

**A COMPARATIVE EXPERIMENTAL STUDY BETWEEN THE
BIODIESELS OF JATROPHA AND PALM OILS BASED ON
THEIR PERFORMANCE AND EMISSIONS IN A FOUR
STROKE DIESEL ENGINE**

**A
THESIS**

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

Master of Engineering

**In
Thermal Engineering**

Submitted by

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CERTIFICATION

I, Deepesh Nagar, declare that this thesis report entitled "*A comparative experimental study between the biodiesels of jatropha and palm oils based on their performance and emissions in a four stroke diesel engine*", submitted towards fulfillment of the requirements for the award of Master's Degree in Thermal Engineering, in Mechanical Engineering Department of Thapar University, Patiala, is entirely my own work. This document has not been submitted for any degree in any other institution.

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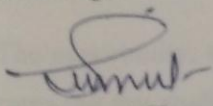
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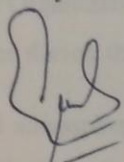
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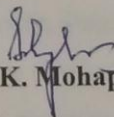
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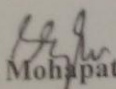

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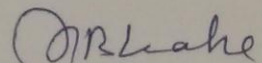

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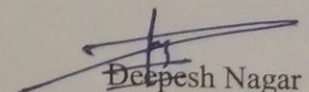
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ABSTRACT

Stringent emission norms and depletion of oil resources have led the researchers to find alternative fuels for internal combustion engines. The main objectives of this study are to investigate the effects of using different types of fuel samples in terms of emission characteristics and feasibility of using alternative fuels. A total of four fuel samples, such as 100% diesel fuel (D100); 20% jatropha biodiesel and 80% diesel fuel (JB20); 20% palm biodiesel and 80% diesel fuel (PB20); and 10% jatropha biodiesel, 10% palm biodiesel and 80% diesel fuel (JPB20) respectively were used to analyze the performance on the basis of brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature and exhaust emissions referring to carbon monoxide, carbon dioxide, and oxides of nitrogen. Short-term engine performance tests are conducted on a single-cylinder, four-stroke, variable compression ratio, compression ignition engine using the four fuel samples mentioned above at load of 0, 2, 4, 6, 8 Kg and compression ratios of 12, 14, 16. It is found from the results that biodiesels differ very little from diesel in performance and are better than diesel with regard to hydrocarbon and carbon monoxide emissions. However oxides of nitrogen are found to be higher for biodiesels but not significantly higher when compared with diesel.

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NOMENCLATURE

BP	Brake Power
BMEP	Brake Mean Effective Pressure
BTE	Brake Thermal Efficiency
EGT	Exhaust Gas Temperature
BSFC	Brake Specific Fuel Consumption
NO, NO ₂ and NO _X	Oxides of Nitrogen
HC	Hydrocarbon
CO ₂	Carbon Dioxide
CO	Carbon Monoxide
PM	Particulate Matter
ASTM	American Society of Testing and Petroleum
ISO	International standard organization
EU	European Union
US	United States
H ₂ SO ₄	Sulphuric Acid
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
IC	Internal Combustion
DI	Direct Injection
CI	Compression Ignition
CR	Compression Ratio
FIP	Fuel injection pump

TAG	Triacylglycerols
FA	Fatty Acids
FFA	Free Fatty Acids
FAME	Fatty Acid Methyl Ester
HHV	Higher Heating Value
PFAD	Preheated Palm Fatty Acid Distillate
PKO	Palm-Kernel Oil
RSM	Response Surface Methodology
FS1	100% diesel fuel
FS2	5% palmdiesel (palm biodiesel) and 95% diesel fuel
FS3	5% jatropha oil and 95% diesel fuel
FS4	5% jatropha oil, 5% palmdiesel and 90% diesel fuel
FS5	10% jatropha oil, 10% palmdiesel and 80% diesel fuel
API	American Petroleum Institute
vk	Kinematic viscosity
Ws	Weight of the sample
Wc	Weigh of carbon residue
Cr	Carbon residue
Ms	Mass of sample burnt
Wc	Water equivalent of the calorimeter
ΔT	Rise in temperature
t	Time for flow
Hc	Heat of combustion of the fuel sample
As	Ash content
Wa	Weight of ash
Av	Acid value

