Performance Evaluation and Emissions Characteristics of a Compression Ignition Engine Using Castor oil based Biodiesel

A Dissertation
submitted in partial fulfillment of the requirement
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Masters in Technology
in
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Submitted
By
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Under Supervision of
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CERTIFICATE

This is to certify that thesis entitled, "**Performance Evaluation and Emissions Characteristics of a Compression Ignition Engine Using Castor oil based Biodiesel**" submitted by **Ms. DISHIKA** in partial fulfillment of the requirements for the award of **Masters in Technology** Degree in **Environmental Science & Technology** at **Thapar University, Patiala** is an authentic work carried out by her under our supervision and guidance.

To the best of our knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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DECLARATION

I, the undersigned, hereby declare that the research work presented in the M.Tech project entitled "**Performance Evaluation and Emissions Characteristics of a Compression Ignition Engine Using Castor oil based Biodiesel**" has been carried out by me under the supervision and guidance of ***Dr. S.K. Mahla, Assistant Professor, School of Energy & Environment, Thapar University, Patiala***.

Further, I declare that no part of this Dissertation has been submitted for a degree or any other qualification of any other university or examining body in India/elsewhere.

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ABSTRACT

As world is confronted with twin crisis of fossil fuel depletion and environmental degradation, greater use of fossil fuels, high import cost of diesel & petrol, growing pollution has make biodiesel an attractive alternative fuel to meet the future energy demand. Biodiesel is an alternative, clean, environmental friendly and biodegradable fuel. As nation is facing a shortage of edible oil, it would not be feasible to produce biodiesel by edible oils. Castor oil is non-edible oil thus it opened a good opportunity to study its suitability to produce castor biodiesel. The major issue with castor oil was its viscosity which creates poor fuel atomization, carbon deposits formation problems in the conventional diesel engine. A well known base transesterification method was used for castor biodiesel production using methanol and NaOH. The fuel properties of castor biodiesel blend B100 were studied and compared with petrodiesel. Blending of biodiesel with diesel in different proportions such as B20, B40, B50 were tested in diesel engine.

In this present work, an experimental investigation has been carried out in a single cylinder diesel engine at a constant speed of 1500 rpm from no load to 60% of full power to evaluate the performance and emission characteristics of castor biodiesel blends such as B20, B40 and B50. The fuel properties such as calorific value, kinematic viscosity, flash and fire point, cloud and pour point of castor biodiesel have been determined as per ASTM standards. The performance parameters include brake power, brake specific fuel consumption, brake thermal efficiency. The measurement of exhaust emissions includes hydrocarbon, carbon dioxide and carbon monoxide has been carried out at different loads with different blends of biodiesel. Test results indicate that at full load, the brake power produced by castor biodiesel blend B20 is 3.125% less than that of diesel and brake specific fuel consumption of castor biodiesel blend B20 and diesel is almost same. At all loads, brake thermal efficiency of castor biodiesel blend B20 is higher than that of diesel and other blends B40, B50. The castor biodiesel blends emits carbon dioxide, hydrocarbon and carbon monoxide slightly lower than that of diesel at all loads. It is concluded that castor biodiesel blend B20 is a best candidate of alternative fuel among all tested fuel at full load conditions.

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NOMENCLATURE

CI	Compression ignition
BP	Brake power
FC	Fuel consumption
BSFC	Brake specific fuel consumption
BSEC	Brake specific energy consumption
BTE	Brake thermal efficiency
B100	100% biodiesel
B20	20% biodiesel + 80% diesel
B40	40% biodiesel + 60% diesel
B50	50% biodiesel + 50% diesel
ASTM	American society of testing and materials
IS	Indian standards
EN	European standards
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbon
FFA	Free fatty acid
NaOH	Sodium hydroxide
NaCL	Sodium chloride
KOH	Potassium hydroxide

CHAPTER 1
INTRODUCTION

1.1 Biodiesel

Biodiesel is an oxygenated diesel engine fuel that can be obtained from vegetable oils or animal fats by conversion of the triglycerides to esters via transesterification. It has similar properties to diesel oil. Biodiesel derived from vegetable oils and animal fats lead to the study of alternative to petroleum based diesel fuels. Biodiesel is a clean, nontoxic, biodegradable, renewable fuel. Biodiesel can be used in diesel engines without any major modifications. It also reduces the emission produce from diesel engine. Problems with castor biodiesel is its high viscosity, density, lower calorific value and poor non-volatility which leads in pumping problem, poor combustion of diesel engine. It is necessary to reduce the viscosity of castor oil by several ways such as preheating, blending, transesterification, thermal cracking. Transesterification is most commonly used method for reducing the viscosity of castor oil. Castor oil is made up of triglyceride, which is an ester of fatty acids and one glycerol. Transesterification is process that converts castor oil using methanol and NaOH into biodiesel, which is fatty acid alkyl ester. [1]

1.2 Need for biodiesel

As the supply of fossil fuel is limited, whilst energy demand continues to rise, hence there is need of alternative renewable fuel for future utilization. The world is confronted with twin crisis of fossil fuel depletion and environmental degradation. Increasing use of petroleum or fossil fuels in transportation will intensify local air pollution & magnify the global problems caused due to gases emitted from diesel engines. [2]

In India, Energy consumption is increasing at rapid rate due to rapid industrialization, transportation & mechanization. India is second highest country after China in Asia in terms of energy demand. At present, Biodiesel is a most promising source of renewable energy with high potential to replace petroleum-derived diesel fuel. Biodiesel is biodegradable & more environment friendly than fossil fuel. Emissions such as total hydrocarbons & CO are low with biodiesel as compared to petroleum diesel. This may be due to more complete combustion caused by sufficient amount of oxygen in biodiesel molecules. India is having great demand of edible oil for cooking purpose. The main source of biodiesel in India can be non-edible castor oil. It was reported that if 10% of total production of castor seed oil is transesterified into biodiesel, then about 79782 tons of CO_2 emission can be saved on annual basis [3]. The CO_2 released during combustion of biodiesel can be recycled through next crop production, therefore no additional burden on environment. Biodiesel considered as priorities among biofuels includes sustainability, reduction of greenhouse gases emissions, regional development, social structure, agriculture & security of supply. Greater use of conventional fossil fuels, high import cost of diesel and petrol from countries, growing emissions of pollutants will make biodiesel an attractive alternative fuel to meet the energy demand. [3]

1.3 Objective of work

The major objective of present investigations is to assess feasibility of producing biodiesel- diesel blends in appropriate proportions for meeting emerging specifications of diesel fuel and the effect of blending on fuel properties. It is also proposed to evaluate the performance characteristics of these blends in a stationary single cylinder engine on test bed and also conduct emission assessment.

This would involve the following:

- Production of biodiesel from castor oil by base- catalyzed transesterification.
- Physico-chemical properties of biodiesel and compare it with ASTM standards.
- Comparative performance evaluation of castor oil methyl ester with baseline diesel at different load conditions in C.I single cylinder engine.
- Emission characteristics (HC, CO, NO_X and smoke etc.) of different blends of biodiesel and diesel comparison with diesel fuel.

1.4 Background and sources

Rudolf diesel, famous for the invention of diesel engine, was the first to use vegetable oil (peanut oil) to the diesel engine at the 1900 world exhibition in Paris. He also proclaimed that every diesel engine can be supplied with vegetable oil. His prediction has come true & lots of countries are taking step towards green energy. [4]

As nation is facing a shortage of edible oil, it would not be feasible to produce biodiesel by edible oils. India is world leader in castor seed and dominates the international castor oil trade. The growing period of castor plant is shorter than jatropha plant. Castor oil is non-edible oil which is a colorless or pale yellowish extracted from the seeds of castor oil plant. The Indian variety of castor seed has an oil content of 48% from which 42% can be extracted. [3]

Castor oil consists of 80-90% ricinoleic acid. Ricinoleic acid is highly viscous. Thus, a high proportion of castor oil biodiesel should not be used in engines. Due to high viscosity of castor oil biodiesel, blends more than 30% cannot be used as fuel for diesel engines without modification to the engine. Various methods are adopted to reduce the viscosity of castor oil such as preheating, transesterification, blending. [4]

Table 1.1 Composition of Castor Oil [5]

Acid name	**Fatty Acid Composition**
Ricinoleic acid	85- 90%
Linoleic acid	4-5%
Oleic acid	2-4%
Stearic acid	1%
Palmitic acid	1%
Others	0.3-1%

1.5 History of biodiesel

- **1826 –** Samuel morey built the prototype internal combustion engine in the United States. It ran off a biofuels, alcohol.
- **1866 –** Nikolaus August Otto designs an early combustion engine which ran off alcohol.
- **1893 –** Rudolf Diesel invents the internal combustion engine that ran off kerosene.
- **1896 –** Henry Ford built his first automobile, a quadricycle, to run on ethanol.
- **1908 –** Ford's famous model T was designed to run on ethanol, gasoline or combustion of the both.

- **1920 –** Ford's biofuels turned out to be fairly popular, especially with ethanol represented about 25% of standard oil's fuel sales.
- **1940 –** Ford was forced to close ethanol plant due to stiff competition from low prices petroleum- based fuels.
- **1940 –** During world war π, because of the disruptions to normal oil supplies virtually all the participating nations made use of biofuels to power their war machinery.
- **1973 –** OPEC stops supplying to USA and people begin to look for those sources.
- **1979 -** Iranian revolution sends oil prices rocketing and industrialized nations go to recession.
- **1979 –** Dr. Charles Peterson of the University of Idaho begins research into production and use of biofuels.
- **1989 –** Dr. Thomas Reed, who was on the faculty at Colorado School of Mines, first learned about the conversion of vegetable oils and animal fats into biodiesel.
- **1990 –** The Denver Regional Transportation District agrees to power their buses by Reeds fuel.
- **1991 –** Prof Leon Schumacher was approached by members of the Missouri Soybean Merchandising Council about conducting research on new uses of soybean oil.
- **1995 –** NOPEC Corporation began initial production at its huge 18 million gallons capacity batch process biodiesel plant in Florida, USA.
- **1996 –** The truck ran on B100 for 90,000 miles before the test was ended.
- **1998 –** US Congress designates B20 as an approved alternative fuel.[8]

1.6 Development of biodiesel in India

India is one of the largest petroleum consuming & importing country. India imports about 70% of its petroleum demand. Biodiesel is a promising alternative fuel in terms to meet the energy demand. Biodiesel can be produced from edible (sunflower, cottonseed) and non-edible oils (castor, jatropha). In India, Edible oil is in short supply & consumption is high. Plantation of trees bearing non-edible oil seeds can be carried out over wasteland. India is largest producer of castor oil. Gujarat accounts for 86% of India's castor seed production followed by Andhra Pradesh & Rajasthan. There are various biodiesel producers in India-

1. Natural Bioenergy Limited
2. Reliance Life Sciences
3. Southern Online Biotechnologies Limited
4. Gomti Energy Limited
5. Royal Energy Limited
6. Chemical Biotech Limited
7. Coastal Energy Limited [3]

Efforts –

- First successful trial run on superfast passenger train was conducted on December 31, 2002 by Indian Railway on Delhi-Amritsar Shatabdi Express with use of 5 % biodiesel which helped Railways in fuel bill reduction.
- The Southern Railway adopted a three prolonged strategy of large scale processing of oil into biodiesel and making a use of it in road vehicles.
- A big hype was created by UP Jatropha mission of Uttar Pradesh. It was a joint venture. They were going to tie up with Panchayat to plant jatropha on wasteland.
- TERI, New Delhi has been involved with the cultivation of jatropha on degraded sites and promotion of jatropha for biodiesel on an industrial scale.
- The IOCL has tested passenger cars in association with the TATA.
- Gujarat State Road Transport and Haryana State (Rewari depot) are running their buses using B5. [6]

1.7 Castor biodiesel as diesel substitute

Biomass derived oils are quite promising alternative fuels for diesel engines. Concept of using vegetable oil as fuel in 1885, when Dr. Rudolf diesel developed first diesel engine to run on vegetable oil. There are more than 350 oil bearing crops identified whose cetane number & calorific value are comparable with those of diesel fuels and are compatible with diesel engine. It also reduces particulate emission relative to petroleum diesel. [4]

Crude oil can also be used directly in engine as fuel. Due to its lack of chemical esterification reactions, this method has some benefits such as easy transportation, high heating values than biodiesel, saving time, energy, money.

