PERFORMANCE AND EMISSION CHARACTERISTICS OF A CRDI ENGINE FUELLED WITH DIESEL-LINSEED BIODIESEL USING EGR TECHNIQUE

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SUBMITTED BY

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CANDIDATE'S DECLARATION

I, **Manish Kumar,** hereby certify that the work which is being presented in this thesis entitled **"Performance and Emission Characteristics of a CRDI Engine Fuelled With Diesel-Linseed Biodiesel Using EGR Technique"** is submitted in the partial fulfilment of the requirement for degree of **Master of Technology (Thermal Engineering)** in Department of Mechanical Engineering at **Delhi Technological University** is an authentic record of my own work carried out under the supervision of **Dr. Naushad Ahmad Ansari** and **Dr. Raghvendra Gautam.** The matter presented in this thesis has not been submitted in any other University/Institute for the award of Master of Technology Degree. Also, it has not been directly copied from any source without giving its proper reference.

Manish Kumar

Place: Delhi
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CERTIFICATE

This is to certify that this thesis report entitled, **"Performance and Emission Characteristics of a CRDI Engine Fuelled With Diesel-Linseed Biodiesel Using EGR Technique"** being submitted by **Manish Kumar (Roll No.: 2K18/THE/16)** at Delhi Technological University, Delhi for the award of the Degree of Master of Technology as per academic curriculum. It is a record of bonafide research work carried out by the student under my supervision and guidance, towards partial fulfilment of the requirement for the award of Master of Technology degree in Thermal Engineering. The work is original as it has not been submitted earlier in part or full for any purpose before.

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ABSTRACT

The shrinking petroleum sources and ecological issues have contributed to a demand for more environmentally sustainable and renewable fuels. Due to its biodegradability, high cetane number, low sulphur content, aromatic compound and low volatility, biodiesel received from different renewable sources has been regarded as suitable alternative fuels. Biodiesel extracted from non edible biomass feedstock such as linseed oil are noticed to be achievable choices for developing nations such as India where utilization and cost of edible oil is very high. In past few years biodiesel is rising as an alternative fuel that is a good substitute for neat diesel fuels. Biodiesel is primarily derived from fats and oils by multiple methodologies such as dilution, pyrolysis, micro- emulsification and transesterification, but these days, transesterification is the most commercial technique used for production of biodiesel. The aim of present work is to preparation of linseed biodiesel and study of the impact of performance and emissions of linseed methyl ester on CRDI VCR engine with EGR having single-cylinder, 4- strokes, water cooled operated at a constant speed of 1500rpm. A water-cooled eddy current dynamometer is connecting with the engine to measure the load on the engine. The engine was adjusted at 23^{o} CA bTDC fuel inject timing (suggested by the manufacturer) and 18:1 compression ratio. The several performance and emission characteristics like brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), mechanical efficiency, brake mean effective pressure (BMEP), carbon dioxide (CO_2) emission, unburned hydrocarbon emission (UHC), NOx emissions, and smoke opacity were analysed on a 4 stokes single cylinder with 18:1 compression ratio operated at constant speed 1500rpm of CRDI VCR engine. The test results of LB10 and LB20 were compared with diesel with or without EGR. It was observed that CO and UHC emission was increased with blend content while brake thermal efficiency decreased with blend concentration. NOx emission was marginally reduced by the use of EGR.

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NOMENCLATURE

ASTM	American Standard Test Method
BMEP	Brake Mean Effective Pressure
BP	Brake Power
BSFC	Brake Specific Fuel Consumption
bTDC	Before Top Dead Centre
BTE	Brake Thermal Efficiency
CI	Compression Ignition
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRDI	Common Rail Direct Injection
EGR	Exhaust Gas Recirculation
FIP	Fuel Injection Pressure
F1	Engine cylinder fuel supply
F2	Engine cylinder airflow
HC	Hydrocarbon
KOH	Potassium Hydroxide
LB10%	Diesel 90% + Linseed Biodiesel 10%
LB20%	Diesel 80% + Linseed Biodiesel 20%
N	Contact-free velocity sensor (shaft speed of the engine)
NOx	Oxides of Nitrogen
NaOH	Sodium Hydroxide

PT	Pressure transducer
T1	Temperature of inlet jacket in engine jacket and calorimeter
T2	Temperature of outlet water from engine jacket
T3	Outlet water temperature from calorimeter
T4	Inlet temperature of exhaust gases into calorimeter
T5	Outlet temperature of exhaust gasses into calorimeter
VCR	Variable Compression Ratio
W	Load sensor (eddy current dynamometer)

CHAPTER 1

INTRODUCTION

Any country's progress is subjected to its economic and environmental development in which energy play an important role. The utilization of natural resources in an optimised way can improve the economic growth of any country. The requirement of energy is boost up continuously due to growth in population, the industrial sector, and transportation, especially for developed countries [1-3]. Nuclear energy, Renewable energy (e.g. geothermal, hydro, wind, solar, etc) and Fossil fuels (e.g. coal, natural gases & petroleum) are the major source of energy consumption. Measurement of growth of a nation depends on per capita energy consumption besides per capita income and GDP (Gross domestic product) [4]. Since the consumption of energy over the world is mainly petroleum and its reserves are limited, therefore every country has aim to extract energy from different resources. In our day to day lifestyle, particularly in the area of agriculture as well as transportation, we use IC engine as an integral part [5,6].

CI engines are the most valuable power source which is used globally in agriculture, transportation, and industrial sector and nonetheless in production of power due to its more reliability, fuel conversion efficiency, and durability. Apart from this CI engine can produce more torque than gasoline engine [7]. The petroleum fuels have an important role in developing a nation and much more for basic human needs [8].

Various reports show the increasing consumption rate of conventional resources over a few years worldwide. Globally, every year 11 billion tons of fossil fuels were consumed. In India, the total crude oil consumption was over 103 MT (million tons) in 2000-2001 which increased over 160 MT by 2010 continuing to 194 MT in 2015-16 and later it increased from 206 to 211 MT in 2019 while the production of crude oil was only approx. 34 MT 2009-10. It became 36.9 MT in 2015-16 to 36 MT in 2016-17. There is negative growth in the following years, as well as output, fell from 35.7 MT in 2017-18 to 34.2 MT in the fiscal year which ended on 31st March 2019 as per PPAC (Petroleum planning and analysis cell) [9,10].

According to the current scenario, coal, natural gases, conventional oils will no longer last more than 50-60 years. Since the products of petroleum are consumed at a large scale in all over the world leads to environmental issue as well as threaten with the scarcity of fuel. According to the current consumption rate, the oil will vanish first among fossil fuels. Coals would be exploited for the next 60 years and natural gases; it is just 40 years only according to various study and reports. In addition, diesel engines emit smoke and high NOx which is recognized as being a leading cause of smog, ozone depletion and acid rain. Smoke is known to be injurious and may cause asthma, cardio-respiratory disorders, and inflammation and lung cancer owing to the long-term use. In modern diesel engine design and innovation, NOx and smoke emissions are remains the main challenge [7].

Due to heavy usage of a traditional source of energy oil (crude oil, gasoline, and diesel) and coal results in the emission of CO_2 in an effective way leads to global warming and disturbed the balance of ecosystems. And other harmful and poisonous gases often release from the engine using gasoline or diesel fuel that releases carbon monoxide (CO), NOx (nitrogen oxide), sulphur dioxide (SO_2) that causes breathing issues, loss of the ozone layer, and acid rain. Therefore the energy crisis is directly linked to the environmental crisis. Hence energy security is a major issue for the planet's economic growth. The energy crisis is greatly affecting by the global economy when energy storage is developed. In the common good of mankind and nature to live in equilibrium, a balance between human activity and climate should be developed in by the use of renewable energy sources. In understanding the threats to both the nature and the social being, governments around the world should pile up the pressure by implementing strict regulations on emissions [11].

Strict environmental regulatory reform and the need for pollution-free fuels have encouraged experts to study on fuels other than gasoline and diesel for vehicles in transportation. Scientists were trying to focus on other forms of green resources. Bio fuel is the most common alternative among renewable sources of energy which has gained the interest of the researchers. Bio fuel production, with particular respect to biodiesel, has currently been seen as a significant replacement for conventional diesel worldwide. According to the IEA (International Energy Agency), the biodiesel market has grown significantly in recent years, and from 2000 to 2008 the world demand of biodiesel has increased tremendously [1,12].

1.1 ALTERNATIVE OF DIESEL FUEL

Most suitable and favourable substitute of liquid fuels is alcohol (methanol or ethanol) and edible oils.

1.1.1 ALCOHOLS

Several countries, such as Brazil, Mauritius, the U.S., and just a few European countries, use ethanol-blended fuel in vehicles. Ethanol is extracted from any feedstock such as maize, wheat, tapioca, sugar cane, and other crops. The grain is grounded first and cooked with water to turn the starch into enzyme sugar. Instead, the sugar is fermented with yeast to create raw ethanol and a strong protein. The untreated ethanol is extracted to produce anhydrous ethanol.

Methanol is obtained from coal, natural gas, agricultural waste, municipal waste, etc. The municipal wastes are first crushed and then passed under a magnet to take away ferrous materials and afterward gasified with oxygen. Water scrubbing and other means are used to clean the synthesis gas to remove any particulates, H_2S, and CO_2. The CO-shift transition for H_2-CO-CO_2 modification, methanol synthesis, and methanol purification is accomplished.

Until alcohol was known to be good for SI (spark ignition) engine, due to its high octane number, not suitable for CI fuel. Ethanol and methanol have been deemed a prime substitute to diesel since 1970, and the most promising strategies for engine production are discussed, including power output, thermal efficiency, pollution, and functionality. The CV of ethanol is 27,000 KJ/kg and for methanol it is 20,000 KJ/kg and is also much lower than that of diesel. The alcohol fuels are best suited for SI engines. There are several strategies by which alcohol fuels can partly or fully displace diesel fuel. Alcohol is a valuable fuel, as it is a renewable source of energy and is obtained through manmade and from natural sources. Alcohols are used for versatile fuel vehicle (FFV) service as a combination of petrol and blend. Alcohol is considered an oxygenated liquid since it includes its oxygen structure [13]. Due to low cetane number and poor heating value of alcohol, it is not widely used in diesel engine.

1.1.2 VEGETABLE OIL

A major criticism for the usage of vegetable oils is their high expense. The current situation is that vegetable oils have higher price levels in the market than petroleum fuels. However, the cost is projected to decline as advances in agriculture and methods of oil extraction improve. There are some 364 known varieties of oil seeds. Among such, India has over 200 varieties among oilseeds. The vegetable oils can be classified as edible and non-edible oil. It is possible to locate those areas to determine the right type of oil seeds for growing plantation ideal for soil. To receive a supply of oil yearly from these plants, the process of existence has to be understood for specific oil crops. Each country can thus reduce its dependence on OPEC (Organization of petroleum exporting countries) for its petroleum needs. India being the country based on agriculture, the agricultural lands are namely plants or trees. Jatropha, Madhuca Indica, Cashew, and Neem, etc. may be planted in the desert or barren lands with reduced expense and labour [14,15].

1.1.3 VEGETABLE OIL AS FUEL

Countries such as Europe, South America, and East Asia started using neat vegetable oils in place of diesel fuel. If the diesel engine uses diesel to start, runs it with vegetable oil, and stops with diesel, the engine's fuel system will function for a long time; while severe carbon build-up deposits on engine components.

