Performance and Emission Characteristics of a Diesel Engine Fuelled with Biodiesel extracted from Linseed oil

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In

Thermal Engineering

By

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DECLARATION

I hereby declare that work done in this Thesis Report entitled, "Performance and Emission Characteristics of a Diesel Engine Fuelled with Biodiesel Extracted from Linseed oil" submitted towards partial fulfillment of requirement for award of degree of Master of Engineering (Thermal) at Thapar University, Patiala, is an authentic record of work carried out by me under the supervision and guidance of Dr. Madhup Kumar Mittal , Assistant Professor of Mechanical Engineering Department, Thapar University, Patiala. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

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ABSTRACT

The depleting reserves of petroleum and environmental issues have led to the search for more environmental-friendly and renewable fuels. Biodiesel obtained from various renewable sources has been recognized as one of the alternative fuel due to its biodegradability, high cetane no, no sulphur emissions and low volatility. Biodiesel derived from non edible feed stocks such as linseed oil are reported to be feasible choices for developing countries including India where consumption and cost of edible oil is very high .The aim of present work is to optimize the biodiesel production from linseed oil through tranesterification process. The optimum conditions for maximum yield were obtained at molar ratio of 5:1, reaction time 60 minutes, and at 0.5% catalyst concentration. The various performance and emission parameters like brake mean effective pressure (BMEP), brake power (BP), brake specific fuel consumption(BSFC), mechanical efficiency (Mech. Eff.), brake thermal efficiency (BthEff), CO emissions, CO_2 emissions, HC emissions, NOx emissions were evaluated at different loads and compression ratios in a 4 stroke, single cylinder variable compression ratio engine. These performance and emission parameters of diesel fuel were compared with that of B10, B15, and B20. The performance parameters of B10 blend were similar to those of diesel. It was found that CO_2, HC and CO emissions decreases as the blend content increases whereas the NO_x emissions increases as the blend content increases.

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NOMENCLATURE

MT	Million Tonnes
HHV	Higher Heating Values
CN	Cetane Number
CO	Carbon Monoxide
HC	Hydrocarbon
CO_2	Carbon Dioxide
NO, NO_X	Nitrogen Oxides
CP	Cloud Point
PP	Pour Point
ASTM	American Society of Testing and Petroleum
CFPP	Cold Filter Plugging Point
KOH	Potassium Hydroxide
FFA	Free Fatty Acid
H_2SO_4	Sulphuric Acid
^{O}C	Degree Celcius
mg	Milligram
g	Gram
NaOH	Sodium Hydroxide
BSFC	Brake Specific Fuel Consumption
BthEff	Brake Thermal Efficiency
DI	Direct Injection

INTRODUCTION

1.1 CONCEPT OF BIODIESEL

Due to scarcity and increasing costs of conventional fossil fuels, biodiesel as a fuel has become more attractive fuel. Experts suggested that current oil and gas reserves would tend to last only for few decades. To fulfill the rising energy demand and replace reducing oil reserves renewable fuel like biodiesel is within the forefront of other technologies. Biodiesel has proved to be a possible alternative for diesel in compression ignition engine. Biodiesel burns like petroleum diesel as it involves regulated pollutants. Diesel fuel can be replaced by biodiesel made from vegetable oils. Biodiesel is now mainly being produced from soybean, rapeseed, and palm oils. In developed countries, there is a growing trend toward using modern technologies and efficient bioenergy conversion using a range of biofuels, which are becoming cost wise competitive with fossil fuels [1]. India enjoys some special advantages in taking up plantation of tree-borne oil seeds for production of bio diesel due to vast unutilized land. The use of biodiesel results in substantial reduction of un-burnt carbon monoxide and particulate matters. It has almost no sulphur, no aromatics and more oxygen content, which helps it to burn fully. Its higher cetane number improves the combustion. Sunflower and rapeseed are the raw materials used in Europe whereas soyabean is used in USA. Thailand uses palm oil, Ireland uses frying oil and animal fats. In India vast research has been done on biodiesel from jatropha oil. It is proposed to use non-edible oil for making biodiesel, as consumption from edible oil is very high in India. [2]

1.2 HISTORY

The history of biodiesel is more political and economical than technological. The early 20th century saw the introduction of gasoline powered automobiles. Due to the low cost of petroleum fuels, the production of gasoline started to increase. On the other hand, resource depletion has always been a concern with regard to petroleum .Therefore work has been started on the use of vegetable oils as fuel to find a suitable alternative for petroleum fuels. Producing biodiesel from vegetable oils is not a new process. The conversion of vegetable oils or animal fats into monoalkyl esters or biodiesel is known as transesterification. Transesterification of triglycerides in oils is not a new process. Life for the diesel engine began in 1893, when the famous German inventor Dr. Rudolph Diesel designed the original diesel engine to run on vegetable oil. Dr. Diesel used peanut oil to fuel one of his engines at the Paris Exposition of 1900. Dr. Diesel ran his engine on peanut oil and declared "the diesel engine can be fed with vegetable oils and will help considerably in the development of the agriculture of the countries which use it" Vegetable oils were used in diesel engines until the 1920s. During the 1920s, diesel engine manufacturers altered their engines to utilize the lower viscosity of petro diesel, rather than vegetable oil. The use of vegetable oils as an alternative renewable fuel competing with petroleum was proposed in the early 1980s. The advantages of vegetable oils as diesel fuel are its portability, ready availability, renewability, higher heat content, lower sulfur content, lower aromatic content, and biodegradability. The commercial production of biodiesel started after 1990. Dr. Diesel believed that engines running on plant oils had potential and that these oils could one day be as important as petroleum-based fuels. Since the 1980s, biodiesel plants have opened in many European countries, and some cities have run buses on biodiesel, or blends of petro and biodiesels. More recently, Renault and Peugeot have approved the use of biodiesel in some of their truck engines. Recent environmental and domestic economic concerns have prompted the use of biodiesel throughout the world. In 1991, the European Community (EC) proposed a 90% tax deduction for the use of biofuels, including biodiesel. Biodiesel plants are now being built by several companies in Europe. [2]

1.3 PRODUCTION OF BIODIESEL

Many developed countries have active bio-diesel programmers. Currently bio-diesel is produced mainly from field crop oils like rapeseed, sunflower etc., in Europe and soybean in US. Malaysia utilities palm oil for biodiesel production. Total production of vegetable oil in 2012-2013 is around 7.45 MT [3]

Table1.1 List of vegetable oil production in India (2012-2013) [3]

Vegetable Oil	**MT**
Groundnut	0.12
Soya	1.76
Rape / Mustard	2.01
Sunflower	0.21
Palm oil	0.08
Cotton seed oil	1.13
Other oil & fats	2.14
TOTAL	**7.45**

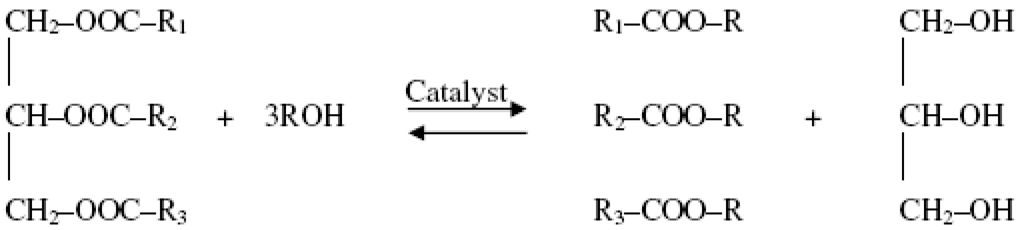
1.3.1 METHODS OF PRODUCTION OF BIODIESEL

- **THERMALCRACKING (PYROLYSIS):** Pyrolysis, defined as the conversion of one substance into another by means of heat or by heat with the aid of a catalyst [4]. It involves heating in the absence of air or oxygen and cleavage of chemical bonds to yield small molecules [5]. The chemistry of pyrolysis is difficult to characterize because of different rate of reaction and different products at the end of reaction. Pyrolyzed material can be vegetable oils, animal fats, natural fatty acids and methyl esters of fatty acids. The equipment for thermal cracking and pyrolysis is expensive. The products obtained from this process are chemically similar to petroleum-derived gasoline and diesel fuels. This process lowers the viscosity, flash point and pour point of product obtained. It also lowers the cetane number. The disadvantage of this process is that oxygen is removed at the end of the reaction which removes the environmental benefits of using oxygenated fuels.

- **MICROEMULSIFICATION:** A micro emulsion is defined as a colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the 1±150 nm range formed spontaneously from two normally immiscible liquids [6]. This process reduces the higher viscosity of vegetable oils. Micro emulsions of vegetable oils can be prepared with solvents such as methanol, ethanol, 1-butanol etc. Spray characteristics of oil are improved after this process.

- **DILUTION:** Direct use of vegetable oils or the use of blends of the oils has been considered to be not satisfactory and impractical for both direct and indirect diesel engines. The high viscosity, high acid composition, high free fatty acid content, as well as gum formation due to oxidation and polymerization during storage and combustion, carbon deposits and lubricating oil thickening are some problems which are encountered by the direct use of vegetable oils or the use of blends in the DI engines.

- **TRANSESTERIFICATION:** Transesterification (also called alcoholysis) is the reaction of a fat or oil with an alcohol to form esters and glycerol. A catalyst is usually used to improve the reaction rate and yield. Because the reaction is reversible, excess alcohol is used to shift the equilibrium to the products side. Fig 1.1 shows the tranesterification reaction with alcohol.



Triglyceride **Alcohol** **Fatty methyl ester** **Glycerol**

Fig 1.1 Transesterification reaction [7]

The alcohols which are used in this process are methanol, ethanol, propanol, butanol and amyl alcohol. Methanol and ethanol are used most frequently, especially methanol because of its low cost and its physical and chemical advantages. Methanol can quickly react with the triglycerides and the catalyst like NAOH is easily dissolved in it. Generally to complete a transesterification stoichiometrically, a 3:1 molar ratio of alcohol to triglycerides is needed. In practice, the ratio needs to be higher to drive the equilibrium to a maximum ester yield. The reaction can be catalyzed by alkalis, acids, or enzymes. The alkalis include NaOH, KOH, carbonates and corresponding sodium and potassium alkoxides such as sodium methoxide, sodium ethoxide, sodium propoxide and sodium butoxide. Sulfuric acid, sulfonic acids and hydrochloric acid are usually used as acid catalysts. Lipases also can be used as biocatalyst [8]. Alkali-catalyzed transesterification is much faster than acid-catalyzed transesterification and is most often used commercially. This process raised the cloud point and pour point. This process is use with oils having less fatty acid content. This process is generally preferred over all other process for the biodiesel production.

1.3.2 FACTORS AFFECTING PRODUCTION OF BIODIESEL

- Increase in the molar ratio of alcohol to vegetable oil increases the yield of methyl ester from vegetable oil up to a particular limit. After a higher molar ratio than a particular limit the glycerol becomes difficult to separate.
- Amount and type of catalyst also affects the conversion rate from vegetable oil to methyl ester. For oils having less fatty acid content alkaline transesterification is used and for oils having higher fatty acid content acid transesterification is used.
- Stirring helps in higher conversion rate of methyl ester from vegetable oil.
- Impurities present in vegetable decreases the conversion rate into methyl ester.

1.4 PROPERTIES OF BIODIESEL

Biodiesels are characterized by their viscosity, density, cetane number, cloud and pour points, distillation range, flash point, ash content, sulfur content, carbon residue, acid value, copper corrosion, and higher heating value (HHV). The most important variables affecting the ester yield during the transesterification reaction are the molar ratio of alcohol to vegetable oil and reaction temperature. Some of the properties of the biodiesel are discussed below.

- **VISCOSITY:** Viscosity is the most important property of biodiesels since it affects the operation of fuel injection equipment, particularly at low temperatures when an increase in viscosity affects the fluidity of the fuel. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors. The conversion of triglycerides into methyl or ethyl esters through the transesterification process reduces the molecular weight and reduces the viscosity. Biodiesels have a viscosity close to that of diesel fuels. As the oil temperature increases its viscosity decreases. The major problem associated with the use of pure vegetable oils as fuels for diesel engines is high fuel viscosity in the compression ignition. Therefore, vegetable oils are converted into their methyl esters (biodiesel) by transesterification.
- **DENSITY:** Density of biodiesel is more than the diesel therefore biodiesel should be put at the top of diesel while using in the engine as a blend otherwise it will be not mixed properly.
- **CETANE NO (CN):** Higher the cetane number better are the ignition properties of the fuel. The cetane no of biodiesel should be higher. The CN is a measure of the ignition quality of diesel fuels, and a high CN implies short ignition delay. The CN of biodiesel is generally higher than conventional diesel. The CN of biodiesel is higher because of its long fatty acid chain and more saturation content. The CN of biodiesel is generally higher than conventional diesel. CN no affects performance parameters like combustion, stability, white smoke, noise and emissions of CO and HC. Due to higher CN, combustion efficiency of biodiesel is higher.

- **CLOUD POINT:** The CP is the temperature at which wax first becomes visible when the fuel is cooled. Biodiesel has higher CP than conventional diesel fuel. The specifications for the cloud point are not provided by the ASTM D 6751 but care should be taken while using fuel in cold climates.[9]
- **POUR POINT:** It is the lowest temperature at which the fuel can flow. Biodiesel has a higher PP compared to conventional diesel [9].
- **COLD FILTER PLUGGING POINT (CFPP):** At low temperatures the fuel may start to thicken which affects the performance of fuel lines, fuel pumps and injectors. It reflects the cold weather properties of fuel therefore additives should be used to improve the CFPP.
- **FLASH POINT:** The temperature at which fuel started to ignited when exposed to flame or spark .The flash point of biodiesel is higher than the conventional diesel fuel. It is around 160^{o} for biodiesel. Flash point affects the combustion quality and low flash point is harmful to fuel pumps, seals. ASTM D 6751 specified a flash point of 130^{o} C.
- **WATER CONTENT:** water content has a negative effect on the yield of methyl esters. But it has positive effect on the formation of methyl ester using supercritical methanol method. [10]

1.5 ADVANTAGES OF BIODIESEL

The advantages of biodiesel are as follows

- It is a renewable substitute for petroleum and diesel fuels.
- It has low sulphur and aromatic content.
- It is readily available and biodegradable fuel.

- It has higher flash point than diesel.
- Its combustion efficiency is high.
- It has better lubricity properties than diesel.
- It has lower HC, CO2, CO emissions as compared to petroleum and diesel fuels.
- It has less particulate emissions than petroleum and diesel fuels.

1.6 DISADVANTAGES OF BIODIESEL

The disadvantages of biodiesel as a fuel are as follows:

- It has higher viscosity and low energy content than diesel.
- It has higher cloud and pour point.
- It has higher NO_X emissions as compared to diesel.
- It has lower engine speed and power.
- Some of the problems with biodiesel are injector coking, engine compatibility,
- High price and high engine wear.
- Fuel consumption with biodiesel is higher as compared to diesel and petroleum

1.7 LINSEED OIL AS BIODIESEL

Linseed is an important oilseed and fiber crop grown for its seed as well as which is used to manufacture linen. Global output of linseed is estimated around 2.60 million ton per year with Canada, China, U.S and India on the top of the list. Canada, the leading producer, accounts for 80% of the global trade in linseed. India is the third largest producer of linseed. In India, linseed is mainly cultivated as a rabi crop which is sown during October–November and harvested in February–April. Linseed oil mercilessly extracted from the linseed constitutes 35% on oil content in the seeds. Global production of linseed oil is estimated from 600,000 to 700,000 ton. Linseed is a cool season crop. Its cultivation is confined to low elevations, but it can be successfully grown up to 770 meters. Areas with the annual rainfall ranging from 45–75 cm are best suited for its cultivation. Biodiesel is produced from linseed oil through a process called transesterifcation, with this process the higher fatty acids are separated to methyl and ethyl esters using methanol and catalyst KOH. Since India is net importer of vegetable oils, edible oils cannot be used for production of biodiesel. India has the potential to be a leading world producer of biodiesel, as biodiesel can be harvested and sourced from non-edible oils like Jatropha, Curcus, Pongamia Pinnata, Neem, Mahua, Castor, Linseed, etc. Some of these oils produced even now are not being properly utilized. Out of these plants, Mahua and Linseed grows in arid and wastelands. Implementation of biodiesel in India will lead to many advantages like green cover to wasteland, support to agriculture and rural economy and reduction in dependence on imported crude oil and reduction. [11]

1.8 OBJECTIVES OF PRESENT WORK

The proposed study has been carried out with biodiesel derived from linseed oil with the following objectives.

1. Optimization of production of biodiesel extracted from linseed oil through transesterification process.
2. Determination of the properties of optimized biodiesel produced from linseed oil.
3. Evaluation and comparison of the various performance parameters of linseed biodiesel such as brake power, brake specific fuel consumption, brake mean effective pressure, brake thermal efficiency, mechanical efficiency with diesel fuel.

4. Evaluation andcomparison of various emission characteristics of linseed biodiesel such as hydrocarbon emissions, carbon dioxide emissions, carbon monoxide emissions and nitrogen oxide emissions with diesel fuel.

CHAPTER 2

LITERATURE REVIEW

Patil et al. [12] compared the biodiesel production from edible and non edible oils in order to optimize the biodiesel production process. A two step transesterification was used for non edible oil and single step transesterification process was used for edible oil. Yield of about 90-95% for Jatropha.curcas, 80-85% for Pongamia glabra, 80-95% canola, 85-96% for corn were obtained using KOH as a catalyst. It was founded that high FFA oils could not be transestrified with the alkali catalyst. Molar ratio of 6:1, 0.5% H_2SO_4 acid catalyzed esterification process at $40\underline{+}5^OC$, and 9:1, 2% KOH alkali catalyzed at 60^OC were favored for jatropha oil. An alkali transesterification process was applied to convert the canola and corn oil to its esters. The maximum ester yield for canola and corn was obtained at 1% and 2% alkali catalyst, 9:1methanol to oil ratio and at 60^O C and 80^OC, respectively. Further research and development on some advanced methods such as supercritical methanol process, microwave method were suggested.

Canakci et al. [13] investigated the use of low cost, high FFA feedstock's to obtain the biodiesel. Feedstock with high FFA could not be transesterified with traditional alkaline catalysts. Alkali catalysts form soaps with high FFA and removes the catalysts from the reaction which prevents the separation of glycerin and the ester.FFA content varied with the variation in molar ratio, reaction time and acid catalyst amount. The two step transesterification reduces the FFA content to less than 1%. FFA level was decreased faster by ethanol than by methanol. The acid value of yellow and brown grease was decreased to 2 mg KOH/g by two step acid catalyst pretreatment process of the mixture. In the first pretreatment step, using a 10:1 molar ratio and

30 min of reaction time, the acid value of the high FFA feedstock was reduced from 41.33 mg KOH/g to 1.37 mg KOH/g using 15% acid catalyst.$NAOH_3$ as a catalyst was more effective than KOH.

