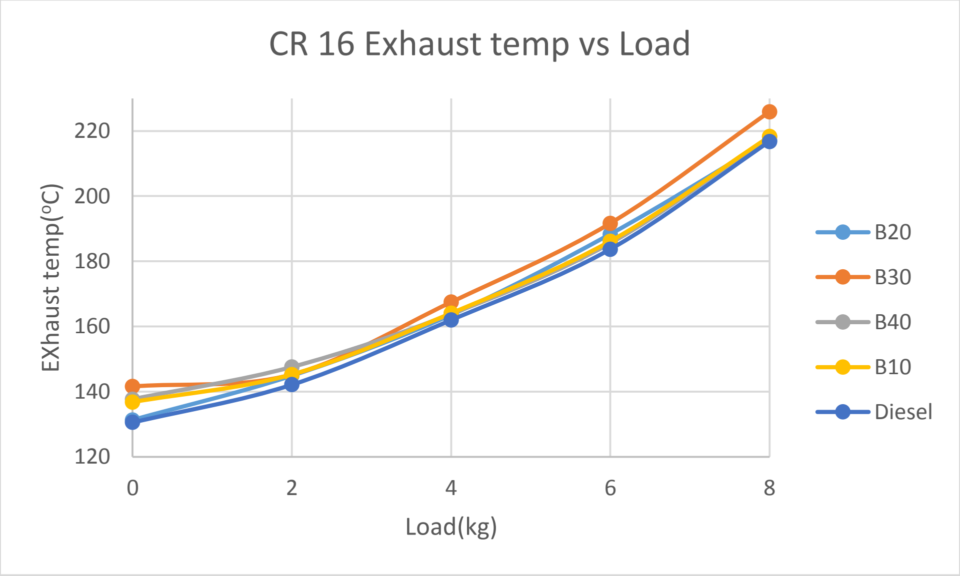


Figure 4.30: variation of EGT vs Load for diesel and different biodiesel blends at compression ratio 16:1

The above figures shows the variation of exhaust gas temperature with load for diesel and different biodiesel blends. From all the figures it can be seen that exhaust temperature of gases has shown parabolic increasing trend with increase in the load for all the CR. Similar trends for exhaust gas temperatures were also obtained by Dhar et al.2012 using neem oil based biodiesel as fuel in direct injection diesel engine and Sakthivel et al.2014 and Nayak et al. 2014 using fish oil ethyl ester and mahua oil biodiesel respectively as fuel with diesel. As the amount of biodiesel was increased from 10 to 30% the temperature of exhaust gasses has also increased at all the CR due to improvement in the combustion process as the biodiesel has more cetane number as compared to diesel. The cetane number also leads to decrease in ignition delay hence giving availability of more time for combustion process which leads to complete combustion of A/F ratio of fuels hence further giving maximum exhaust temperature. As the amount of biodiesel is increased the effect of low calorific value became more predominant. On further increase of biodiesel amount ie B40 the decrease in exhaust temperature was recorded due to lower calorific value of the biodiesel which decreases the overall heat content of fuel blend leading low exhaust temperatures.