The most significant differences between diesel and vegetable oils are:

- Viscosities are substantially higher, about 10 times higher than diesel.
- Vegetable oils have lower CV than diesel.
- Vegetable oils improve the stoichiometric F/A ratio, owing to the availability of molecular oxygen.
- Thermal cracking of vegetable oils occurs at temperatures of injected fuel in diesel engines [16].

1.2 DIESEL ENGINE PERFORMANCE WITH VEGETABLE OIL

Vegetable is unsuitable for SI engine due to its low volatility and less octane number. Vegetable oils possess the similar properties as of diesel this make it suitable alternatives of diesel. The important benefit of vegetable oil is, it can use in diesel engine without modification in engine. Usually, vegetable oils have a number of molecules of carbon, oxygen, and hydrogen in them. These have a common structure to diesel fuel, but differ in arrangement of structure of chains, and having relatively high molecular weight and viscosity [17].

Biodiesel can be extracted from various raw materials such as waste oil, vegetable oils which are not edible, animal fat, etc. Out of these mostly are renewable and having no harmful impact on human food scarcity. Even that biodiesel is used as a replacement for diesel, it is highly important to know engine parameters that affect combustion mechanisms owing to their direct effect on BTE and the discharge pollution of a vehicle. Biodiesel has increasingly become a commercially available product due to the development of non-edible vegetable oils and could be used according to market demand for biodiesel production; about 364 varieties of edible and non-edible seed oils are accessible and are ideal for replacing diesel fuel in two forms, i.e. blending and pure. A huge area of forest available in India yields non-edible oils like Karanja (Pongamia pinnata), Linseed (Linum Usitatissimum), Neem (Azadirachta indica), Kusum (Schleicher oleosa), Mahua (Machuca indica), Ratanjyot (jatropha curcus), and Polanga (Calophyllum inophyllum), etc., Which are simple and can be easily and effective for processing biodiesel [18,19].

1.3 BIODIESEL HISTORY

Biodiesel background is more ideological and financial than scientific. The early 20th century witnessed the advent of gasoline-powered cars. Gasoline production began to rise because of the low price of petroleum fuels. On the other hand, the scarcity of resources was and still is a major concern when it comes to crude oil. Therefore studies have begun on the usage of vegetable oils as resources to consider a more appropriate solution to crude oil. Transesterification is also processing vegetable oils or animal fats into biodiesel mono-alkylic esters.

At the Paris Exposition in 1900, Dr. Rudolf Diesel used oil of peanut to power his engine. Dr. Diesel used peanut oil in his engine and stated “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”. Until the 1920s, diesel engines were run on vegetable oil. Manufacturers of diesel engines have altered their motors to employ petro diesels lower viscosity rather than vegetable oil. The use of vegetable oils as an important alternative fuel compared with crude oil was scheduled in the early 1980's. The advantages of vegetable oils over diesel fuel are their portability, biodegradability, ready supply, lower aromatic content, renewability, and lower sulfur content. Dr. Diesel supposed that engines operating on plant oils had potential and that such oil might one day be as essential as petroleum- based fuels. Biodiesel plants have been planning to open in many European countries since the 1980s. Renault and Peugeot more recently implemented the biodiesel in some of their truck engines. Current environmental and regional economic issues have ignited the worldwide use of biodiesel. In 1991, the European Community (EC) implemented a tax exemption of 90% for using bio fuel including biodiesel. Several companies are now constructing biodiesel plants in Europe [20].

1.4 BIODIESEL AS A FUEL

Biodiesel can be produced in the climate-friendly area and can also be marketed by the government. Therefore the need and demand for boosting biodiesel contribute to sustainable social development. Such conditions would alleviate the fear of fossil resources disappearance [21].

Due to the following reason, biodiesel becomes the most suitable choice for an alternatives fuel:

- It does not comprise of any sulphur and fossil oil residues and aromatic hydrocarbons since it is achieved from vegetable sources.
- It can be used in CI engines without much change in the design and is rich in oxygen fuel.
- It reduces pollutants such as smoke opacity, CO_2, HC, and CO.
- Along with a more self-lubricating tendency than fossil fuel, it also increases engine efficiency [22-24].

However, it can be identified that [25-29] out of several vegetable oil advantages, there are a few problems with it when used in engines such as high density and viscosity, more iodine value, and low volatility. Transesterification method will reduce viscosity as well as density but its density and viscosity are still higher. Some researchers found that the high density of biodiesel advanced the injection timing at the time of starting while some other experts say that biodiesel bulk modulus is higher than diesel advance the injection timing at starting [30-31]. Because of this, the rate of NOx is higher for biodiesel fuel. Biodiesel atomization is caused by increased average size droplets that result in increased spray penetration of the tips due to high surface tension and biodiesel viscosity. Relatively high tension also decreases the magnitude of Weber number which in turn has increased the average droplet size. It has also been stated that the average droplet size has been more impacted by viscosity than density. Therefore we first need to reduce biodiesel viscosity to boost fuel atomization [32]. Blending diesel with biodiesel will solve the aforementioned issue, which decreases viscosity. Another way of improving atomization is to inject biodiesel at higher pressures leads to increasing the diffusion of biodiesel spray. Biodiesel can be described as a fuel that consists of fatty acid (long-chain) mono-alkylic esters extracted from animal fat and vegetable oils [33]. Theoretically, any vegetable oil or animal fat that typically contains triglycerides from long chains of saturated and unsaturated fatty acids may be used under diesel engines. However, earlier studies using pure vegetable oils as fuel in a diesel engine resulted in various engine problems such as pumping issues, carbon particles deposition on pistons and head of engine, engine damage, gumming, injector fouling, atomization, and corrosion of long-run lubricating oil [34-36]. High viscosity, density, iodine and low non-volatility can cause this. Therefore several study proposed that vegetable oils be transesterified to reduce the high viscosity of the product. Transesterification is a process to process vegetable oil into biodiesel to be fit for use in diesel engines [37,39].

1.5 METHODS FOR CONVERSION OF VEGETABLE OIL INTO BIODIESEL

i) Transesterification
ii) Thermal cracking (Pyrolysis)
iii) Micro-emulsification

iv) Dilution

TRANSESTERIFICATION PROCESS:

To achieve biodiesel, vegetable oil or animal fat undergoes a chemical reaction known as as transesterification. It represents a reversible reaction in which vegetable oil or animal fat combines with alcohol (generally methanol) by the help of a catalyst (normally a base of NaOH or KOH) and produces the resulting alkyl esters (methyl ester in case of methanol) of the fatty acid mixture present in the parent vegetable oil or animal fat. The reaction is shown below. Catalyst role is mainly about improving reaction rate and increasing yields.

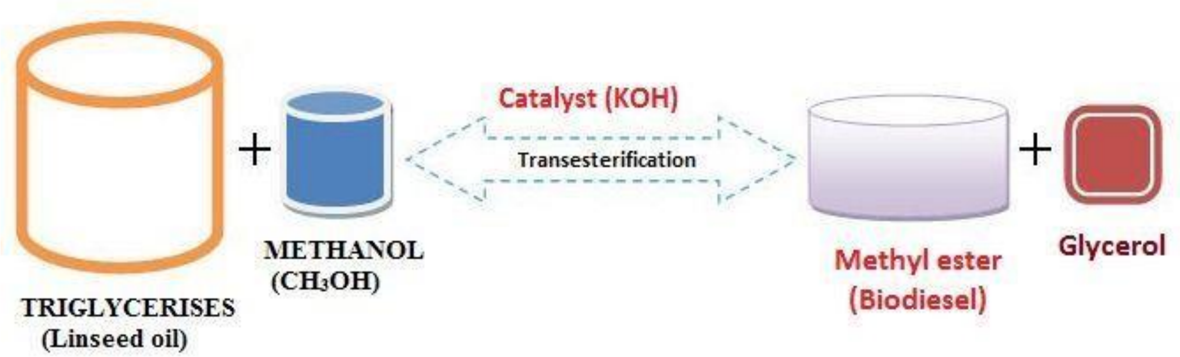

Figure 1.3: The Transesterification reaction

PYROLYSIS

In the absence of oxygen, pyrolysis is a process of heating organic matter such as biofuels. The different products can be achieved from the same substance by applying a separate route of reaction, and catalyst can enhance the rate of a reaction. Pyrolysis of vegetable oil or animal fat can produce a good hydrocarbon which serves as a fuel.

MICRO-EMULSIONS

The micro-emulsion is an emulsion type that is confined to a micro-scale like a droplet as a magnitude range distribution of 10-150nm. It is described as a colloidal suspension of fluid microstructures (1-150nm) in a solvent forming two immiscible phases. Methanol and ethanol are commonly used as solvents. This procedure is primarily utilized for vegetable oil with strong viscosity [41].

1.6 ADVANATGE OF BIODIESEL

- It can globally be produced, biodegradable, safe and renewable fuel.
- It can be used diesel engines without any modification in design.
- Biodiesel has somewhat close physical properties to diesel fuel.
- It is free from aromatic compounds and sulphur.
- Alternatively, it can produce the same capacity as neat diesel.
- Implementation of biodiesel in CI engines greatly decreases emissions of HCs, CO contaminants, sulphates, aromatic compound, and particulate matter [55,56].
- The balance of CO_2 on the earth is not disturbed by the use of biodiesel because atmospheric CO_2 is removed during the photosynthesis cycle by the vegetable oil plant as the plant rises. Biodiesel, therefore, gives net CO_2 gain over traditional fuels.
- It also greatly decreases air toxics associated with petroleum diesel fumes and is estimated to cause cancer and other issues in health and the environment. Biodiesel is also a self-lubricating chemical, improving engine life by reducing wear and tear [42,43].

1.7 DISADVANTAGE OF BIODIESEL

As a fuel some drawbacks of biodiesel are as follows:

- Higher viscosity that causes fuel atomization problems and injectors choke.
- It contains low energy content and a high cloud point and a point of pouring over diesel become problematic for storage and handling.
- Since biodiesel having low energy content, engine output such as fuel efficiency, strength and torque can be decreased by 8% to 15% relative to diesel.
- Biodiesel released NOx higher than diesel fuel.
- Biodiesel costs are still a big concern.

The problem of greater NOx pollution may be minimized by the variety of different ways in certain other studies. EGR is one of the most effective methods to reduce NOx pollution [44].

1.8 EGR SETUP

The exhaust gas recirculation (EGR) procedure is commonly regarded as one of the most successful strategies for controlling pollution from diesel engines, primarily NOx and small particulate. Typically that involves the discharge of part of the exhaust gas associated with the intake of fresh air charge into the combustion chamber for combustion and the spray of fuel in the usual power cycle of the diesel engine. EGR is an easy and quick method of managing noxious pollution during treatment phase. Next exhaust gasses are cooled utilizing a cooling system that is directly attached to the exhaust outlet, then percentage of cooled exhaust gasses are added to the intake manifold through which they join the combustion chamber after mixed with fresh charge [45].

$$\textbf{EGR (\%)} = (M_{EGR} / M_i) * 100$$

M_{egr} **= Recirculate exhaust gas mass** M_i **= Intake air mass**

1.9 LINSEED OIL

Linseed oil, whose scientific name is Linum usitatissimum, falls in the group of the Linaceae and Linum genus having 100specie. It has developed in Mediterranean coastal countries and develops in Argentina, India, Canada, and the United States. Linseed is a cool, yearly temperate tuber, broad, with large, narrow stems 60–80 cm. Figure1.4 displays linseeds plant and their seeds. Except at peak, it has smaller branching. Their leaves are lanceolate and greyish green. Flowers are 5 petalled in a ring, in several cases pure blue or green. The sepals are lanceolate, about almost as long as they reach to the fruit. The fruits look like capsules and are spherical. The seeds are round, smooth, 4.5–6mm in height, light to dark brown, and dazzling. The linseed includes several unsaturated fats, along with mucilage [46]. Linseed plant required fertile, good textured and loamy type soils, and rainfall quantity at the time of growing is an important factor. Limited moisture and relatively cool environments, particularly during the period from flowering to maturation, seem to support both oil yield and quality of oil. The seed is stored in circular capsules at the lower limbs of the branches, each comprising one to ten seeds [47].