Crude oil has more disadvantages such as high viscosity, intensive corrosion and failure mechanisms of combustion due to presence of matters in unrefined oil, rapid pollution of lubricant oil, low volatility & carbon sediment formation on engine components. Hence, the direct use of crude castor oil is not an appropriate method.

The possible solutions were proposed to change oil properties in order to make it more suitable for diesel engine. [4]

1.8 Technical aspects

Castor oil can be easily available in India. It is non-edible oil extracted from castor bean. Castor biodiesel is renewable fuel and environment friendly. This triggers the researches all over the world to consider non-edible oil as alternative to petroleum diesel.

The major problem with castor oil is its viscosity which is much higher than mineral diesel. The fuel injector systems of diesel engines are sensitive to fuel viscosity changes. High viscosity leads to poor atomization which in turn results in poor combustion, ring sticking, injector cocking, injector deposits, injector pump failure & lubricating oil dilution by crankcase polymerization. Viscosity of castor oil has to be decreased to improve diesel engine performance.

The main reason of high viscosity & low volatility of castor oil is its large molecular sizes of triglycerides. Technical problems associated with castor oil during diesel engine testing are classified into two groups-

1. Operational problems – These related to starting ability of engine, less ignition, poor combustion & performance.
2. Durability problems – These related to deposits formation, carbonization of injector tip, ring sticking, lubricating oil dilution.

High viscosity of castor oil cause large droplet size& high spray jet penetration. This spray jet acts as a solid stream instead of a spray of small droplets. Due to this, fuel is not able to distributed or mixed with oxygen required for burning in combustion chamber. This turn out to be poor combustion accompanied by loss of power & economy.

Blending, Thermal cracking, Transesterification of castor oil are methods to overcome these all technical problems of diesel engine. [7]

1.9 Method of biodiesel production

1.9.1 Direct use & Blending

In this method, castor oil is directly use as fuel for diesel engine. Blending is also done if it is highly viscous. Castor oil is mixed with diesel to form various proportions of blends. The advantages of direct use of castor oil in diesel engines are –

1. Liquid nature- portability
2. Heat content (80% of diesel fuel)
3. Easily availability
4. Renewability

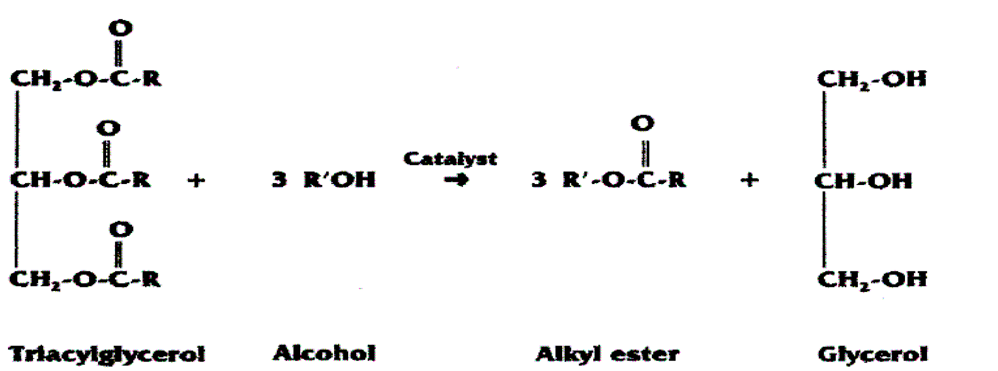
Table 1.2 Problems associated with direct use of castor oil in engine [2]

Problem	Cause	Potential Solution
Short term		
Cold weathering starting	High viscosity and low flash point	Preheat the fuel before injection
Plugging and gumming of lines, injectors	Natural gum in castor oil & presence of ash particles	Partially refine the oil to remove gums or filter the oil.
Engine knocking	Improper injection	Use higher compression engine or adjust injection timing
Long term		
Coking of injector	High viscosity of castor oil, poor combustion	Heat the fuel prior to injection or chemically alter oil to ester.

Carbon deposits	High viscosity of castor oil, incomplete combustion of fuel	Preheat fuel prior to injection
Excessive engine wear	Poor combustion at part load with vegetable oil	Preheat fuel prior to injection, switch engine to diesel fuel operations at part load

1.9.2 Transesterification

To improve the performance of castor oil in diesel engine, castor oil is modified by transesterification process. It is a procession of conversion of raw castor oil into biodiesel which is fatty acid alkyl ester by methanol and NaOH as a catalyst. Transesterification is a three step reversible reaction in which castor oil react with a short chain alcohol and alkaline catalyst to form fatty acid methyl esters & glycerol. Glycerol is removed from fatty acid methyl esters. Due to low solubility of glycerol in the oil, separation occurs quickly.



Transesterification reaction (R – Fatty acid chain, R^1- CH_3) [8]

The main components of transesterification process-

1. Castor oil – Castor oil should be free from gums and ash impurities. Castor oil is refined or filtered prior to use. Castor oil can be preheated prior to transesterification process.
2. Alcohol- Alcohols that can be used in transesterification process are methanol, ethanol, propanol, and butanol. But methanol is mostly used because of its low cost, polar group, shortest chain alcohol.
3. Catalyst – Basic as well as acidic catalysts are used in transesterification reaction.

a) Basic catalysts lead to higher conversion rate at low temperature, atmospheric pressure & minimum reaction time which reduce the cost of process. Hydroxides & methoxides are used in which hydroxides are preferred because they are cheaper. Use of basic catalyst is limited. Oil reacts with catalyst through saponification reaction forming soaps.
b) Acidic catalysts require greater reaction time, alcohol, catalyst concentration & temperature. Acidic catalysts prevent the formation of stable emulsions & generate less waste water. Sulfuric acid, phosphoric acid, hydrochloric acid.[8]

Alkaline catalysts are most preferable than acidic catalysts for castor oil transesterification.

For base-catalyzed transesterification, factors that affects the reaction are-

1) Molar ratio of alcohol to oil
2) Temperature
3) Reaction time
4) Moisture content
5) Free fatty acid (FFA)

For maximum yield of transesterification reaction, alcohol should be free from moisture & FFA content of oil should be less than 1%. [8]

1.10 Fuel characterization

The fuel is prepared and tested in laboratory of MERADO Ludhiana.

1. Density- It is mass per unit volume. Biodiesel are heavier than the diesel. Biodiesel should always be blended at top of diesel fuel.
2. Kinematic viscosity- It is measure of resistance to flow of a liquid due to interval friction of one part of a fluid moving over another. Viscosity affects the atomization of a fuel upon injection into the combustion chamber and ultimately the formation of engine deposits. The viscosity of biodiesel is lower than that of diesel fuel.
3. Calorific value- The total quantity of heat liberated by completely burning of one unit mass of fuel. The calorific value of a substance is the amount of energy released when the substance is burned completely to a final state and has released all of its energy.

4. Flash point and fire point - It is temperature at which it will ignite when exposed to a flame of light. The flash point of biodiesel is higher than that of diesel. Due to this reason, biodiesel are safer to store and handle. The flash point increase with increase in the percentage of biodiesel in the blends.
5. Cloud point- It is the temperature at which a haze of crystals appears in the fuel under test conditions. Biodiesel has higher cloud point than that of diesel fuel.
6. Pour point- It is the lowest temperature at which diesel will begin to flow.

1.11 Advantages of biodiesel over petrodiesel

1. Biodiesel is non-toxic, biodegradable, renewable source of energy, less green house gases emissions than petrodiesel.
2. Biodiesel is only alternative fuel that can run over conventional diesel engine without any type of modification.
3. Biodiesel can be direct use or mixed in any ratio of diesel fuel. The most commonly used blend B20 is a mix of 20% castor biodiesel with 80% diesel.
4. Biodiesel contains 10% oxygen by weight and no sulfur. Biodiesel cut down the CO_2 emission upto 80% and sulfur emission upto 100%.
5. Combustion of biodiesel alone provides over 90% reduction in total unburnt hydrocarbon and 75-90% reduction in aromatic hydrocarbons.
6. Biodiesel has higher flash point leads to safer handling and storage. [3]

1.12 Energy security

Energy is the basic need for economic development of country. With increase in population, Energy consumption is increasing in agriculture, industrial, domestic and pubic sectors. To meet the demand of population, capital is required which affects the economy of country.

India's population is increasing with rapid rate, Energy security has become a core issue. Government of India has taken multiple steps which involve encouraging private sector participation, research programme in field of alternative biofuels.

Diesel is the main transport fuel in India. Biodiesel can be used instead of diesel fuel or blending with diesel fuel is an imperative need. As nation is facing a shortage of edible oils, it would not be feasible to stress upon edible oils for biodiesel. The main sources of biodiesel in India can be non-edible oils such as castor, ratanjot, karanja.

Biodiesel from non-edible oils can be used as blend with diesel or in its pure form. Biodiesel can be produced domestically and used in diesel engines, directly substituting for supplies of petrodiesel. [3]

CHAPTER 2
LITERATURE SURVEY

2.1 Introduction

A large work has been done on different aspects of biodiesel. This chapter involves the literature on biodiesel production by alkaline transesterification of castor oil and fuel characteristics, evaluation of performance of castor oil biodiesel in diesel engine, analysis of emission characteristics of different blends of biodiesel and diesel and comparison with diesel fuel.

2.2 Categorization of literature

Literature is divided into two categories-

1. Biodiesel production and comparison of fuel characteristics.
2. Performance of biodiesel blends in diesel engine and conduct emission assessment.

2.2.1 Biodiesel production and fuel characteristics

Mohammed H. Charkrabarti and Rafiq Ahmad, 2008 [10]

They studied the transesterification of castor oil with KOH dissolved in methanol. The castor oil was extracted from its seed using an oil expeller in Karachi, Pakistan and was refined in NED University laboratories. Castor oil was reacted with a solution of KOH dissolved in an appropriate quantity of methanol at various temperatures. The stirring was continued for various times. The product was placed in the separating funnel and left overnight to settle. The glycerine settled to bottom of the funnel and was removed in the measuring cylinder. The impure methyl ester was washed with sulphuric acid and distilled water prior to drying at 150˚C. The operating condition varied in range; KOH catalyst concentration 2.1-3 gm for 250 ml feedstock; temperature 30-200˚C; reaction time 30-360 minutes. The authors have reported that ester content 48% which is highest and glycerine 52%. When reaction is carried out with 65 ml methanol, 2.5 gm KOH catalyst and reaction time 360 minutes at a temperature of 700˚C, converting 250 ml of castor feedstock. They also performed parallel experiments involving two stage process via esterification by acid followed by normal transesterification.This procedure was recommended by Marchetti et al. In this two stage esterification process by Mohammed et al, ester content was reported upto 85%. The author obtained castor biodiesel viscosity of 13.75 mm^2 and density 0.9279 at 150˚C. The raw castor oil used by authors having viscosity 239.39 mm^2/sec. Acid esterification was carried out for approximately 1 hour at 50˚C, followed by transesterification using potassium hydroxide as catalyst at 70˚C.

Penugonda suresh babu and Venekata ramesh mamilla, 2012 [4]

They studied transesterification of castor oil (treated with mineral turpentine oil) with methanol in the presence of NaOH as catalyst. He took the one liter of castor oil was react with 300-330 ml of methanol & 10 ml of concentrated sulphuric acid at 65-70˚C for 6 hours and mixture was stirred continuously. The mixture was allowed to settle for 8 hours after reaction. The glycerine was removed from bottom of separating funnel. Biodiesel was washed out with 200 ml hot water at 40˚C.To adjust the viscosity esterified castor oil was further treated with mineral turpentine oil (M.T.O). The conversion rate was about 92% at 60˚C. The fuel properties of castor biodiesel were compared well with Indian biodiesel standards and ASTM. Castor oil has density 950 kg/m^3 after treatment of transesterification & mineral turpentine oil it reduces to 878 kg/m^3 comparable with density of diesel which was 880 kg/m^3. The castor oil has flash point 230˚C but after treatment it reduces to 125˚C comparable with flash point of diesel which is 47˚C.Castor oil has viscosity 240 mm^2/sec after treatment it reduces to 5.5 mm^2/sec comparable with viscosity of diesel which was 2.27 mm^2/sec. Net calorific value of castor oil is 37 MJ/Kg after treatment it was to 39.5 MJ/Kg comparable with diesel 42.5 MJ/Kg. Cetane number of castor oil is 40 after treatment it was 47 comparable with cetane number of diesel which was 47. Increased cetane number of castor oil ester treated with M.T.O results into better combustion.