Kumar et al. [**14**] reported the study of kinetics and simulation of alkali-catalyzed transesterification of linseed oil in a batch reactor. They investigated the effects of temperature, catalyst concentration, and molar ratio on the conversion rate from triglyceride to methyl ester. The equilibrium conversions of approximately 88–96% in 40 minutes were founded. They stated that with increase in temperature by 10^{O}C an increase of 2–3% in equilibrium conversion was achieved. They observed that catalyst concentration of 0.5–1.0% had no significant effect on equilibrium conversion. An increase of 1–3% in equilibrium conversions were observed with an increase in molar ratio from 6:1 to 9:1. They estimated the overall activation energies of 6.50 kcal/mol and 6.37kcal/mol with 0.5% and 1.0% NaOH catalyst respectively .They observed that there was not any significant increase in the equilibrium conversion for molar ratio greater than 12:1. They compared the properties of non-edible oils and biodiesel produced with that of mineral diesel. They observed that due to transesterification process there was a significant decrease in kinematic viscosity of vegetable oils Due to the improvement in the other properties of biodiesel with the transesterification process they stated that the biodiesel derived from non-edible vegetable oils could prove to be a suitable alternative fuel for diesel.

Jawalkar et al. [15] investigated and compared the results of performance and emissions characteristics of single cylinder vertical direct injection Kirloskar diesel engine by using different blend of mahua and linseed oil. They founded that with an increase of injection pressure, the BthEff was increased and BSFC was reduced more for mahua biodiesel in comparison to Linseed biodiesel. They observed that as proportion of blend is increased the brake thermal efficiency was decreased. They observed that, the BthEff of M50 was 13.49% lower than that of L50 at 160 bar pressure at full load. They also observed that as the proportion of blend increased the BSFC was decreased. They investigated that CO emissions were lower for mahua oil than from linseed oil. They also observed that at 20% load, the HC emission of engine were higher for mahua oil in comparison with linseed oil.

Gandhi et al. [16] investigated the biodiesel production from crude jatropha curcas oil from transesterification process using one step alkali catalyst. They observed the effect of different molar ratio like 5.5:1, 6:1, 6.75:1, 7.5:1, and 8:1 on the yield of biodiesel. They varied reaction temperature from 50 ^{O}C to 70 ^{O}C. The maximum yield of 80.5 was observed .They founded that the yield was low due to the higher fatty acid content in crude jatropha curcas oil. They also observed that kinematic viscosity was reduced after transesterification process and the different properties were according to the ASTM specifications.

Puhan et al. [17] observed the effect of varying the injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine. They noticed that at 240 bar injection pressure, the efficiency of engine was nearly same as that of engine operated on diesel. They noticed that at 200 bar injection pressure the carbon monoxide; hydrocarbon and smoke emissions were lower than with diesel. They also noticed the nitrogen oxide emissions were slightly increased with linseed methyl ester. They analyzed that ignition delay was lower at higher injection pressure compared to diesel and also peak pressure was higher. They also founded that although thermal efficiency was higher at 240 bar injection pressure but emissions were increased. According to them this may be due to the change in fuel spray structure at higher injection pressure. They observed that thermal efficiency was decreased in compare to diesel at 200 bars. At last they concluded that the performance and emission characteristics were improved at 240 bar injection pressure with linseed methyl ester in DI diesel engine.

Raheman et al. [18] evaluated the performance of Ricardo E6 diesel engine with biodiesel from mahua oil (B100) by varying the compression ratio and ignition timing. They observed that brake thermal efficiency decreases and brake specific fuel consumption (BSFC) increases at all compression ratio (18:1 to 20:1) and injection timing (35^O- 45^O b TDC).According to them a reverse trend was observed with these parameters when there was increment in compression ratio and with advancement with injection timing. They also observed that with the blend BSFC increment and the performance was decreased. They concluded that blending could be done up to 20 % at any compression ration and injection timing. At last they concluded that MBD (100) could be used without affecting the performance of Ricardo engine at CR20 and IT b40.

Buyukkaya et al. [19] investigated the experiment results to evaluate the performance, emission and combustion of a DI diesel engine by using different blends (B5, B20, B75) of neat rapeseed oil. They observed that the smoke opacity was reduced up to 60%, and brake specific fuel consumption (BSFC) was increased up to 11% compared to diesel fuel. They envisaged that CO emissions were reduced by 9% with B5 and 32% with B100. They observed that at the maximum torque, BSFC was 8.5% higher and at the maximum rated power it was 8% higher than that of the diesel fuel. They observed that the best brake thermal efficiency of engine was achieved with B20. They described that, the use of rapeseed oil as a blend had not any positive effect on BSFC of the engine. At the same time, they observed that NOx emissions were higher with biodiesel. According to them, research is needed to for the reduction of NOx emissions. They observed a shorter ignition with the blend. They calculated the ignition delays for standard diesel, B5, B20, B70 and B100 fuels to be 8.5^O, 7.75^O, 7.25^O, $6.50^O$and 5.75^O CA respectively

Kumar et al. [20] investigated the operating characteristics of a single-cylinder four-stroke variable compression ratio engine fueled with esterified tamanu oil. They conducted the experiments at various loads like 0 kg, 3 kg, 6 kg, 9 kg, and 12 kg with engine speed of 1500 rpm and at different compression ratio from 14:1 to 18:1.They investigated the impact of compression ratio on fuel consumption, combustion parameters, and exhaust gas emissions .They analyzed the performance characteristics like specific fuel consumption, brake power, mean effective pressure, brake thermal efficiencies, and exhaust gas temperature. They also studied the emission characteristics like hydrocarbon, nitrogen oxides, carbon monoxide, and carbon dioxide emissions. They investigated the effect of intake valve closing event-timing modulation on effective compression ratio by increasing the compression ratio .According to them the BTE of the esterified tamanu oil in VCR engine was slightly higher at higher compression ratios and the SFC was lower for this condition. They observed that this was due to better combustion, and increase in the energy content of the biodiesel. The maximum BP obtained at the compression ratio 18 was 3.51 kW and SFC was 0.24 kg/kW-hr. They found that the BMEP for the esterified tamanu oil was higher at high compression ratios and lower at low compression ratio. The BthEff of the biodiesel for compression ratio 18 was 30.57% at maximum load of 12 kg. The brake thermal efficiencies were found to be increased for all compression ratios. According to them the exhaust gas temperature was decreased at higher compression ratio due the lower calorific value of biodiesel and lower temperature at the end of the compression. They observed that the hydrocarbon emissions were higher at low compression ratio and lower for high compression ratio and the emission of oxides of nitrogen (NO_X) from the esterified tamanu oil were higher for high compression ratio. They concluded that by increasing the compression ratio, the engine performance like SFC and brake thermal efficiencies were comparably better in the VCR engine. Their results proved that the esterified tamanu oil can be used in VCR diesel engine.

Aydin et al. [21] described the effects of different blends like 5% (B5), 20% (B20), and 50% (B50) of cottonseed oil methyl ester in a single cylinder, direct injection, air-cooled diesel engine at partial and full load condition. They investigated the effects of blend on the engine fuel consumption and exhaust emissions at 2000 rpm of engine speed. They observed that for both, half load engine condition and easy loaded engine operation, at 2000 rpm engine speed the BSFCS of B5 were lower than those of others fuels. According to them at partial loads, for diesel and B5 fuels the exhaust gas temperatures were found to be higher than those of B20 and B50 as a result of higher thermal efficiencies of B5 and diesel fuels. They observed that the lowest CO emissions were obtained for biodiesel blends, at 50% load due to their rich oxygen content and optimal air–fuel ratio. They stated that the NOx emissions were decreased with the use of B20 and B50 blends. They observed that SO2 emissions were decreased with increase on biodiesel content in the blend. The lowest SO2 values were found for B50 usage for all loads.

Adaileh et al. [22] measured the performance of diesel engine fuelled by a biodiesel extracted from waste cooking oil for a four stroke single cylinder diesel engine loaded at variable engine speed between 1200-2600 rpm. According to them B20 produced significant reductions in the CO, HC, and smoke emissions compared with standard diesel and B5.They observed that biodiesel had more volumetric consumption than diesel due to its more oxygen content. They investigated that exhaust emissions were reduced and performance was improved with biodiesel as fuel. They also observed that biodiesel can be safely used in engines upto lower amount of blending upto 20%. According to them after treatment of engine was required for the reduction of particulate emissions. They observed that NOx emissions were increased with the amount of blending and with the use EGR, these emissions could be reduced. They evaluated that with the increase in engine speed fuel consumption rate, brake thermal efficiency, equivalence ratio, and exhaust gas temperature were increased while at the same time the BSFCs, emission of CO2, CO and the NOx were reduced with the engine speed.

Sharma et al. [23] discussed the latest aspects of development of biodiesel. Effect of molar ratio, moisture content, reaction temperature, specific gravity, stirring had been discussed in this research paper. Apart from this biodegradability and satiability of biodiesel had also been discussed. According to their observation methanol being cheaper was the commonly used alcohol during transesterification reaction. They observed that among the catalysts, homogeneous catalysts such as sulphuric acid, sodium hydroxide, potassium hydroxide are commonly used at industrial level production of biodiesel. They also investigated the use of heterogeneous catalysts such as calcium oxide, magnesium oxide and others are to decrease the catalyst amount and production cost of biodiesel. According to them transesterification reaction can be completed even without catalyst by using supercritical methanol but it would increase the production cost of biodiesel as it was energy intensive. They observed that the molar ratio of alcohol to oil required for acid transestertification was from 6:1 and 18:1 for alkaline transesterification it ranged from 5:1 and 12:1. They observed that the temperature ranged between 45^{O}C and 65^{O}C as the boiling point of methanol is 64.7^{O}C and heating beyond this temperature would burn methanol. However, they observed that higher temperature was employed while using supercritical methanol (200^{O}C–300^{O}C). They described that a balance had to be maintained between the composition of saturated and unsaturated fatty acid in the biodiesel fuel. According to them high saturated fatty acid content would increase the oxidative stability but the pour point and cloud point were increases which is not desirable and on the other hand higher unsaturation content increased the pour point and cloud point but decreased the oxidative stability.

Jimenez et al. [24] investigated the injection characteristics like injection timing, injection delay, injection duration, mean injection rate, and injection pressure with the diesel engine. They tested different fuels like mineral diesel, neat biodiesel made from rapeseed oil, bioethanol/diesel fuel and bioethanol/biodiesel blends up to 15%. According to them for all injection characteristics the influence of bioethanol in biodiesel was much more significant that in diesel fuel. They observed that the E15B85 blend gave the best results because its injection characteristics were closest to those of diesel fuel. They observed that bioethanol fuelling in biodiesel fuel proved to be more effective than in diesel in terms of fuel consumption. They stated that biodiesel fuelling was decreased with addition of bioethanol. According to their observation injection timing was retarded and injection delay was increased with addition of bioethanol due to its lower viscosity this was the reason for the reduction of NO_X emissions. According to them injection duration was slightly increased with addition of bioethanol in diesel. They also explained the reduction of injection pressure was more in case of bioethanol addition in biodiesel than the addition of bioethanol in diesel which was also the another reason of reduction of NOX emissions. At the end they concluded that blending of bioethanol in biodiesel and diesel up to 15% was more effective than higher amount of blending.

Gumus et al. [25] studied the effects of fuel injection pressure on the exhaust emissions and brake specific fuel consumption (BSFC) of a direct injection (DI) diesel engine when it was fueled with four different injection pressure (0.18 ,0.20,0.22,0.24 bar) at different loads in terms of mean effective pressure. According to them there was an increase in exhaust gas temperature, smoke opacity, the emissions of CO_2, CO and NOx when the load on the engine was increased.

They observed that NO_X emissions were increased with blend due to increase in peak pressure .They also observed that CO emissions, UHC emissions, smoke opacity were decreased with blend because of better combustion. According to them due to lower heating value of biodiesel there was higher BSFC than diesel. According to their observation the BSFC of higher biodiesel blend was decreased when the injection pressure was increased. At the end they concluded that with the increase in injection pressure there was decrease in smoke opacity, UHC, and CO, and CO_2, O_2 and NO_X were increased.

Singh et al. [26] investigated the performance, emission and combustion characteristics of a diesel engine using different blends of methyl ester of karanja with mineral diesel in compression ignition engine. They blended karanja methyl ester with diesel in proportions of 5%, 10%, 15%, 20%, 30%, 40%, 50% and 100% by mass. They observed that, KME100 had higher brake thermal efficiencies at all load conditions compared to that of diesel fuel. Almost all blends showed slightly better BthEff than diesel at higher load conditions. According to them the higher thermal efficiencies might be due to the additional lubricity provided by the fuel blends. They observed that the BSEC (brake specific energy consumption) for KME30 was lower as compared to that of diesel fuel. The availability of the oxygen in the karanja methyl ester-diesel fuel blend might be the reason for this lower BSEC. They founded that exhaust gas temperature for KME100 was highest .They also observed that for the diesel fuel; the exhaust gas temperature was the lowest among all the tested fuels. The exhaust gas temperature rose from $135^{O}C$ at no load to $347^{O}C$ at full load for KME100, while for KME20 the exhaust gas temperature raised from $136^{O}C$ at no load to $339^{O}C$ at full load. They also concluded that the mechanical efficiency of KME30 was higher than diesel at lower loading conditions and at higher loads.

Patel et al. [27] studied the performance and exhaust emission analysis of thermal barrier coated diesel engine using rice bran oil biodiesel. They observed that by coating the combustion chamber elements with thermal barriers the performance of engine was increased and emissions were decreased. They investigated that the brake thermal efficiency was increased with load for all fuel modes. The brake thermal efficiency of rice bran oil biodiesel blend was found to be lower than diesel fuel. The brake thermal efficiency of B10, B20 and B40 was observed to be near to the diesel fuel. The maximum brake thermal efficiency of 20.0 % was observed. They described that fuel consumption was increased as the blending percentage was increased in the engine. The fuel consumption of rice bran biodiesel blends (B10, B20, B40 and B100) was found to be higher than that of the conventional diesel fuel. The variation of mechanical efficiency with load for diesel fuel was slightly increased than the biodiesel blends of B10, B20, B40 and B100. The maximum increased efficiency was found to be 10-15 % of the diesel fuel at full load. They envisaged that specific fuel consumption was decreased with brake power for biodiesel blends. According to their study the maximum SFC of B100 was higher than the diesel fuel. They observed that in comparison of diesel a slightly increased (10-15 %) of SFC was found for rice bran biodiesel blends B10, B20, B40, B100 at all loads. The indicated thermal efficiency of diesel fuel was found to be less as compared to biodiesel blends. Maximum indicated thermal efficiency was 44.8 % of B100 at 3.3 KW brake power .According to their observation the HC emissions increased with brake power for all fuel modes and these emissions decreased as the rice bran biodiesel percentage was increased. The HC emissions of B100 blends were lower than all fuel modes. They also described that CO emissions of the rice bran biodiesel blends were lower than that of diesel fuel. The minimum CO emissions were observed with the B100 blend. The NOx emissions of the rice bran biodiesel blends were low at lower loads and high at higher loads compared with the diesel fuel. B100 blends were observed less NO_X as compared to all fuel modes.

Sivalakshmi et al. [28] studied the performance and emission characteristics of a diesel engine fuelled by neem oil blended with alcohols. They observed that the brake thermal efficiency was improved with the use of neem oil–alcohol blends with respect to those of neat neem oil. The smoke intensity was observed to be reduced with the blends. The NOx emission was slightly reduced with the use of neem oil–alcohol blends. The CO and HC emissions with neem oil–alcohol blends were observed to be lower with respect to those of neat neem oil at higher loads.

CONCLUSION

Extensive work has already been done on biodiesel production from edible oils. In developing countries like India where cost and consumption of edible oil is very high, the biodiesel production from edible oils does not seems to be economically feasible. But biodiesel production from non edible oils is economically feasible due to less cost of non edible oils. However a lot of work has also been done on non-edible oils such as jatropha, neem, karanja, mahua not much work has been reported on biodiesel production from linseed oil. India is the 3^{rd} largest producer of linseed oil and awareness about the extraction of biodiesel from linseed oil is very less. Limited amount of work has been done on the optimization of biodiesel production and the evaluation of performance and emission characteristics of diesel engine fueled with linseed biodiesel. In the present study a total of 27 experiments were done for the complete optimization of linseed biodiesel production by varying the different reaction parameters. The performance and emission parameters of variable compression ratio engine fueled with three different blends of optimized linseed biodiesel were compared with those of diesel.

CHAPTER 3

EXPERIMENTAL SETUP AND METHADOLOGY

This chapter deals with the procedures and steps acquired for the preparation of biodiesel obtained from linseed oil. In this chapter, methods adopted for the measurement of different properties of optimized linseed biodiesel from three different blends (B10, B15, B20) has been discussed. These three blends were fuelled in a compression ignition (C.I.) engine. The performance parameters such as BP, Brake Thermal Efficiency (BthEff), Brake Specific Fuel Consumption (BSFC), Brake mean effective pressure (BMEP) and Mechanical efficiency (MechEff) are measured. Emission parameters such as Carbon Monoxide (CO), Carbon Dioxide (CO_2), Un-burnt Hydro carbon (UHC), Nitrogen Oxides (NOx) are also evaluated. These performance and emission parameters of Linseed biodiesel are compared to those of pure diesel.

3.1 PRODUCTION OF BIODIESEL

- Linseed oil was purchased from PARDEEP TRADERS, LUDHIANA @ 100 Rs per liters. Biodiesel was prepared in the laboratory at Mechanical Engineering Research and Development Organization (MERADO) Ludhiana, Punjab (India). Various materials like potassium hydroxide (KOH), sodium hydroxide (NAOH), methanol, ethanol, phenolphthalein, were used in the preparation of biodiesel.

  Various steps used in preparation of biodiesel from linseed oil are described as below:

- Firstly the required sample of linseed oil was taken in a conical flask and preheated to 60^oC.

- Then methanol (by volume) and KOH (by weight) was mixed and stirred in a separate conical flask.
- After that the stirred sample was added in the preheated linseed oil sample and again mixed properly by stirring.
- This mixture was then constantly stirred for different reaction time (30 min, 45min, and 60min) at a constant temperature of 60 ^{O}C inside a water bath shaker.
- After this the stirred sample was taken out and was poured in a separating funnel to separate the glycerol from the methyl ester.
- After 24 hours the glycerol was removed and separated to obtain the methyl ester.
- For the purification purpose methyl ester was washed and dried to remove the excess methanol, KOH, and other impurities.

Fig 3.1 shows separation of glycerol from linseed methyl ester in a separating funnel.

Fig 3.1 Separation of methyl ester at different KOH concentration

The steps mentioned above are repeated for different molar parameters like molar ratio (5:1, 6:1, 7:1) with different KOH concentration (0.5%,0 .1%, 1.5%) at different reaction time of 30 min, 45 min, 60 min. The total 27 samples were prepared by using these parameters and these samples were compared on the basis of maximum conversion yield, minimum viscosity, and minimum fatty acid content.

3.2 DETERMINATION OF PROPERTIES OF THE BIODIESEL

Estimation of the following properties of the produced biodiesel is discussed as below:

- Kinematic viscosity
- Calorific value
- Flash point
- Fire point
- Cloud point
- Pour point.
- Ash content
- Carbon residue

3.3 APPARATUS USED FOR ESTIMATION OF PROPERTIES

The following apparatus were used for the estimation of properties of the biodiesel produced from the linseed oil.