The environment condition and soil types in India are capable of producing linseeds. It is decided to plant in India as cold-crop during October or November and harvested during March or April. In India, separate states have a suitable land area for linseed plantation. In yield and grazing land, MP (Madhya Pradesh) dominates, led by UP (Uttar Pradesh) and Bengal, Rajasthan, Karnataka, Maharashtra, Bihar, and West Bengal produce linseed even in wide areas. Madhya Pradesh and Uttar Pradesh both together contribute to linseed production by about 70%. The linseed production is usually higher in northern India than in central and southern India. The irrigated crop can yield 1200 to 1500 kg per hectare, and ranks third among Australia and Canada's linseed-producing countries [48]. This is spread throughout Asia in nations. This is an essential olive seed worldwide. Linseeds are a source of good quality protein, soluble fiber and a large proportion of polyunsaturated fatty acids. The study corresponds to 30%–40% lipids, 20%–25% proteins, 4%–8% ashes, 3%–4% ash and 20%–25% dietary fibre [49]. Linseed oil's chemical composition differs according to the regional area and range. Oils originating from multiple sources have varying concentrations of fatty acids. Linseed oil is primarily made of three glycosides, andolein , linolenic, and linolein and. There is also a small amount of free fatty acids, for example, arachidic and palmitic. Linseed oil triglycerides contain five important fatty acids. Oleic, stearic Palmitic, linoleic and a-linolenic were the principal fatty acids that are usually present in linseed oil [50-52].

1.10 OBJECTIVES

The proposed research was performed using linseed oil biodiesel with the following goals.

1. Biodiesel extraction through transesterification process from linseed oil.
2. Determination of viscosity and density of diesel, and different blends in accordance to appropriate ASTM standards.
3. Engine setup preparation for fuel testing and gas analyzer for emission testing.
4. Performance analysis for different blends ratio LB10 and LB20 of linseed biodiesel for different output parameters such as brake power, brake specific fuel use, brake means effective pressure, brake thermal capacity, and mechanical efficiency, along with comparison of their results with diesel with or without the use of EGR.
5. Assessment for different blends of linseed biodiesel for different emission characteristics such as smoke opacity, HC, CO_2, CO, and NOx with comparison of results to conventional diesel.

CHAPTER 2

LITERATURES REVIEW AND RESEARCH GAP

Sivalakshmi et al. [53] carried out an experiment to run the diesel engine by using they stated that BTE was improved by using mixture of alcohol and neem oil compared to pure neem oil. As the blend content increases, the smoke opacity gets reduced accordingly. NOx in exhaust emission was significantly reduced when engine run with alcohol added neem oil. The CO and UHC emissions of alcohol added neem oil was observed to be lower than pure neem oil at maximum load condition.

Singh et al. [54] did an experiment on a CI engine by using blend of Karanja methyl ester (KME) with diesel at different concentration and studied their impacts on various parameters. It was observed that KME100 has highest BTE at all loads. Even all blend content of KME has more BTE than diesel at full load. The BSEC of KME30 was less than neat diesel. They observed that the temperature of flue gases for KME100 was the maximum. It was also found that the EGT (Exhaust Gas Temperature) of diesel was lowest among all test fuel. Also the mechanical efficiency of KME30 was better than neat diesel.

M. N. Varma and G. Madras [55] studied the manufacture of biodiesel from Linseed and Castor oil by employing Methanol and Ethanol at 200bar with subcritical and supercritical methanol and ethanol situations from 200 to 350 ° C. The reaction kinetics was first order, and the activation energies were calculated from the dependence of the rate coefficients on temperature. Biodiesel was also enzymatically manufactured in supercritical carbon dioxide (CO2) using Novozym 435. A generalized model was proposed to explain the enzymatic transesterification kinetics for castor oil using methanol and ethanol, based on the Ping Pong Bi with efficient inhibition mechanism.

J. Hussain et al. [56] conducted an experiment to study the impact of EGR on 3 cylinder CI engine. It was seen that with EGR at lower load the BTE was slightly improved as well as BSFC was reduced in comparison to without EGR. As the EGR rates increases the NOx emission was reduced significantly but the BTE and other emissions were disturbed also. It was concluded that higher EGR rates can be implemented at lower loads to be effective. Also it was found that 15% EGR was efficient to optimize emissions and performance of the engine.

W. Zhang et al. [57] did a test and studied about emission of NOx and smoke with some combustion property by employing EGR and enrich oxygen air on a diesel engine. The researchers have concluded that an acceptable arrangement of EGR rates and oxygen level leads to less emission of smoke and NOx. Opacity of smoke significantly reduces as diesel engines are burned with oxygen. The findings of computational simulation show that oxygen rich combustion suppresses HACA processes and decreases the release of new molecule PAHs.

X. Walke et al. [58] studied the influence of EGR on the performance of a CI engine with diesel. They realised that with rising EGR rates, the BTE gets reduces. That decrement is marginal, though. At maximum load condition, smoke opacity concentration keeps rising, and BSFC rises moderately with higher EGR rates. It was seen that there was a significant reduction in NOx by the influence of EGR.

K. Ashok et al. [59] carried out an experiment on a diesel engine run with blend of rice-Bran oil and diesel and studied their effects. All the properties of rice-bran biodiesel are within a limited range except CV. It was noticed that as the %age of biodiesel increases in the blend the BSFC gets increases and BTE reduces accordingly. With the increment of rice-bran level in blend the emission of CO and HC gets drop while NOx increases significantly

P. Bedar et al. [60] carried out an experiment on a diesel engine having one cylinder operated with the blend of Simarouba glauca oil and diesel with implementation of EGR. It was noticed that there is an improvement in performance of the engine when run with B10 blend and simultaneously there is a reduction in smoke, CO and UHC emission and slightly increment in NOx. EGR levels are gained by 10 % and 15% in terms of efficiency and pollution, but adverse patterns are found at an EGR average of 20%. It is observed that combination B10 blend and 15% EGR caused lower emissions without affecting the efficiency of the engine.

Y. H. Teoh et al. [61] wants to reduces NOx and smoke opacity compared to neat diesel simultaneously by using PME (palm oil methyl ester) running on a CRDI system. It was found that the EGR rate and the injection timing have great effect on the output of the engine. In order to meet strict EURO requirements, from 0 to 50% a wide range of EGR rates were implemented to reduce the NOx level. It was observed that 30%

EGR rate applied on the engine run PME blend fuel having better emissions without affecting the engine efficiency.

Dr. K Srinivasa Rao [62] carried out an experiment on a diesel engine running with Cotton seed biodiesel and EGR. NOX pollution decreased with EGR was detected for both blends. The enhanced engine models are obtained for all blended fuels with EGR limit of 15%. The analyses demonstrate that biodiesel cotton seed with EGR is used to lower NOx.

Gautamedara et al. [63] conducted an experiment to study the impact of cold EGR on a diesel engine. Test results reveal that at 350bar injection pressure, there is negotiate-off between delayed and split injections under maximum load. The BTE of delayed injetion was found to be 33.61% where as the BTE of split injection was 29.06% at 5% EGR rate. Yet higher EGR flow levels were both delayed by 10 per cent and split injection has almost the same 30.1% BTE. Split injection decreases combustion period, ignition delay and engine exhaust temperatures compared to individual retarded injection for greater EGR flow rates.

D. Agarwal et al. [64] studied the impact of EGR on a constant speed CI engine’s efficiency, pollution, contaminants and reliability. Outlet temperature is continuing to decrease with EGR. BTE reported an increase and BSFC reduced with EGR at low load conditions compared to EGR-free loads. At higher load, with EGR the trend of BSFC and BTE are almost similar to without EGR trend. When EGR applied, the emissions of smoke opacity, UHC and CO gets increases while there is a reduction in NOx. It was found that 15% EGR rate is suitable for reducing NOx emissions.

Sanjay mohite et al. [65] was carried out experiment on Karanja and linseed is the possible bio fuels crops which can be used for the biodiesel processing. The main objective of this work is to find out the usefulness of using a blend of karanja oil and linseed oil to generate biodiesel. Karanja oil contains a significant level of free fatty acid and the level of free fatty acid in linseed oil comparatively low. Karanja biodiesel is prossesed through a two-step esterification reaction that is expensive, dangerous to human health and toxic due to concentrated acid use. Linseed biodiesel can generate through alkali-base transesterification that is much faster and yields higher than acid-base transesterification. A processing method is produced to manufacture biodiesel from the blend of karanja and linseed oil that is quicker, healthier and non toxic. Yields ranging from 68.2 to 78.9% have been obtained with changing various factors such as catalyst quantity, mixing period as well as molar ratio. Optimum parameters are also set to achieve optimum biodiesel yield from a blend of linseed and karanja oils being transesterified.

Pathikrit bhowmick et al. [66] performed an experiment on CRDI system having 1 cylinder and air cooled run on a blend of Calophyllum Inophyllum biodiesel (CIB) (10%) and diesel and study the effect of varying injection strategy and EGR. This work also focuses on the processing of CIB. The test findings show that 10% of the pilot fuel and 90% of the main injection strategy (B10@P10-M90) are advantageous with reference to pure diesel among all other injection strategies. B10@P10-M90 fuel injection strategy delivers 35.8% maximum efficiency and 0.25 kg/kWh lowest fuel consumption in comparison to all injection strategies. However, at maximum load condition B10@P10-M90 causes a significant rise in NOx emission approx 18.9% more than neat diesel. It was found that when 10% and 15% EGR rate were applied with B10@P10-M90 then there was a reduction in NOx by 14.4% and 27.6% respectively compared to without EGR.

Shailaja. M et al. [67] performed an experiment on a diesel engine run on a blend of sesame oil and diesel. Sesame oil biodiesel has proven to be theoretically suitable fuel for diesel engine. Better efficiency and emissions with sesame biodiesel was observed in comparison to neat diesel. Since there is no need of modification in the design of diesel engine, sesame biodiesel can be used directly in the diesel engine.

M. Ahmad et al. [68] performed experiment on sesame oil for converting it into biodiesel. Biodiesel was formulated using sesame seed oil transesterification with Methanol and catalyst NaOH. The optimization of this base catalyzed the maximum biodiesel yield at 1:7, 1:8, 1:9, and 1:10 molar ratio (oil: methanol) at 86, 88,90 and 92 percent respectively. The various properties of Sesame biodiesel are like kinematic viscosity (5.77), pour point (18^{o}C), flash point (110^{o}C), cetane number 53, specific gravity (0.887), and sulphur content (0.0083). All these fuel properties fulfil AST specification.