Deshpande D.P, Haral S.S, Gandhi S.S, 2012 [11]

They studied transesterification reaction on castor oil in a batch reactor using KOH as a catalyst. The variables chosen for the study were residence time, oil to methanol ratio, catalyst concentration & reaction time. The effects of these variables on viscosity of castor biodiesel were studied. They concluded that viscosity decreases with increasing time from 38 to 48 minutes. Optimum reaction time is 45 minutes with lowest viscosity 14.10 cst. Specific gravity decrease as residence time increased from 30 to 45 minutes, further increase in residence time 60 to 90 minutes, specific gravity increases.

At optimum residence time 45 minutes, with increase in oil to alcohol ratio 1:6 to 1:9 molar ratio results in decreasing the product viscosity. Further increase in oil to alcohol ratio to 1:12, two layers are not formed. At 1:9 oil to alcohol ratio, specific gravity of biodiesel is found to be lowest.

At temperature of 30˚C biodiesel formed gave lower viscosity further increases upto 50˚C. For optimum catalyst concentration, various conditions were kept constant. Catalyst concentration of 1 wt % gave lowest value of viscosity.

They concluded that optimum operating condition for 100ml castor transesterification, oil to methanol molar ratio 1:9, temperature 30˚C, catalyst concentration 1 wt% & run time 45 minutes.

J.M. Encinar et al, 2010 [9]

They worked to optimize the variables affecting transesterification process for biodiesel production from castor oil, non-edible oil by acid catalysis (sulphuric acid & phosphoric acid) and basic catalysis (potassium methoxides & potassium hydroxide) and to characterize the biodiesel for its use as fuel in compression ignition engines. The most suitable catalyst for this process proved to be potassium methoxides with optimum concentration of 1 wt%.

They studied operation variables were methanol/oil molar ratio (3:1, 6:1, 9:1), temperature (25, 35, 45, 55, 65˚C) and catalyst concentration (2, 3, 4 wt% in acid catalyst and 0.5, 1, 1.5 wt% in basic catalyst).Evolution of each process was followed by gas chromatography, determining the content of methyl esters at different reaction times. The best molar ratio of methanol was 9:1 for both acid & basic catalysis. Above 9:1 molar ratio, methyl ester begins to decrease. Biodiesel was characterized by a set of parameter according to European standard, EN14214.

The best conditions for transesterification process were 9:1 methanol/oil molar ratio, 65˚C temperature and the use of potassium methoxides as catalyst with concentration

1 wt %. In the conditions, biodiesel presents satisfactory values of water content, iodine & saponification values, flash and combustion points and temperature of 50% distillate. However, values of density, kinematic viscosity, cetane index & cold filter plugging point that are heavily dependent on oil, move away from those required by the European standard. In the best conditions of reaction, ester content was 94.66% close to 96.5% required by European standard EN14214.

Bello E.I & Makanju A, 2011 [12]

They studied the use of castor oil methyl ester as possible alternative fuel for diesel engine was investigated. The oil was extracted in a soxhlet extractor using normal hexane as solvent. To overcome the high kinematic viscosity of the neat castor oil, a high molar ratio of 6:1 was used to produce the methyl ester. The viscosity of the ester was high & further reduced by blending with diesel fuel to reduce it to within the American society for testing and materials (ASTM) D 6751-02 limits for biodiesel. The biodiesel was characterized and tested in a single cylinder diesel engine. The results obtained gave properties, torque outputs & specific fuel consumption that are close to those of diesel fuel that confirmed that it can be used as alterative fuel for diesel engines. The torque and power characteristics are about 10% less than that for diesel fuel but load carrying capacity is about 20% higher as a result of it oxygen content which allowed for more complete combustion & operate at lower speed.

The specific fuel consumption is 10% less than that for diesel fuel and is consistent with the difference in heating values of the fuel. The minimum specific fuel consumption occurred at 1950 rpm.

2.2.2 Performance of biodiesel in diesel engine and its emission assessment

Sumedh S. Ingle et al, 2013 [1]

The biodiesel derived from castor seed oil has been used. Transesterification method is used to convert castor oil into biodiesel. Experiments were carried out on a single cylinder, vertical, 4-stroke cycle, single acting, totally enclosed, water cooled, compression ignition engine. Diesel, biodiesel (B100) & its blends B20, B40, B60, and B80 were used to test the engine. The performance & emission characteristics of the

engine were studied at different engine loads (25%, 50%, 75%, and 100%) of the load corresponding to the load at maximum power at an average engine speed of 1500 rpm.
Brake specific energy consumption (BSEC) decreases with increase in brake mean effective pressure up to full load. At atmospheric temperature, B60 shows lowest BSEC. It was observed that as biodiesel percentage increases BSEC decreases.
With increase in load, exhaust gas temperature also increases. This reveals that the effective combustion is taking place in the early stage of strokes & there is reduction in the loss of exhaust gas. When biodiesel concentration is increased, exhaust gas temperature increases by same value but for blend B80 shows low exhaust gas temperature at full loads. The highest exhaust gas temperature may be because of better consumption of the castor methyl ester as it contains oxygen molecule which helps in proper consumption.
Smoke opacity increases with increase in brake mean effective pressure. At atmospheric temperature, B60 shows less smoke opacity as compared to other bends. They concluded that at blend B60, BSEC is lowest with highest exhaust gas temperature & lowest smoke opacity as compared to other blends.

Leonardo De A. Monteiro et al, 2013 [13]
The use of biodiesel can meet the demand of fossil fuel for generation of power & transportation in rural area. The performance of castor biodiesel is evaluated with automotive & a stationary diesel engine. The application of B20, B10 and preheated net biodiesel is considered. The application of B10 & B20 blends for power generation was observed from dynamometric bench tests where blend were performed similar to fossil diesel. With preheated neat biodiesel, brake torque loss & specific fuel consumption increase were observed.
The operational performance of castor biodiesel was evaluated by dynamometric tests conducted with two turbocharged diesel engines. Specific fuel consumption of blends B10 & B20 were lower than those of diesel oil. It confirmed that increase in fuel density & thermal efficiency of engine overcomes the effects of reduction of energy content by biodiesel. This results in feasibility of its application in generation of electrical work. B100 of castor oil was preheated leads to torque loss & increase the specific fuel

consumption upto 10% at below 2000 rpm. For this reason, it is recommended to use B100 biodiesel from castor preheated only in low speed motors & generation equipment which operate at speeds of below 1800 rpm.

Mohammed H.Chakrabarti, Mehmood Ali, 2009 [14]

They studied that castor oil was converted to biodiesel by transesterification & blended to 10% quantity with high speed mineral diesel (HSD) fuel. A two step acid-base process, acid pretreatment followed by base transesterification reaction using methanol & H_2SO_4 and KOH as catalysts to produce castor biodiesel. Different fuel properties of biodiesel were found out & then tested in C.I. engines to assess emission characteristics.

The fuel was tested in C.I engine in order to analyze the engine performance as well as emissions from engine. Blends of biodiesel emit less environmental emissions except higher amount of CO_2 & NO_X. Higher amount of CO_2 is emitted due to higher O_2 & carbon contents of biodiesel results in complete combustion of fuel in C.I engines. Higher amount of NO_X emitted due to higher temperature of combustion than mineral diesel fuel. The brake power & torque of biodiesel is less than that for mineral diesel fuel because of lower calorific value of biodiesel as compared to diesel.

Castor oil B10 gave higher brake power & torque as compared to canola oil B10. Exhaust temperature of biodiesel blends are higher than diesel due to oxygenated nature of biodiesel. Castor oil B10 gave higher exhaust temperature than canola oil B10. Castor biodiesel give better engine performance than canola oil biodiesel. Castor oil is non-edible oil & it is valuable raw materials for biodiesel production in Pakistan. More work is necessary in trying to reduce its viscosity so that its biodiesel could meet the ASTM D6751 standard limit. There is further need of investigation on higher blends.

Molla Asmare et al, 2014[15]

They studied transesterification of castor oil with methanol to produce biodiesel in the presence of KOH as catalyst. The fuel properties of castor biodiesel & their blends like density, kinematic viscosity, iodine value, cetane number etc. were found out and analyzed with diesel fuel & compared with ASTM D6751 and EN 14214. Design expert 8.D.7.1 version software was used for analysis of biodiesel. The optimum conditions for castor biodiesel were reaction temperature of 59.89˚C & methanol to oil ratio of 8:10:1 & catalyst 1.22 wt % of oil at reaction time of 2 hr & 600 rpm. The maximum yield of methyl ester content was 94.5 % w/w of oil. B45 of castor biodiesel were satisfied the ASTM D6751 & EN 14214 limits & also reduced viscosity of castor biodiesel. Castor oil was used for biodiesel having high oil content & non-edible in nature.

Castor oil has high density & kinematic viscosity which was reduced by high molar ratio using transesterification ranged from 46- 92.5%. The heating value of castor biodiesel is lower than that of diesel & higher cetane number as compared to diesel.

Pradip Lingfa, 2013 [16]

They studied that castor oil, non-edible vegetable oil methyl ester were produced and blended with diesel fuel at various proportions. Experiment was carried out to analysis of the performance and emission characteristics of a compression ignition engine fuelled with blends of castor biodiesel with diesel fuel. Engine performance and emission analysis were analyzed using biodiesel blends (2%, 5%, 10%) in 4.4 kW single cylinder air cooled four stroke C.I engine at different loads.

The castor biodiesel was produced using both acid and base transesterification method which has properties similar to that of diesel and also lowers the viscosity of castor oil. The castor oil were added into alcohol and catalyst and heated to about 2-3 hours at constant temperature of 65˚C at 350-400 rpm. After that, water washing is done for 3-4 times. After water washing the methyl esters was heated in oven for temperature of 100-105˚C to remove traces of water results in formation of crystal clear biodiesel of castor oil. The kinematic viscosity of castor oil reduced after transesterification process.

The biodiesel was fuelled in compression ignition engine to analyze the engine performance and emission characteristics. The BSFC castor biodiesel blends decreases at increasing loads but further increase in biodiesel blends increase the fuel consumption due to lower calorific value and higher viscosity. The biodiesel blends of castor methyl ester shows higher NO_X compared to diesel fuel. The emission characteristics like CO, HC and smoke were lower at different load compared to diesel. They concluded that 10% blend of castor biodiesel gave best performance of engine and also emission characteristics.

S.Jafarmadar, J.Pashae, 2013 [17]

They studied the effects of adding castor oil and its blends with diesel fuel on engine performance (power, BSFC, torque), emission (NO_X, CO, HC, CO_2, PM) and combustion characteristics (exhaust gas temperature) for an unmodified diesel engine. Biodiesel is recommended for substitute for petroleum based diesel because biodiesel is a renewable resource with an environmentally friendly emission profile and is biodegradable.

The experiments were carried out on a semi-heavy duty Motorsazan MT4.244 agricultural engine. The engine is a 3.99 liters, turbocharged, four cylinders direct injection diesel engine. Performance and emissions of a diesel engine fuelled with 5, 10, 15, 20, 30% blends of castor biodiesel was observed at different loads and 1400 rpm. The engine tests results that B10 and B15 blends at full load are proposed in terms of performance efficiency and environmentally friendly emissions. B15 and B20 at full load performance give the best brake specific fuel consumption ((BSFC) of engine. It was observed that the maximum increase in BSFC when compared to those of pure diesel fuel is 10.7% and observed in B30 and B20 at 50% load.