1. INTRODUCTION

1.1 Introduction to biodiesel concept

The scarcity of conventional fossil fuels, growing emissions of combustion generated pollutants, and their increasing costs will make biomass sources more attractive [1]. On the other hand, biomass use, in which many people already have an interest, has the properties of being a biomass source and a carbon-neutral source [2]. Experts suggest that current oil and gas reserves would suffice to last only a few more decades. To meet the rising energy demand and replace reducing petroleum reserves, fuels such as biodiesel and bioethanol are in the forefront of alternative technologies. Accordingly, the viable alternative for compression-ignition engines is biodiesel.

Biodiesel is the monoalkyl esters of vegetable oils or animal fats. Biodiesel is the best candidate for diesel fuels in diesel engines. Biodiesel burns like petroleum diesel as it involves regulated pollutants. On the other hand biodiesel probably has better efficiency than gasoline. Biodiesel also exhibits great potential for compression-ignition engines. Diesel fuel can also be replaced by biodiesel made from vegetable oils. Biodiesel is now mainly being produced from soybean, rapeseed, and palm oils. The higher heating values (HHVs) of biodiesels are relatively high. The HHVs of biodiesels (39 to 41 MJ/kg) are slightly lower than those of gasoline (46 MJ/kg), petro diesel (43 MJ/kg), or petroleum (42 MJ/kg), but higher than coal (32 to 37 MJ/kg) [1].

Biodiesel is pure, or 100%, biodiesel fuel. It is referred to as B100 or “neat” fuel. A biodiesel blend is biodiesel blended with petro diesel. Biodiesel blends are referred to as BXX. The XX indicates the amount of biodiesel in the blend (i.e., a B80 blend is 80% biodiesel and 20% petro diesel).

The majority of energy demand is fulfilled by conventional energy sources like coal, petroleum, and natural gas. Petroleum-based fuels are limited reserves concentrated in certain regions of the world. These sources are on the verge of reaching their peak production. The scarcity of known petroleum reserves will make renewable energy sources more attractive [3]. World energy

demand continues to rise. The most feasible way to meet this growing demand is by using alternative fuels. One such fuel that exhibits great potential is biofuel, in particular biodiesel [4]. The term biofuel can refer to liquid or gaseous fuels for the transport sector that are predominantly produced from biomass [5]. Biofuels include energy security reasons, environmental concerns, foreign exchange savings, and socioeconomic issues related to the rural sector. In developed countries there is a growing trend toward using modern technologies and efficient bioenergy conversion using a range of biofuels, which are becoming cost wise competitive with fossil fuels [4].

It is well known that transport is almost totally dependent on fossil-, particularly petroleum-, based fuels such as gasoline, diesel fuel, liquefied petroleum gas (LPG), and natural gas (NG). An alternative fuel to petro diesel must be technically feasible, economically competitive, environmentally acceptable, and easily available. The current alternative diesel fuel can be termed biodiesel. Biodiesel use may improve emissions levels of some pollutants and deteriorate others. However, for quantifying the effect of biodiesel it is important to take into account several other factors such as raw material, driving cycle, vehicle technology, etc. Use of biodiesel will allow a balance to be sought between agriculture, economic development, and the environment [1].

1.2 History

The process for making fuel from biomass feedstock used in the 1800s is basically the same one used today. The history of biodiesel is more political and economical than technological. The early 20th century saw the introduction of gasoline powered automobiles. Oil companies were obliged to refine so much crude oil to supply gasoline that they were left with a surplus of distillate, which is an excellent fuel for diesel engines and much less expensive than vegetable oils. On the other hand, resource depletion has always been a concern with regard to petroleum, and farmers have always sought new markets for their products. Consequently, work has continued on the use of vegetable oils as fuel [4].