3.3.1. The redwood viscometer: The redwood viscometer as shown in Fig 3.2 is commonly used for determination of viscosities of lubricating oils. This instrument does not give a direct measure of viscosity in absolute units but it enables the viscosities of oil to be compared by measuring efflux of 50 ml of oil through the standard orifice of the instrument under standard conditions.

Fig 3.2 The Redwood Viscometer

The procedure to determine viscosities of biodiesel by using redwood viscometer is as below:

Level the instrument with the help of the leveling screws on the tripod. Fill the water bath with water to the height corresponding to the tip of the indicator up to which the oil is filled in the cylindrical cup. Keep the brass ball in position so as to seal the orifice. Then pour the oil under test carefully into the oil cup up to the tip of the indicator. Keep the 50 ml flask in position below the jet. Keep the oil and water well stirred and note their temperatures. When the temperature of the oil and water are steady, raise the ball valve and suspend it from the thermometer bracket. Simultaneously start a stop watch .When the level of oil dropping into the flask reaches the 50 ml mark, stop the watch and note the time in seconds. Replace the ball valve in position to seal the cup to prevent overflow of the oil. Refill the oil into the indicator tip of the oil cup and repeat the experiment two more times. Mean of these three readings is calculated as t_m(s).

If t_m <34

$$V = 0.24 * t_m – 50/t_m \qquad (3.1)$$

If t_m(s) >34

$$V = 0.26*t_m - 179/t_m \qquad (3.2)$$

Where t_m is mean time in seconds

V is kinematic viscosity in centi stokes.

3.3.2 Bomb calorimeter: The gross heat of combustion of fuel samples was determined as per IS: 1448 [P: 6]: 1984 with the help of a Widson Scientific Works make Isothermal Bomb Calorimeter (Plate 3.4). A fuel sample of 1 ml was burnt in the bomb of calorimeter in the presence of pure oxygen. The sample was ignited electrically. As the heat was produced, the rise in temperature was measured. The water equivalent (effective heat capacity of the calorimeter) was also determined using pure and dry benzoic acid as test fuel. Each sample was replicated three times. The gross heat of combustion of the fuel samples was calculated using the equation given below:

$$Hc= (Wc*\Delta T)/Ms \qquad (3.3)$$

Hc = Heat of combustion of the fuel sample, Cal / g

Wc = Water equivalent of the calorimeter, Cal /^{O}C

Δ T = Rise in temperature,^{O}C

Ms = Mass of sample burnt

Fig 3.3 shows the bomb calorimeter used for determining the calorific value of linseed biodiesel.

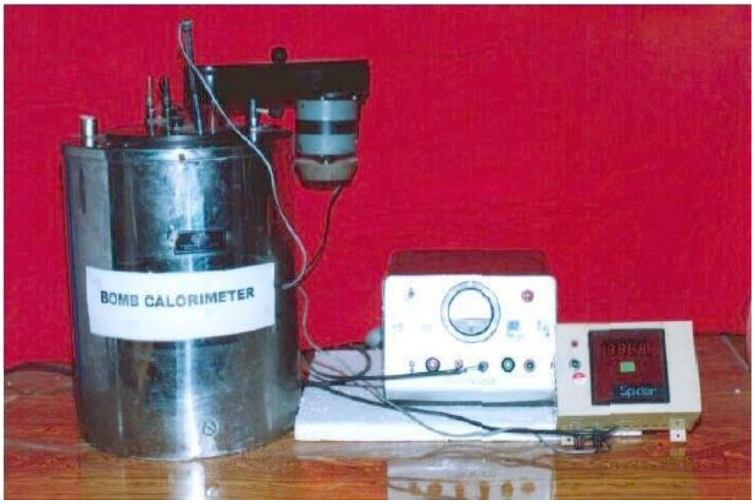


Fig 3.3: The bomb calorimeter

3.3.3 Pensky Martin (closed) apparatus: The flash and fire point of the fuel samples were determined as per IS: 1448.The oil sample under test was poured into the oil cup up to the mark. The apparatus used for determing the flash and pour point is shown in Fig 3.4.

Fig 3.4: PenskyMartin apparatus

The fuel sample was stirred at a slow constant rate. The apparatus is heated so that the oil temperature increases by about 5 to 6^{O}C per minute when the stirrer is rotated at approximately 60 revolutions per minute. The temperature was measured with the help of a thermometer of -10 to 400^{O}C range. At every 1^{O}C range, flame was introduced for a moment with the help of a shutter. The flash point was taken as that minimum temperature at which, on introducing the test flame into the oil cup a distinct flash was observed. The fire point was recorded as the temperature at which fuel vapor catches fire and stays for minimum of five seconds.

3.3.4 Cloud and pour point apparatus: The Cloud and Pour point of fuel samples were determined as per IS: 1448 [P: 10]: 1970 using the Cloud and Pour point apparatus. The apparatus mainly consists of 12 cm high glass tubes of 3 cm diameter. These tubes are in an air jacket, which is filled with a freezing mixture of crushed ice and sodium chloride crystals. The oil was pour into the test jar to a height of about 5 cm. Thermometers were introduced in the oil and the cooling bath. At every degree fall of the oil temperature, the test jar was momentarily withdrawn for examination and replaced immediately. The process was continued until at a particular temperature of the oil, cloudiness or haziness appeared in the oil near the bottom of the test jar. This temperature was taken as the cloud point of the oil under test.

The apparatus and the procedure for the pour point are same as for cloud point; only the sample was pre-heated to 48^{O}C and then cooled to 35^{O}C in air before it was filled in the glass tube. Thereafter, the cooled samples were placed in the apparatus and withdrawn from the cooling bath at 10^{O}C interval for checking its flow ability. The pour point was taken to be the temperature at which no motion of fuel was observed for five seconds on tilting the tube to a horizontal position. Three replications were made for each fuel type. The apparatus used for determining cloud and pour point is illustrated in Fig 3.5.

Fig 3.5 cloud and pour point apparatus.

3.3.5 Ash content apparatus: Ash in a fuel can result from oil, water soluble material compounds or extraneous solids, such as dirt and rust. The ash content of diesel, linseed oil and its blends with diesel was measured as per the standard ASTM D482-IP 4 of Institute of Petroleum, London. An electric muffle furnace of Wiswo make was used in the experiment. In order to measure the ash content, sample was taken in a silica dish. The dish was first weighed empty and then with the fuel sample. The sample weight was obtained from the difference between the initial and final weight of the dish. The sample was then placed in the muffle furnace and heated at 775 ± 25^{O}C two hours. The dish was then cooled to room temperature in a desiccator. Thereafter, the dish was weighed to the nearest 0.01 mg using an electronic balance. Each sample was replicated three times. The ash content was obtained using the equation given below.

$$As = (Wa/Ws)*100 \qquad (3.4)$$

Where

As= Ash content in percentage

Wa =Weight of ash in miligrams

Ws=Weight of sample in miligrams.

3.3.6 Rams bottom apparatus The measurement was made in accordance with the ASTM D189IP 13 of Institute of Petroleum, London. This procedure determines the amount of carbon residue left after evaporation and pyrolysis of an oil. It is intended to provide some indication of relative weight of the oil taken was determined. The bulb was then placed in a sheath consisting of an iron tube which is about 76 mm long and 25.5 mm internal diameter, having a flat closed end. The sheath was immersed in bath of molten lead to a depth of not less than 72 mm, and then the lead bath was heated to 550 ^{O}C for 20 minutes. The bulb was then taken out, cooled and weighed. The result was reported as % carbon residue of the weight of linseed oil taken for the experiment. The following equation is used to determine the % carbon residue in the oil.

% of carbon residue in the oil= $(W2/W1)*100$ (3.5)

W1= weight of the oil taken for test, g

W2=weight of the carbon residue deposited, g

The apparatus used for determining the carbon residue content in the sample is illustrated in the Fig 3.6.

Fig 3.6 Carbon residue (rams bottom) apparatus

3.3.7 Acid value: The acid value or number defined as the mg KOH required to neutralize the free fatty acid present in one gram of sample. The total acid value of different fuel samples was measured as per method describe by Cox and Pearson, 1962. The procedure described below was followed in order to determine total acidity of various fuels selected for the study:

- Dissolve 1 to 10 g of oil in 50 ml of the neutral solvent (neutral solvent is the mixture of 25 ml ether, 25 ml alcohol and 1 ml of 1% phenolphthalein solution and neutralize with N/10 alkali) in a 250 ml conical flask.

- Add a few drops of phenolphthalein.

- Titrate the contents against 0.1N KOH.

- Shake constantly until a pink color which persists for 15 seconds is obtained.

During the course of study, each sample was replicated three times. The total acidity of a fuel sample was then calculated using equation given below:

$$Av = (56.1N*Tv)/Ws \qquad (3.5)$$

Av = Acid value, mg of KOH/g

Tv = Titrate value, ml

N = Normality of the potassium hydroxide solution

Ws = Weight of sample in grams.

3.4 EQUIPMENTS USED FOR EVALUATION OF THE ENGINE PERFORMANCE

The experiments for determining engine performance and emissions were performed in internal combustion engine lab and SAI lab at THAPAR UNIVERSITY PATIALA. The following engine and engine accessories were used for experiments.

3.4.1 The variable compression ratio ignition engine: A single cylinder, water cooled variable compression ratio ignition engine was used. The following engine performance parameters were analyzed:

- Brake power (BP)
- Brake mean effective pressure (BMEP)
- Mechanical efficiency (MechEff)
- Brake thermal efficiency (BthEff)
- Brake specific fuel consumption. (BSFC)

The variable compression ratio engine used for experiments is illustrated in Fig 3.7.

Fig 3.7 variable compression ratio engine

The specifications of engines used in the present study is shown in table 3.1

Engine specifications	
MODEL	TV1(KIRLOSKAR)
TYPE	Single cylinder 4 strokes, Water cooled.
Compression ratio	12 to 18
Rated power	3.5 KW @1500 rpm
Bore	87.5 mm
Stroke length	110 mm

Connecting rod length	234 mm
Orifice diameter	20 mm
Dynamometer	Eddy current type
Dynamometer arm length	145 mm
Load indicator:	Digital, Range 0-50 Kg, Supply 230V AC
Load sensor	Load cell, type strain gauge, range 0-50Kg
Speed indicator	Digital with non contact type speed sensor
Temperature sensor	Thermocouple, Type K
Rota meter	Engine cooling 40-400 LPH; Calorimeter 25-250 LP

3.4.2 Eddy current dynamometer: The engine was coupled with an eddy current dynamometer to measure power and torque. With the help of a load cell connected to the dynamometer ,various loads i.e. 0 kg, 2 kg, 4 kg, 6 kg were applied on the engine. Load sensor was connected with load cell which indicated the load on the load indicator. The SAJ make AG 20 eddy current dynamometer was used for present evaluation. The construction of eddy-current dynamometer has a notched disc (rotor) which is driven by a prime mover (such as engine, etc.) and magnetic poles (stators) are located outside with a gap. The coil which excites the magnetic pole is wound in circumferential direction. When current runs through exciting coil, a magnetic flux loop is formed around the exciting coil through stators and a rotor. The rotation of rotor produces density difference, then eddy-current goes to stator. The electromagnetic force is applied opposite to the rotational direction by the product of this eddy-current. Fig 1.8 illustrates the eddy current dynamometer.

Fig 3.8 eddy current dynamometer

3.4.3 Horiba analyzer: Hydrocarbon (HC) emissions were analyzed by horiba analyzer. It has its own individual sensors. In this, one end of cable is connected to the inlet of the analyzer and the other end is connected at the end of the exhaust gas outlet. The horiba analyzer is illustrated in Fig 3.9.

Fig 3.9 Horiba gas analyzer

3.4.4 Flue gas analyzer (KM9106): The emission parameters such as carbon monoxide (CO), Nitrogen oxide (NO) and carbon dioxide were evaluated by this analyzer. The flue gas analyzer is illustrated in Fig 3.10

Fig 3.10 Flue gas analyzer

3.5 PROCEDURE OF EXPERIMENT

The experiment was performed firstly with the diesel and then with three different blends of linseed oil (B10, B15, and B20).The steps used are described as below:

- Firstly the diesel was filled in a fuel tank.
- Initially the compression ratio of 12:1 was adjusted.
- After setting the water supply, the cooling water and calorimeter flow was set up at 300 LPH and 70 LPH respectively.
- All the election connections were checked properly and then the electric supply was started.
- The engine performance analysis software package "Engine soft" for on screen performance analysis was opened.
- Then the valve provided at the burette was opened to supply the diesel to the engine.
- Then engine was started and ran for few minutes at no load conditions.
- The log option of the software was selected after that fuel supply was turned on. After one minute the display was changed to input mode and then value of flow of water in cooling jacket and calorimeter was entered. The first reading for the engine was noted for no load condition. Then the fuel knob was turned back to regular position.
- The same steps were repeated for different loads.
- All the readings were saved and then same procedure was done for 14:1 compression ratio.
- The compression ratio was changed by changing the screw arrangement.
- The same procedure was done for 16:1 compression ratio

- After noting all the readings engine was brought to no load conditions and after that engine and computer was turned off to stop the experiment. The fuel supply was also stopped after some time.

3. Precautions taken during experiment.

- All the nuts and bolts are checked properly before starting the engine.
- Care was taken to ensure the proper oil level in the tank of the engine.
- The engine was continuously attended so that during the power failure, the supply of cooling water to the engine and dynamometer may not be stopped.
- Fuel tank and fuel line was cleaned properly.
- Before starting the engine it was ensured that water supply was on.
- Sensitive instruments like pressure crank angle and other sensors were handled carefully.

3.7 Exhaust emission evaluation

The exhaust emission parameters were analyzed by the horiba and flue gas analyzer. The exhaust emissions parameters with their respected test methods are given in Table 3.2

Table 3.2 Emission parameter test method

S.NO.	Parameters	Test methods
1.	Hydro carbon as HC (ppm)	Horiba analyzer.
2.	Carbon monoxide as CO (ppm)	Flue gas analyzer(KM9106)
3.	Nitrogen oxides (NO) as NO_X (ppm)	Flue gas analyzer(KM9106)
4.	Carbon dioxide as CO_2 (%)	Flue gas analyzer(KM9106)

Experimental procedure for exhaust evaluation:

- Sensors were inserted into the provided outlet for exhaust gases for the required load condition.
- The analyzer was attached to the exhaust outlet and the exhaust gases were passed to the analyzer with the help of sensors.
- After this the displayed three readings on the digital screen of analyzer were noted.
- Mean value of these three readings were calculated.
- Then the sensors were removed.
- The above steps are repeated for different fuels and different load conditions.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Experimental Results

The experiments results are grouped into three categories as given below:

- Optimizing of tranesterification of linseed oil.
- Comparison of diesel and its blends on performance parameters.
- Comparison of diesel and its blends on emissions parameters.

4.1.1 Optimizing of tranesterification of linseed oil: The optimization of production of biodiesel from linseed oil from tranesterification process was evaluated on varying the various parameters such as reaction time, KOH concentration and molar ratio. By varying these reaction parameters, a total of 27 samples were prepared. The reaction temperature for transesterification process was kept at 60^{O}C. On comparing these samples on the basis of minimum viscosity, maximum yield and minimum fatty acid content, the optimized result was obtained at molar ratio of 5:1, 0.5% KOH and at a reaction time of 60 minutes. The maximum yield of 98% was obtained at these coditions. The FFA content and viscosity at the optimized conditions were evaluated as 0.0705 and 4.376 centi poise respectively. The table for the complete process optimization of tranesterification process is shown as below:

Table 4.1 Optimization table for the production of biodiesel from linseed oil

S.N0.	molar ratio	Linseed sample (ml)	KOH (%)	methanol (ml)	reaction time (min.)	reaction temp(^{O}C)	yield (%)	FFA (%)	Viscosity (centi stokes)
1	5:1	200	0.5	40	30	60	57	0.197	5.301

2	5:1	200	1	40	30	60	81	0.141	5.204
3	5:1	200	1.5	40	30	60	86	0.169	5.063
4	5:1	200	0.5	40	45	60	98	0.141	4.824
5	5:1	200	1	40	45	60	95	0.169	4.337
6	5:1	200	1.5	40	45	60	65	0.141	4;345
7	**5:1**	**200**	**0.5**	**40**	**60**	**60**	**98**	**.0705**	**4.376**
8	5:1	200	1	40	60	60	92	0.112	4.202
9	5:1	200	1.5	40	60	60	70	0.126	4.136
10	6:1	210	0.5	35	30	60	73	0.098	5.899
11	6:1	210	1	35	30	60	84	0.084	4.717
12	6:1	210	1.5	35	30	60	94	0.112	4.674
13	6:1	210	0.5	35	45	60	96	0.126	5.611
14	6:1	210	1	35	45	60	68	0.112	5.324
15	6:1	210	1.5	35	45	60	78	0.846	4.254
16	6:1	210	0.5	35	60	60	96	0.169	4.932
17	6:1	210	1	35	60	60	72	0.098	4.133
18	6:1	210	1.5	35	60	60	84	0.126	4.097
19	7:1	210	0.5	30	30	60	95	0.098	4.531
20	7:1	210	1	30	30	60	79	0.169	4.624
21	7:1	210	1.5	30	30	60	74	0.112	4.537
22	7:1	210	0.5	30	45	60	95	0.112	6.104
23	7:1	210	1	30	45	60	93	0.155	4.865
24	7:1	210	1.5	30	45	60	90	0.098	4.531
25	7:1	210	0.5	30	60	60	83	0.169	4.932
26	7:1	210	1	30	60	60	81	0.098	4.133
27	7:1	210	1.5	30	60	60	73	0.112	4.388

The various properties of optimized biodiesel were compared with those of diesel and according to the specifications provided by ASTM standards. It was observed that properties of linseed biodiesel given in Table 3.4 were conforming to the latest biodiesel standards. The calorific value of optimized linseed biodiesel was 9262 kcal/kg which is 7.9 % lower than diesel fuel. The flash and fire point of linseed biodiesel were observed to be higher than of diesel fuel. The cloud and pour point were also observed to be lower for biodiesel fuel.

Table 4.2 Properties of diesel and linseed biodiesel according to ASTM standards.

Property of oil	ASTM standards	Diesel	Linseed(B100)biodiesel
Density kg/m^3	------------	850	875.8
Kinematic viscosity (cSt)	1.9-6.0	2.049	4.336
Flash point, ^{O}C	>130	78	154
Fire point, ^{O}C	>53	83	160
Cloud point, ^{O}C	-3 to 12	<10	-2
Pour point, ^{O}C	-15 to 10	-6	-6
Calorific value, kJ/kg	> 33000	42000	38896.2
Carbon residue, (%)	<0.05	0.0214	0.0179%
Ash content,%	0.02% max	0.02	0.02
FFA, %	<2.5	-----	0.0705
pH	-----	-------	7.7

4.2 Effect of parameters on transesterification of linseed oil.

The effect of various parameters such as catalyst concentration, reaction time, molar ratio etc. on production of biodiesel from linseed oil through transesterification process is presented in this section.