Rishi Malhotra et al. [69] did an experiment on a diesel engine run with the blend of linseed biodiesel (10%) and neat diesel (90%) with additives camphor **(**0.5% and 1% concentration). From the investigation it was found that at initial load BTE was highest among all biodiesel blend fuel but as the load value increases on engine BTE of biodiesel blend fuel become more than neat diesel. For BTE, incorporating camphor was noticed with positive effect. It was also seen that the BSFC of biodiesel blend fuel was more than neat diesel. Emission of NOx, HC, CO2 and CO of blended fuel was found more than diesel. On camphor addition at any load all the emission gets marginally reduced.

G. S. Warkhade and A. V. Babu [70] carried out an experiment on diesel engine run with the blend of linseed biodiesel and petro-diesel. The engine run with variable CR and engine load. From this experiment it was found that at CR 16:1 and 14:1, there is hike in ignition delay by 3.3% and 30% whereas at CR 18:1, it was dropped by 28.3%.

A. Jawalkar et al. [71] conduct an experiment on a diesel engine having single cylinder which is run on linseed and mahua oil blend at different ratio with neat diesel. From this investigation it was observed that when compared to linseed, mahua biodiesel has higher BTE and lower BSFC as the fuel injection pressure was rises. Also, with increase in blend ratio, the BTE gets decreases. At maximum load condition, it was found that the BTE of the blend ratio M50 was 13.49% less that L50 at 160bar fuel injection pressure. Mahua biodiesel has less emission of CO than linseed.

RESEARCH GAP

Considerable research has also been conducted on the development of biodiesel from oil seeds. Biodiesel development from edible oils does not appear economically viable in developing countries like India where the cost and use of edible oil is very high. But production of biodiesel from non-edible oils is financially efficient because of the lower cost of non-edible oils. However much research has also been done on non-edible oils including Karanja, Neem, Kusum, Jatropha, Mahua not much research has been documented on the development of biodiesel from linseed oil. India is the 3rd largest producer of linseed oil and there is very little knowledge regarding biodiesel production from linseed oil. Little research has been conducted on assessing the efficiency and pollution characteristics of a CRDI diesel engine fuelled with linseed biodiesel with EGR technique. The evaluation of performance and exhaust pollution of CRDI diesel engine was performed with EGR techniques when the engine powered with linseed biodiesel (10% and 20%). The results were also compared with the neat diesel.

CHAPTER 3

TEST PROCEDURE AND METHODOLOGY

This section explores the transesterification process for the formation of linseed biodiesel. Also, the properties of LB10 and LB20 blend different with diesel have been obtained. These four blends were used to run the CRDI engine and various combustion and performance characteristics like BP, BSFC, BMEP, BTE, and mechanical efficiency are calculated. Apart from this we also obtained emission parameters like smoke opacity, CO, NOx, CO_2, and UHC. These values were compared with diesel with the plotted graph has been shown.

3.1 LINSEED BIODIESEL FORMATION

Linseed oil was brought from HIMANI INTERNATIONAL, DELHI @ Rs 250 per litre. Biodiesel was prepared in the automobile lab of Mechanical engineering Department at Delhi Technological University, DELHI (INDIA). In the formation of linseed biodiesel some materials such as KOH, Methanol, NaOH, phenolphthalein and Isopropyl Alcohol were used. The following guidelines require in linseed biodiesel preparation:

At first, FFA (Free Fatty Acid) of the Linseed oil sample was checked which should be less than 5%. FFA was calculated with the help of N/10 dilution of NaOH, isopropyl alcohol, linseed oil, and phenolphthalein. The setup is shown in figure 3.1. It came out 2.2%. It means a sample of linseed oil can use for the transesterification process; otherwise, it becomes the saponification process.

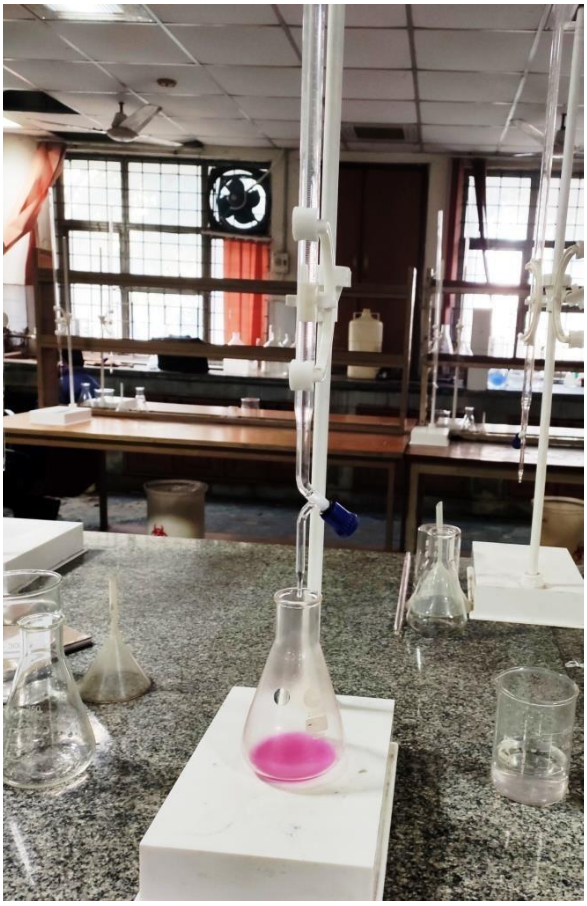

Figure 3.1: Testing of FFA of linseed oil sample

i. From the jar of linseed oil, 200ml was taken in a beaker and pre-heated up to 100-110 ^{o}C so that to remove water content from the oil.
ii. In parallel time, KOH by weight and methanol by volume was taken in a separate conical beaker and stirred to form a solution.
iii. After removal of water content from preheated oil heating was stooped and oil is allowed to cool.
iv. When the preheated oil came at 60 ^{o}C, the methanol and KOH were mixed with oil, and stirring was continued on a magnetic stirrer.
v. The mix solution was maintained at 60 ^{o}C and stirring continued for approx 30 to 45 minutes.

Figure 3.2: Separation of biodiesel from glycerol

vi. After that, took a separating funnel and the stirred sample was poured in it from the beaker to isolate glycerol and biodiesel.

vii. The sample was left in separating funnel around 24 hours and glycerol was separated from biodiesel.

viii. Finally, the extra impurities, KOH and methanol were eliminated through water washing.

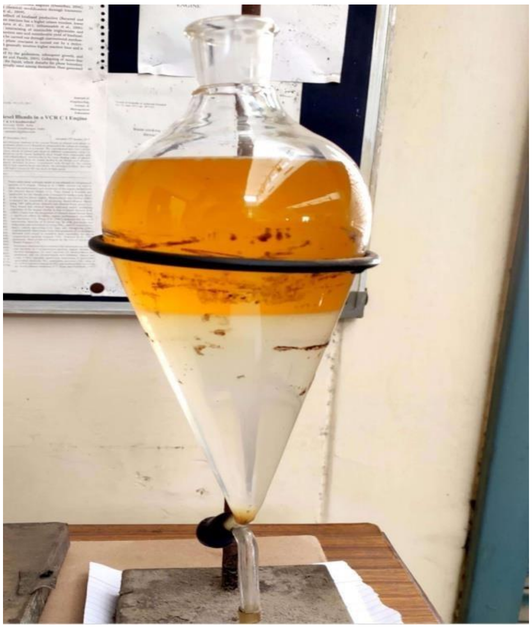

Figure 3.3: Water Washing

3.2 DENSITY AND VISCOSITY OF DIESEL, LINSEED OIL AND ITS BLEND BL10 AND BL20

The density and viscosity of linseed blends, linseed biodiesel and diesel are calculated with the help of viscometer shown in figure 3.4.

Figure 3.4: Viscometer

Table 3.1: The density and viscosity of different blends

Properties	ASTM Method	Diesel	LB10	LB20	Linseed methyl ester
Density(g/cm^3)	ASTM D7042	0.830	0.8382	0.8461	0.8757
Kinematic viscosity (mm^2/sec)@40°C	ASTM D7042	2.9783	3.0874	3.1714	3.8894

3.3 EXPERIMENTAL INVESTIGATION OF THE ENGINE PERFORMANCE PARAMETERS

The experimental engine tests were done on CRDI VCR engine setup in the automobile lab of Mechanical engineering Department at Delhi Technological University, DELHI (INDIA). The various tests were carried out for conventional diesel and different blend of linseed biodiesel on a single-cylinder, 4-strokes, and water-cooled VCR engine operated at constant speed of 1500 rpm with (cold) EGR or without EGR (Exhaust Gas

Recirculation) as shown in Figure 3.5. The various specification of the engine set up is listes in table 3.2. The engine performance parameters are evaluated in this experimental investigation such as BP, BSFC, BTE, mechanical efficiency, and BMEP.

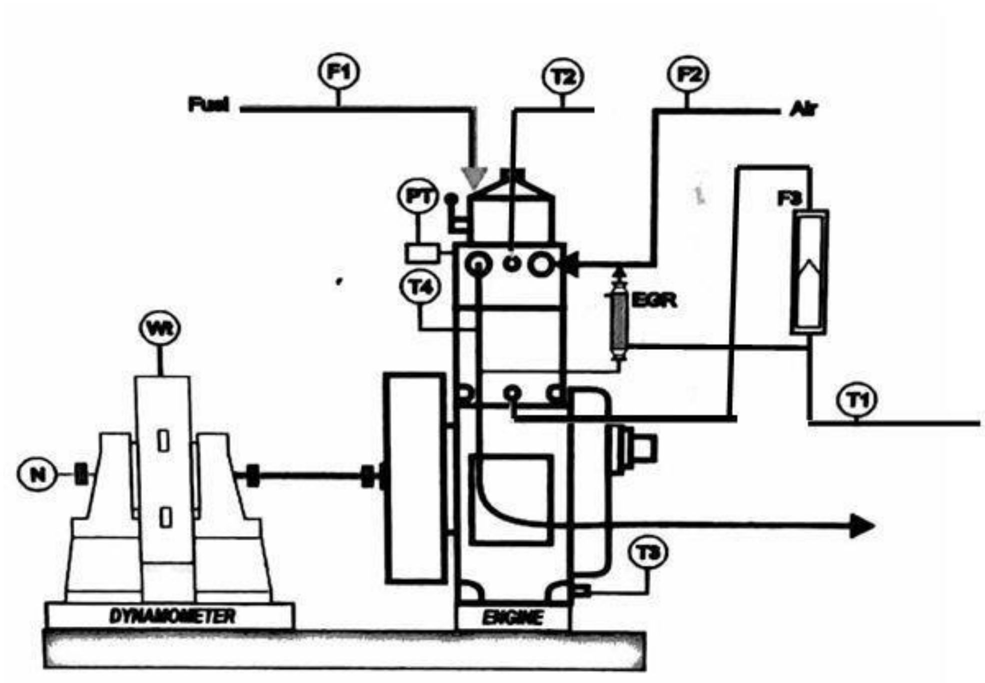

Figure 3.5: The CRDI diesel engine set up

Table 3.2: The technical specifications of the engine setup

MODEL	KIRLOSKAR
No. of cylinders	1
No. of strokes	4
Cylinder diameter	87.5 mm
Stroke length	110 mm
Compression ratio	12:1 to 18:1
Power	3.5 kW
Speed	1500 rpm
Connecting rod length	234 mm
Dynamometer	Eddy current, water-cooled type
Dynamometer arm length	185 mm
Load indicator:	Digital, Range 0-50Kg, Supply 230 VAC
Load sensor	Load cell, type strain gauge, range 0-50Kg

Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
Temperature sensor	Type two wire, Input Thermocouple
Rota meter	Cooling of engine 40-400 LPH; Calorimeter 25-250 LPH

3.3.1 EDDY CURRENT DYNAMOMETER

There is a connection link between engine and eddy current dynamometer which measured mainly power and torque. Several loads like 0kg, 3kg, 6kg, 9kg, and 12kg were applied on the CRDI engine through dynamometer by the help of load cell which is connected with load sensor and the load was displayed on the load indicator. There is a rotor look like notch disc which is powered by prime mover and stator (magnetic poles) are situated externally with a gap. The magnetic poles excited by the coil which is wrapped in the circumferential direction. The prime mover spins the rotor and delivers the voltage to the thrilling coil or stator casing. Therefore, magnetic flux is generated and those magnetic fluxes are cuts off by the rotor. Thus, the eddy current produced in the rotor contrary to the magnetic flux change.