Producing biodiesel from vegetable oils is not a new process. The conversion of vegetable oils or animal fats into monoalkyl esters or biodiesel is known as transesterification. Transesterification

of triglycerides in oils is not a new process. Duffy and Patrick conducted transesterification as early as 1853. Life for the diesel engine began in 1893, when the famous German inventor Dr. Rudolph Diesel published a paper entitled “The theory and construction of a rational heat engine”. The paper described a revolutionary engine in which air would be compressed by a piston to a very high pressure, thereby causing a high temperature. Dr. Diesel designed the original diesel engine to run on vegetable oil [1].

Dr. Diesel was educated at the predecessor school to the Technical University of Munich in Germany. In 1878, he was introduced to the work of Sadi Carnot, who theorized that an engine could achieve much higher efficiency than the steam engines of the day. Diesel sought to apply Carnot’s theory to the internal combustion engine. The efficiency of the Carnot cycle increases with the compression ratio the ratio of gas volume at full expansion to its volume at full compression. Nicklaus Otto invented an internal combustion engine in 1876 that was the predecessor to the modern gasoline engine. Otto’s engine mixed fuel and air before their introduction to the cylinder, and a flame or spark was used to ignite the fuel-air mixture at the appropriate time. However, air gets hotter as it is compressed, and if the compression ratio is too high, the heat of compression will ignite the fuel prematurely. The low compression ratios needed to prevent premature ignition of the fuel-air mixture limited the efficiency of the Otto engine. Dr. Diesel wanted to build an engine with the highest possible compression ratio. He introduced fuel only when combustion was desired and allowed the fuel to ignite on its own in the hot compressed air. Diesel’s engine achieved efficiency higher than that of the Otto engine and much higher than that of the steam engine. Diesel received a patent in 1893 and demonstrated a workable engine in 1897. Today, diesel engines are classified as “compression-ignition” engines, and Otto engines are classified as “spark-ignition” engines [4].

Dr. Diesel used peanut oil to fuel one of his engines at the Paris Exposition of 1900 [1]. Because of the high temperatures created, the engine was able to run a variety of vegetable oils including hemp and peanut oil. At the 1911 World’s Fair in Paris, Dr. Diesel ran his engine on peanut oil and declared “the diesel engine can be fed with vegetable oils and will help considerably in the development of the agriculture of the countries which use it”. One of the first uses of transesterified vegetable oil was powering heavy-duty vehicles in South Africa before World War II. The name “biodiesel” has been given to transesterified vegetable oil to describe its use as a diesel fuel [3]. Vegetable oils were used in diesel engines until the 1920s. During the 1920s,

diesel engine manufacturers altered their engines to utilize the lower viscosity of petro diesel, rather than vegetable oil.

The use of vegetable oils as an alternative renewable fuel competing with petroleum was proposed in the early 1980s. The advantages of vegetable oils as diesel fuel are its portability, ready availability, renewability, higher heat content (about 88% of No. 2 petroleum diesel fuel), lower sulfur content, lower aromatic content, and biodegradability. The energy supply concerns of the 1970s renewed interest in biodiesel, but commercial production did not begin until the late 1990s. Dr. Diesel believed that engines running on plant oils had potential and that these oils could one day be as important as petroleum-based fuels. Since the 1980s, biodiesel plants have opened in many European countries, and some cities have run buses on biodiesel, or blends of petro and biodiesels. More recently, Renault and Peugeot have approved the use of biodiesel in some of their truck engines. Recent environmental and domestic economic concerns have prompted resurgence in the use of biodiesel throughout the world. In 1991, the European Community (EC) proposed a 90% tax deduction for the use of biofuels, including biodiesel. Biodiesel plants are now being built by several companies in Europe; each of these plants will produce up to 1.5 million gallons of fuel per year. The European Union accounted for nearly 89% of all biodiesel production worldwide in 2005.