4.2.1 Effects of catalyst concentration and reaction time on methyl ester formation

In the present study, KOH was chosen to catalyze the reaction due to its relatively low cost. The experiments were conducted with varying catalyst concentrations and reaction times using a methanol-to-oil molar ratio of 5:1 and a reaction temperature of 60^{O}C. The effects of these variables on the methyl ester formation are shown in Fig. 4.1

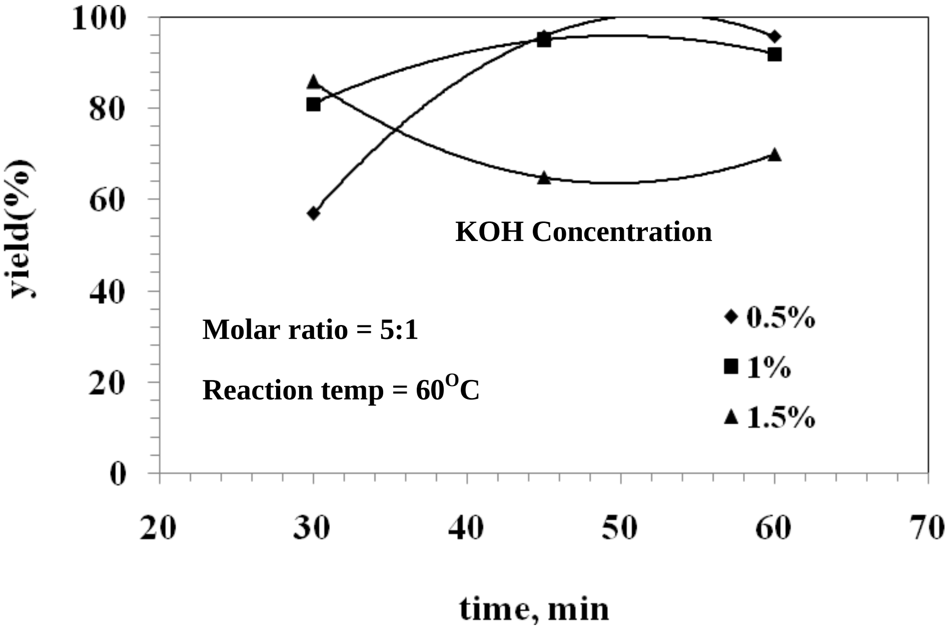


Fig 4.1 Variation of ester yield with reaction time and KOH concentration at 5:1 molar ratio

The results show that the catalyst concentration had a significant effect on tranesterification. As the catalyst concentration is increased from 0.5% to 1.5%, the methyl ester content increases from 57% to 86% at a reaction time of 30 minutes. Further increase in catalyst concentration decreases the ester yield because of incomplete reaction due to soap formation at higher catalyst concentrations. The reason is that high FFA content in the oil deactivates the catalyst and the addition of excess catalyst as compensation gives rise to the formation of emulsion (Ma and Hanna, 1999) which increases the viscosity, leading to the formation of gels and problem associated with glycerol separation and loss in ester yield [29].

It is also observed that as the reaction time is increased from 30 minutes to 45 minutes, the yield increases or decreases depending upon the catalyst concentration. Beyond a reaction time of 45 minutes, the maximum rise in yield is obtained with the catalyst concentration of 0.5%. The maximum yield is found to be 98% at catalyst concentration of 0.5% with reaction time of 45 minutes and the yield remains almost constant till the reaction time is increased up to 60 minutes.

The effect of catalyst concentration on ester yield at molar ratio of 6:1 and 7:1 are shown in Fig 4.2 and 4.3 respectively. These figures illustrates that the effect of catalyst concentration on ester yield has the similar trend as shown in Fig 4.1 at molar ratio of 5:1.

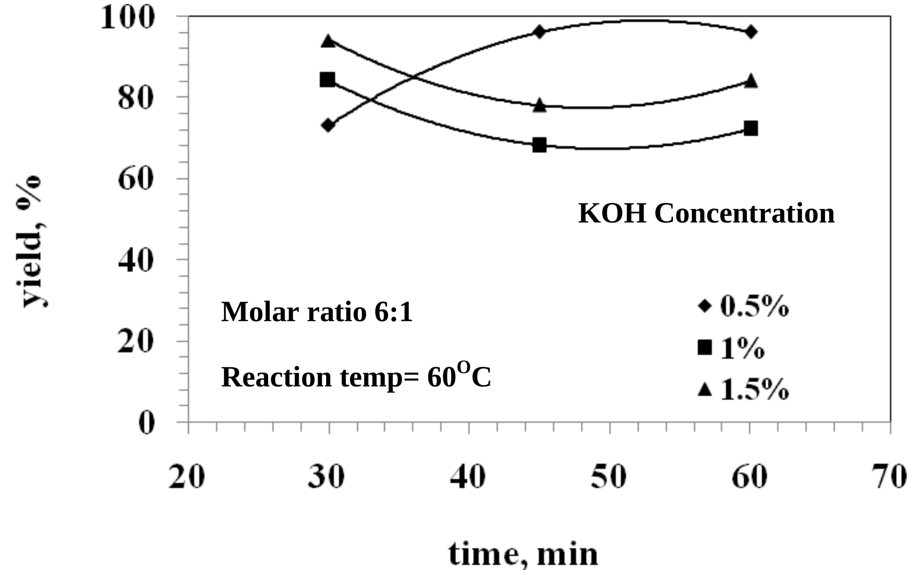


Fig 4.2 Variation of ester yield with reaction time and KOH concentration at 6:1 molar ratio

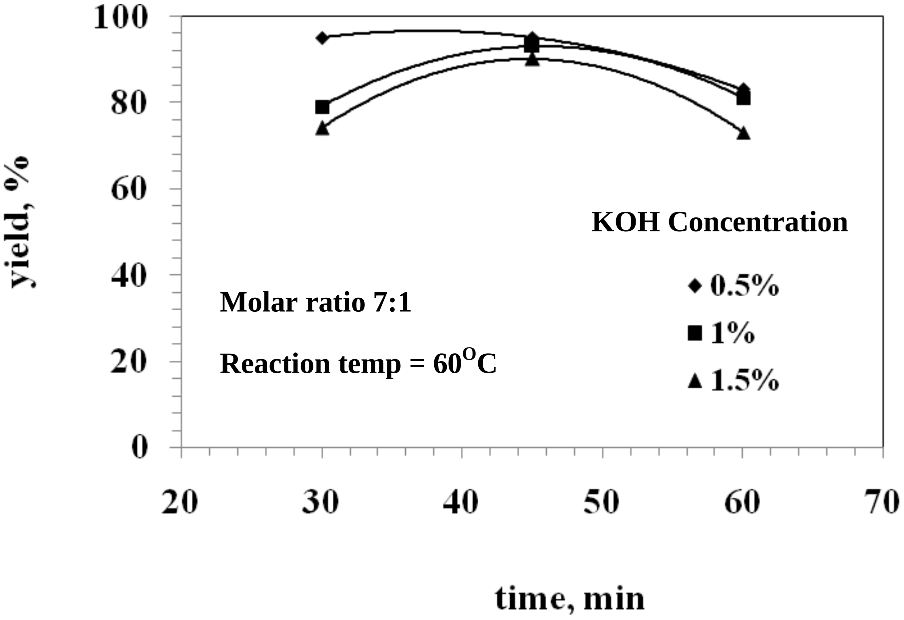


Fig 4.3 Variation of yield with reaction time and KOH concentration at 7:1 molar ratio

4.2.2 Effects of molar ratio and reaction time on methyl ester formation

Out of these values of catalyst concentration, the maximum yield is observed with catalyst concentration of 0.5%, therefore Fig 4.4 is drawn to evaluate the effect of molar ratio on yield at a catalyst concentration of 0.5%. The effect of molar ratio and reaction time is illustrated in Fig 4.4. It was observed that the yield increases as the molar ratio increases from 5:1 to 7:1 at a reaction time of 30 minutes. This is because as transesterification reaction is reversible in nature therefore excess methanol is required to force the equilibrium towards completion to obtain high yield of methyl ester. But higher molar ratio is generally not preferred because of increase in energy consumption for recovering unreacted methanol. In addition excessive methanol dissolves in by product glycerin which makes the separation difficult. It was also observed that maximum yield of 98% was obtained with molar ratio of 5:1 at reaction time of 45 minutes and 60 minutes.

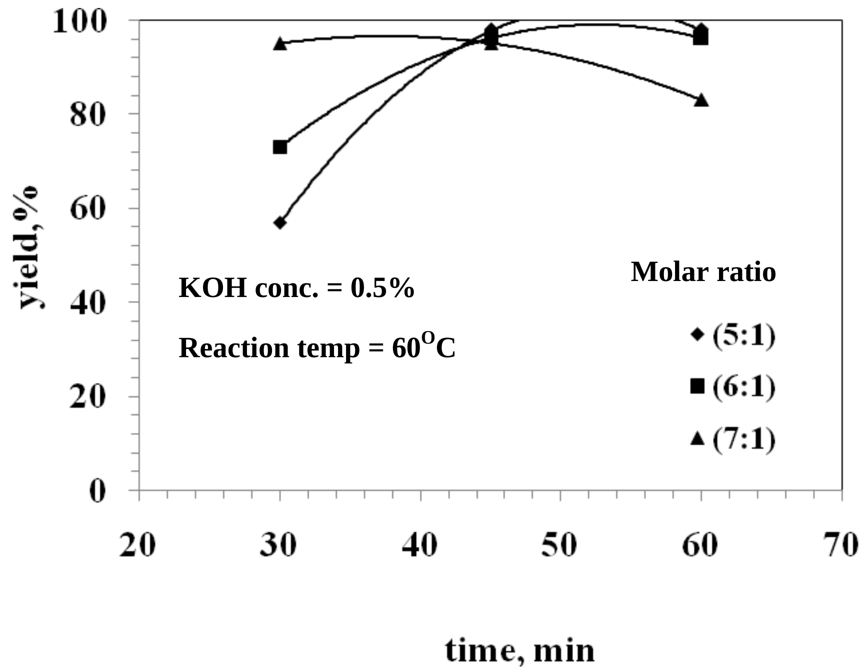


Fig 4.4 Variation of yield with reaction time and molar ratio at .5% KOH concentration

4.2.3 Effects of molar ratio and reaction time on viscosity of methyl ester

The effect of increasing KOH concentration and molar ratio on viscosity is illustrated in the figure 4.5. It was observed that the viscosity increases as the molar ratio increases from 5:1 to 7:1. Increase in molar ratio increases the solubility of methanol in glycerin due to which separation becomes difficult and glycerin remains in solution which increases the viscosity. It was also observed that viscosity decreases with increase in reaction time due to removal of more glycerol during separation. Minimum viscosity was observed at molar ratio of 5:1 at reaction time of 60 minutes.

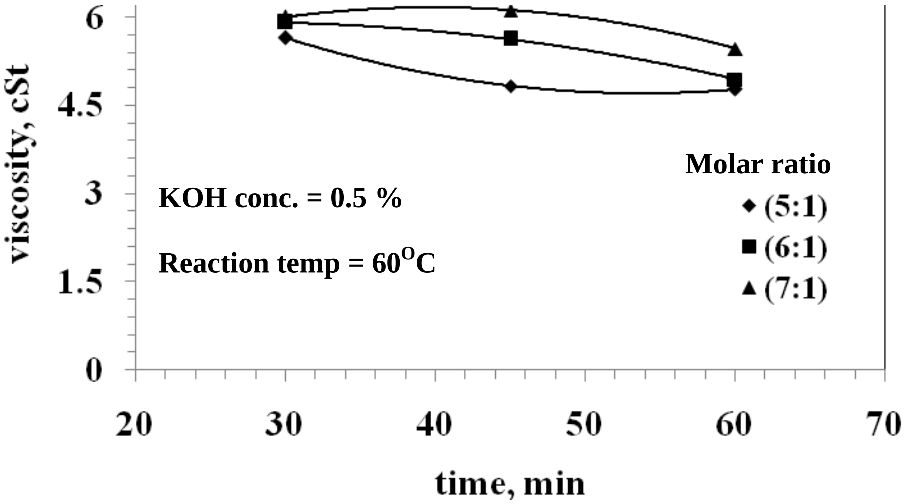


Fig 4.5 Variation of viscosity with time and molar ratio at 0.5% KOH concentration

4.2.4 Effects of molar ratio and reaction time on FFA content of methyl ester.

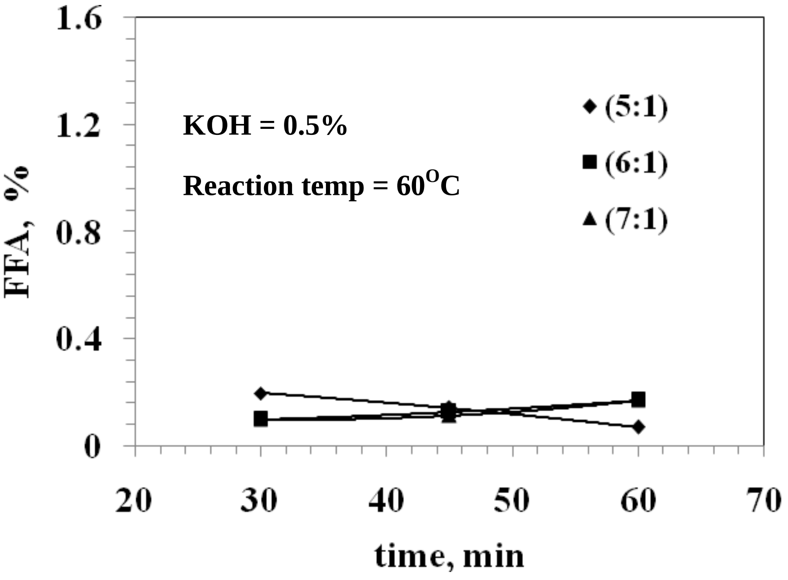


Fig 4.6: Variation of FFA content with reaction time and molar ratio

Out of three molar ratio (5:1 to 6:1), the FFA content for 5:1 at 60 minutes was observed to be lower as shown in Fig. 4.6. As the reaction time increased the FFA content was also observed to be decreased. Therefore due to due to higher viscosity, lesser FFA content and lower viscosity optimum conditions for biodiesel production were obtained at molar ratio of 5:1, reaction time of 60 minutes and at .5% KOH concentration

4.3 Engine Performance and Emission parameters of Linseed Oil and its Blends

The experiments were performed with the diesel, B10, B15 and B20 at different compression ratio (CR12, CR14, CR16) in the variable compression ratio engine. The performance parameters like brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BthEff), mechanical efficiency (MechEff), brake mean effective pressure (BMEP), cylinder pressure were evaluated

4.3.1Performance parameters

4.3.1.1 BRAKE POWER (BP)

- **Effect of blend**

  The variation of BP with the load and amount of blend at different compression ratio is illustrated in the figures below. BP was observed to be decreased with the amount of blend in the diesel. This is due to the low heating or calorific value of blends. The brake power of diesel was observed to be higher than the biodiesel blends. The BP of B10 was higher than other blends due to its more calorific value. It was observed that at higher loads the variation in BP is less due to less heat losses at higher loads. It was also observed that as the load increased the brake power increases, due to increase in torque with load. The variation of brake power (BP) with load and blend proportion at CR16, CR 14 and CR 12 is illustrated in fig 4.7, 4.8, 4.9 respectively.

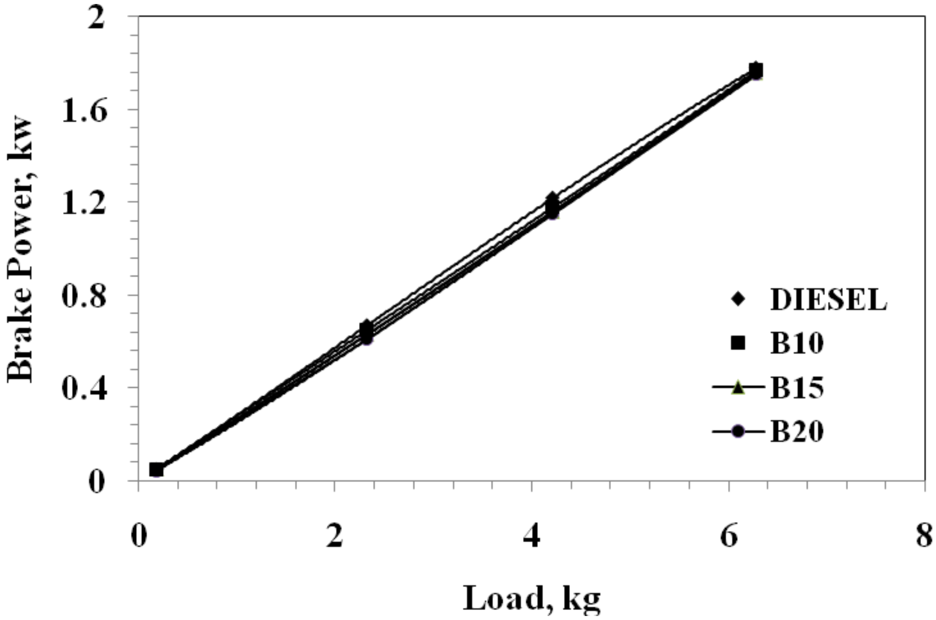


Fig 4.7: Variation of brake power with load at compression ratio 16

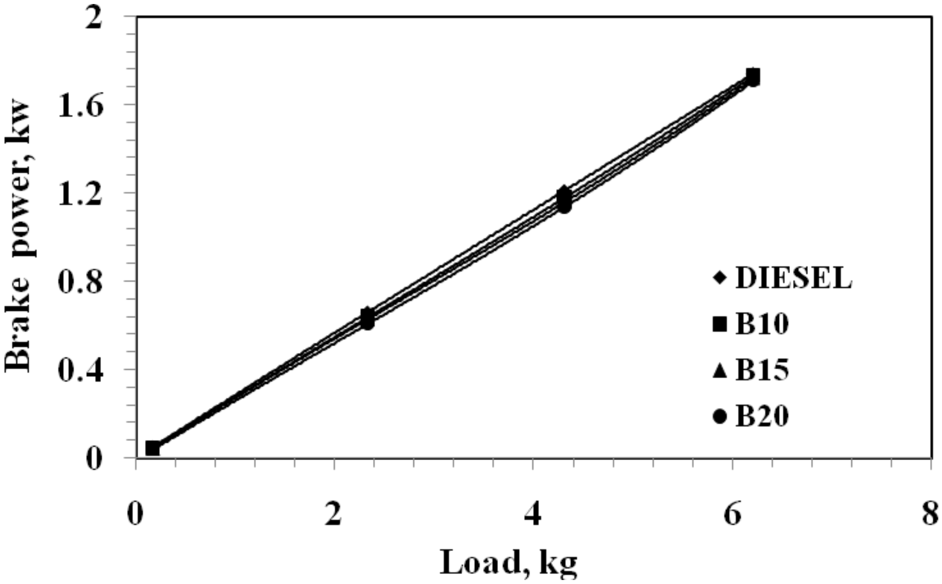


Fig 4.8: Variation of brake power with load at compression ratio 14

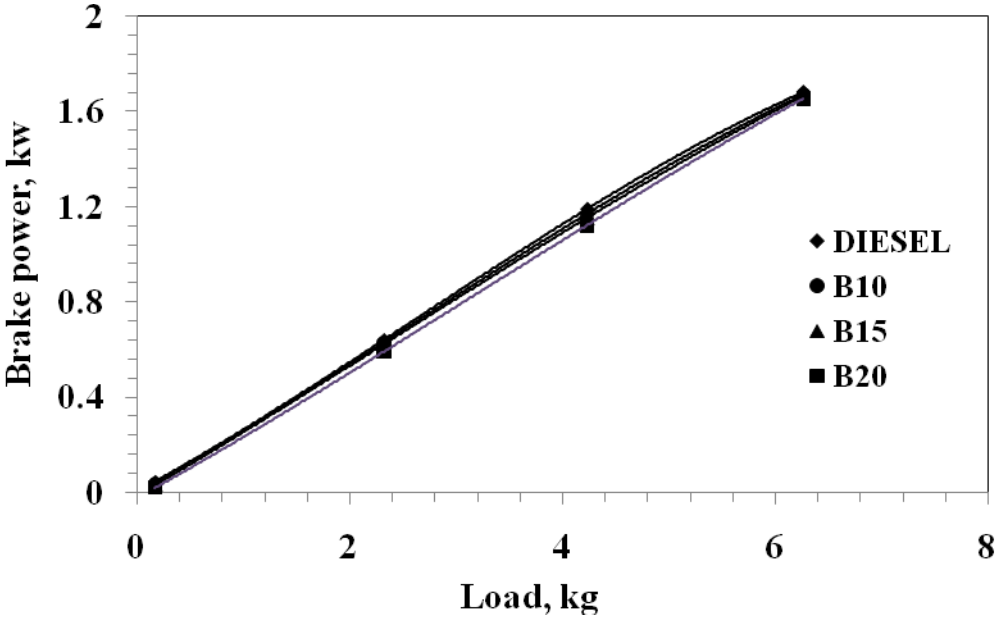


Fig 4.9: Variation of brake power with load at compression ratio 12

- **Effect of compression ratio**

It is seen that engine break power increased, as the compression ratio was increased. This is due to the increase in brake torque at high compression ratios. Increase in compression ratio induces greater turning effect on the cylinder crank. This means that the engine is giving more push on the piston, and more torque is generated. The effect of varying compression on brake bower of B10 blend is illustrated in the fig 4.10. It was observed that the BP with CR16 was higher than with CR14 and CR12 at all loads.