Figure 3.6: Eddy Current Dynamometer

3.3.1 AVL EXHAUST GAS ANALYZER

The emission parameters like smoke opacity, CO, NOx, CO2 and UHC are measure by AVL gas analyzer (AVL DIX 650) as shown in figure 3.7. In this system, the one end is connected with gas analyzer while the other end is connected with the exhaust gas pipe. The technical specification of the gas analyzer is listed in table 3.3.

Table 3.3: The specifications of AVL exhaust gas analyzer

Type	AVL DIX 650
Operating temperature	5...40 ^{0}C
Storage temperature	0...50 ^{0}C
Warm up time	Approx... 2 min
Humidity	10 ... 90 % non condensing
Dimension	344 x 252 x 85 (W x H x D)
Weight	2.2 kg
Interface	USB, Bluetooth Class 1, RS 232 (AK Protokoll)
Certification	2004/22/EC (MID); OIML R99 Class 0
Voltage supply	Via AVL DITEST CDS Basic Unit: 11..25 V DC
Power consumption	Approx. 20 VA

Figure 3.7: AVL Exhaust Gas Analyser

3.4 EXPERIMENTAL PROCEDURE

Initially, the engine was operated with diesel and after that it runs with LB10 and LB20.

The following steps are used for the experiment

i. At first, diesel was filled in fuel tank of CRDI VCR engine adjusted with a compression ratio 18:1.
ii. Then the water is supplied through the motor. The calorimeter and cooling water flow was set 75LPH and 150LPH (litre per hour) respectively
iii. Confirmed the proper water supply for the piezo cooling sensor and eddy current dynamometer.

iv. After that, strictly checked all the electric point and connection supplied power to the system.
v. Then diesel was allowed into the engine by opening the knob of the burette.
vi. The specific gravity and the calorific value are adjusted through the configure option present in the software for the experiment.
vii. The engine was adjusted with injection pressure at 600 bar and injection angle at 23^0CA bTDC by configuring option in the software.
viii. At zero load condition, the engine was operated for 10 minutes by selecting the run option on the software.
ix. Pressed the log-on option shown in the software and allow the diesel supply. The display changed into input mode and after 1 minute. Thereafter the water flow was entered in calorimeter and cooling jackets. Noted the first reading at zero load condition and value saved in the software by making a file.
x. After that turned the fuel knob to the previous position.
xi. The same steps were repeated for different load i.e. 3kg, 6kg, 9kg, and 12kg. Their corresponding values were saved in the software.
xii. These above-mentioned procedures were repeated for a different blend of linseed biodiesel i.e. BL10 and BL20 by changing the fuel in the tank and also the corresponding value of the specific gravity and CV were adjusted accordingly in the software.
xiii. All these steps followed again by applying EGR (14%) this time and values were recorded.
xiv. After saving all the values corresponding to different blend at different loads, supplied zero loads to the engine and after that turn off the system and engine.
xv. After a few minutes, the water supply was stopped too.

The following precautions are taken during the experiment:

i. All the joints parts like nut and bolt were checked strictly and it should be tight before operating the engine.
ii. The availability of fuel in the fuel line and the fuel tank must be sufficient.
iii. Proper cleaning of the flue line and fuel tank to remove the impurities.
iv. The motor for the water supply turned on before starting the system for cooling.
v. Sensor and sensitive instrument handed carefully.

The following steps were taken for evaluation of emission parameters:

i. When the engine was set on a particular load for a particular blend then put the gas analyzer sensor inside the exhaust pipe of the engine.
ii. The exhaust gases passed through sensors and readings were displayed on the digital screen.
iii. When the data is stabilized, 3 subsequent values were taken and their mean value was noted for analysis purposes.
iv. The exhaust pipe then removed from the sensor.
v. These steps were repeated for different blends at different load conditions.
vi. Their corresponding readings were noted accordingly.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this section two main objectives were discussed:

- Evaluation of performance parameters of diesel and its blend.
- Evaluation of emission parameters of diesel and its blend.

4.1 EVALUATION OF PERFORMANCE PARAMETERS OF DIESEL AND ITS BLEND

When experiments were performed with diesel and their blends in CRDI engine, various performance parameters like BP, BTE, BFSC, BMEP, and Mechanical Efficiency were discussed concerning load and blend simultaneously with or without EGR.

4.1.1 BRAKE POWER (BP)

Figure 4.1 displays load variation of the brake power and various combinations with or without EGR. The graph show that initially at no load condition the BP is the almost equal for all diesel and linseed biodiesel blends. As the load increases gradually the BP increases for all test fuel because the torque increases but BP of diesel increases more comparison to LB10 and LB20. It was probably due to fact that diesel has a higher CV than biodiesel blends. BP of linseed blend reduces at partial loads compared to diesel due to greater viscosity and density but low CV than diesel leads to improper combustion of fuel. At 100% load condition BP of LB20 is 11% less than diesel.

From the Figure 4.1 it is also seen that as EGR (14%) apply on the engine the BP tends to decreases. This can be because of reason that the quantity of oxygen available for ignition comparably reduces because exhaust gas replaces intake air. The BP of diesel and LB10 with EGR gets reduce by 4.95% and 5.35% respectively while for LB20 it gets slightly increase by 1.21% at full load.

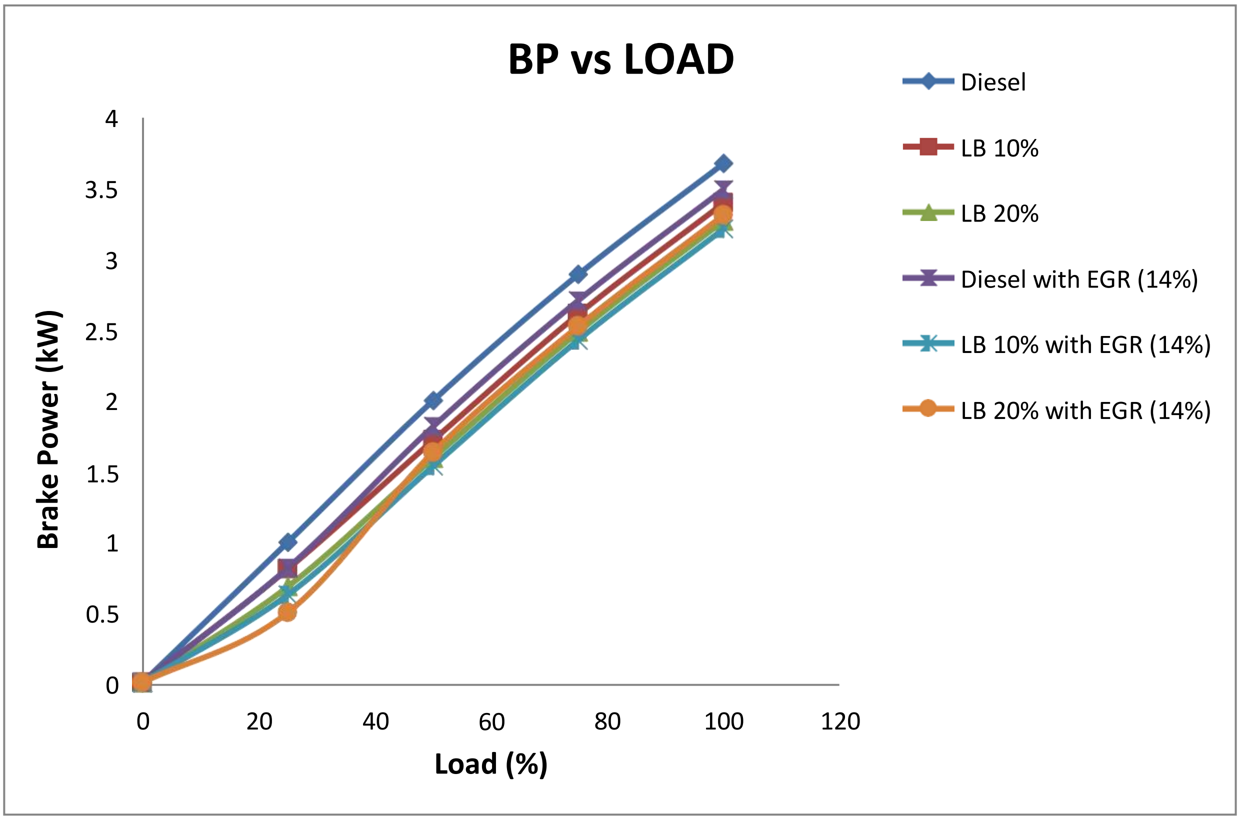

Figure 4.1: Brake power variation with load and different blend with or without EGR

4.1.2 BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

The BSFC response of two different linseed blends i.e. LB10 and LB20 are shown in figure 4.2. From the graph it was cleared that BSFC reduces drastically as engine load increases for both blend and diesel. The reason behind this may be that primarily cause for this may be that the rise in the quantity of fuel required to power the engine is smaller than the improvement in magnitude of BP owing to comparability with less portion of the heat loss at higher engine loads. The BSFC of neat diesel was observed to be less than LB10 and LB20. As the fraction of linseed increases in blend, it was found that the BSFC was rising. The BSFC of LB20 was more than diesel and LB10 due its high density. As the %age of biodiesel increases the density of fuel increases corresponding. For the same volume of fuel, there is more mass injection for high densities of biodiesel blend leads to greater BSFC.

In general, BSFC increases with higher EGR levels for all linseed / diesel blends, with higher LB20 fuel consumption. This may be due to the reduction in in-cylinder temperature by employing EGR which results in inadequate combustion. The variation of BSFC with load and different blend with or without EGR are shown in figure 4.2.