1.3 Definitions

Biodiesel (Greek, bio, life + diesel from Rudolf Diesel) refers to a diesel equivalent, processed fuel derived from biological sources. Biodiesel is the name for a variety of ester based oxygenated fuels from renewable biological sources. It can be made from processed organic oils and fats.

Chemically, biodiesel is defined as the monoalkyl esters of long chain fatty acids derived from renewable bio lipids. Biodiesel is typically produced through the reaction of a vegetable oil or animal fat with methanol or ethanol in the presence of a catalyst to yield methyl or ethyl esters (biodiesel) and glycerin [1]. Fatty acid methyl esters or biodiesels are produced from natural oils and fats. Generally, methanol is preferred for transesterification because it is less expensive than ethanol [4].

In general terms, biodiesel may be defined as a domestic, renewable fuel for diesel engines derived from natural oils like soybean oil that meets the specifications of ASTM D 6751. In technical terms (ASTM D 6751) biodiesel is a diesel engine fuel comprised of monoalkyl esters of long-chain fatty acids derived from vegetable oils or animal fats, designated B100 and meeting the requirements of ASTM D 6751. Biodiesel, in application as an extender for combustion in CIEs (diesel), possesses a number of promising characteristics, including reduction of exhaust emissions [1]. Chemically, biodiesel is referred to as the monoalkyl esters, especially methyl ester, of long-chain fatty acids derived from renewable lipid sources via a transesterification process.

Biodiesel is a mixture of methyl esters of long-chain fatty acids like lauric, palmitic, stearic, oleic, etc. Typical examples are rapeseed oil, canola oil, soybean oil, sunflower oil, palm oil, and their derivatives from vegetable sources. Beef and sheep tallow and poultry oil from animal sources and cooking oil are also sources of raw materials. The chemistry of conversion into biodiesel is essentially the same. Oil or fat reacts with methanol or ethanol in the presence of a sodium hydroxide or potassium hydroxide catalyst to form biodiesel, methyl esters, and glycerine.

1.4 Biodiesel as an alternative to diesel engine fuel

Biodiesel is a processed fuel that can be readily used in diesel-engine vehicles, which distinguishes biodiesel from the straight vegetable oils or waste vegetable oils used as fuels in some modified diesel vehicles. In general, the physical and chemical properties and the performance of ethyl esters are comparable to those of methyl esters. Methyl and ethyl esters have almost the same heat content. The viscosities of ethyl esters are slightly higher and the cloud and pour points are slightly lower than those of the methyl esters. Engine tests have demonstrated that methyl esters produce slightly higher power and torque than ethyl esters.

Biodiesel is a clear amber-yellow liquid with a viscosity similar to that of petro-diesel. Biodiesel is non-flammable and, in contrast to petro diesel, is non-explosive, with a flash point of 423 K for biodiesel as compared to 337 K for petro diesel. Unlike petro diesel, biodiesel is biodegradable and non-toxic, and it significantly reduces toxic and other emissions when burned as a fuel. Currently, biodiesel is more expensive to produce than petro diesel, which appears to be the

primary factor in preventing its more widespread use. Current worldwide production of vegetable oil and animal fat is not enough to replace liquid fossil fuel use (maximum replacement percentage: ca.20 to 25%) [4].

Methyl esters of vegetable oils (biodiesels) have several outstanding advantages among other new-renewable and clean-engine fuel alternatives. Methanol as a monoalcohol is generally used in the transesterification reaction of triglycerides in the presence of alkali as a catalyst [4]. Methanol is a relatively inexpensive alcohol. Several common vegetable oils such as sunflower, palm, rapeseed, soybean, cottonseed, and corn oils and their fatty acids can be used as the sample vegetable oil. Biodiesel is easier to produce and cleaner with equivalent amounts of processing when starting with clean vegetable oil. Tallow, lard, and yellow grease biodiesels require additional processing at the end of the transesterification process due to the presence of high free fatty acids. Diesel derived from rapeseed oil is the most common biodiesel available in Europe, while soy-bean biodiesel predominates in the United States.