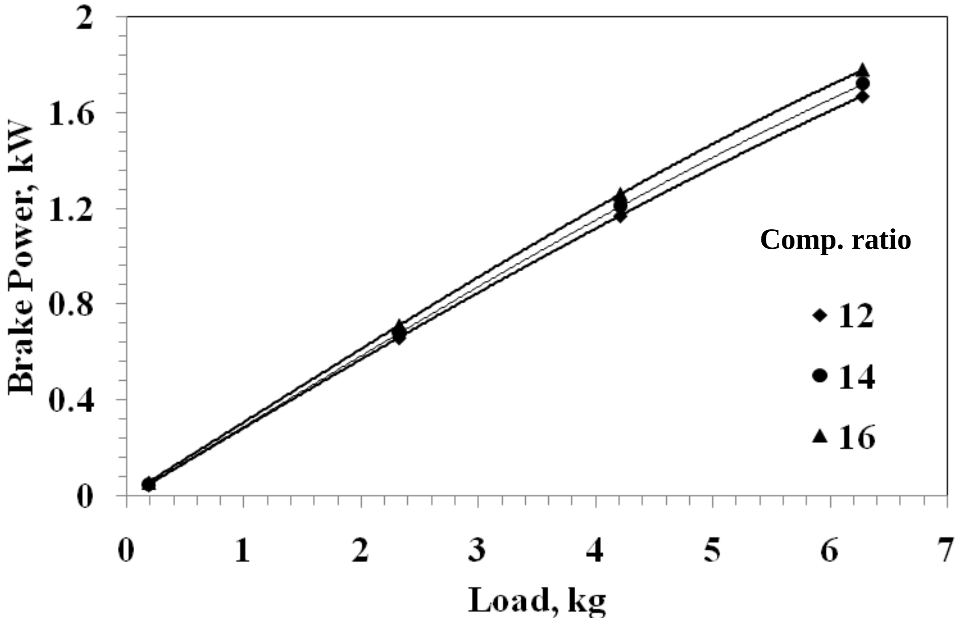


Fig 4.10 variation of brake power with compression ratio

4.3.1.2 BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

- **Effect of load and blend**

The brake specific fuel consumption of three different blends of linseed biodiesel i.e. B10, B15, and B20 were compared with the diesel fuel. It was observed that BSFC decreased sharply with load for all fuels and at any compression ratio. The main reason for this can be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads. The BSFC of all biodiesel blends was found to be higher than diesel fuel. As the proportion of biodiesel blend increased, the BSFC was observed to be increased. The BSFC of LB20 was higher than all other fuels. This is due to the higher density of linseed biodiesel. As the percentage of blend increases the density also increases. The higher densities of biodiesel blends caused higher mass injection for the same volume. Due to high density of biodiesel the fuel consumption is more. The variation of BSFC of diesel and different blends with load at CR16 is shown in the fig. 4.11.

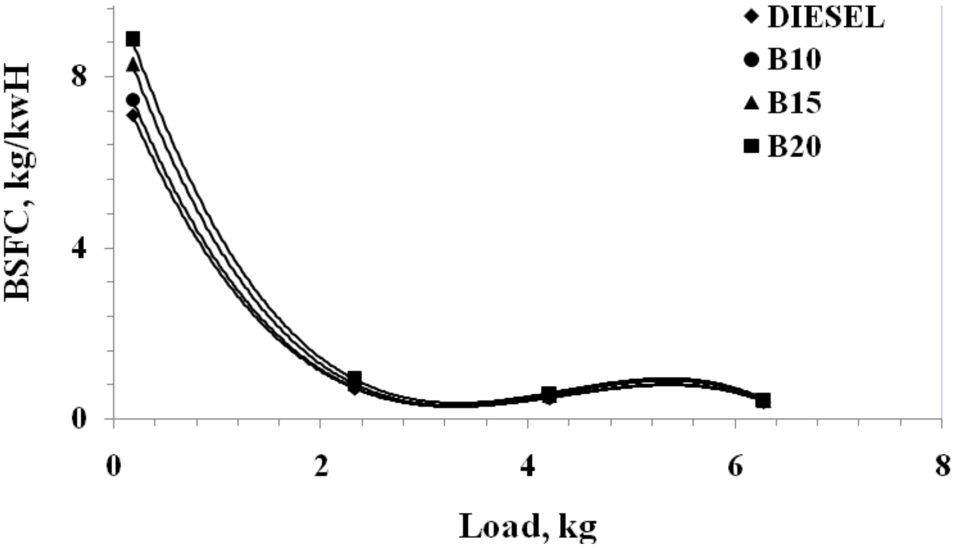


Fig 4.11 Variation of BSFC with load at compression ratio 16

The variation of BSFC at full load was less as compared to part loads. This was due to less variation in brake power (BP) at full loads. The variation of BSFC with load for CR14 and CR12 is illustrated in fig 4.12 and 4.13 respectively.

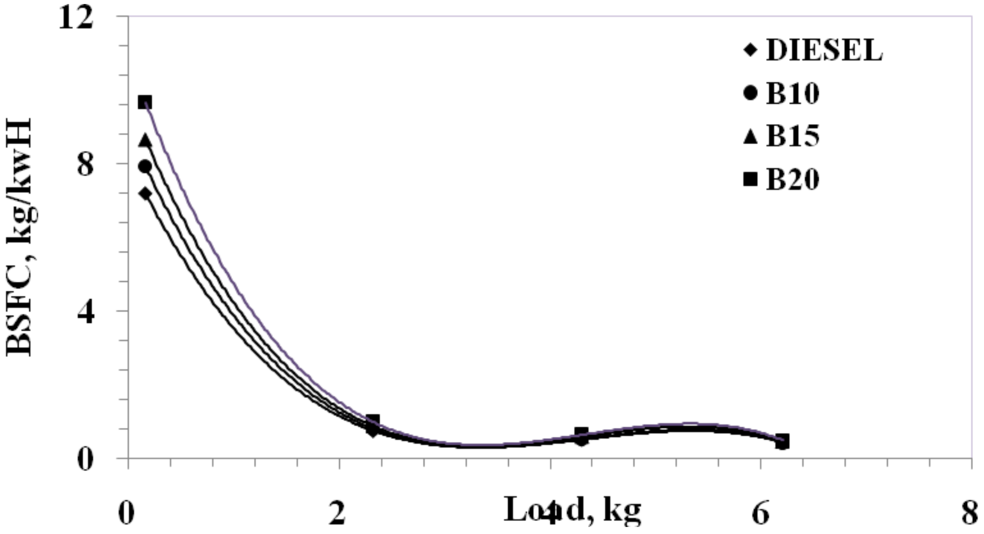


Fig 4.12 Variation of BSFC with load at compression ratio 14

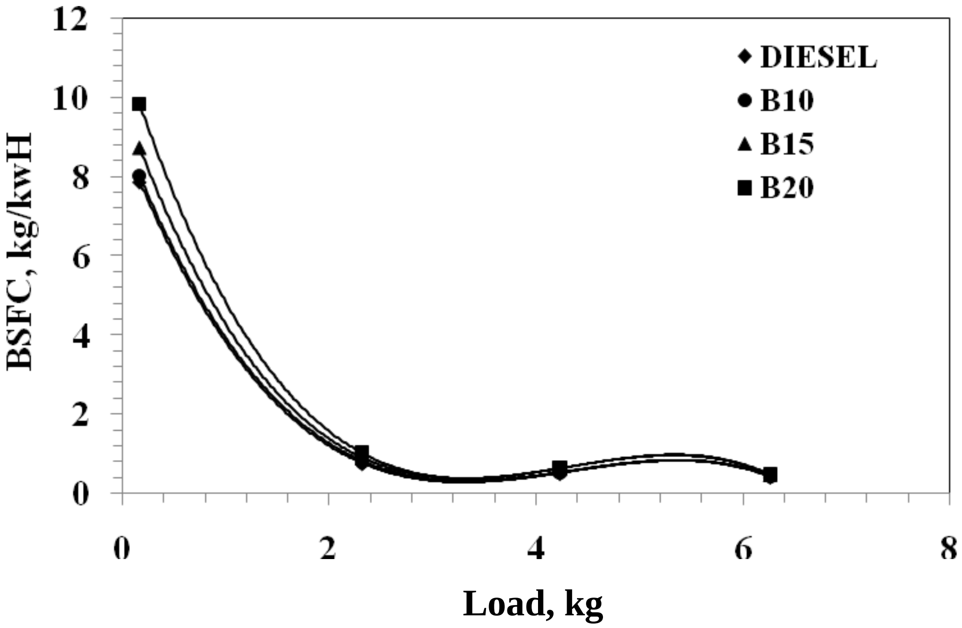


Fig 4.13 of BSFC with load at compression ratio 12

Effect of compression ratio on brake specific fuel consumption

The brake specific fuel consumption was observed to be decreased with the increase in compression ratio from 12 to 16.The brake specific fuel with CR 16 was found to be less than that of CR14 and CR12**.** This is mainly due to the increase in brake power with compression ratio. The higher compression ratio induces better combustion due to increase in temperature inside the combustion chamber which led to improved combustion and hence increase in brake power and therefore decrease in brake specific fuel consumption. The variation of brake specific fuel consumption with increase in compression ratio of B10 blend is illustrated in fig 4.14.

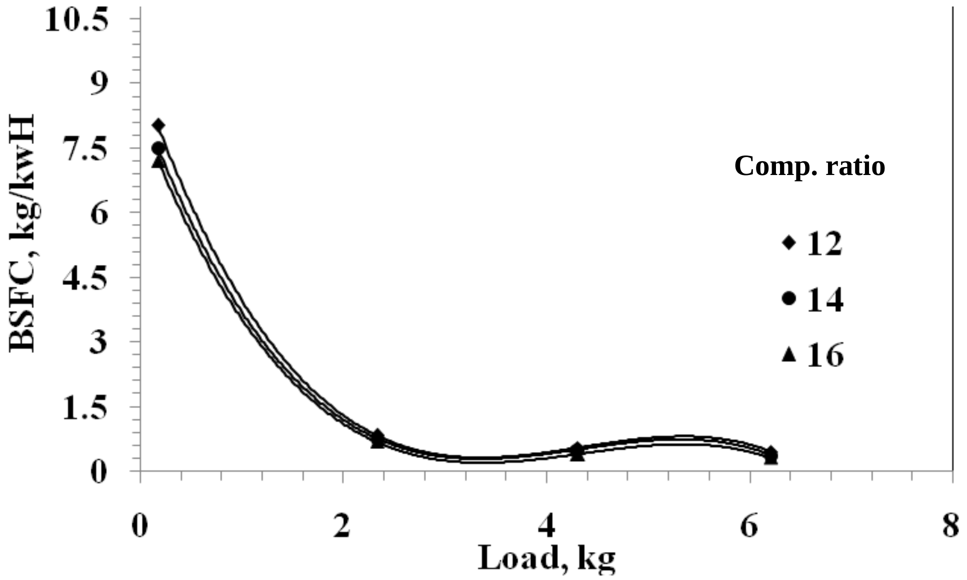


Fig 4.14 Variation of BSFC with load and compression ratio

4.3.1.3 BRAKE THERMAL EFFICIENCY

Effect of load and blend: The brake thermal efficiency was observed to be low at part loads. The brake thermal efficiency was improved with the load for the main reason that relatively less portion of the power is lost with increasing load. Also, brake thermal efficiency is found to decrease with the increase in blend content .This is due to the higher viscosity of blends which led to the poorer atomization and poor combustion. The another reason for the decrease in brake thermal efficiency with the blend content is due to the increase in fuel consumption which is mainly due to higher density of blends. The variation of the brake thermal efficiency with load and blend content at different compression ratio is illustrated in fig 4.15.

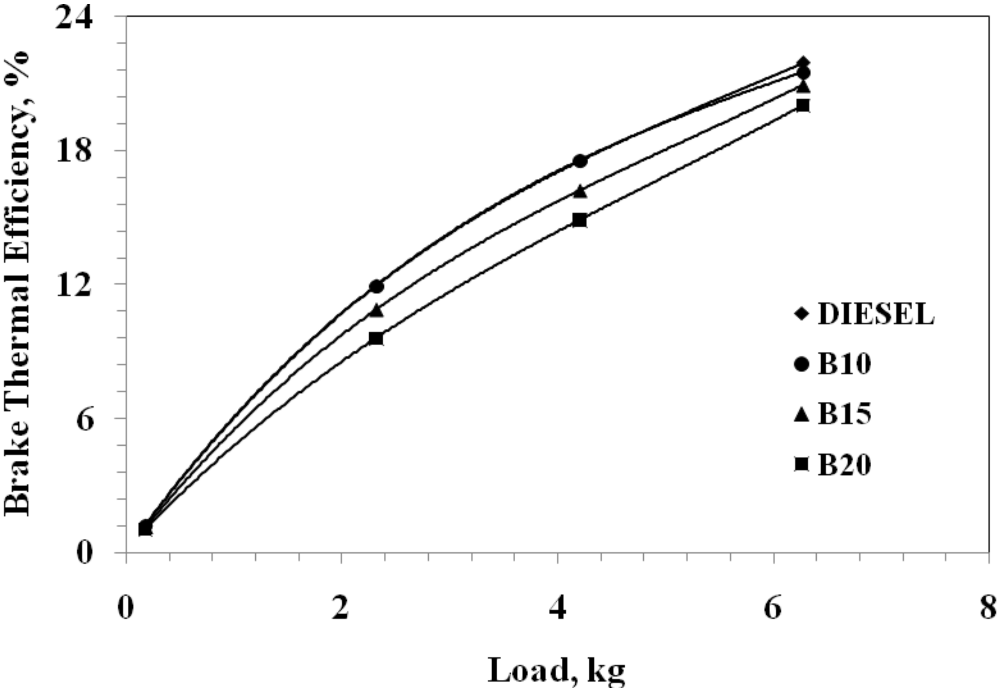


Fig 4.15 Variation of Brake Thermal Efficiency with load at compression ratio 16

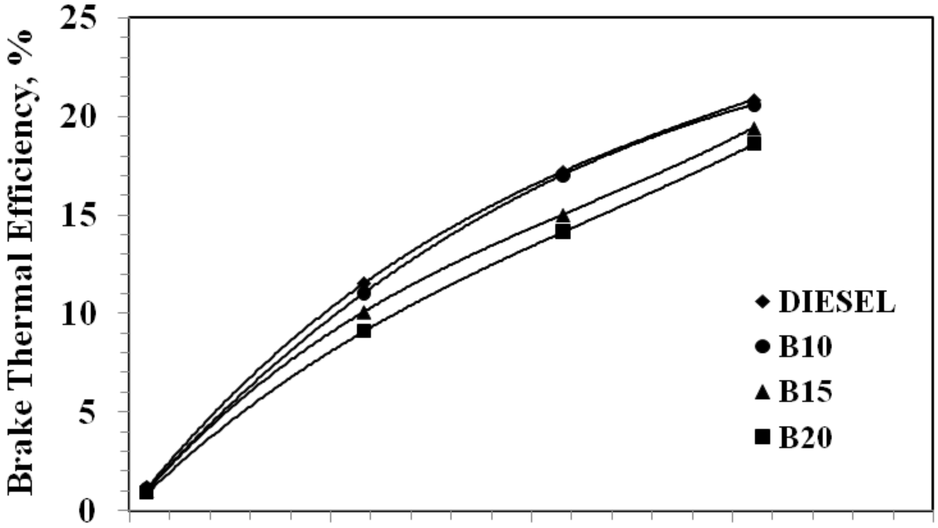


Fig 4.16 Variation of Brake Thermal Efficiency with load at compression ratio 14

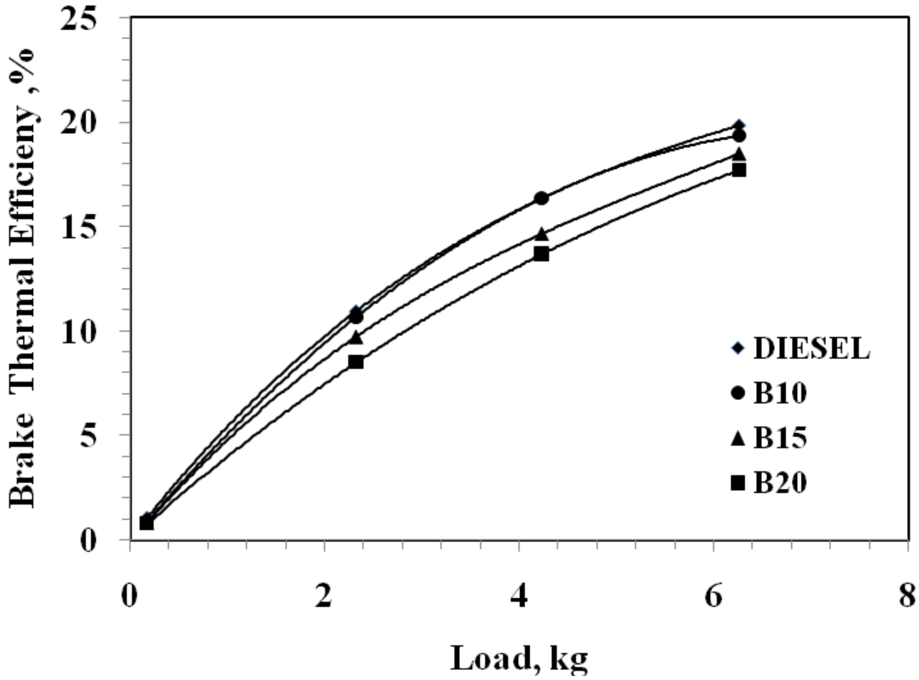


Fig 4.17 Variation of Brake Thermal Efficiency with load at compression ratio 12

At CR 16 the highest brake thermal efficiency was found to be 21.9% with diesel fuel and among blends, the brake thermal efficiency of B10 i.e. 21.4% was the highest.