4.3 Emissions parameters

4.3.1 CO emissions

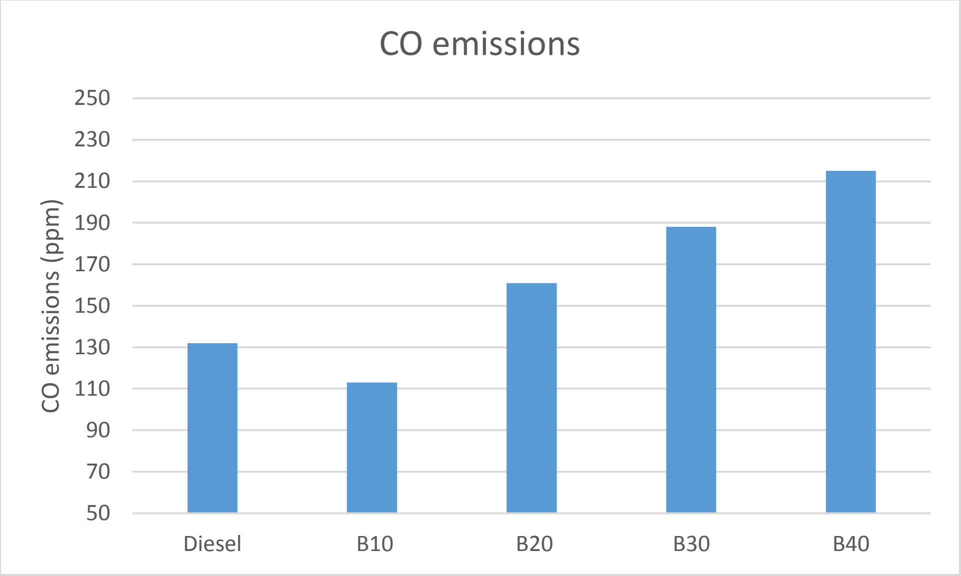


Figure 4.31: variation of CO emissions vs biodiesel blend %age for load 6 at compression ratio 14:1

The above figure shows the CO emissions for diesel and other biodiesel blends at 6 load and 14 CR. The CO emissions has decreased by 14.39% on addition of 10% biodiesel (B10). On further addition of biodiesel i.e. methyl esters the CO emissions has increased due to incomplete combustion caused by the improper mixing at higher concentrations of biodiesel. An increase of 62% was obtained in CO emissions in comparison to diesel when biodiesel was added at 40% concentration. As with increase in biodiesel amount of methyl ester increases which leads to improper combustion of mixture due to deficiency of oxygen. As on lower concentration i.e. B10 the oxygen amount was sufficient for combustion of mixture leading to lower CO emissions.

4.3.2 NOx emissions

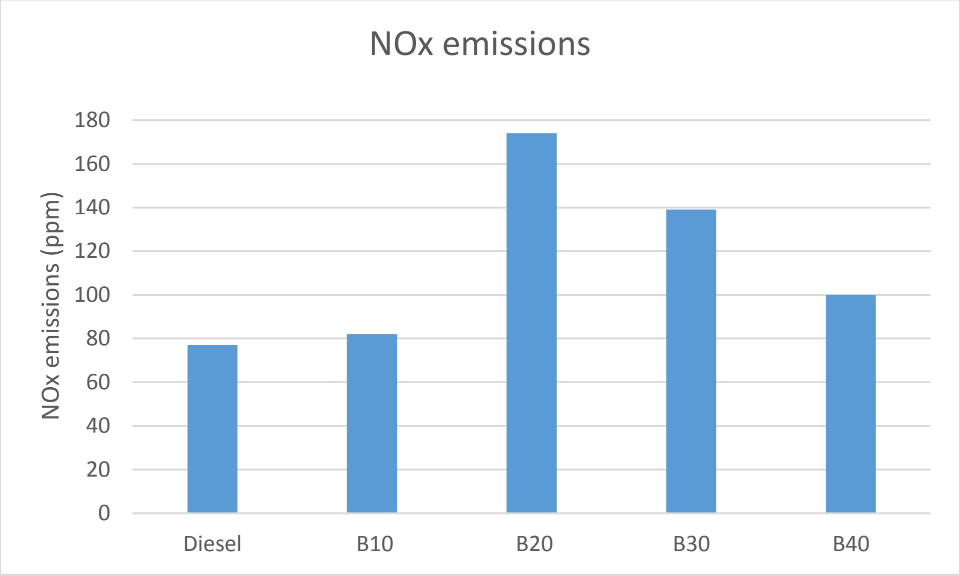


Figure 4.32: variation of NOx emissions vs biodiesel blend %age for load 6 at compression ratio 14:1

This figure shows the variation of NOx emission with the increasing biodiesel concentration in it at CR 14 at load 6 kg. A slight increase of 6.5% in NOx emission was seen on addition of 10% biodiesel concentration. The NOx emission became almost 2 times of the emissions obtained for diesel when biodiesel was added at 20% volumetric concentration. This increase was due to the proper combustion of A/F mixture which liberated maximum amount of heat due to which temperature of gases went up and lead to nitrogen present in air to combine with oxygen and increase NOx emissions. On further addition of biodiesel the NOx emissions has decreased but these were more than emissions obtained for diesel. As with increase in concentration the amount of methyl ester increases which lead to improper mixing and combustion due to lower amount of oxygen present leading to lower exhaust temperature and hence lesser NOx emissions.