Maximum reduction of PM emission is 73.2% and observed in B15 at 50% load. At these conditions, NO_X increases 4%. At B30 and 25% load condition, PM and NO_X emissions decreases 37% and 9% respectively while at the same time CO and UHC increase. The results show that in B15 and at 25 % load, NO and PM emissions decreases by 6 and 64% respectively and BSFC increases 1.5%.The experimental results proved that castor oil biodiesel can partially be substituted by the diesel fuel without any modification in diesel engine.

M. H. Shojaeefard et al, 2013 [6]

They investigated the effects of castor oil biodiesel blends were examined on diesel engine performance and emission characteristics. The castor methyl ester were produced from transesterification method and measuring its fuel properties. The experiments were carried out on a four cylinder, turbocharged, direct injection diesel engine. Engine performance and emissions were analyzed at various speeds.

The biodiesel was prepared by adding 1% weight of KOH and 1:5 molar ratio of methanol in castor oil. The mixture is stirred for 45 minutes at temperature of 60˚C.The various fuel properties were found out and compared them with ASTM standard limit. The engine used for the study was an agricultural, four cylinders, water-cooled, direct injection diesel. To evaluate the performance of engine speeds of 1200 rpm and 2000 rpm were considered.

Experiment was carried out with lower blends of castor oil (0, 5, 10, 15, 20 and 30 % of biodiesel) at full load which is 75% at different speeds. They concluded that engine power decreases with the increase of biodiesel content due to lower heating value and higher viscosity of biodiesel blends. Power of the B10 blend was higher by 0.3% than that of the diesel fuel. For B5, B15, B20, B30 blends was decreases by 1.94, 1.16, 4.46 and 8.05% respectively as compared to diesel. The maximum torque occurs at 1200 rpm and decreases with speed increase. Torque of B15 blend is little more than diesel torque. BSFC increases with increasing biodiesel content in blends due to high density of castor biodiesel. As engine is supplied with more fuel mass flow results in increase in the specific fuel consumption. With increase in the biodiesel content in blends, BTE decreases.

They concluded that with the use of B30 blend in the diesel engine, there is maximum reduction is about 7.5%. The NO_X emission of biodiesel blend fuel is higher than that of pure diesel. Maximum increase in NO_X emission of B30 blends of biodiesel which is about 11.31% as compared to diesel. Lowest $N0_X$ emission is of B15 blend due to low exhaust gas temperature. CO emission decreases with increasing biodiesel content in blends. The maximum and minimum reduction in CO emission of B30 and B5 is about 37% and 3.5% respectively. The HC emission reduces by increasing blends of biodiesel. HC reduction in B5, B10, B15, B20 and B30 is about 5.9, 20.9, 18.8, 0 and 19.3% respectively. Reduction in HC is mainly due to presence of more oxygen in biodiesel which results in better combustion. Biodiesel has more oxygen than diesel, the fuel –rich zones reduce and PM emission decreases. The maximum reduction of PM occurs in B30 blend which is 52%.They concluded that blends of up to 30% can be used as substitute fuel for diesel engines without any modifications to the engine. B15 of castor oil was selected as an optimum blend for diesel engine due to small increase in torque, lowest increase in NO_X emission and admissible CO, HC and PM emissions.

M.Ozanli et al, 2012 [18]

They studied to evaluate the use of various blends of castor oil methyl ester with diesel fuel. Performance and emissions of castor biodiesel with diesel fuel were evaluated in the compression ignition engine. The castor biodiesel was blended with diesel fuel at 5%, 10%, 25%, 50%, 100% ratios. The fuel properties of castor biodiesel and its blends were studied out. The castor biodiesel was produced by alkaline transesterification.

The molar ratio of alcohol to oil (6:1) and NaOH catalyst was mixed with castor oil at 60˚C for 60 min. after separation of castor biodiesel, biodiesel was blended with diesel at different volumetric ratio of 5%, 10%, 25%, 50% and 100% and fuel properties of blends were measured. Fuel properties of biodiesel, diesel and their blends such as heating value, cetane number, density, sulphur content, viscosity, and pour point were determined. They concluded that cetane number and pour point of biodiesel were better and lower heating value, density and viscosity were lesser than that of diesel fuel.

Engine performance and exhaust emission tests were performed on three cylinders, four strokes, natural aspirated, water-cooled, direct injection compression ignition engine. Test fuels were run at 200 rpm interval at full load condition. The performance results showed that blends of castor biodiesel provided increase brake specific fuel consumption and decrease brake power output. The power output of engine reduced by 4.12% with B25 blend as compared with diesel fuel. CO and CO_2 emissions were reduced by 16.92 and 17.20% respectively with the use of B50 blend in diesel engine. CO and CO_2 emissions were reduced by 12.82% and 14.10% respectively with blend B25 as compared with diesel fuel. NO_x emissions were increased by 43.16% using B50 blend. NO_x emissions of B25 blend were increased 21.33% as compared with diesel fuel.

Castor methyl ester-diesel fuel blends can be used as alternate fuel in diesel engines without any modification. They concluded that B25 castor methyl ester-diesel fuel blend can be the best alternative fuel blend for diesel engines for engine performance and emission characteristics.

N.L.Panwar et al, 2010 [19]

They studied out the performance of diesel engine fueled with methyl ester of castor seed oil. Castor methyl ester was prepared by transesterification method using 2% of KOH dissolved in methanol (30% by weight) at 60˚C for 30 min. The experiment was carried out on a singe cylinder, four stroke variable compression ratio (VCR) diesel engine at rated speed of 1500 rpm at different loads. Windows based engine performance analysis software package was used for online performance evaluation.

They concluded that with increase in load, brake power also increases for all blends of biodiesel. At maximum load, B10 blend has developed more brake power than other blends. As load increases, fuel consumption also increases. But at maximum load, B10 gives low fuel consumption as compared to B0, B05 and B20. Therefore, fuel consumption is improved at maximum load in blend B10. This may be due to decrease in overall calorific value with increasing blend of biodiesel. At no load, brake power is less and brake specific fuel consumption (BSFC) is more on that load for all blends. The brake specific fuel consumption for B10 is lower than that of diesel for all loads. Brake thermal efficiency was also tends to increase with increasing load due to reduction in heat loss and more power developed. The brake thermal efficiency is higher for B10 at full load than that of B0, B05 and B20. The blend of B20 has lower brake thermal efficiency due to reduction in calorific value and increase in fuel consumption as compared to B10.

After analysis of exhaust gas temperature graph, they concluded that the exhaust gas temperature was lower upto B05 after that it increased with increasing blends. The highest exhaust gas temperature is observed in B20 blend which is about 265˚C than that of diesel engine. NO_x emission of blend B10 is lower than that of B0. NO_x increases with increase in load and maximum at full load for all blends.

The study revealed that calorific value of castor methyl ester is lower than that of diesel by 15%. The calorific value of blend B10 is 2% less than that of diesel. When B10 blend was fueled in diesel engine, it developed better power than that of diesel. The NO_X emission shows same trend as that of diesel at lower loads and slightly higher at full loads. Hence, castor oil can be used as alternative fuel for diesel engines.

Harveer Singh Pali et al, 2013 [20]

They conducted the performance and emission characteristics of a medium capacity diesel engine fueled with castor biodiesel. The biodiesel was prepared by two-stage esterification and transesterification of castor oil. The castor oil is treated with 1:6 molar ratio of ethanol to oil and 0.75% of KOH at 65˚C for 90 minutes under constant speed. The various different fuel properties were analyzed such as kinematic viscosity, calorific value, density, free fatty acid content, acid value and flash point. The density of prepared castor biodiesel was slightly higher than diesel. Castor biodiesel has more flash point than that of diesel. For evaluation of performance of castor biodiesel, a single cylinder, four stroke, vertical, air cooled, kirloskar diesel engine was used.

They concluded that brake thermal efficiency was increasing with increase in load due to less heat loss and more power developed. The brake thermal efficiency for B10 was 25.87% at full load that was higher than that of diesel (24.53%). The brake thermal efficiency for B10 is much better than B0, B05 and B20. The brake specific energy consumption (BSEC) for B05 has lower value than that of diesel. It was concluded that BSEC was best improved by blending biodiesel upto 20%. The major decrease in $CO_{2,}$ CO, HC and smoke emissions was observed in B20. The CO emission for B20 was 0.45% at full load which is lower that diesel of 0.6%. At full load, HC emission for diesel was 70 ppm that was dropped to 64 ppm for B20. Smoke opacity was decreased with increase in biodiesel blend proportions. B20 has smoke opacity about 78% which was lower than that of diesel (98%). Emission of NO_x was also showed the upward trend with increase in biodiesel blend ratios. This revealed that castor oil methyl ester blends can be used in compression ignition engine without any modification leading to reduced emissions of CO, HC, smoke with slight increase in NO_X emissions. B20 was considered as a best candidate as green fuel among all the blends studied.

Ramesh Babu Nallamothu et al, 2013 [21]

They carried out the investigation in extracting, transesterifying, studying the fuel properties of castor methyl ester and its blends with diesel fuel and in running a diesel engine. Castor oil was extracted by using a mechanical pressing machine. Transesterification of castor oil is comprised dissolving 2g KOH in 100 ml methanol at 50˚C. The fuel properties of various blends B100, B80, B40, B20, B10 and B5 were tested and it satisfied the ASTM standards. The kinematic viscosity of B80 and B100 were out of the standard given by ASTM to use directly on the compression ignition engine. The viscosity of castor methyl ester is higher as that of petrodiesel. The energy content of biodiesel is lesser than that of petrodiesel. The performance of castor methyl ester and its blends were tested in a four stroke diesel engine, analyzed and compared with that of petrodiesel. The performance test results of blends (B5, B10, B20 and B40) were similar as that of performance of petrodiesel. The torque and power were reduced as increase in blends of biodiesel. This is due to the lowering of the heating value of fuel with increase in the percentage of the biodiesel in the blends. At lower torque, power output is reduced due to reduction in the volumetric efficiency. At higher torque, power output is reduced due to increased time for heat losses. The fuel consumption was increased with higher percentage of biodiesel in the blends. Biodiesel has lesser energy content compared to petrodiesel. B5 gave the better performance than that of diesel. It was found to be very similar making castor methyl ester a suitable alternative fuel for petrodiesel.

Ch. S. Naga. Prasad et al, 2009 [22]

They studied performance of castor non-edible vegetable oil and its blends with diesel on a single cylinder, 4-stroke, naturally aspirated, direct injection, water cooled, eddy current dynamometer kirloskar diesel engine at 1500 rpm for different loads. The various physical and chemical properties were determined. The properties like density, viscosity, flash point and fire point of castor oil is higher and calorific value is 0.936 times that of diesel. The blend having 25% of biodiesel has density and viscosity about 15 cst same as that of diesel at 30˚C and does not require any heating prior to injection into combustion chamber. Blends containing 50%, 25% and 0% diesel require preheating upto 70, 80, 95˚C respectively. They concluded that the performance and emission characteristics of 25% blend of castor is better than that of all other blends as compared with diesel. At rated load, castor oil emission such as CO, UHC, smoke were 56.41%, 20.27%, 31.32% respectively higher than that of diesel. The amount of NO_X released was 44% lower as compared to those of diesel. This is due to incomplete combustion of the fuel and delay in the ignition process. The brake thermal efficiency of castor oil was 33.45% lower than that of diesel. The brake specific consumption of castor oil was 54.76% higher as compared to those of diesel. This is due to higher viscosity and lower calorific value of the fuel. The maximum brake thermal efficiency of castor oil is obtained at 76.92% of the total load about 4 Kw. The emissions such as CO, UHC and smoke for blend of 25% of castor oil were higher by 145%, 41.17%, and 48% as compared to that of diesel. The NO_x emission was decreased by 31.03% as compared to diesel. This is due to incomplete combustion of the fuel. These results revealed that blends upto 25% without preheating and upto 50% with preheating can be substituted as fuel for diesel engine without any modification in the engine.