The emergence of transesterification can be dated back to as early as 1846 when Rochieder described glycerol preparation through the ethanolysis of castor oil [5]. Since that time alcoholysis has been studied in many parts of the world. Other researchers have also investigated the important reaction conditions and parameters in the alcoholysis of triglycerides such as fish oils, tallow, soybean, rapeseed, cottonseed, sunflower, safflower, peanut, and linseed oils [1].

The advantages of biodiesel as diesel fuel are its portability, ready availability, renewability, higher combustion efficiency, and lower sulfur and aromatic content [5], higher cetane number, and higher bio-degradability. The main advantages of biodiesel given in the literature include its domestic origin, which would help reduce a country's dependency on imported petroleum, its biodegradability, high flash point, and inherent lubricity in the neat form [4].

The major disadvantages of biodiesel are its higher viscosity, lower energy content, higher cloud point and pour point, higher nitrogen oxide (NO_x) emissions, lower engine speed and power, injector choking, engine compatibility, high price, and greater engine wear. The technical disadvantages of biodiesel/fossil diesel blends include problems with fuel freezing in cold weather, reduced energy density, and degradation of fuel under storage for prolonged periods. One additional problem is encountered when blends are first introduced into equipment that has a long history of pure hydrocarbon usage. Hydrocarbon fuels typically form a layer of deposits on the inside of tanks, hoses, etc. Biodiesel blends loosen these deposits, causing them to block fuel

filters. However, this is a minor problem, easily remedied by proper filter maintenance during the period following introduction of the biodiesel blend [4].

Direct use of vegetable oils and/or the use of blends of the oils have generally been considered to be not satisfactory and impractical for both direct and indirect diesel engines. The high viscosity, acid composition, free fatty acid content, and gum formation due to oxidation and polymerization during storage and combustion, carbon deposition, and oil thickening are obvious problems [5]. Biodiesel has significant potential for use as an alternative fuel in compression ignition engines. Biofuels are non-toxic, biodegradable, and free of sulfur and carcinogenic compounds as they are obtained from renewable sources. Biodiesel is a plant-derived product and contains oxygen in its molecules, making it a cleaner-burning fuel than petrol and diesel [4].

Biodiesel is a clean burning alternative fuel produced from domestic, renewable resources that are much more efficient to produce and use than gasoline. The developmental history of biodiesel is more political than technological.

Table 1.1 shows the availability of modern transportation fuels. The advantage of biodiesel in this aspect is that it is a derivative of natural products. As demand rises, the production of the required agricultural products can be increased to compensate. Biodiesel is a technologically feasible alternative to fossil diesel, but now a days biodiesel costs 1.5 to 3 times more than fossil diesel. As far as actual fuel costs are concerned, the cost of biodiesel currently is comparable to that of gasoline. Biodiesel will be a reasonably available engine fuel in the near future [4].

Table 1.1: Availability of modern transportation fuels [4]

Fuel type	Current Availability	Future Availability
Gasoline	Excellent	Moderate-poor
Biodiesel	Moderate	Excellent
Compressed natural gas (CNG)	Excellent	Moderate
Hydrogen fuel cell	Poor	Excellent

Biodiesel has got better lubricant properties than fossil diesel. Its oxygen content improves the combustion process, leading to a decreased level of tail pipe polluting emissions. Biodiesel is non-

toxic and quickly biodegrades. The risks of handling, transporting, and storing biodiesel are much lower than those associated with fossil diesel. The competitiveness of biodiesel relies on the prices of biomass feedstock and costs, which are linked to conversion technology. Depending on the feedstock used, byproducts may have more or less relative importance. Biodiesel is not competitive with fossil diesel under current economic conditions, where the positive externalities, such as impacts on the environment, employment, climate changes, and trade balance, are not reflected in the price mechanism [1].