4.3.3 CO_2 emissions

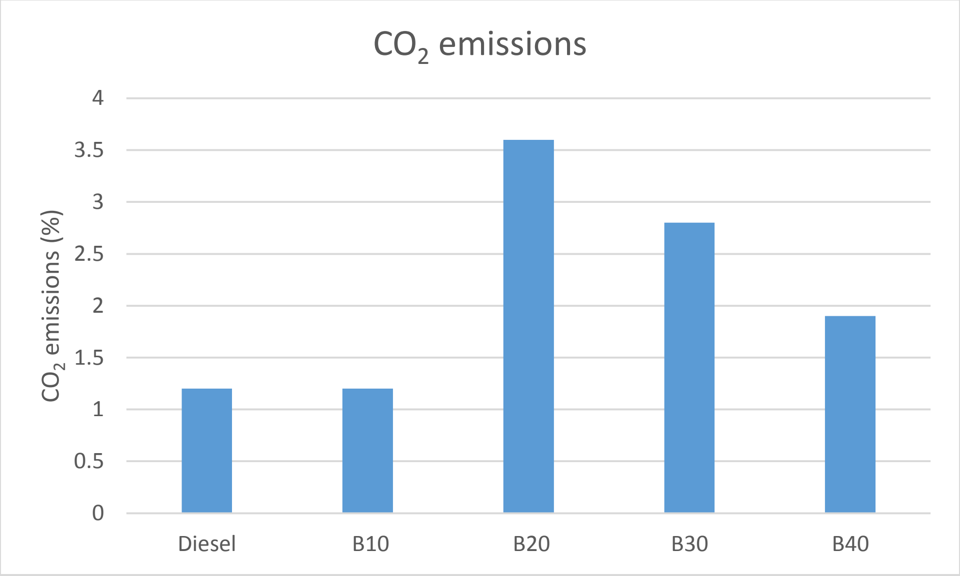


Figure 4.33: variation of CO_2 emissions vs biodiesel blend %age for load 6 at compression ratio 14:1

This figure shows CO_2 emissions with increasing biodiesel concentration at 6 load and 14 CR. The CO_2 emissions were almost same for the diesel and B10 blend. The CO_2 emissions became almost thrice of the emissions obtained from diesel because at 20% concentration of biodiesel in the blend the proper combustion of A/F mixture took place which lead to the conversion of C and CO into CO_2. The further addition of biodiesel blend has led to decrease in CO_2 emissions due to improper mixing and combustion due to high viscosity of biodiesel and oxygen deficiency respectively.

Dhar et al. 2012, Radha et al. 2011, Nayak et al. 2014, Sakthivel et al. 2014, Al_dawody et al. 2014, Solaimuthu et al. 2015 have shown mixed variation of CO, NOx and CO_2 emissions on addition of biodiesel depending upon the specific properties of the fuel, intermixing, oxygen availability, viscosity etc. The combustion characters of the fuel is also influenced by the ambient conditions such as humidity, temperature etc. of the air where experiments are being performed.

CHAPTER 5

CONCLUSION

Biodiesel was prepared from the neem oil using transesterification process which includes a two stage process first stage is acid catalyzed stage and the second stage is base catalyzed stage. In the process it was seen that the molar ratio optimum for the acid catalyzed stage was 9:1 at 1% catalyst concentration and 50^oC was found to be the optimum temperature for the process. Further it was seen by considering the affecting factors i.e. conversions and FFA values that for the second stage i.e. base catalyzed stage the optimum molar ratio was found to be 15:1 and catalyst concentration of 1% at 50^oC temperature for the production of biodiesel.