CHAPTER 3
METHODOLOGY

3.1 Objective

Biodiesel is an alternative fuel that derived from vegetable and animal fats. With increase in energy demand and limited fossil fuel, biodiesel has become an emerging option as an alternative fuel. Research is directed towards alternative renewable fuels. With the use of biodiesel, our dependence on imported fuel will get reduced. Biodiesel is an environment friendly alterative fuel which can be used in conventional diesel engine without any modification. Biodiesel was prepared from castor oil by transesterification using NaOH and methanol. The different blends were prepared i.e. B20, B40 and B50. The fuel properties of castor biodiesel and its blends were determined. The performance parameters such as brake power, brake specific fuel consumption, brake thermal efficiency found out when biodiesel and its blends were fuelled in single cylinder, compression ignition engine. The emission characteristics such as CO, HC and CO_2 in the exhaust gas were measured.

3.2 Methodology

The project work can be divided into following steps:-

1. Production of biodiesel
2. Estimation of fuel properties of biodiesel and its blends
3. Blending of biodiesel with diesel
4. Performance characteristics
5. Emission characteristics
6. Comparison of performance and emission characteristics of biodiesel with diesel.

3.2.1 Production of biodiesel

Castor oil was purchased from local supplier in Patiala. Castor oil biodiesel was produced in lab by the method of base catalyzed transesterification.

1. The castor oil of 500 ml was taken in the flask
2. Mixture of 130 ml of methanol and 2.5 g of sodium hydroxide were freshly prepared in the another flask and stirred it until the flasks of sodium hydroxide dissolves in the methanol. [24]
3. Add freshly prepared mixture of methanol and sodium hydroxide into 500 ml of castor oil at ambient temperature and quickly stirred for 1 hour without heating as good solvability is present in alcohol transesterification.
4. The products were allowed to settle overnight in the separating funnel.
5. After that glycerol were removed from the bottom of separating funnel.
6. The crude biodiesel was washed with distilled water for about 3-4 times or until the layer is neutral.
7. After washing, crude biodiesel was stirred and heated at 110˚C to remove the moisture traces in the biodiesel and allow it for cooling at room temperature.
8. The light yellow colored and crystal clear castor biodiesel was produced and stored for usage.

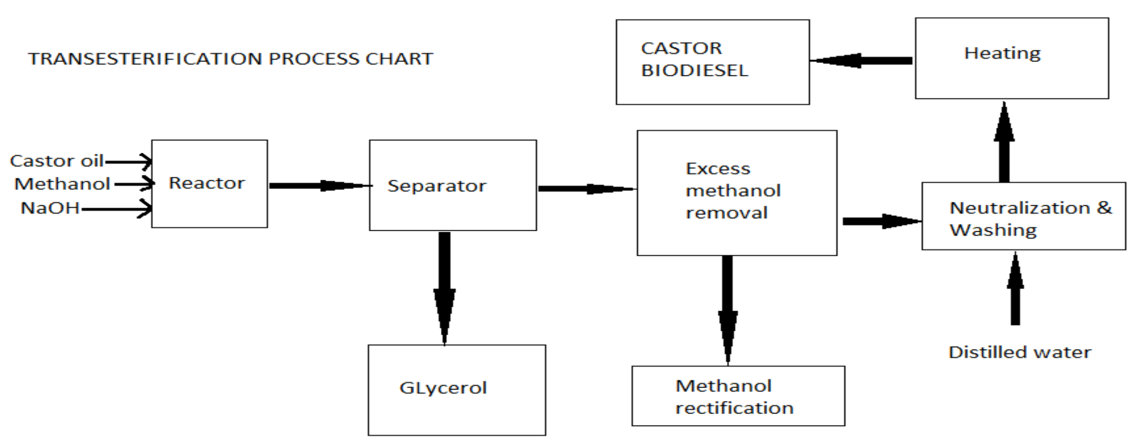


Plate 3.1 Transesterification process chart of castor oil

Castor seeds

Pure Castor oil

Transesterification set up

of castor oil

Castor Biodiesel

from castor oil

Plate 3.2 Biodiesel production from Castor oil

3.2.2 Estimation of fuel properties of castor biodiesel at MERADO, Ludhiana [25]

After transesterification of castor oil, fuel properties of produced biodiesel were determined. The following fuel properties were measured-

1. Kinematic viscosity
2. Calorific value
3. Density
4. Flash point and Fire point
5. Cloud point and Pour point
6. Free fatty acid (FFA) value

Various apparatus & procedures were used to determine these fuel properties-

1. **Redwood viscometer**- It is used for determining the viscosity of oil expressed as a time of flow in seconds through specified hole over a metallic piece.

   Preparation of redwood apparatus

a) First clean the cup with a solvent such as carbon tetrachloride and then dry it thoroughly using tissue paper. Clean the jet hole by any line thread.
b) Using the circular spirit level, set up the viscometer. Fill the bath with water for determination at 93˚C and below, for higher temperatures, with oil having a low viscosity at the test temperature for determination about 93˚C fill the bath to a level not less than 10mm, below the rim of the oil cup at the test temperature.

Plate 3.3 Redwood viscometer

Procedure

a) Viscometer bath was set to a few degrees above the desired test temperature. Sample was poured into the oil cup through a filter of metal gauge. Temperature of the bath was adjusted until the sample in the cup is maintained at the test temperature stirring the contents of the bath and cup during this procedure using continuous stirring for the bath. Sample was stirred during the preliminary period, closing the bottoms of the jet but don't stir the sample during actual determination. When the temperature of the sample has become steady at the desired value, the liquid level was adjusted by allowing the sample to flow out until the surface of the sample touches, the filling point. Oil cup and curved slot was placed in the vocer. Clean, dry, stand 50 ml was placed from the bottom of the jet. Flask was not insulated in any way. Ball valve was located and simultaneously supports the oil cup thermometer by means of the hock wire stem. Stop the tie recorder at the instant the sample reaches the graduation mark of the flask and the final reading of the coil cup thermometer was noted.

b) Any determination of the temperature of the sample in the oil cup varies during the run by more than 0.1˚C for temperatures of 60˚C or below by more than 0.3˚C or by more than 8.5˚C at 121˚C was rejected.

2. **Bomb calorimeter-** It is an apparatus used to measure the calorific value of the fuel.

Procedure-

a) Accurately weigh in the crucible of sample about 1 gram of the air dried material ground to pass through IS sieve 20 (2110 microns).

b) Stretch a piece of the firing wire across the electrode within the Bomb Tie 15 cm. length of sewing cotton around the wire; place the crucible in position and arrange the loose ends of the thread in each determination.

c) Introduce into the body of the bomb 2 ml of distilled water.

d) Reassemble the bomb, screws have the fingers, finally tightening it necessary, avoiding excessive pressure.

e) Charge the bomb as slowly with oxygen from a cylinder to a pressure of 25 atmospheres without displacing its original content.

f) Close the valve and detach the bomb from the oxygen supply.

g) Weigh into the calorimeter vessel a quantity of water sufficient to submerge the cover of the bomb to a depth of a least 2cm leaving the terminal projecting.
h) Use the same weight of water in all tests.
i) Transfer the calorimeter vessel to the water jacket; lower the bomb carefully into the calorimeter vessel and having a circuit through a switch for subsequent firing of the charge.
j) Adjust the stirrer place the thermometer and covers in position and start the stirring mechanism which must be kept in continuous operation at a constant speed during the experiment.
k) After an interval of not less than 10 readings for 5 minutes at equal intervals of not more than 1 minute, tapping the thermometer lightly during 10 seconds prior to each reading. If, over a period of 5 minutes, the average deviation of the individual values of the rate of change of temperature is less than 0.00172˚C per minute, close the circuit momentarily to fire the charge and continue the observation of the temperature at intervals of similar duration to those of the preliminary period.
l) If the rate of change of temperature is not constant within this limit, extend the preliminary period until it is constant.
m) In that period of time, that time extends from the instant of firing until the time after which the rates of change of temperatures again becomes constant, take the earlier readings to 0.001˚C.
n) Determine the rate of change of temperature in the after period by taking reading at 1 minute.
o) Remove the bomb from the calorimeter and after the lapse of half an hour from the time of firing, allow the acid mist to settle, release the pressure by opening the valve. Verify that the combustion has been completed by absence of sooty deposit within bomb.
p) Wash out the contents of the bomb with hot distilled water into a hard glass beaker washing the bomb cap the crucible.
q) Add a measured excess of 0.1 N sodium carbonate solution and boil down to 10 ml to convert any metallic sulfates or nitrates to the less soluble carbonate or hydroxide.
r) Filter, wash and makeup to 100 ml.

s) To determine the sulfur content, take 50 ml of this solution and follow the method.

t) Determine the total acidity by titrating 50 ml of this solution with 0.1 N hydrochloric acid using methyl orange as indicator, titer representing the excess alkali in one-half of the quantity of sodium carbonate solution added to the washings.

Plate 3.4 Bomb calorimeter

3. **Density using weighing balance-**

Procedure-

a) Weigh the 50 ml empty beaker.

b) Weigh the beaker having water of 50 ml.

c) Again, weigh the beaker having castor biodiesel of 50 ml.

d) Using following formula, calculate the value of density of castor biodiesel.

$$\textbf{Density} = \frac{\textbf{Weight of beaker with water – Weight of empty beaker}}{\textbf{Weight of beaker having oil – weight of empty beaker}}$$

4. **Pensky- Martens flash and fire apparatus –** It is used to measure the flash and fire point of a fuel. Biodiesel has lower flash point as compared to diesel.

Plate 3.5 Pensky-marten flash & fire point apparatus

Procedure-

a) Fill the fuel sample in the test cup upto the specified level and heat by heating the air with the help of a heater

b) Stir the fuel sample at a slow constant rate

c) Heat the sample in such a way that the rate of temperature rise is approximately 5˚C per minute.

d) Measure the temperature with the help of a mercury thermometer having range -10 to 400˚C.

e) At every 1˚C temperature, introduce the flame for a moment with the help of a shutter.

f) Record the temperature at which a flash will be appeared in the form of sound and light as the flash point.

g) Record the temperature at which fuel vapour catches.

5. **Cloud and pour point apparatus-** The method of cloud and pour point is intended for use only on oils. In the determination of the cloud point, the sample was cooled under prescribed conditions and was inspected at intervals of 1˚C until a cloud or haze appears.

In the determination of pour point, the sample cooled under prescribed conditions and was inspected at intervals of 3˚C until it will no longer move when the place of surface was held vertical for 65 seconds, the pour point was then taken as 3˚C above the temperature of cessation of flow.

Procedure

a) Fill the 12cm high and 3cm in diameter glass tube of the apparatus enclosed in an air jacket with a freezing mixture of crushed ice and NaCL crystals
b) Take out the glass tube containing fuel sample from the jacket at every 1˚C interval as the temperature fails.
c) Inspect the cloud information.
d) Consider the point at which a haze will be first seen as the cloud point.
e) Follow the same procedure for determination of pour point.
f) Preheat the sample at 48˚C and then cool to 35˚C in air.
g) Fill the sample in the glass tube.
h) Place the cooled sample in the apparatus and withdraw from the cooling bath at 1˚C interval for checking its flow ability.
i) Consider the temperature 1˚C above the temperature at which no motion of fuel will be observed for five seconds on tilting the tube on the horizontal position.
j) Make three replications to have accurate results.

Plate 3.6 Cloud & Pour point apparatus

6. **Free fatty acid value (FFA)-**

Procedure

a) For preparation of neutral ethanol, add 2-3 drops of phenolphthalein indicator in ethanol. Slowly add KOH until light pink color appears.
b) Take 1g of biodiesel in the flask.
c) Add 10 ml neutral ethanol and 2-3 drops of phenolphthalein indicator.
d) Titrate with 0.1 N KOH solution until pink color appears.
e) Using following formula, calculate free fatty acid (FFA) value-

$$\% \text{ FFA} = \frac{28.2 \times \text{normality of KOH} \times \text{volume of KOH consumed}}{\text{Weight of sample}}$$

3.2.3 Blending of castor biodiesel with diesel

Blending of biodiesel with diesel was done. Biodiesel is slightly heavier than conventional diesel fuel. This allows of splash blending by adding biodiesel on top of diesel for making blends. If biodiesel is first put at the bottom and then diesel is added, it will not mix.