Biodiesel from virgin vegetable oil reduces carbon dioxide emissions and petroleum consumption when used in place of petroleum diesel. This conclusion is based on a life cycle analysis of biodiesel and petroleum diesel, accounting for resource consumption and emissions for all steps in the production and use of the fuel.

Table 1.2: Technical properties of biodiesel [4]

Common name	Biodiesel (bio-diesel)
Common chemical name	Fatty acid (m)ethyl ester
Chemical formula range	$C_{14} - C_{24}$ methyl esters or $C_{15-25}H_{28-48}O_2$
Kinematic viscosity range (mm ² /s, at 313 K)	3.3-5.2
Density range (kg/m ³ , at 288 K)	860-894
Boiling point range (K)	>475
Flash point range (K)	430-455
Vapor pressure (mm Hg, at 295 K)	<5
Solubility in water	Insoluble in water
Physical appearance	Light to dark yellow, clear liquid
Odor	Light musty/soapy odor
Biodegradability	More biodegradable than petroleum diesel
Reactivity	Stable, but avoid strong oxidizing agents

1.5 Sources of biodiesel

There are various other biodiesel sources: almond, andiroba (*Carapa guianensis*), babassu (*Orbignia* sp.), barley, camelina (*Camelina sativa*), coconut, copra, cumaru (*Dipteryx odorata*), *Cynara cardunculus*, fish oil, groundnut, *Jatropha curcas*, karanja (*Pongamia glabra*), laurel, *Lesquerella fendleri*, *Madhuca indica*, microalgae (*Chlorella vulgaris*), oat, piqui (*Caryocar* sp.), poppy seed, rice, rubber seed, sesame, sorghum, tobacco seed, and wheat.

Vegetable oils are renewable fuels. They have become more attractive recently because of their environmental benefits and the fact that they are made from renewable resources. Vegetable oils are a renewable and potentially inexhaustible source of energy, with energy content close to that of diesel fuel. Global vegetable oil production increased from 56 million tons in 1990 to 88 million tons in 2000, following a below-normal increase. The source of this gain was distributed among the various oils. Global consumption rose 56 million tons to 86 million tons, leaving world stocks comparatively tight [4].

A variety of biolipids can be used to produce biodiesel. These are

- (a) Virgin vegetable oil feedstock; rapeseed and soybean oils are most commonly used, though other crops such as mustard, palm oil, sunflower, hemp, and even algae show promise;
- (b) Waste vegetable oil;
- (c) Animal fats including tallow, lard, and yellow grease; and
- (d) Non-edible oils such as *jatropha*, neem oil, castor oil, tall oil, etc.

The widespread use of soybeans in the USA for food products has led to the emergence of soybean biodiesel as the primary source for biodiesel in that country. In Malaysia and Indonesia, palm oil is used as a significant biodiesel source. In Europe, rapeseed is the most common base oil used in biodiesel production. In India and Southeast Asia, the *jatropha* tree is used as a significant fuel source [2].

Algae can grow practically anywhere where there is enough sunshine. Some algae can grow in saline water. The most significant distinguishing characteristic of Palm oil is its yield and hence its biodiesel yield. According to some estimates, the yield (per acre) of oil from algae is over 200 times the yield from the best performing plant/vegetable oils [5]. Microalgae are the fastest growing photosynthesizing organisms. They can complete an entire growing cycle every few days. Approximately 46 tons of oil/hectare/year can be produced from diatom algae. Different

algae species produce different amounts of oil. Some algae produce up to 50% oil by weight. The production of algae to harvest oil for biodiesel has not been undertaken on a commercial scale, but working feasibility studies have been conducted to arrive at the above number [4].

Specially bred mustard varieties can produce reasonably high oil yields and have the added benefit that the meal left over after the oil has been pressed out can act as an effective and biodegradable pesticide.