Experiments were performed on the duel fuel diesel engine using diesel and neem oil based biodiesel at different volume concentrations. Performance and exhaust emission parameters were measured during investigation at different loads and compression ratios. It has been found that the brake power has shown increasing trend with the load at all the compression ratios. Similar trend was observed for diesel as well as the biodiesel as fuel at all the concentrations. BSFC has shown decreasing trends with the load at all the compression ratios also at lower loads decrease in BSFC is more due to higher rate of increase of brake power at lower loads as compared to rate of increase in fuel consumption. Brake thermal efficiency has shown linear increasing trend with load at lower loads whereas the curve becomes almost flat at higher loads due to the small rise in the brake power at higher loads. No change in the brake thermal efficiency was found on addition of biodiesel because the biodiesel has almost same heating value and fire point to that of diesel. The mechanical efficiency has increased with increase in the load at all the compression ratios. Volumetric efficiency has shown decreasing trend with increasing load due to high engine temperatures at higher loads. The exhaust gas temperatures has increased with increase in the load due to the use of rich air fuel mixtures at higher loads. Carbon monoxide emissions has increased on addition of biodiesel to the diesel whereas NOx emissions has increased up to 20% volume concentrations and after that it has increased on further addition of biodiesel this is due to the maximum temperatures obtained in the engine because of proper combustion of air fuel mixture at this concentration. CO2 emissions has become almost thrice to that of CO2 emissions obtained for diesel, at 20% volume concentration of biodiesel whereas it has decreased on further addition of biodiesel. After analyzing the performance parameters it has been found that the brake thermal efficiency, mechanical efficiency have maximum BSFC and exhaust gas temperatures were also obtained for the same biodiesel blend (B10). The CO emissions has slightly increased on addition of B10 however it was less as compared to emissions obtained for other blends. A slight decrease in NOx emission was observed at B10 whereas NOx emission has increased for all other blends. Also CO2 emissions were similar to that of diesel for this blend (B10) however these have increased on further addition of biodiesel. From this it can be concluded that the blend B10 is optimum for the variable compression ratio compression ignition engine considering performance and exhaust emission parameters. Also it was seen that the variation in performance parameters for different compression ratios was seen to be constant at all the loads when it was seen for a particular biodiesel blend except the EGT and BSFC. These two parameters i.e. EGT and BSFC were seen to be lowest at all the loads for a particular biodiesel blend hence it can be concluded that CR 14 is optimum for the operation of the engine.

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APPENDIX: A1

Table A1.1: Molar ratio variation in acid catalyzed stage

Molar ratio variation					
Temperature	Conversions	Molar ratio	Acid conc.	Time	FFA
50	103.91	6:01	1%	35	6.12
50	88.2	9:01	1%	35	3.199
50	95.87	12:01	1%	35	1.199
50	99.2	15:01	1%	35	1.145

Table A1.2: Catalyst concentration variation in acid catalyzed stage

Catalyst Conc. variation H_2SO_4					
Temperature	Conversions	Molar ratio	Acid conc.	Time	FFA
50	96.02	12:01	0.50%	35	1.281
50	95.87	12:01	1%	35	1.199
50	95.54	12:01	1.50%	35	0.7998
50	98.03	15:01	1.50%	35	1.138
50	99.17	15:01	1%	35	1.145
50	98.11	15:01	0.50%	35	1.241

Table A1.3: Temperature variation in acid catalyzed stage

Temperature variation					
Temperature	Conversions	Molar ratio	Acid conc.	Time	FFA
45	93.25	12:01	1%	35	0.8952
50	95.87	12:01	1%	35	1.199
55	98.05	12:01	1%	35	1.599

Table A1.4: molar ratio variation for 6:1 acid catalyzed oil in base catalyzed stage