Table 3.3 Preparation of castor biodiesel blends

Blends	Biodiesel (%)	Diesel (%)
B20	20%	80%
B40	40%	60%
B50	50%	50%

Procedure-

a) Take a cylindrical flask of 2 liter.
b) 1 liter of total volume of blends was prepared.
c) The blend B20 was prepared by taking 200 ml of castor biodiesel and 800 ml of diesel.
d) The blend B40 was prepared by taking 400 ml of biodiesel and 600 ml of diesel.
e) The blend B50 was prepared by taking 500 ml of castor biodiesel and 500 ml of diesel.

f) Different blends were put in different bottles to store it.

g) These blends were used in engine testing for evaluation of performance and emission.

3.2.4 Performance characteristics

The three different blends B20, B40, B50 were fuelled in the conventional diesel engine.

3.2.4.1 Specifications of the engine

A single cylinder, 4-stroke compression ignition engine having fixed compression ratio is used to determine the performance parameters-

Table 3.4 Specification of diesel engine

Engine model	Kirloskar oil engines limited India
Engine type	Vertical, 4-stroke, fixed compression diesel engine
Cooling media	Air-cooled
No. of cylinder	Single cylinder
Dynamometer	Eddy current dynamometer
Speed	1500 rpm
Compression ratio	16.5:1
Bore/Stroke	80/110 mm
Rated power	3.7 KW
Injection pressure	200 Kg/cm^2
Engine weight	175 Kg
Volts	240
Amps	17.5

3.2.4.1.1 Eddy current Dynamometer [26]

A dynamometer is a load device which is used to measure power output of an engine. Eddy current dynamometer is an electromagnetic load device. Eddy current dynamometers use a varying magnetic field in a coil to generate eddy currents in the end faces of the cooling chambers. Magnetic field creates a torque which opposes the direction of rotor. At a constant excitation of the coil, the opposing torque increases with the speed of rotation of the dynamometer.

Plate 3.7 Compression diesel engine

3.2.4.1.2 Resistive type load panel

The resistive type load panel consists of voltmeter, currentmeter. The engine can be loaded with five coils of 1000 Kw each.

3.2.4.2 Engine testing procedure

Firstly, the engine is fuelled with diesel in order to get baseline data of the engine and then with castor biodiesel blends. The various performance parameters and emissions of the engine were determined.

a) All electrical and manual connections were checked.
b) Start the engine.
c) Introduce load by switching on the connection of 1000W coil plate. Increase the load by placing three coils of 1000W each in series and switch on them for full load.
d) Increase the load at fixed speed of 1500 rpm to get the stability of engine operation.
e) Observe the readings-

- Loads (%)
- Fuel consumption timing (seconds)
- Volumetric reading (cc)
- Dynamometer voltage and current

f) Record the observations at load.

g) Stop the engine.

The following engine performances parameter were measured- [26]

a) **Fuel consumption (FC)** – It is measured by determining the time required to consume the given volume of fuel using a glass burette.

$$\textbf{Fuel consumption} = \frac{\textbf{volume x 3.6 x specific gravity}}{\textbf{Time}} \quad \textbf{Kg/hr}$$

b) **Brake Power (BP)** - It is the output power of an engine measured by developing the power into a brake dynamometer on the output shaft. This power from shaft is measured by a dynamometer.

$$\textbf{Brake Power} = \frac{\textbf{volts x current}}{\textbf{0.88 x 1000}} \quad \textbf{KW}$$

c) Brake specific fuel consumption (BSFC) – It is rate of fuel flow per unit of power output. It is an also measure of the efficiency of the engine by using fuel supplied to produce work. Lower value of BSFC represents the less amount of fuel has been used by engine to produce same amount of work.

$$\textbf{BSFC} = \frac{\textbf{Fuel Consumption}}{\textbf{Brake Power}} \quad \textbf{Kg/KW.hr}$$

d) Brake thermal efficiency (BTE) – It is ratio of the thermal energy in the fuel to the energy delivered by the engine at the crankshaft. Brake thermal efficiency is the ratio of the power output of the engine to the rate librated by the fuel during the combustion.

$$\textbf{BTE} = \frac{\textbf{Brake Power x 3600x100}}{\textbf{FC x Calorific value}} \quad \%$$

3.2.5 Emission characteristics

Emission characteristics were estimated with the automatic emission analyzer. The following emissions were measured –

a) Hydrocarbon (HC)

b) Carbon monoxide (CO)

c) Carbon dioxide (CO_2)

3.2.5.1 Specification of automatic exhaust emission analyzer

An automatic exhaust emission analyzer is used to measure emissions of hydrocarbon, carbon dioxide, carbon monoxide.

Table 3.5 Specification of exhaust emission analyzer

Model	HG-540
Measuring emissions	HC, CO, CO_2
Measuring method	HC, CO, CO_2 – NDIR method
Response time	10-20 seconds
Warming up time	5-10 minutes
Flow rate	2-4 L/min
Power	AC 90-250 V/50-60 Hz
Operating temperature	0˚C-40˚C

Plate 3.8 Exhaust emission analyzer

3.2.5.2 Procedure

a) Press power on key. This leads to automatic warming up & ready the system.

b) Insert probe to the exhaust outlet.

c) Press measure key. Start automatic zero calibration of device & measuring of emissions.

d) Pull out the probe after measurement.

e) Press purge key to clean up the system inside and for auto zero reading.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Fuel properties analysis

The fuel properties were determined by various apparatus at MERADO, LUDHIANA. The results of fuel properties were analyzed with the petrodiesel.

Table 4.6 Comparative properties of castor biodiesel and diesel [23, 25]

Properties	ASTM method	ASTM limit	Castor Biodiesel	DIESEL
Calorific value (KJ/Kg)	IS:1350	>33000	39967.19	42000
Density (Kg/cm^3)	ASTM D1298	-	900	830
Viscosity (cst)	IS:1448[P: 25] 1976	<5	7.37	3.04
Flash point (˚C)	IS:1448[P:32] 1992	>130	180	68
Fire point (˚C)	IS:1448[P:32] 1992	>53	185	73
Cloud point (˚C)	IS:1448[P:10] 1970	-3 to 12	2	-1
Pour point (˚C)	IS:1448[P:10] 1970	-15 to 10	- 3	-6

The calorific value of castor biodiesel is 4.84% less than that of diesel. The kinematic viscosity of castor biodiesel is 58.7% higher as compared to diesel. The flash point and fire point of castor biodiesel is higher than that of diesel. The castor biodiesel has more density than that of diesel. The cloud point and pour point of castor biodiesel is more as compared to those of diesel. The properties of castor biodiesel has meets the standards like ASTM, IS at some point.

4.2 Performance parameters selection

The entire test was conducted at constant speed of 1500 rpm and fixed compression ratio of 16.5 from no load to full load in compression ignition diesel engine. The following parameters were recorded by diesel engine testing:

1. Voltage
2. Current
3. Flue flow rate
4. Air flow rate
5. Emissions (CO, CO_2, HC)

Calculated Performance Parameters

1. Brake Power
2. Brake thermal efficiency
3. BSFC
4. BSEC

Exhaust emission characteristics (ppm, % vol.)-

1. CO (ppm)
2. CO2 (% vol.)
3. HC (ppm)

Fuels tested on diesel engine-

1. Diesel (baseline)
2. Biodiesel B20/D80
3. Biodiesel B40/D60
4. Biodiesel B50/D50

4.2.1 Brake power

At compression ratio 16.5, the graph shows the variation of brake power with respect to load during engine operation on B20, B40, B50 and Diesel.

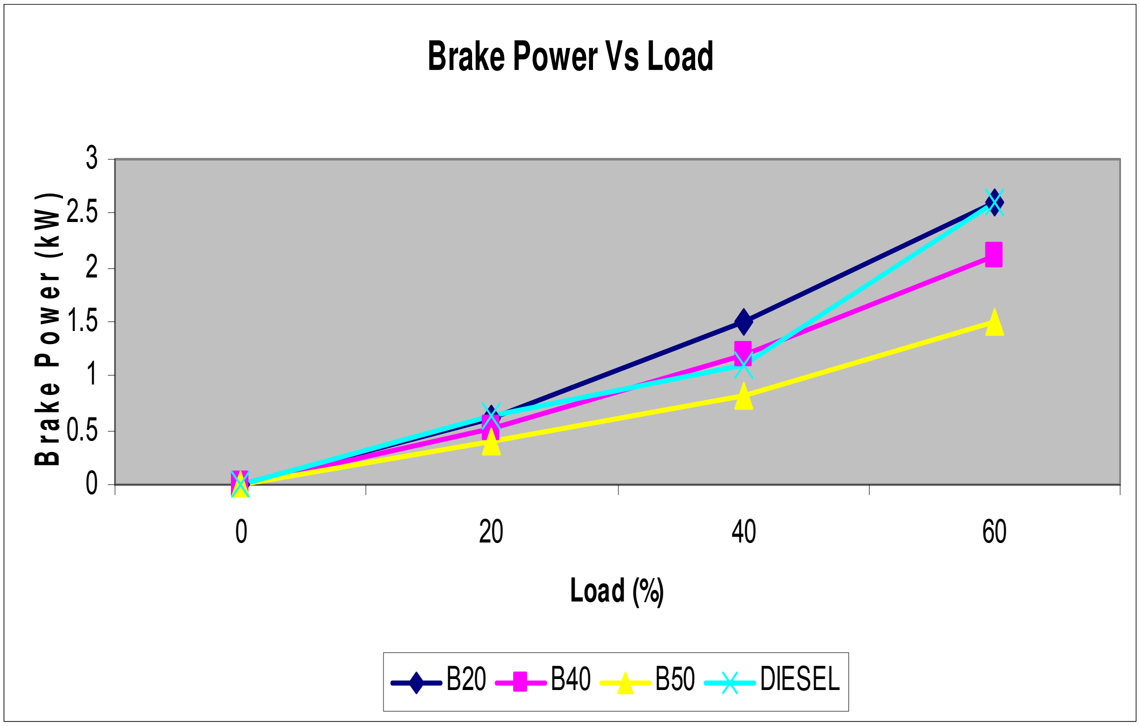


Figure 4.1 Variation in brake power with change in load

Brake power is the output power of an engine measured by developing the power into a brake dynamometer on the output shaft. Brake power increases with increase in the load during engine operation.

At full load, diesel has slightly same brake power than that of castor biodiesel B20 blend. The brake power decreases with increase in percentage of castor biodiesel in different blends due to low heating value of the biodiesel. Diesel has highest brake power due to high calorific value among all blends of castor biodiesel. Castor biodiesel blend B20 blend developed more brake power as compared to B40 & B50 blends at all loads.

At full load, brake power of castor biodiesel B20 is same as that of diesel. At full load, the brake power of castor biodiesel blend B40 is 19.2% less than that of diesel. At full load, brake power of castor biodiesel blend B50 is 42.3% less than that of diesel.

4.2.2 Fuel consumption

Figure 4.2 illustrates the relation between engine load and fuel consumption. With increase in engine load, the fuel consumption increases.