Effect of compression ratio

With the increase in compression ratio the brake thermal efficiency was found to be increased. The brake thermal efficiency with the compression ratio16 was found to be highest at all loads. The trend is observed because at higher compression ratio, the air temperature is high which results in better combustion of fuel. The variation of brake thermal efficiency with load and compression ratio for B10 blend is illustrated in the fig 4.18.

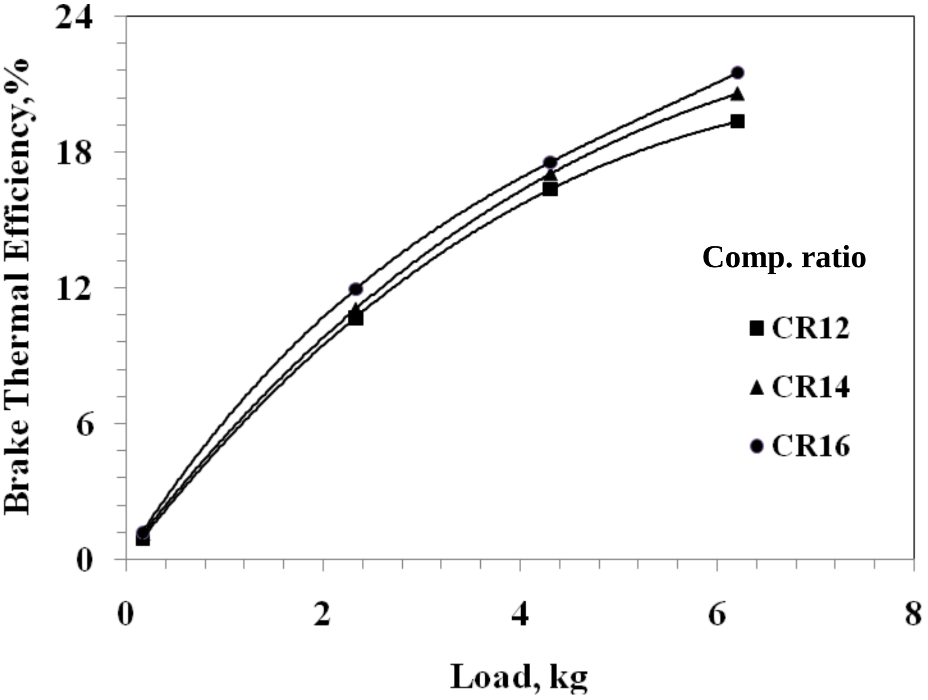


Fig 4.18 Variation of Brake Thermal Efficiency with load and compression ratio

4.3.1.4 MECHANICAL EFFICIENCY

Effect of blend

The mechanical efficiency of diesel fuel was observed to be lowest at all loads. With increase in load the mechanical efficiency increases due the increase in brake power. Blended fuels exhibited better mechanical efficiency compared to the neat diesel fuel. This is due to better lubricity properties of blended fuels compared to diesel. The mechanical efficiency of B20 blend was observed to be the highest among all fuels i.e. Diesel, B10, B15.This is due to more viscosity, B20 blend have better lubricity properties. The mechanical efficiency of B20 was 35.7% while that of diesel was 34.4% at full load at CR14 and at CR16 it was 39.1% and 36.5%

with B20 and diesel respectively. The variation in mechanical efficiency with load at different compression ratio is illustrated in figures 4.19, 4.20, 4.21.

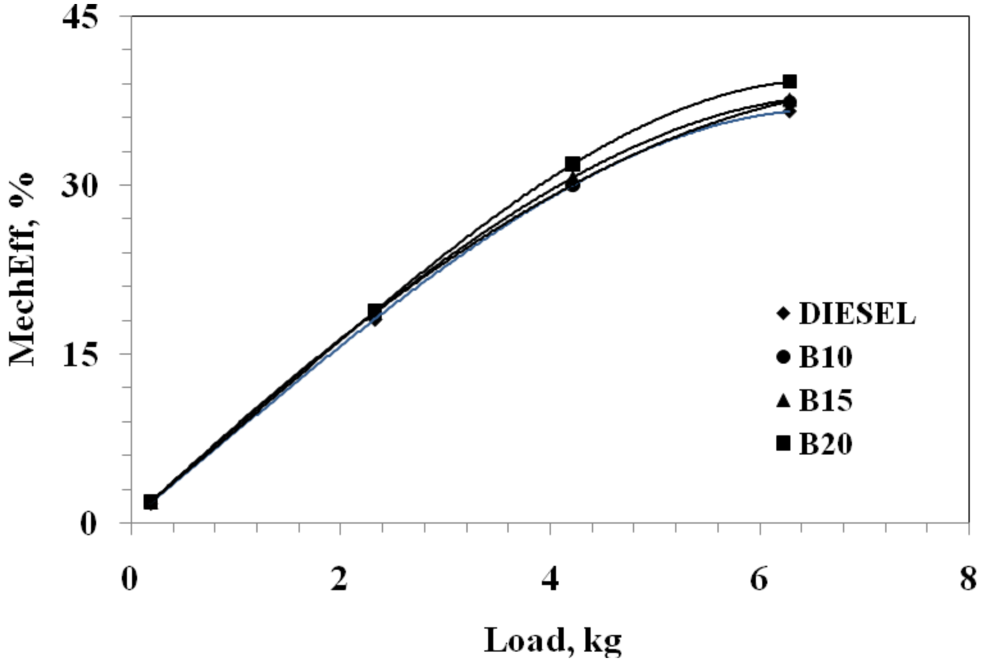


Fig 4.19 Variation of Mechanical Efficiency with load at compression ratio16

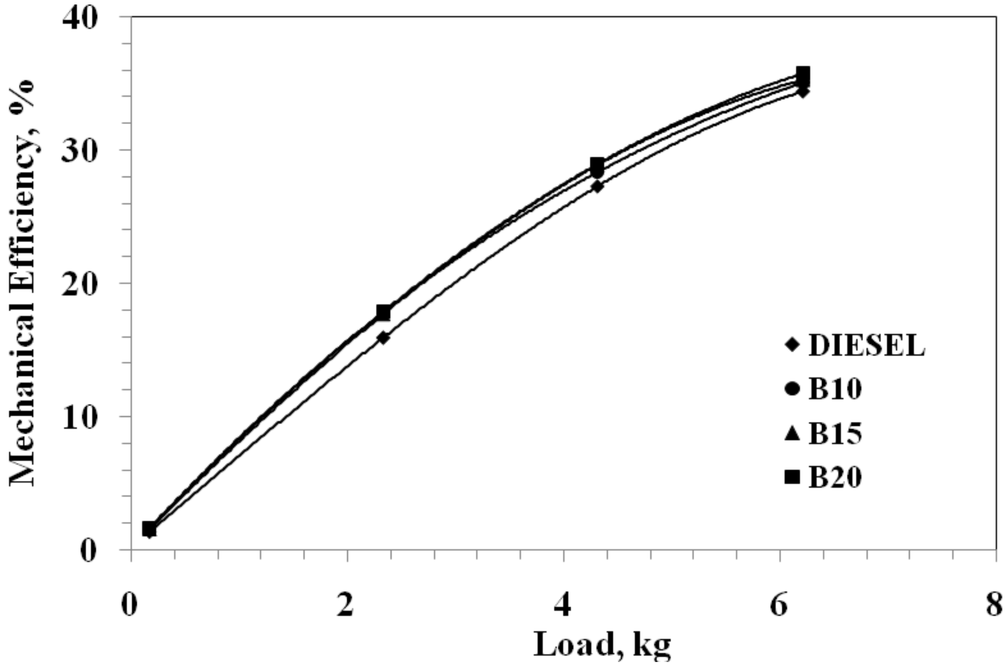


Fig 4.20 Variation of Mechanical Efficiency with load at compression ratio14

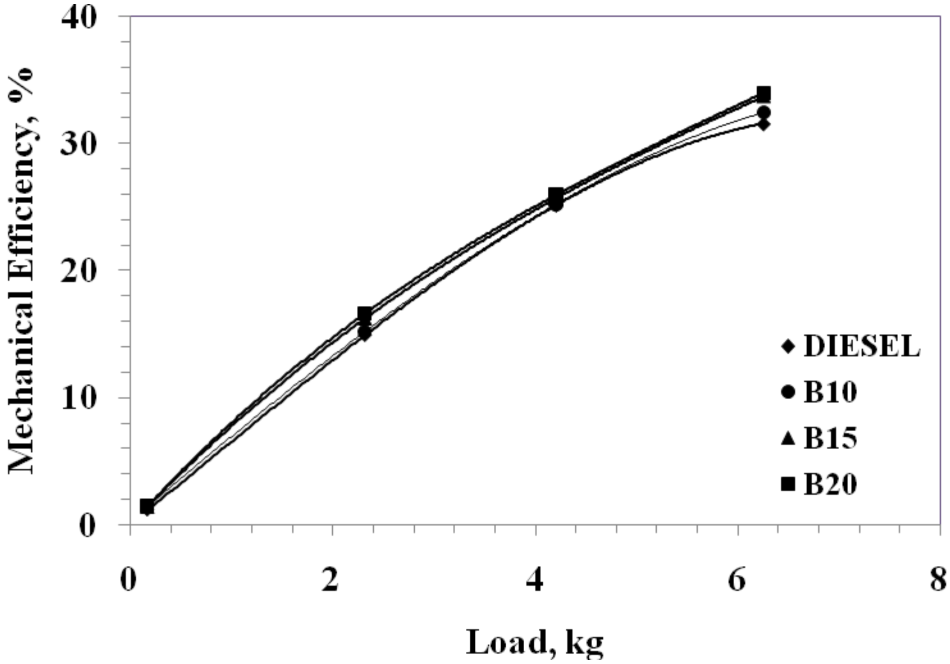


Fig 4.21 Variation of Mechanical Efficiency with load at compression ratio 12

Effect of compression ratio

It was observed that with increase in compression ratio the mechanical efficiency increases. The mechanical efficiency of at CR 16 was higher than at CR14 and CR12 at all loads. The mechanical efficiency of B20 at CR 16 at full load was 39.1% while that at CR14 and CR12 was 35.7% and 33.9% respectively. The variation of mechanical efficiency of B20 blend at all compression ratios is illustrated in fig 4.22. This increase in mechanical efficiency is observed due to the increase in brake power with the increase in compression ratio. Since the brake power at CR 16 is higher than at CR14 and CR 12 therefore mechanical efficiency is higher at CR 16.

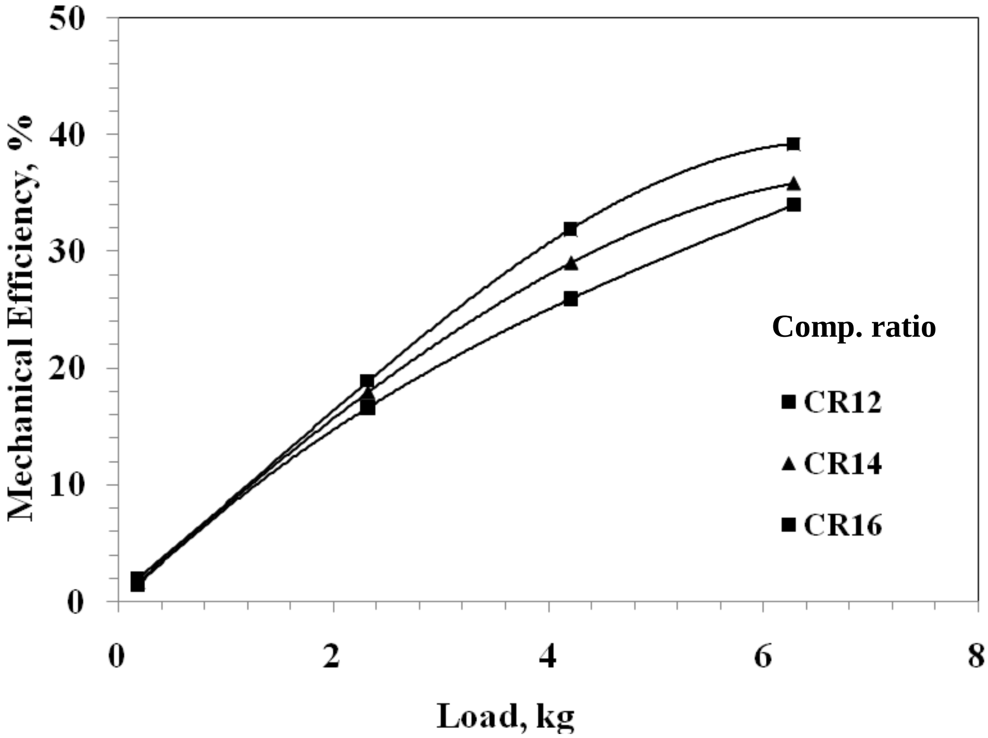


Fig 4.22: Variations in mechanical efficiency with compression ratio of B20 blend.

4.3.1.5 BRAKE MEAN EFFECTIVE PRESSURE

The mean effective pressure is the average pressure on the piston heat over a cycle in the combustion chamber of an engine, which measures the capacity of the engine to do work.

Effect of blend and compression ratio

There were slight variations in brake mean effective pressure with content of blend. With increase in load brake mean effective pressure was observed to be increased. The BMEP was lower for higher loads as compared to B10.It may be due to the proper burning of fuel due to oxygen content in the biodiesel molecule. The BMEP is also found to be increased with the compression ratio; the BMEP with CR 16 was fond to be higher than other compression ratio at all loads. The BMEP of B10 was observed to be nearly same in comparison to diesel fuel. The variation of BMEP at CR16, CR14, and CR12 is shown in Figures 4.23, 4.24, 4.25 respectively.

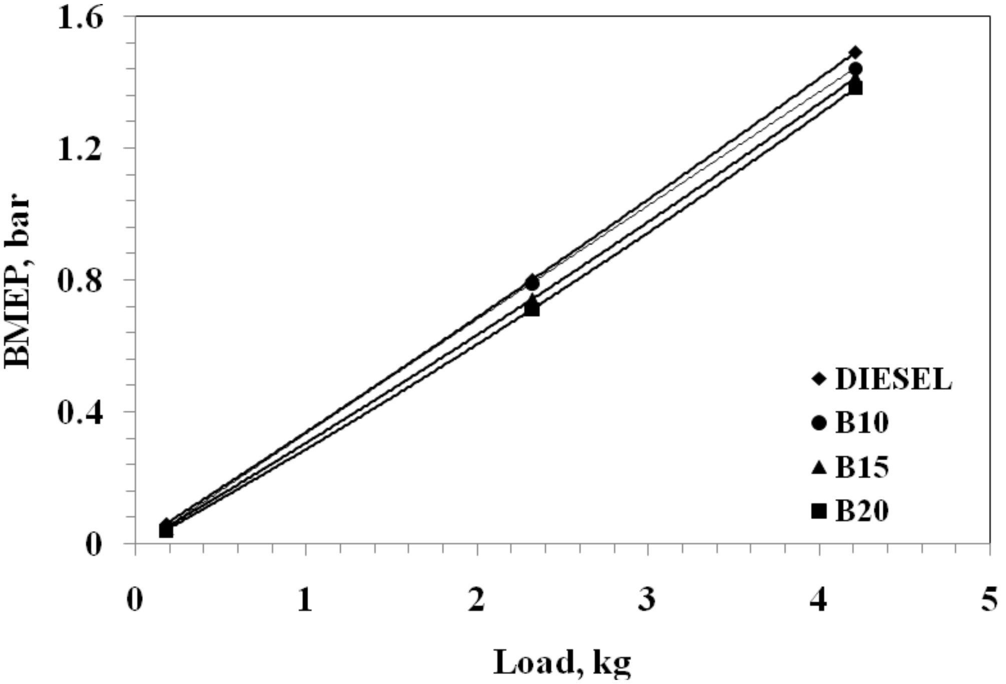


Fig 4.23 Variation of Brake Mean Effective Pressure with load at compression ratio 16

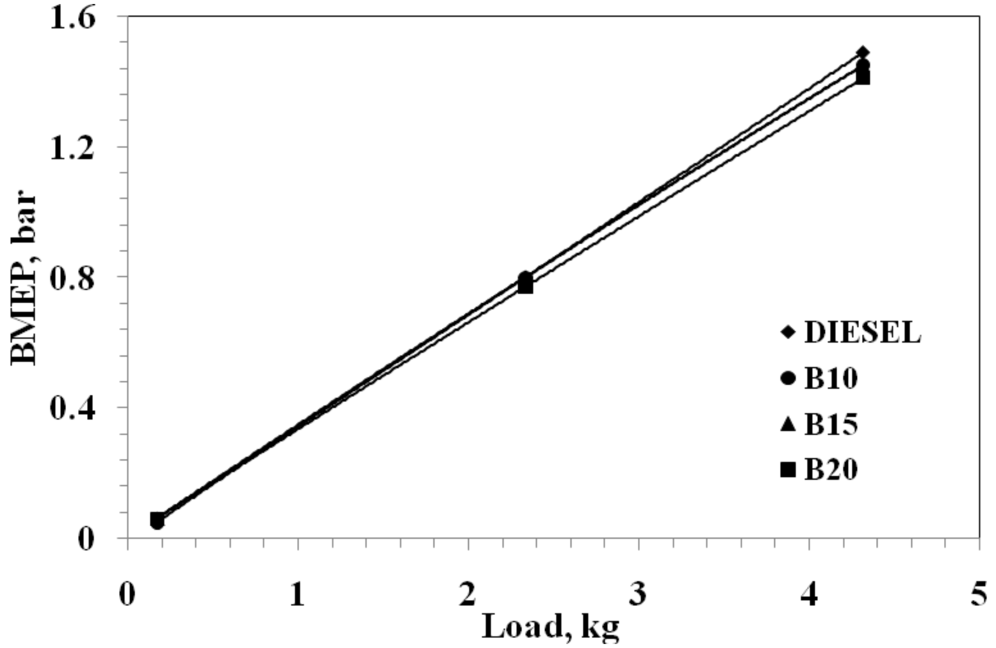


Fig 4.24: Variation of Brake Mean Effective Pressure with load at compression ratio 14