Molar ratio variation					
Temperature	Conversion	Molar ratio	Catalyst%	Time	FFA
50	75.08	9:01	1	35	0.599
50	88	12:01	1	35	0.399
50	75	15:01	1	35	0.5998

Table A1.5: Molar ratio variation for 9:1 acid catalyzed oil in base catalyzed stage

Molar ratio variation					
Temperature	Conversions	Molar ratio	Catalyst %	Time	FFA
50	94.16	9:01	1	35	0.6713
50	97.5	12:01	1	35	0.483
50	97.2	15:01	1	35	0.3161

Table A1.6: Catalyst variation in 6:1 acid catalyzed oil for 12:1 molar ratio in base catalyzed stage

Catalyst conc. variation				
Temperature	Conversions	Catalyst%	Time	FFA
50	87.05	0.5	35	0.43
50	88	1	35	0.399
50	90.5	1.5	35	0.3744

Table A1.7: Catalyst variation in 6:1 acid catalyzed oil for 15:1 molar ratio in base catalyzed stage

Catalyst conc. variation				
Temperature	Conversions	Catalyst%	Time	FFA
50	89.84	0.5	35	0.7998
50	75	1	35	0.5998
50	73.2	1.5	35	0.4237

Table A1.8: Catalyst variation in 9:1 acid catalyzed oil for 12:1 molar ratio in base catalyzed stage

Catalyst conc. variation				
Temperature	Conversions	Catalyst%	Time	FFA
50	97.8	0.5	35	0.589
50	97.5	1%	35	0.483
50	97	1.5	35	0.325

Table A1.9: Catalyst variation in 9:1 acid catalyzed oil for 12:1 molar ratio in base catalyzed stage

Catalyst conc. variation				
Temperature	Conversions	Catalyst%	Time	FFA
50	93.99	0.5	35	0.4612
50	97.2	1	35	0.3161
50	95.23	1.5	35	0.3142

APPENDIX: A2

Table A2.1: Brake power at varying load and compression ratio.

CR	LOAD	DIESEL	B10	B20	B30	B40
12	0	0	0.01	0.03	0.03	0.02
	2	0.49	0.51	0.43	0.42	0.65
	4	1.03	1.08	1.03	1.06	1.05
	6	1.6	1.64	1.71	1.62	1.7
	8	2.27	2.26	2.22	2.24	2.21
14	0	0.01	0.01	0.03	0.03	0.02
	2	0.45	0.46	0.42	0.53	0.47
	4	1.07	1.08	1.08	1.07	1.07
	6	1.71	1.67	1.65	1.66	1.63
	8	2.24	2.25	2.19	2.23	2.22
16	0	0.03	0.03	0.03	0.03	0.03
	2	0.45	0.44	0.46	0.43	0.51
	4	1.03	1.1	1.1	1.09	1.05
	6	1.64	1.71	1.66	1.66	1.65
	8	2.27	2.26	2.21	2.22	2.24

Table A2.2: Brake specific fuel consumption (BSFC) at varying load and compression ratio

CR	LOAD	DIESEL	B10	B20	B30	B40
12	0	0	0	0	0	0
	2	0.82	0.78	0.92	1.06	1.05
	4	0.48	0.46	0.48	0.52	0.52
	6	0.37	0.4	0.35	0.4	0.38
	8	0.33	0.33	0.34	0.33	0.34
14	0	0	0	0	0	0
	2	0.99	0.97	0.95	0.84	0.95
	4	0.51	0.46	0.51	0.51	0.56
	6	0.38	0.39	0.36	0.39	0.43
	8	0.33	0.35	0.34	0.36	0.36
16	0	0	0	0	0	0
	2	0.97	1.01	0.96	1.05	0.98
	4	0.52	0.48	0.5	0.5	0.52
	6	0.38	0.39	0.39	0.39	0.39
	8	0.32	0.33	0.36	0.36	0.38

Table A2.3 Brake thermal efficiency at varying load and compression ratio.