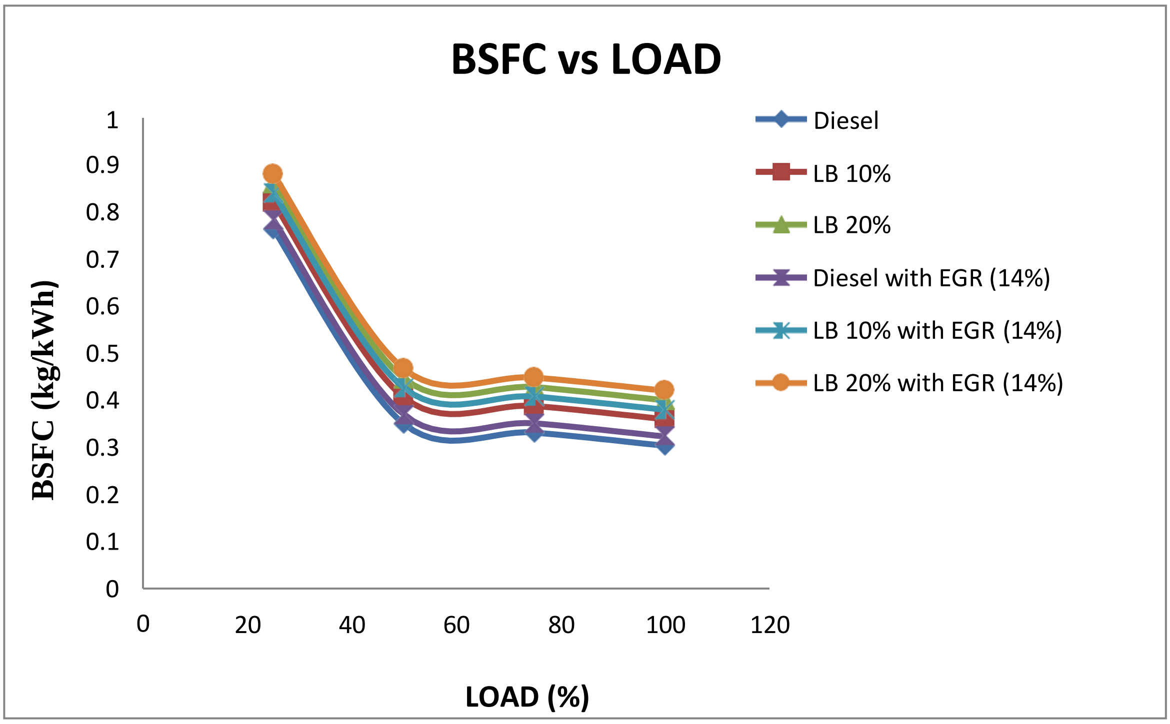

Figure 4.2: BSFC variation with load and different blend with or without EGR.

4.1.3 BRAKE THERMAL EFFICINCY (BTE)

Figure 4.3 shows the variation of BTE with load indicating BTE as a function of engine load for all test fuel. The rate of change of BTE was greater at lower loads, while it dropped with load increases further. This may be because at maximum load the rate of rise in BP decreases while the rate of increase of BSFC remains almost stable. Due to this the drop in the rate of BP increases at greater loads leads to fall in the rate of BTE. Also, as the blend concentration increases in fuel, the BTE is observed to be decreases accordingly. This is because biodiesel content fuel has high viscosity and low CV than diesel lead to poorer atomization of fuel and ignition. BTE decreases also due to increase in BSFC with blend content.

BTE for all linseed/diesel blends can be seen to decrease very slightly when EGR applied. As EGR (14%) applied it disrupts the proper combustion of fuel and ignition rate gets decreases because the quantity of oxygen available for ignition is continuously decreases as exhaust gases injected in combustion chamber in place of fresh air.

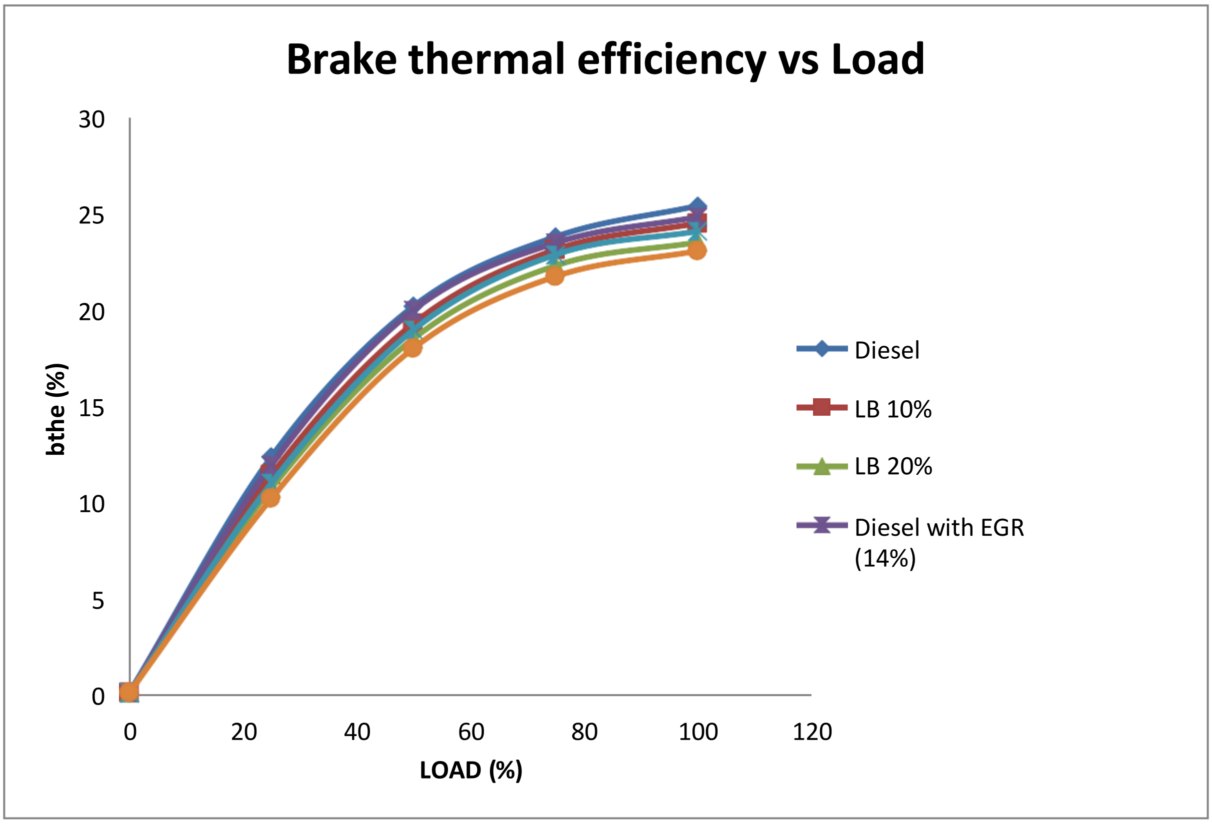

Figure 4.3: BTE variation with load and different blend with or without EGR

4.1.4 BRAKE MEAN EFFECTIVE PRESSURE (BMEP)

Mean effective pressure is the average pressure dependent on measured power consumption within the cylinder of IC engines. As the pressure of the manifold increases, it increases. Small changes were observed in BMEP with blend content as shown in figure 4.4. Also as load increases, BMEP was noticed to be rise. That could be attributed to the appropriate fuel combustion in the biodiesel molecule owing to the oxygen content.

With EGR, BMEP gets reduces for all test fuel due to improper fuel combustion in combustion chamber. Effects of blend, load, and EGR on BMEP are shown in Figure 4.3.

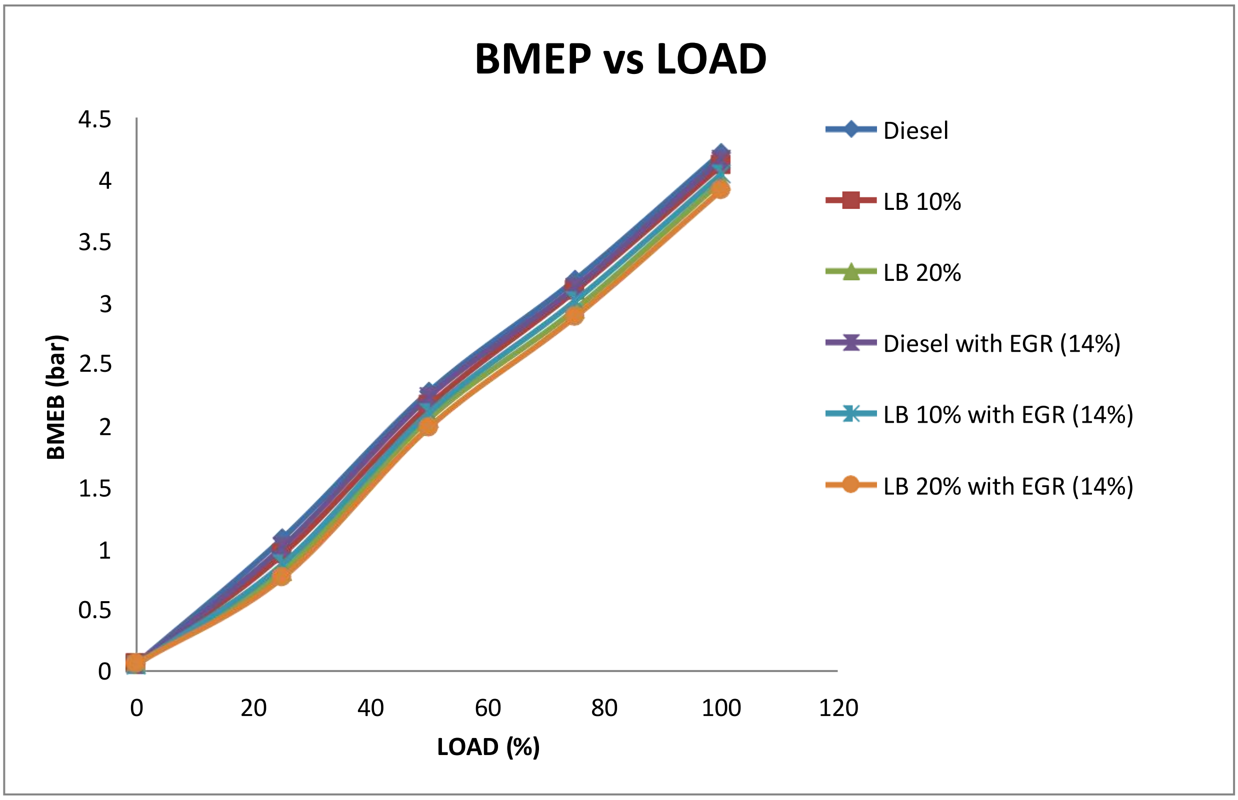

Figure 4.4: BMEP variation with load and different blend with or without EGR

4.1.5 MECHANICAL EFFICIENCY

It was found that the mechanical efficiency of neat diesel fuel is the minimum. The mechanical efficiency rises with increment due to the increase in BP. Compared with neat diesel fuel, blended fuels displayed higher mechanical efficiency. That may be because blended fuels have greater lubricity properties compared to fossil diesel. It has been observed that the mechanical efficiency of the LB20 blend is the greatest among neat diesel and LB10. Since LB20 is more viscous which make it having more lubricity. The other justification may be that the increasing trend in BP at higher loads is lower than lower loads, while the rise in IP at all loads is the same.

With EGR the mechanical efficiency is marginally decrease for all loads and test fuel. This was probably due to fact that there is decrease in temperature in cylinder by employing EGR which leads to inappropriate combustion. The variation of mechanical efficiency with load and different blend with or without EGR is shown in figure 4.5.