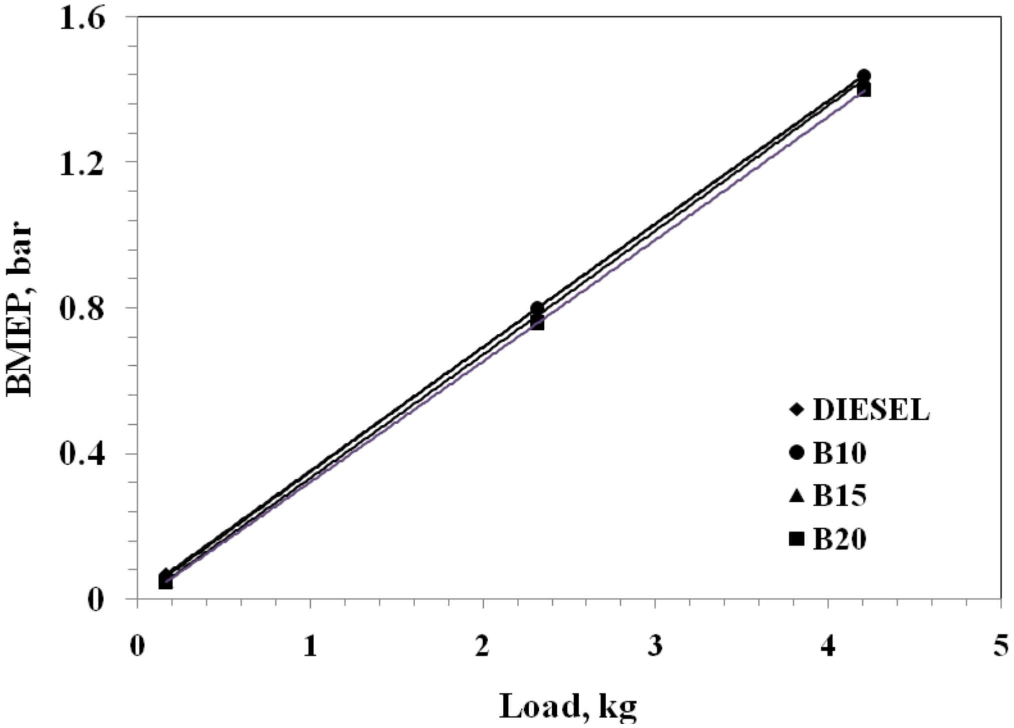


Fig 4.25: Variation of Brake Mean Effective Pressure with load at compression ratio 12

4.3.1.6 Variation in cylinder pressure

The variation of cylinder pressure for diesel, B10, B15, B20 with crank angle at CR16, CR14, and CR12 was compared. It was observed that peak pressure was obtained between 300^o to 450^o.The maximum peak pressure of B10 was observed to be nearly same of diesel fuel at all compression ratios. This may be due to high calorific value which led to better combustion. The cylinder pressure was found to be decreased with content of blend. This may be due to high viscosity of biodiesel blends due to which proper atomization may not take place. On increasing compression ratio the cylinder pressure the peak pressure was found to be increased .This may be due to better combustion at high compression ratio. The variation of cylinder pressure at CR16, CR14, and CR12 is shown in the figures 4.26, 4.27 and 4.28 respectively.

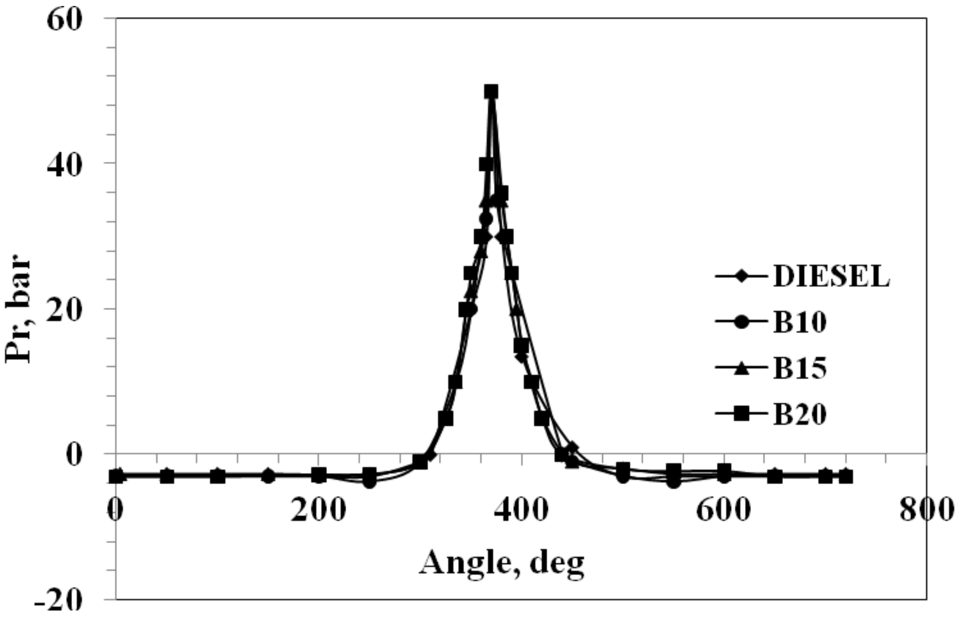


Fig 4.26 Variation of cylinder pressure with crank angle at compression ratio16

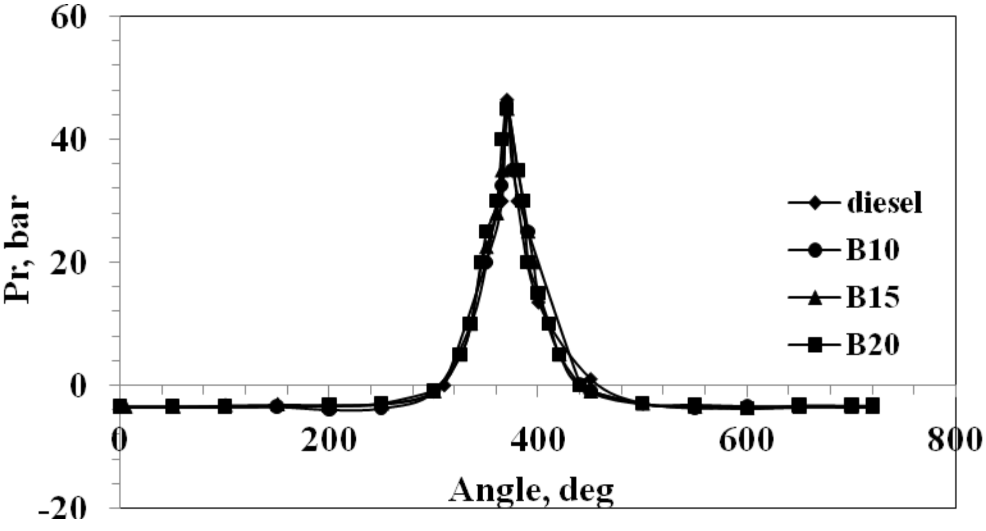


Fig 4.27 Variation of cylinder pressure with crank angle at compression ratio 14

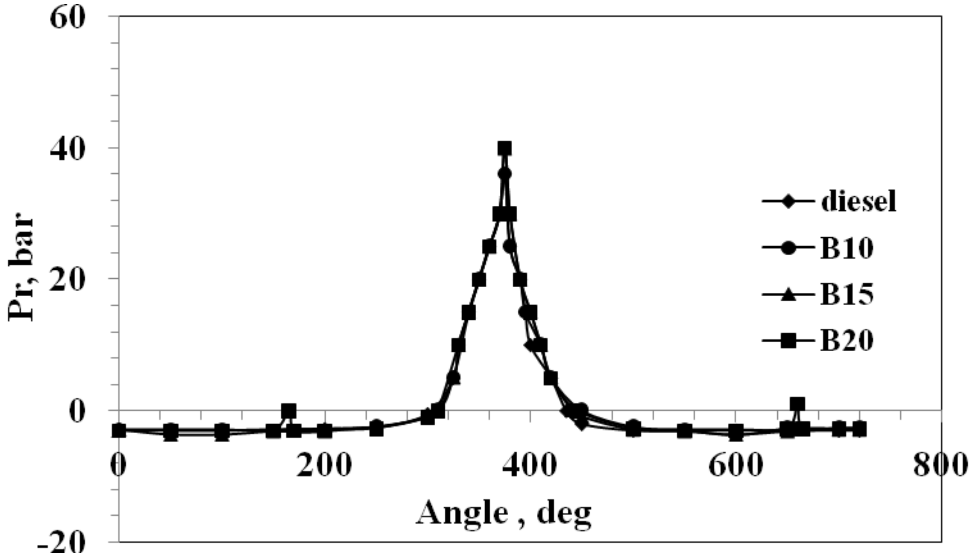


Fig 4.28: Variation of cylinder pressure with crank angle at compression ratio 12

4.4 EMISSION PARAMETERS

4.4.1 HYDROCARBON EMISSIONS (HC)

The variation of hydrocarbon emissions with load for diesel, B10, B15, B20 are compared at two different compression ratios. It was observed that with increase in load the hydrocarbon emission increases .It is due to entering of rich fuel air mixture in the combustion chamber because of increase in fuel consumption. This leads to improper combustion due to which unburnt hydrocarbon emissions increases. It was also observed that with increase in blend content the HC emission decreases. This is due to the high cetane no of biodiesel blends. Higher cetane no lowers the combustion delay which improves the combustion. Another reason for low hydrocarbon emission with the increase in blend content is due to more oxygen content than diesel fuel. It was observed that HC emissions for diesel fuel were highest and for B20 blend it was lowest. The HC emissions for different fuels with load at CR 16 and CR 14 are illustrated in the figures 4.29 and 4.30 respectively.

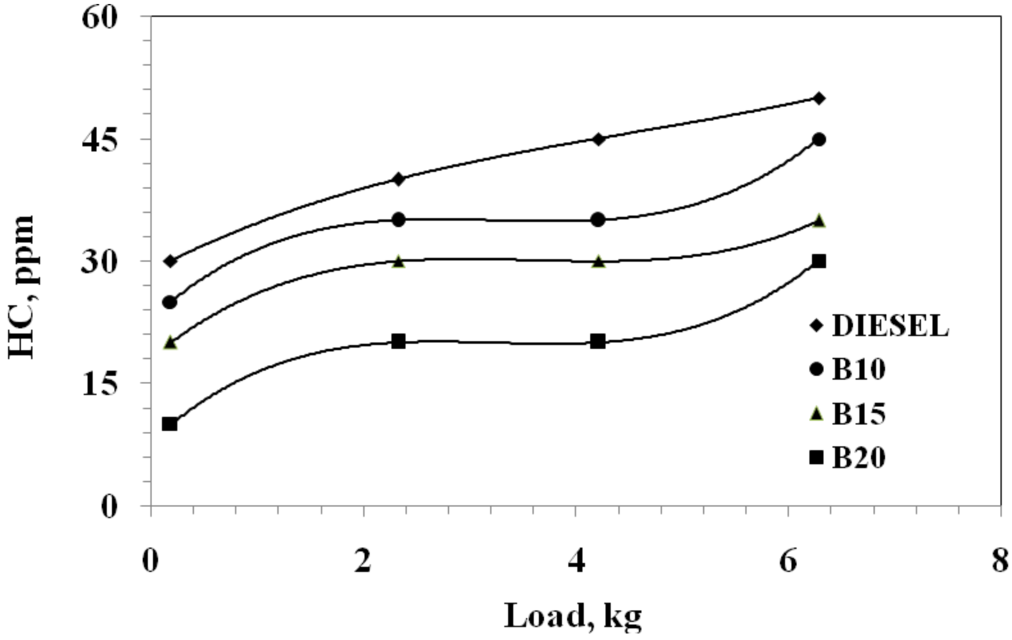


Fig 4.29: Variation of hydrocarbon emissions with compression ratio 16

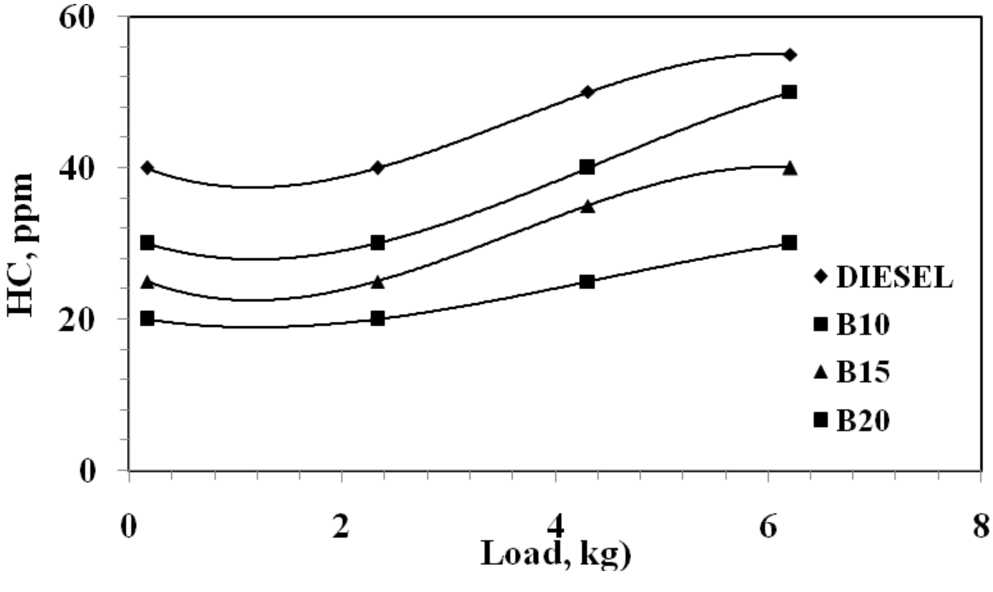


Fig4.30: Variation of hydrocarbon emissions with load at compression ratio 14

4.4.2 CARBON MONOXIDE (CO) EMISSIONS

The carbon monoxide emissions results from incomplete combustion. The CO emissions for diesel fuel, B10, B15, B20 with load are compared at CR16 and CR14.

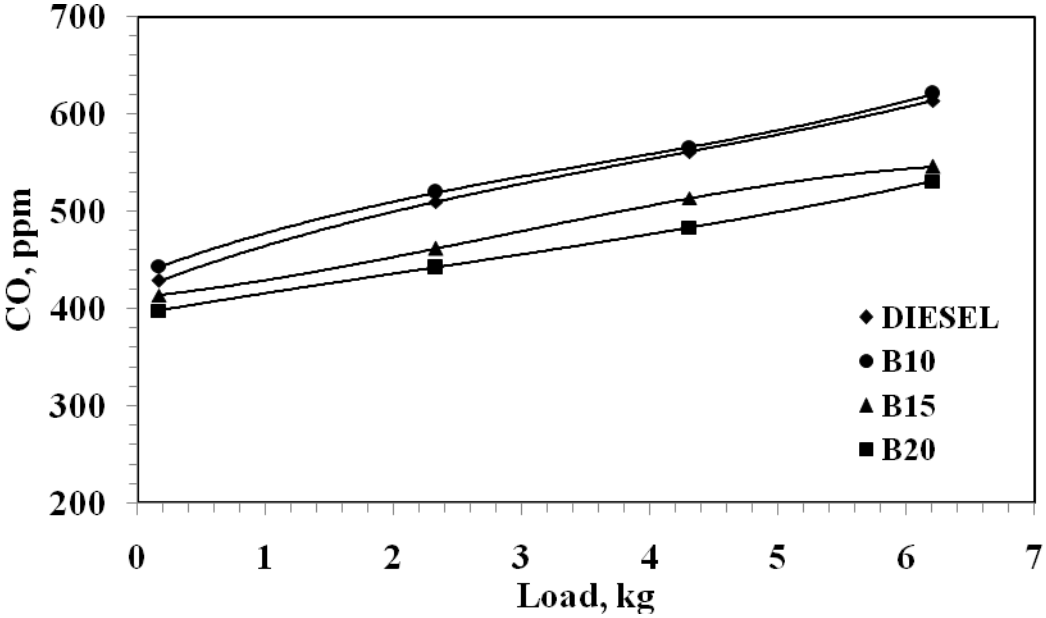


Fig 4.31: Variation of carbon monoxide emissions with load at compression ratio 16

It was observed that with increase in load the CO emissions increased .This is due the injection of rich air fuel mixture which led to incomplete combustion of fuel. It was observed the CO emissions of B10 blend were nearly same as that of diesel fuel. But with further increase in blend content the emissions were observed to be decreased. This may be due to the higher oxygen content which leads to complete combustion. The CO emissions were decreased with increase in compression ratio because of increase in air temperature which lowers the delay period and improves the combustion. The CO emissions for the B20 blend at CR16 were found to be the lowest among all fuels. The CO emissions for Diesel, B10, B15, and B20 with load at CR14 compression ratios are illustrated in the fig 4.32.

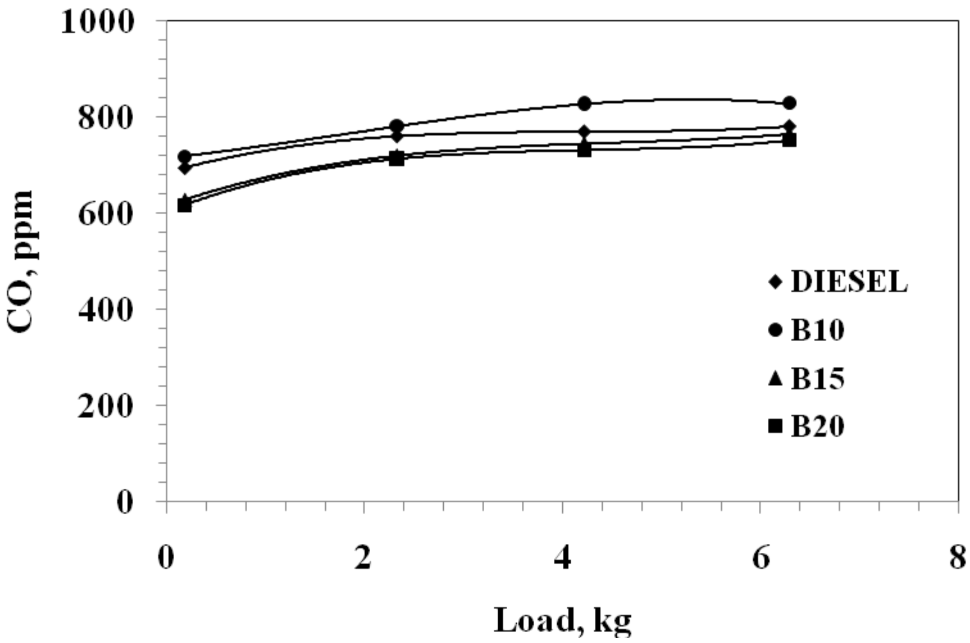


Fig 4.32 Variation of CO emissions with load at compression ratio 14

4.4.3 NO_X EMISSIONS

The NO_X emissions of diesel, B10, B15, B20 with load at compression ratios CR14 and CR16 were compared. NO_X emissions are temperature dependent. It was observed that NO emissions increase with increase in load. This is because of increase in temperature inside combustion chamber at high loads. NO_X emissions were observed to be increased with increase in blend content. This is because of high oxygen content in the biodiesel fuel. Nitrogen from air can easily mix with oxygen and produces the NO_X emissions. These emissions were observed to be increase with compression ratio due to lower ignition delay which increases the peak pressure and temperature. The NO_X emissions for diesel, B10, B15, B20 with load at CR16 and CR14 are illustrated in the following figures 4.33 and 4.34 respectively.