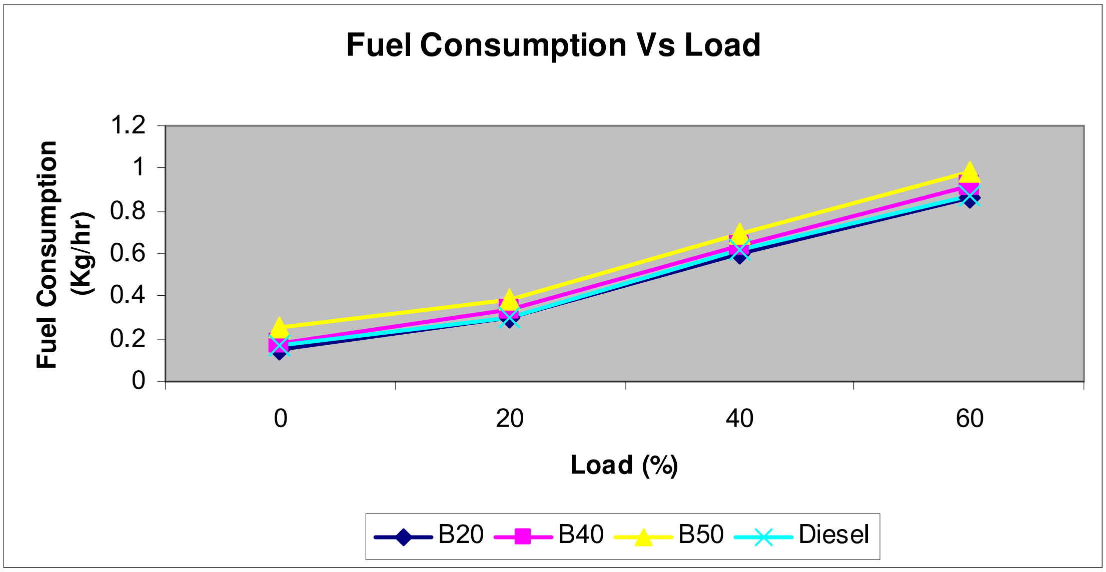


Figure 4.2 Variation in fuel consumption with change in load

Fuel consumption is a measure of how efficiently the fuel supplied to the engine is used to produce power. Fuel consumption is measured by determining the time required to consume the given volume of fuel using a glass burette. Low value of fuel consumption is desirable for given engine performance so that lesser amount of fuel is consumed by engine. The fuel consumption of diesel engine depends on the relationship among volumetric efficiency fuel injection, fuel density, viscosity and lower heating value. More biodiesel and its blends are needed to produce the same amount of energy due to its lower heating value as compared to diesel fuel.

Diesel fuel shows less fuel consumption as compared to all of biodiesel blends of B20, B40 and B50. It is due to decrease in calorific value by increasing the percentage of biodiesel in blend. At all load, biodiesel blend B20 shows lesser fuel consumption than blend B40 and B50 and diesel.

At full load, the fuel consumption of castor biodiesel blend B20 is 6.52%, 12.24%, 2.27% lesser than B40, B50 and diesel. Castor biodiesel blend B20 shows improved fuel consumption at full load.

4.2.3 Brake Specific Fuel Consumption (BSFC)

Graph shows variation in brake specific fuel consumption with respect to load as shown in figure 4.3.

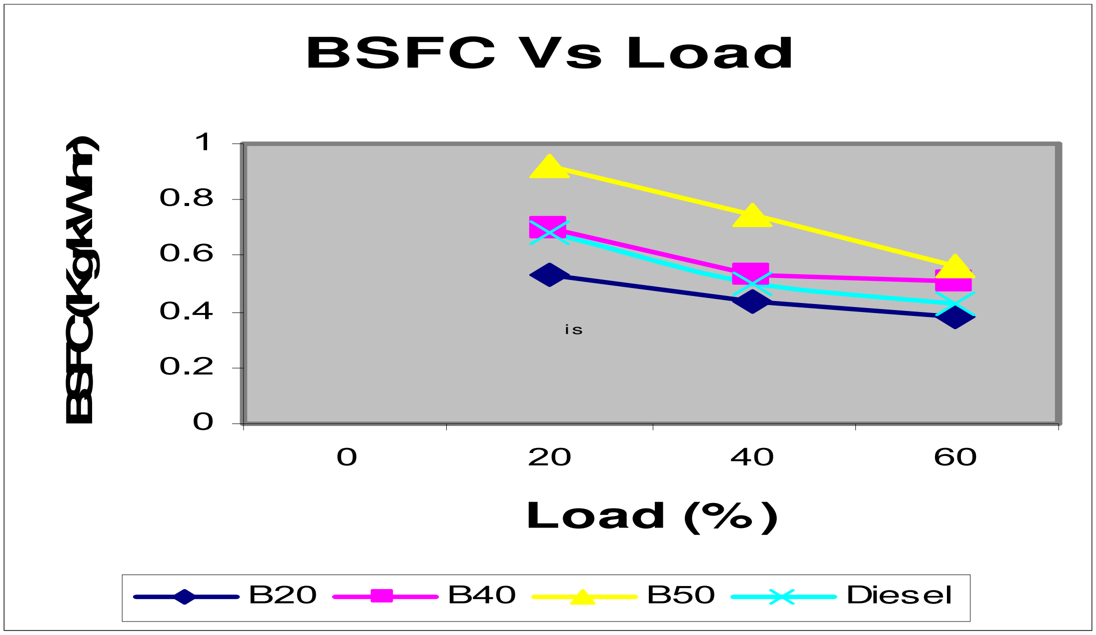


Figure 4.3 Variation in BSFC with change in load

The brake specific fuel consumption is the amount of fuel needed by engine to produce 1 KWh of useful energy output. The lower BSFC value of diesel is attributed to the lower density and weaker molecule bonds leading to a lower flash point. The brake specific fuel consumption decreases with increase in the engine load for all tested blends. This is due to higher percentage increase in brake power with respect to load as compared to fuel consumption.

Castor biodiesel blend B20 has lesser brake specific fuel consumption than that of diesel for all loads. Higher blends B40 and B50 of castor biodiesel have high brake specific fuel consumption than that of diesel at full load. This is due to the fact that with increase in the percentage of biodiesel in the blends, the calorific value decreases. Lower calorific value of biodiesel fuels results in more consumption of fuel to produce same power developed by petrodiesel. Hence, the brake specific fuel consumption increases with increasing percentage of biodiesel in the different blends as compared to diesel.

At full load, the brake specific fuel consumption of castor biodiesel blend is 11.67% lesser than that of diesel. The castor biodiesel blend B40 and B50 has 15.6%, 23.2% more brake specific fuel consumption as compared to diesel.

4.2.4 Brake Thermal Efficiency (BTE)

The graph illustrates variation in the brake thermal efficiency with respect to load.

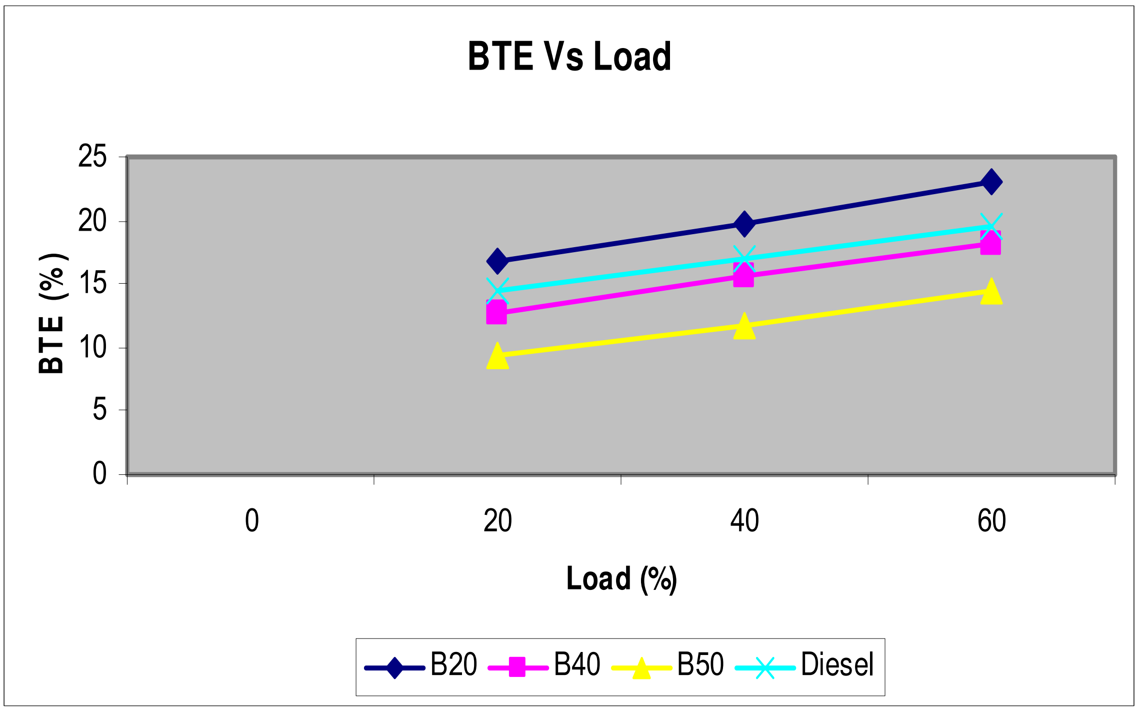


Figure 4.4 Variation in BTE with change in load

The brake thermal efficiency increases with increase in load. This is due to heat loss and more power developed with respect to load. Blend B50 has lower brake thermal efficiency which is due to reduction in calorific value and more fuel consumption as compared to B20 [27].

At full load, the brake thermal efficiency is higher for castor biodiesel blend B20 about 22.92% than that of diesel. Castor biodiesel blend B20 has better brake thermal efficiency than that of B40, B50 and diesel. It is observed that diesel exhibits slightly higher thermal efficiency at all loads than B40 and B50 blends of castor oil. It is due to low heating values and high viscosity of castor biodiesel that affects the combustion process results in lower brake thermal efficiency. The biodiesel molecules contain some amount of oxygen that helps in combustion. The test results indicate that when mass percent of oxygen in fuel exceeds beyond some limit, oxygen loses its positive influence on the fuel energy conversion efficiency. So, brake thermal efficiency of diesel is more than that of higher blends of castor biodiesel B40 and B50.

4.3 Emission characteristics results

4.3.1 Hydrocarbon (HC) Emission

The graph represents the variation of hydrocarbon emission with respect to load. The unburned hydrocarbons in the diesel engine exhaust emits from tested fuel which escapes combustion because

1. It is too lean to burn due to over-mixing with air
2. It is too rich to burn because it did not mix with enough air
3. Fuel trapped along the wall by crevices (narrow regions in the combustion chamber), deposits or oil due to impingement by the fuel spray.

Towards the end of combustion, fuel in the nozzle sac and orifices gets vaporized, enters the combustion chamber and contributes to HC emissions. The mechanism of HC emission is when exhaust value opens the huge amount of gas escaping the cylinder drag with it some of hydrocarbons released fro crevices, oil layer and deposits. During exhaust stroke the piston rolls the hydrocarbon distributed along the walls into a large vortex that becomes large enough that a portion of it is exhausted.

The hydrocarbon emission increases with increasing load for all test fuel. This due to the increase in fuel consumption at each load contributes to higher hydrocarbon emissions. Hydrocarbons are products of incomplete combustion. When fuel has lower tendency to form ignitable mixture, thus leads to higher amount of unburnt hydrocarbon. High viscosity plays an important role in increasing hydrocarbon emission. As hydrocarbons do not get completely burnt, so it comes out in engine exhaust in form of carbon particles.

Figure 4.5 illustrates that the castor biodiesel blend B50 gives lesser hydrocarbon emission as compared to diesel due to more amount of oxygen for better combustion as compared to the petrodiesel.