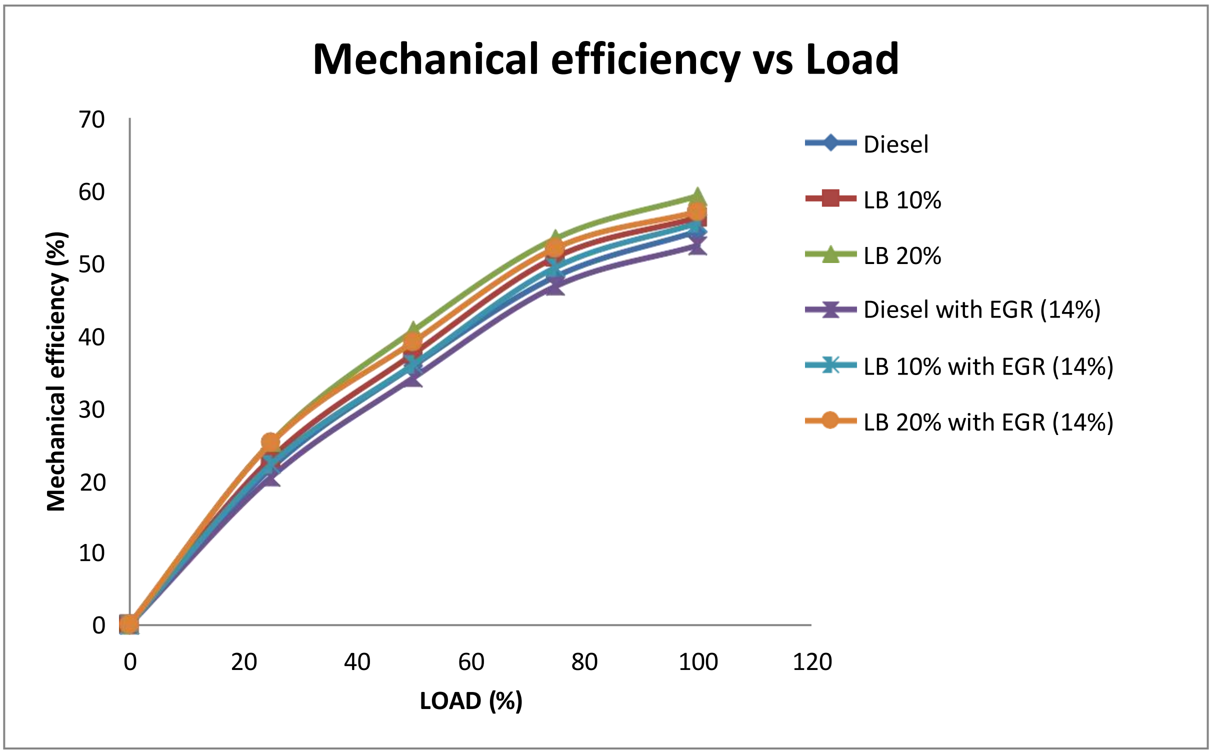

Figure 4.5: Mechanical efficiency variation with load and different blend with or without EGR.

4.2 EVALUATION OF PERFORMANCE PARAMETERS OF DIESEL AND ITS BLEND

4.2.1 NOx EMISSION

High temperature in the combustion chamber is generally responsible for the formation of NOx, which is affected by some factors of the engine input. Compared to diesel fuel, it was cleared from the figure 4.6 that the formation of NOx with linseed/diesel blends concentration was more. Adding linseed biodiesel to diesel affect the CN of blend resulting in a longer delay in ignition. Therefore, during this time span, more quantity of fuel is injected inside the combustion chamber. When the combustion start, due to more availability of oxygen and fuel complete combustion of fuel takes place and flame attains high temperature which is the favourable condition for the NOx formation.

By applying EGR, the NOx emissions in CI engines are reduced. This may be due to the reduced concentration of oxygen in the combustion chamber and decreased temperature of the flame. The availability of oxygen at lower load is more than higher load. More oxygen means proper combustion of fuel and attains high temperature. Therefore, NOx emission may be greater at partial load than higher load. Due to less oxygen availability, the decrease in NOx emission is mainly due to lower in in-cylinder temperature during the combustion of fuel. NOX emissions dropped considerably at high EGR rates but it results in higher BSFC and lowered BTE.

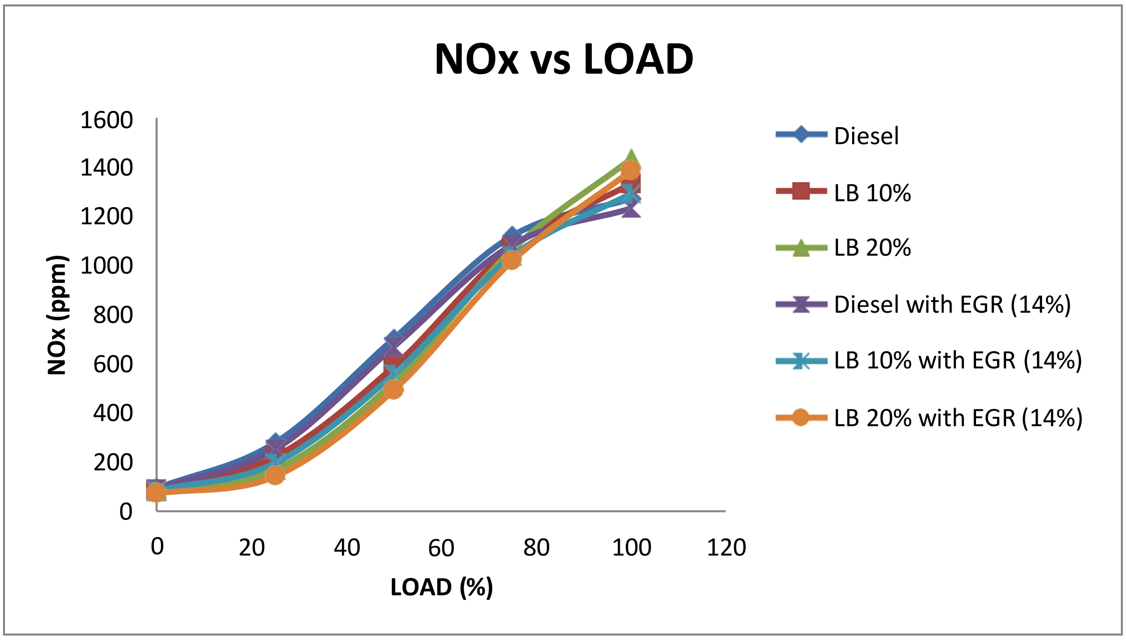

Figure 4.6: NOx emission variation with load and different blend with or without EGR

4.2.2 CARBON MONOXIDE (CO) EMISSION

In general, CO emissions accelerate at low loads and significantly reduce with rising loads because of greater temperature inside the combustion chamber. It can also be shown that CO emissions are rising in the blend, with rising linseed content. The high latent vaporizing heat of linseed blends lowers the temperature inside the combustion chamber and induces a cold effect that enhances CO forming. Also LB10 and LB20 contain more volume of oxygen leads to proper combustion of fuel decreases the formation of CO as converted into CO_2.

The implementation of EGR prevents CO emission due to lower concentration of oxygen, resulting in a small rise in CO emissions as seen in figure 4.7. CO emissions of diesel are higher than other mixtures.

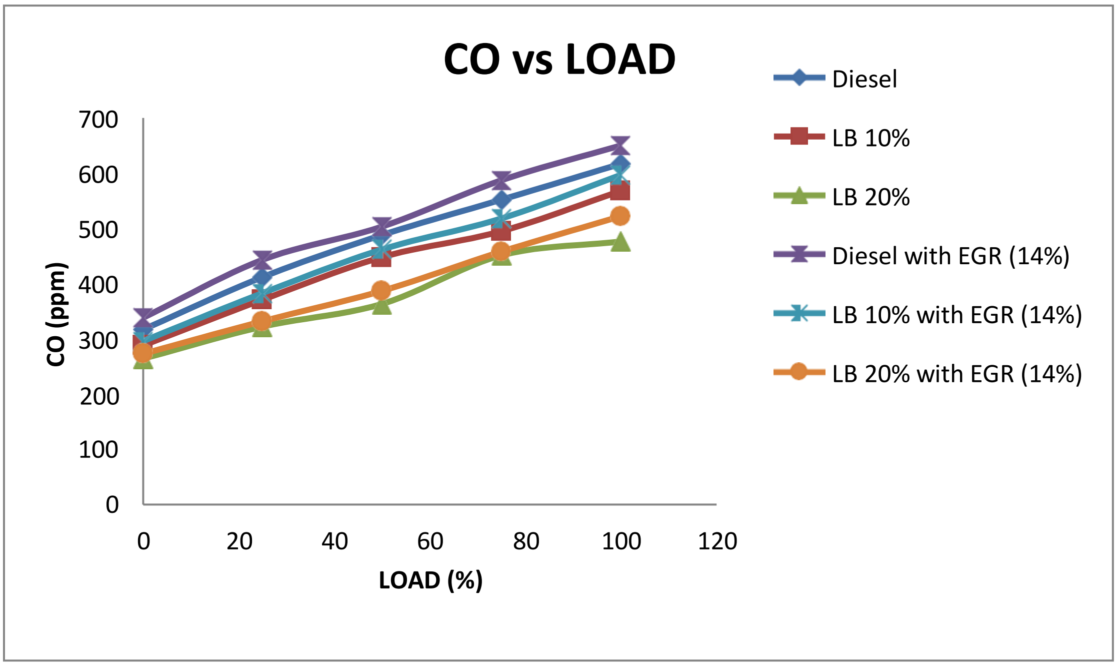

Figure 4.7: CO emission variation with load and different blend with or without EGR

4.2.3 HYDROCARBON (HC) EMISSION

From the figure 4.8 it was cleared that that the HC emission raises with an engine load. This behaviour may be because of high fuel consumption which to entry of more rich fuel in the combustion. This causes insufficient combustion and HC emission increase. It was also found that as the blend ratio increases, HC emission lowers accordingly. This is because biodiesel blends are high in CN. Higher CN does not reduce the delay in combustion that enhances burning.

HC emissions rise with higher EGR levels, with emissions being greater with more linseed concentration. Increase in EGR %age results in lower temperatures of flame due to which ignition cannot takes place easily. Figure 4.8 shows the UHC emission variation with load and different blend with or without EGR.