CR	LOAD	DIESEL	B10	B20	B30	B40
12	0	0.07	0.36	0.79	0.91	0.52
	2	10.48	10.93	9.3	8.09	12.5
	4	17.77	18.53	17.73	16.54	16.47
	6	22.89	21.69	24.46	21.5	22.56
	8	26.02	25.95	25.49	25.66	25.38
14	0	0.23	0.39	0.8	0.69	0.54
	2	8.67	8.84	9.03	10.16	9.02
	4	16.76	18.59	16.87	16.67	15.36
	6	22.66	22.09	23.65	22.02	20.08
	8	25.74	24.23	25.18	24.04	23.91
16	0	0.75	0.76	0.72	0.7	0.66
	2	8.57	8.48	8.89	8.2	8.78
	4	16.05	16.85	17.15	16.99	16.43
	6	23.42	21.71	22.03	21.97	21.9
	8	25.94	25.9	23.8	23.93	22.63

Table A2.4: Mechanical efficiency at varying load and compression ratio.

CR	LOAD	DIESEL	B10	B20	B30	B40
12	0	0.08	0.39	0.91	1	0.44
	2	13.49	13.79	12.24	11.64	16.2
	4	25.88	26.07	25.08	24.91	23.46
	6	34.65	34.46	35.51	34.26	33.65
	8	43.54	42.64	41.98	42.86	39.85
14	0	0.28	0.48	0.96	0.94	0.68
	2	12.79	13.32	12.37	14.73	12.32
	4	26.75	26.93	26.42	25.75	24.25
	6	36.67	36.71	36.72	34.27	34.5
	8	43.41	43.98	42.52	41.53	41.79
16	0	1.02	1.07	1.08	0.96	0.89
	2	11.83	12.71	13.35	11.71	13.45
	4	25.68	25.65	26.97	25.59	24.97
	6	35.82	35.41	36.07	34.75	34.48
	8	43.52	43.76	43.09	42.03	41.93

Table A2.5: Volumetric efficiency at varying load and compression ratio.

CR	LOAD	DIESEL	B10	B20	B30	B40
12	0	84.15	81.21	81.75	80.48	82.89
	2	83.35	80.98	81.89	80.06	81.83
	4	82.9	81.13	80.77	80.21	81.53
	6	82.88	81.02	80.62	79.51	81.17
	8	82.1	80.88	80.37	79.01	81.24
14	0	83.38	83.16	82.02	81.23	81.51
	2	84.05	82.42	81.09	80.6	81.32
	4	83.36	82.25	81.44	80.49	80.67
	6	83.43	82.2	81.62	80.59	81.01
	8	81.83	81.14	82.05	79.37	81.37
16	0	83.75	79.53	81.86	80.66	81.62
	2	82.95	79.04	81.61	80.78	81.2
	4	82.54	79.18	81.51	80.63	81.23
	6	81.78	79.12	81.51	80.86	80.74
	8	81.15	79.21	80.95	80.4	80.65

Table A2.6: Exhaust gas temperature at varying load and compression ratio.

CR	LOAD	DIESEL	B10	B20	B30	B40
12	0	121.07	125.3	156.5	161.53	115.05
	2	129.73	135.42	147.31	149.73	127.14
	4	143.88	154.19	156.38	158.63	144.74
	6	163.47	172.77	172.64	176.14	168.21
	8	189.82	194.59	194.53	197.25	193.35
14	0	125.33	115.9	128.09	157.23	126.57
	2	137.23	131.07	136.99	156.3	138.06
	4	156.81	151.46	155.22	167.74	155.67
	6	182.44	175.97	179.39	188.33	183.47
	8	214.25	215.82	211.73	221.44	218.18
16	0	130.54	136.75	131.28	141.56	137.65
	2	142.12	145.21	144.86	145.21	147.54
	4	161.96	164.02	163.52	167.43	163.81
	6	183.7	186.15	188.31	191.64	185.55
	8	216.76	218.26	217.14	225.89	218.19