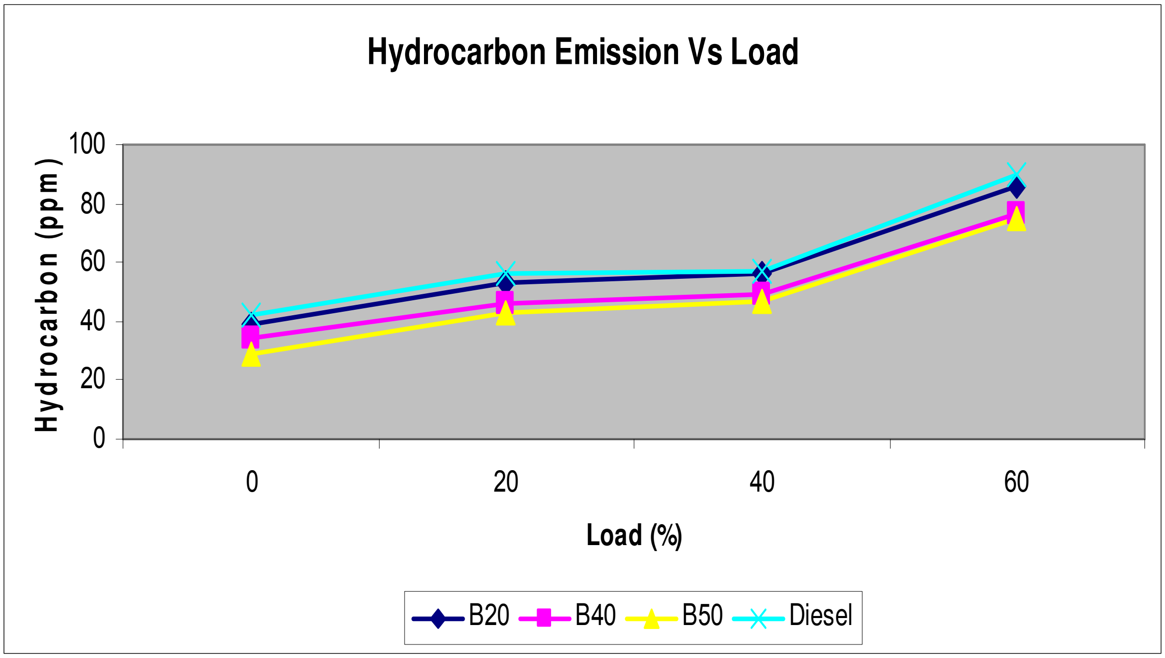


Figure 4.5 Change in quantity of hydrocarbon with load variation

4.3.2 Carbon dioxide (CO_2) Emission

The graph shows variation of carbon dioxide emission with respect to the load. The amount of carbon dioxide emission increases with increasing load. The carbon dioxide emission decreases with increase in the castor biodiesel blends. This is due to presence of more oxygen and lower carbon to hydrogen ratio results in the complete combustion of biodiesel fuel.

Carbon dioxide is an emission that is not regulated but is one of the primary greenhouse gases that responsible for global warming.

Figure 4.6 illustrates that castor biodiesel blend B20 emits lesser carbon dioxide than that of diesel fuel. With increase in content of castor biodiesel in the blend such as B50 results in lesser release of carbon dioxide emission as compared to diesel and B20.

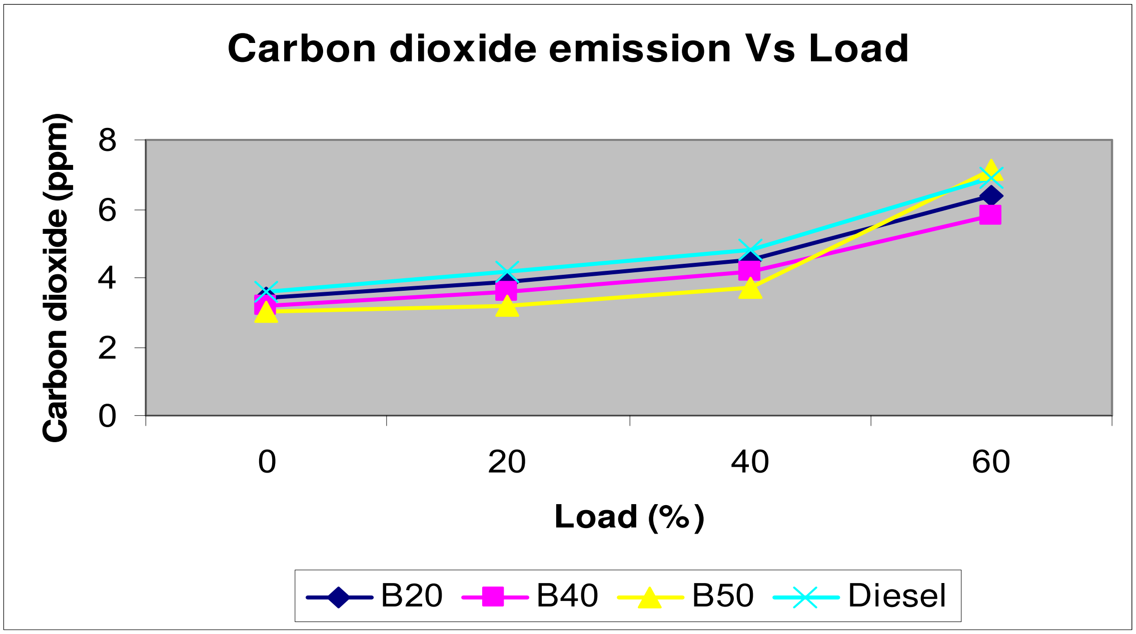


Figure 4.6 Change in quantity of CO_2 with load variation

4.3.3 Carbon monoxide (CO) Emission

The graph represents the variation of carbon monoxide with respect to load. CO is intermediate product of combustion remains in exhaust if the oxidation of CO to CO_2 is not complete. CO is generally formed when mixture is rich in fuel. With increase in the load, the carbon monoxide emissions are increasing for all the castor biodiesel blends. This is due to difficulty in atomization of heavy molecules of biodiesel results in incomplete combustion. This cause more release of carbon monoxide emission due to lack of oxygen during combustion. Carbon monoxide in diesel engine is formed during intermediate combustion stages. As the biodiesel provide more oxygen to the combustion process. Owing to oxygen content in castor biodiesel, in addition to that in the air supplied during induction CO is reduced by combining oxygen with CO to form CO_2.

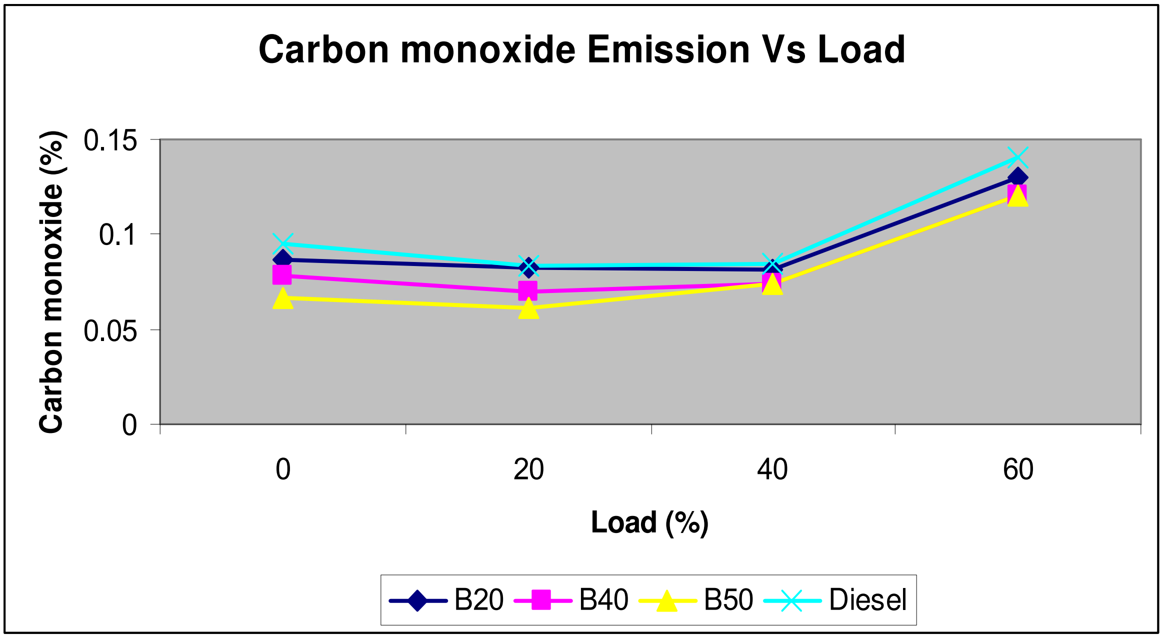


Figure 4.7 Change in quantity of CO with load variation

Figure 4.7 shows that castor biodiesel blend B20 give less carbon monoxide as compared to diesel when fuelled in the diesel engine at all loads. Higher blends of castor biodiesel B40, B50 emits lesser carbon monoxide as compared to diesel fuel.

CHAPTER 5

CONCLUSION AND FUTUREE SCOPE OF WORK

5.1 Conclusions

The overall studies based on production of castor biodiesel, fuel characterization, engine performance and exhaust emission of different blends of castor biodiesel were carried out. The following conclusion were found out –

- The calorific value of castor biodiesel and diesel were found as 39967.19 KJ/kg, 42000 KJ/kg respectively. The calorific value of castor biodiesel is decreased by 4.84% than that of diesel.
- The kinematic viscosity of castor biodiesel and diesel were found as 7.37, 3.04 centistokes at 40°C. The results indicated that the castor biodiesel has kinematic viscosity 58.7 percent more than that of diesel.
- The flash point and fire point of castor biodiesel was found to have higher than that of diesel.
- The castor biodiesel was found to have higher than those of diesel.
- The density of castor biodiesel and diesel were found as 900 kg/cm^3 and 830 kg/cm^3 respectively. The results showed that the castor biodiesel has density more than that those of diesel
- At full load, Brake power produced by castor biodiesel blend B20 is higher than that of other blends B40, B50. The brake power produced by castor biodiesel blend B20 is 3.125% less than that of diesel at full load.
- At full load, brake specific fuel consumption of castor biodiesel blends B50 and B40 are 29.5%, 12.2% respectively higher than that of diesel and BSFC of castor biodiesel blend B20 and diesel is almost same.
- At all loads, brake thermal efficiency of castor biodiesel blend B20 is higher than that of diesel and other blends B40, B50.
- The graphical results of performance parameters shows that castor biodiesel B20 gives better performance than that of others castor biodiesel blends B40, B50 when fuelled in compression ignition diesel engine.

- The castor biodiesel blend emits carbon dioxide, hydrocarbon and carbon monoxide slightly lower than that of diesel at all loads.
- It is concluded that castor biodiesel blend B20 gives better performance and lesser exhaust emission as compared to diesel. So, Castor biodiesel blend B20 can be used as best substitute for diesel fuel.

5.2 Future scope of work

Biodiesel has distinct application to be used as an automotive fuel. Castor biodiesel blend B20 can be used as diesel substitute. Initial cost can be a critical issue. But production cost can be reduced with the use of feedstock technologies & that makes the biodiesel fuel economically fit and cleaner for environment.

The following future scope of the work are-

- Further studies on the innovative and emerging methods for production of castor biodiesel.
- Studies for reduction of high viscosity of castor oil for direct use.
- Studies on the quality control of castor biodiesel by optimizing the process conditions.
- Further studies can be carried out on storage & utilization of by-product like glycerol from castor biodiesel.
- Solutions to the technical problems associated with the use of castor biodiesel in the compression ignition engine.
- Castor biodiesel may be introduced as a diesel fuel blends (B20, B40 and B50) and not as a sole diesel engine fuel (B100).
- Further studies on long term stability of blends of castor.
- Studies on cold weather properties of castor biodiesel.
- Further studies on long term performance evaluation of biodiesel in the conventional diesel engine.
- Government support to activities related to production of castor crop, extraction of castor oil and production of biodiesel & its utilization in daily use for cleaner environment.

- Energy education on biodiesel program should be conducted to get the public acceptance on biofuels.
- Legal framework should be there to enforce the regulations on biodiesel.

APPENDIX

Test results of fuel characterization-

सी.एस.आई.आर.–सी.एम.ई.आर.आई.
कृषि मशीनरी उत्कृष्टता केन्द्र
सामने जी एन ई कालेज, गिल रोड, लुधियाना –141 006

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Under the Aegis of CSIR & CMERI, Durgapur CSIR - CMERI CoEFM

Test Certificate no. MT/2014 – 15/05 , Dated: 12.05.2014 Liaison No: 1631 Issued To : Miss. Disha Jagga (601201004 , SEE) Thapar University Patiala Tel. 9465909058	Customer ref no. Nil Dated: 08.05.2014 No of Samples: one Date samples received: 08.05.2014
Nature of Test:	Characterization of Castor Bio Diesel

'CERTIFICATE'

Calorific Value of Liquid Fuel	**9546 kCal/kg**
Flash Point	**180°C**
Fire Point	**185°C**
Viscocity	**7.37 cst**
Cloud Point	**2°C**
Pour Point	**(-) 3°C**

Reported By:

Checked by:
Head of Department of Bio fuel

Scientist .In Charge
Cdr. V.R.Dahake

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