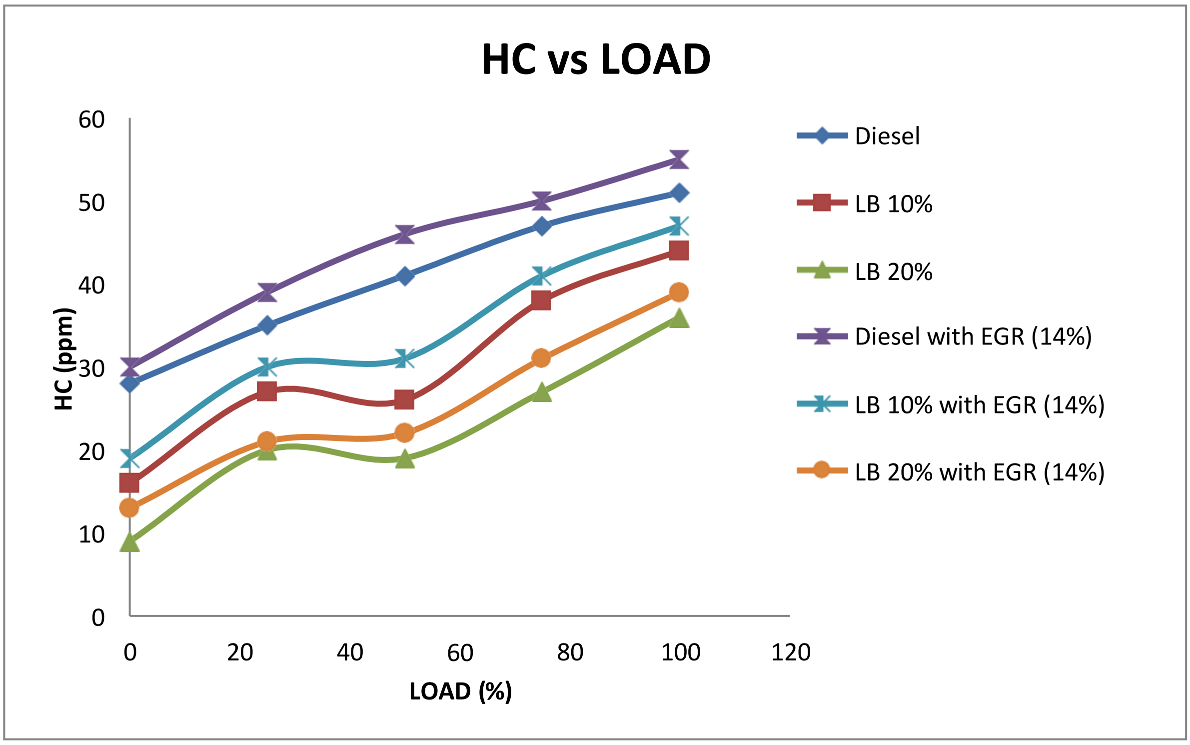

Figure 4.8: HC emission variation with load and different blend with or without EGR

4.2.4 SMOKE OPACITY

It is cleared from the figure that the intensity of smoke opacity raises with an engine load and at high engine loads is remarkably high. It is because more fuel is burnt to achieve more BP or torque at full load. Smoke emission was shown lesser relative to diesel fuel for all linseed/diesel blends. Linseed biodiesel contain enrich-oxygen molecules that improve the quality of burning that result in lower smoke.

When EGR (14%) applied to the engine greater exhaust smoke opacity was shown when compared to without EGR response. High EGR rate reduce the levels of oxygen and disturb the equivalence ratio of the mixture causing inadequate combustion, and facilitate smoke formation. The high EGR also reduces the cylinder temperature and encourages smoke formation. Figure 4.9 shows the variation of smoke opacity with load and different blend with or without EGR.

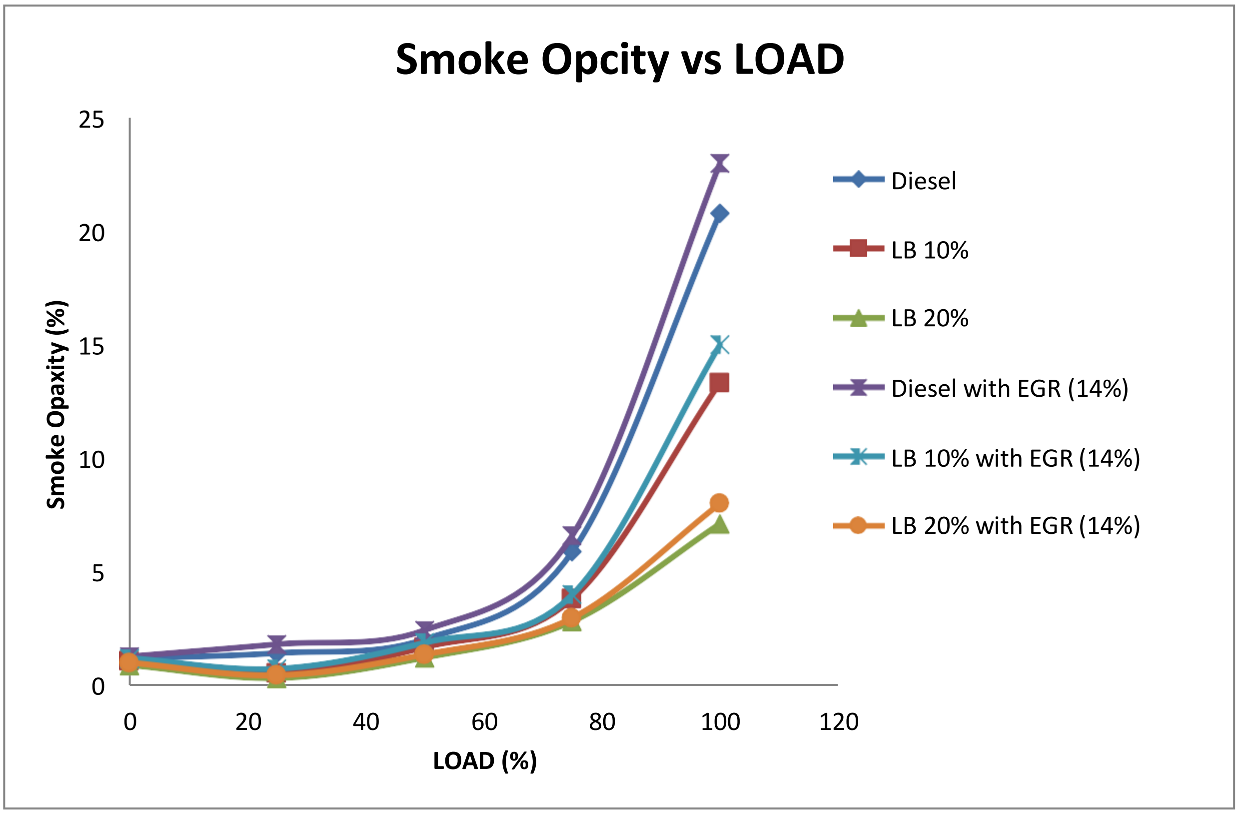

Figure 4.9: Smoke Opacity emission variation with load and different blend with or without EGR

4.2.5 CARBON DIOXIDE (CO_2) EMISSION

CO_2 emissions are relatively high of the emissions gained from diesel because the adequate combustion of A/F mixture occurred for LB20, resulting in the transition of C and CO into CO_2. Owing to inadequate blending and combustion due to high viscosity of biodiesel and oxygen depletion respectively, the introduction of biodiesel blend has resulted in a decrease in CO_2 emissions as clearly seen in figure 4.10.

With EGR the emission of CO_2 gets reduces as the exhaust gas injected in place of fresh air leads to incomplete combustion of fuel in combustion chamber. Thus insufficient supply of oxygen not converts the CO into CO_2 and emission of CO_2 reduces.

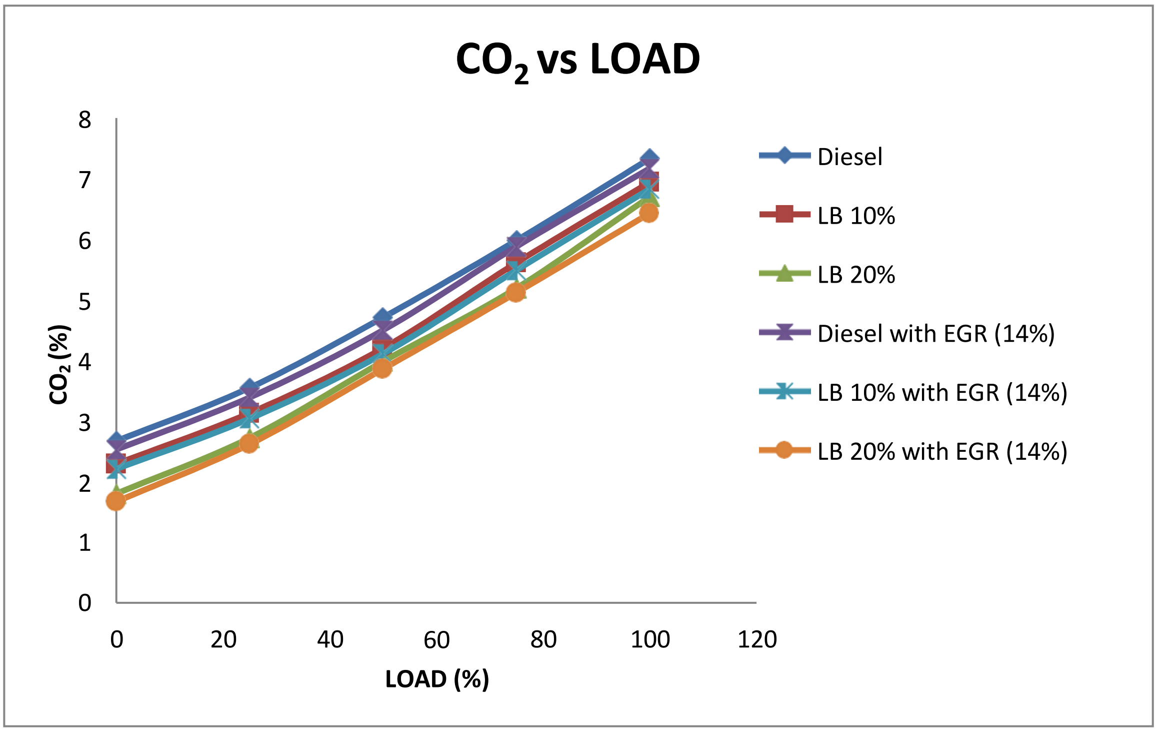

Figure 4.10: Carbon Dioxide emission variation with load and different blend with or without EGR

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSIONS

Linseed biodiesel was produced through transesterification process which involves an acid catalyzed stage. The emission and performance output of LB10 and LB20 were studied with or without EGR (14%) and results were compared with neat diesel. Through this preliminary study we can derive the following conclusion:

- BP and BTE for diesel are greater than LB10 and LB20 with or without EGR. The BTE of neat diesel is 3.54% greater than LB10 and 7.44% higher than LB20. With EGR, the BTE of diesel is 3% greater than LB10 and 7.1 % more than LB20 at 100% load condition.
- The BSFC is drastically reduced with load and diesel has least for all test fuel. The BSFC of LB20 is 10.02% more than LB10 and 24.22% higher than neat diesel for full load.
- The emission parameter like UHC and CO was increased with EGR. By applying EGR, the emission of UHC was increased by 7.27% for diesel, 6.38% for LB10, and 7.69% for LB20 at full load condition. The emission of CO was raised by 5.23% for diesel, 4.85 for LB10, and 8.81% for LB20 at 100% load.
- With EGR and full load condition, NOx emission was reduced by 8.36% for LB20. Also, LB20 has least smoke opacity and it marginally increased with EGR.

5.2 FUTURE SCOPE

Linseed biodiesel obtained from non-edible biomass feedstock is reported to be acceptable options for many countries which are in developing phase like India where the demand of an edible-oil and cost are really high. For any country, the major issue is choice of cheap and accessible feedstock for biodiesel production. Linseed oil is a comparatively cheap and accessible feedstock for production of biodiesel.

Before introducing the fuel in India the researchers recommend the following points:

- The Government should conduct easy and economical way for production of biodiesel.

- The long-term stability of the blend should be evaluated as the blends developed for this analysis were used within a short time period.
- For the full combustion of biodiesel in CI engine, there is a need for further technical study and advancement on some other factors like wear and tear analysis, fuel injection timing as well as crank angle.

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