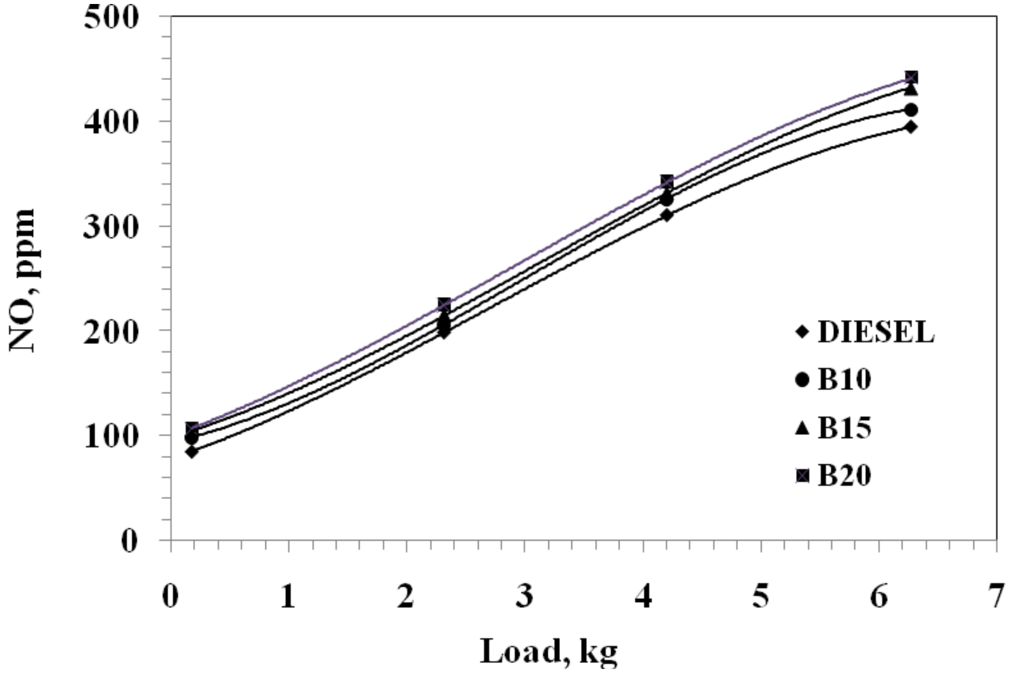


Fig 4.33 Variation of NO_X emissions with load at compression ratio 16

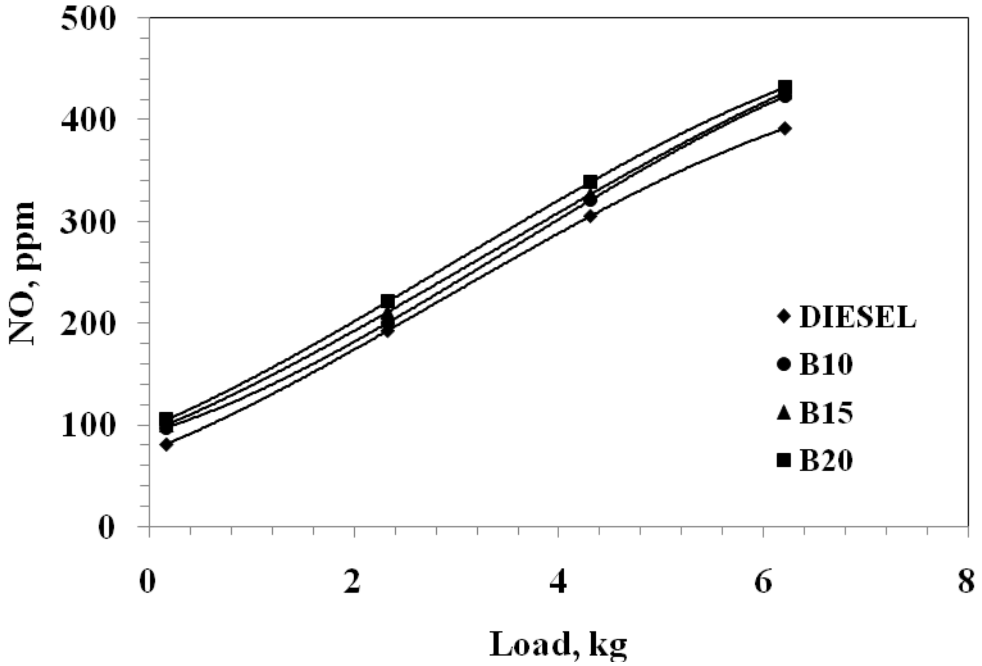


Fig 4.34 Variation of NO_X emissions with load at compression ratio14

It can be seen from the figures that NOx emissions for the diesel were lowest at both compression ratios. The NOx emissions of B20 blend were observed to be highest at all loads and both compression ratios.

4.4.4 CARBON DIOXIDE (CO_2) EMISSIONS

The CO_2 emissions for diesel, B10, B15, B20 with load at CR16 and CR14 were compared. It was observed that with increase in load the CO_2 emissions increases due to better combustion at high loads. The CO_2 emissions with diesel were highest .As the blend content increased, the CO_2 emissions were decreased. Carbon dioxide is formed on complete combustion of the fuel in oxygen. Here, carbon dioxide formation is less due to the fact that biodiesel in general is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel. The CO_2 emissions were observed to be increased with the compression ratio this is due to the lower ignition delay that led to better combustion. The variation of CO_2 emissions with load at CR16 and CR14 are illustrated in the figures 4.35 and 4.36 respectively.

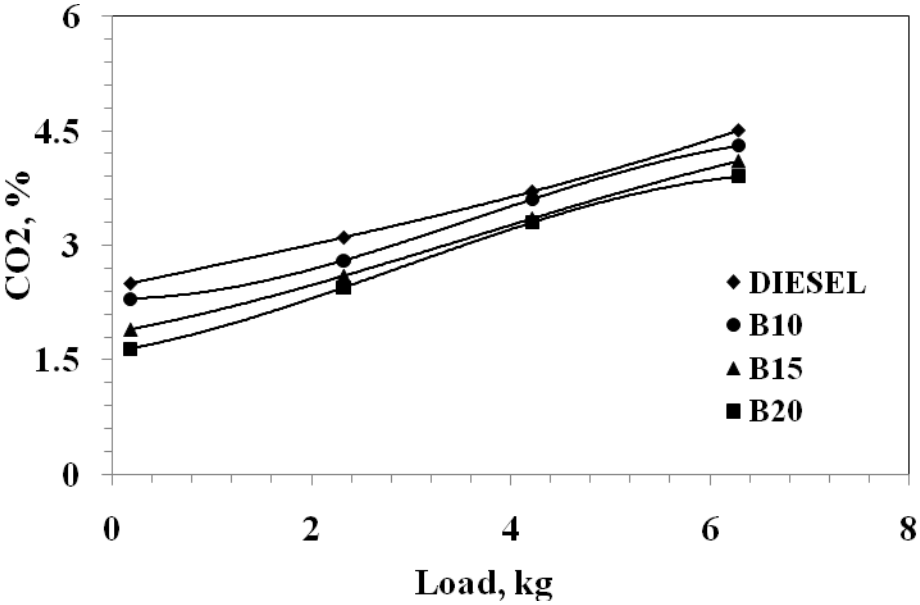


Fig 4.35: Variation of CO_2 emissions with load at compression ratio 16

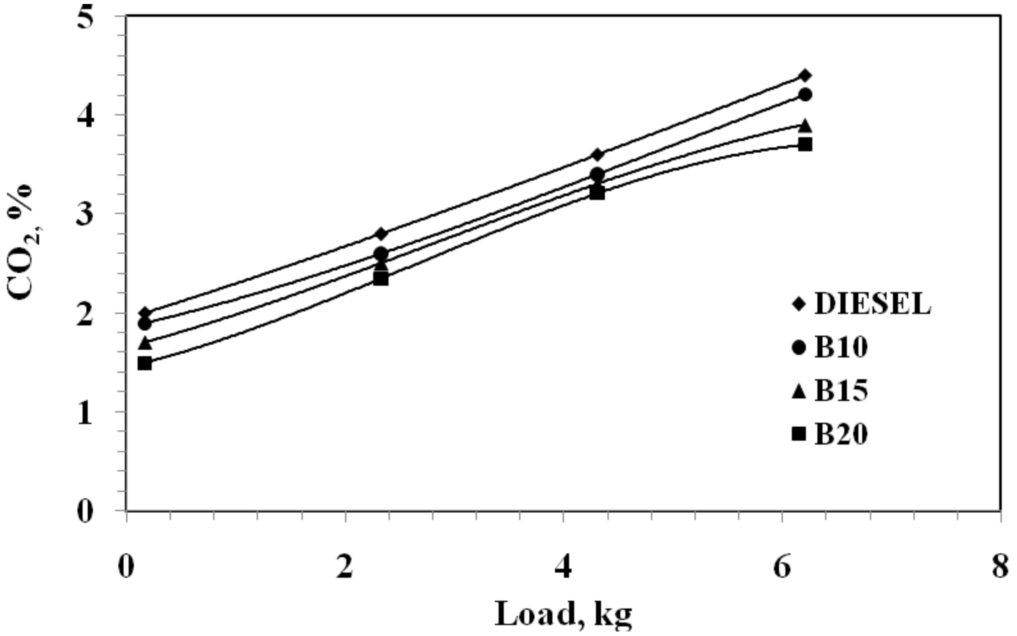


Fig 4.36: Variation of CO_2 emissions with load at compression ratio 14

It was observed that CO2 emissions were lowest for B20 blend at all loads for both compression ratios.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSIONS

The optimization of biodiesel production from linseed oil was evaluated using tranesterification process .The performance and emission parameters for diesel fuel were compared with B10, B15, and B20.The following conclusions can be drawn from the present study:

- The optimum conditions for maximum biodiesel production were obtained at molar ratio of 5:1, reaction time 60 minutes and .5% KOH concentration. A maximum yield of 98% was determined.
- The fuel properties of optimized biodiesel were found to be comparable to diesel and were conforming to the latest biodiesel standards.
- The calorific value of optimized linseed biodiesel was 9261 Kcal/Kg which is 7.9% lower than diesel fuel.
- The flash and fire point of linseed biodiesel were determined to be 154^{o}C and 160^{o}C respectively which are higher than diesel fuel.
- The cloud and pour point were also observed to be lower for biodiesel fuel.
- The performance parameters such as BP, BMEP, brake thermal efficiency, with B10 were observed to be nearly similar to diesel fuel at all loads.B10 have better performance parameters than other blends .At higher compression ratio the performance of VCR engine was better. The BSFC of B10 blend was lowest among the blends.

- The emissions parameters of B10 blend such as CO, CO, and HC were nearly similar to diesel fuel. With increase in blend content these emissions were observed to be decreased. Among all blends, these emissions from B20 blend were observed to be lowest. The NOx emissions for B10 blend were observed to be lowest. The CO and HC emissions were lowered at higher compression ratio while NOx and CO2 emissions were higher at high compression ratio.

5.2 FUTURE SCOPE

Biodiesel derived from non edible feed stocks such as linseed oil are reported to be feasible choices for developing countries including India where consumption and cost of edible oil is very high. Selection of inexpensive and available feedstock for biodiesel production within the country is the major concern. Linseed oil is relatively an inexpensive and available raw material for biodiesel production as India is the 3rd largest producer of linseed in the world. The following points may be considered before introducing the fuel in India:

- Attempts for making proper use of the linseed oil for the production of biodiesel should be undertaken by the government.
- The study of long term stability of blends should be done as the blends prepared for this work were utilized within short span of time.
- Further research and development on the additional fuel property measures, long-term run and wear analysis of biodiesel fueled engine is necessary along with injection timing and duration for better combustion of biodiesel in diesel engines.

- The optimization of linseed oil was studied on varying the three parameters only i.e. molar ratio, catalyst concentration, and reaction time. The effect of other parameters like reaction temperature, different catalyst, stirring rate should also be studied.

- The performance and emission parameters of linseed biodiesel in a single cylinder VCR engine were evaluated on load and compression ratio basis. The effect of other parameters like injection timing, speed, ignition delay on the performance of engine may be studied.
- NOx emissions were found to be increased with linseed oil in comparison to diesel fuel therefore use of NOx reduction techniques such as EGR (exhaust gas recirculation) is recommended. Further research is needed to reduce the NOx emissions.

REFERENCES

[1] Puhan, S., Vedaraman, N., Rambrahaman, B.V., Nagarajan, G. Mahua (Madhuca indica) seed oil: a source of renewable energy in India. *Journal of Scientific and Industrial Research* 64, Page 890–896, 2005.

[2] Ayan Demribas "Biodiesel a realistic fuel alternative for diesel engine"

[3] National Council of Applied Economic Research (NCAER) & The Solvent Extractors' "Overview of Indian Oilseed Sector Outlook for India's Edible Oil Sector,Issues & Challenges" 15th March 2013, Delhi.

[4] Sonntag NOV. "Structure and composition of fats and oils" In: Swern D, editor 4th edition. Bailey's industrial oil and fat products, vol.1, 4th edition. New York: *John Wiley and Sons*; 1979.

[5] Weisz PB, Haag WO, Rodeweld PG. "Catalytic production of high-grade fuel (gasoline) from biomass compounds by shape selective catalysis" *Science,* 206, Page 57–8, 1979.

[6] Schwab AW, Dykstra GJ, Selke E, Sorenson SC, Pryde EH. "Diesel fuel from thermal decomposition of soybean oil" *Jaocs*, 65, Page 1781–6, 1988.

[7] Ayhan Demirbas "Progress and recent trends in biodiesel fuels" *Energy Conversion and Management,* 50, Page 14–34, 2009

[8] Fangrui Ma, Hanna, M. A. "Biodiesel Production: A Review", *Bioresource Technology*, 70, Page1-15, 1999.

[9] C.B. Prakash "A critical review of biodiesel as a transportation fuel in Canada". A technical report. Canada: GCSI – Global Change Strategies International, Inc., Transportation Systems Branch; March 25, 1998

[10] Report of the committee on development of bio-fuel, Planning Commission India, 2003.

[11] Aggarwal, D. L. Kumar, Aggrawal, A.K., "Performance Evaluation of a Vegetable oil fuelled CI Engine" *Renewable Energy*, 2007.

[12] Prafulla D. Patil, Shuguang Deng "Optimization of biodiesel production from edible and non-edible vegetable oils" *Fuel*, 88, Page 1302–1306, 2007.

[13] M. Canakci, J. Van Gerpen "Biodiesel production from oils and fats with high free fatty acids" *American Society of Agricultural Engineers* 44, Page 1429–1436, 2001

[14] Rajeev Kumar, Pankaj Tiwari, Sanjeev Garg "Alkali transesterification of linseed oil for biodiesel production" *fuel*, 104, Page 553-560, 2013

[15] Ashish Jawalkar1, Kalyan Mahantesh1, M Jagadish "Performance and Emission Characteristics of Mahua and Linseed Biodiesel Operated at Varying Injection Pressures on CI Engine" *International Journal of Modern Engineering Research (IJMER)*, 2, Page 1142-1149, 2012.

[16] B. Sanjay Gandhi, S. Sam Chelladurai, D.Senthil Kumaran "Process Optimization for Biodiesel Synthesis from Jatropha Curcas Oil" Distributed *Generation & Alternative Energy Journal*, 26, Page 6-16, 2011

[17] Sukumar Puhan, R. Jegan, K. Balasubbramanian, G. Nagarajan "Effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine" *Renewable energy* ,34, Page 1227–1233, 2008.

[18] H. Raheman, S.V. Ghadge "Performance of compression ignition engine with mahua (Madhuca indica) biodiesel" Fuel, 86, Page 2568–2573, 2007

[19] B. Gokalp , E. Buyukkaya , H.S. Soyhan “Performance and emissions of a diesel tractor engine fueled with marine diesel and soybean methyl ester” *Biomass and bioenergy* ,35, Page 3575-3 583, 2011.

[20] T. Mohanraj a & K. Murugu Mohan Kumar “Operating characteristics of a variable compression ratio engine using esterified tamanu Oil” *International journal of green energy,* 10, Page 285–301, 2012

[21] M. Ozcanli, H. Serin, O. Y. Saribiyik, K. Aydin, and S. Serin “Performance and emission studies of castor bean (Ricinus Communis) oil biodiesel and its blends with diesel fuel” *Energy Sources,* 34, Page 1808–1814, 2012

[22] W.M Adaileh, K.S. Alqdah “Performance of diesel engine fuelled by a biodiesel extracted from waste cooking oil” Energy *Procedia* ,18, Page 1317-1334, 2012.

[23] Y.C. Sharma, B. Singh, S.N. Upadhyay “Advancements in development and characterization of biodiesel: A review”, *Fuel*, 87, Page 2355–2373, 2008

[24] Eloisa Torres-Jimenez, M. Pilar Dorado, Breda Kegl “Experimental investigation on injection characteristics of bioethanol–diesel fuel and bioethanol–biodiesel blends” *Fuel*, 90, Page 1968–1979, 2010

[25] Metin Gumus, Cenk Sayin, Mustafa Canakci “The impact of fuel injection pressure on the exhaust emissions of a direct injection diesel engine fueled with biodiesel–diesel fuel blends” *Fuel*, 95, Page 486–494, 2011

[26] Saswat Rath, Sachin Kumar, R.K. Singh “Performance and emission analysis of blends of karanja methyl ester with diesel in a compression ignition engine” *International Journal of Ambient Energy*, 32, Page 161-166, 2011

[27] Sunil I. Patel, Dipak C. Gosai, Vandana Y. Gajjar "Performance and exhaust emission analysis of thermal barrier coated diesel engine using rice bran oil biodiesel" *International Journal of Engineering and Advanced Technology (IJEAT)*, 2, Page 2249 – 8958, 2013

[28] S. Sivalakshmi A & T. Balusamy "Performance and emission characteristics of a diesel engine fuelled by neem oil blended with alcohols" International *Journal of Ambient Energy* ,32, Page 170-178 ,2011.

[29] Ma, F., Hanna, M.A., "Biodiesel production: a review" *Bioresource Technology* 70, Page 1–15.