1.6 Advantages of biodiesel as diesel fuel

The advantages of biodiesel as a diesel fuel are its portability, ready availability, renewability, higher combustion efficiency, lower sulfur and aromatic content [1], higher cetane number, and higher biodegradability [4].

The main advantages of biodiesel given in the literature include its domestic origin, its potential for reducing a given economy's dependency on imported petroleum, biodegradability, high flash point, and inherent lubricity in the neat form [5].

1.6.1 Availability and renewability of biodiesel

Biodiesel is the only alternative fuel in which low concentration biodiesel-diesel blends run on conventional unmodified engines. It can be stored anywhere that petroleum diesel fuel is stored. Biodiesel can be made from domestically produced, renewable oilseed crops such as soybean, rapeseed, and sunflower. The risks of handling, transporting, and storing biodiesel are much lower than those associated with petrodiesel. Biodiesel is safe to handle and transport because it is as biodegradable as sugar and has a high flash point compared to petroleum diesel fuel. Biodiesel can be used alone or mixed in any ratio with petroleum diesel fuel.

The most common blend is a mix of 20% biodiesel with 80% petroleum diesel, or B20 in recent scientific investigations; however, in Europe the current regulation foresees a maximum 5.75% biodiesel.

1.6.2 Lower emissions from biodiesel

The combustion of biodiesel alone provides over a 90% reduction in total unburned hydrocarbons and a 75 to 90% reduction in polycyclic aromatic hydrocarbons. Biodiesel further provides significant reductions in particulates and carbon monoxide than petroleum diesel fuel. Biodiesel provides a slight increase or decrease in nitrogen oxides depending on the engine family and testing procedures.

Many studies on the performances and emissions of compression ignition engines, fuelled with pure biodiesel and blends with diesel oil, have been conducted and are reported in the literature [1].

Fuel characterization data show some similarities and differences between biodiesel and petrodiesel fuels [4]. The sulfur content of petrodiesel is 20 to 50 times that of biodiesels. Several municipalities are considering mandating the use of low levels of biodiesel in diesel fuel on the basis of several studies that have found hydrocarbon (HC) and particulate matter (PM) benefits from the use of biodiesel.

The use of biodiesel to reduce N_2O is attractive for several reasons. Biodiesel contains little nitrogen, as compared with petrodiesel, which is also used as a reburning fuel. The N_2O reduction is strongly dependent upon initial N_2O concentrations and only slightly dependent upon temperature, where increased temperature increases N_2O reduction. This results in lower N_2O production from fuel nitrogen species for biodiesel. In addition, biodiesel contains trace amounts of sulfur, so SO_2 emissions are reduced in direct proportion to the petrodiesel replacement.

Biodiesel has demonstrated a number of promising characteristics, including reduction of exhaust emissions [5]. Vegetable oil fuels have not been accepted because they are more expensive than petroleum fuels. With recent increases in petroleum prices and uncertainties concerning petroleum availability, there is renewed interest in vegetable oil fuels for compression ignition engines (CIEs) or diesel engines. Alternative fuels for CIEs have become increasingly important due to increased environmental concerns and for various several socioeconomic reasons. In this sense, vegetable oils and animal fats represent a promising alternative to conventional diesel fuel [1].

One of the most common blends of biodiesel contains 20 volume percent biodiesel and 80 volume percent conventional diesel. For soybean-based biodiesel at this concentration, the estimated emission impacts for percent change in emissions of NO_x , PM, HC, and CO were +20%, -10.1%, -21.1%, and -11.0%, respectively. The uses of blends of biodiesel and diesel oil are preferred in engines in order to avoid some problems related to the decrease of power and torque and to the increase of NO_x emissions (a contributing factor in the localized formation of smog and ozone) that occurs with an increase in the content of pure biodiesel in a blend [4]. Emissions of all pollutants except NO_x appear to decrease when biodiesel is used. Figure 1.1 shows the average emission impacts of vegetable-oil-based biodiesel for CIEs.

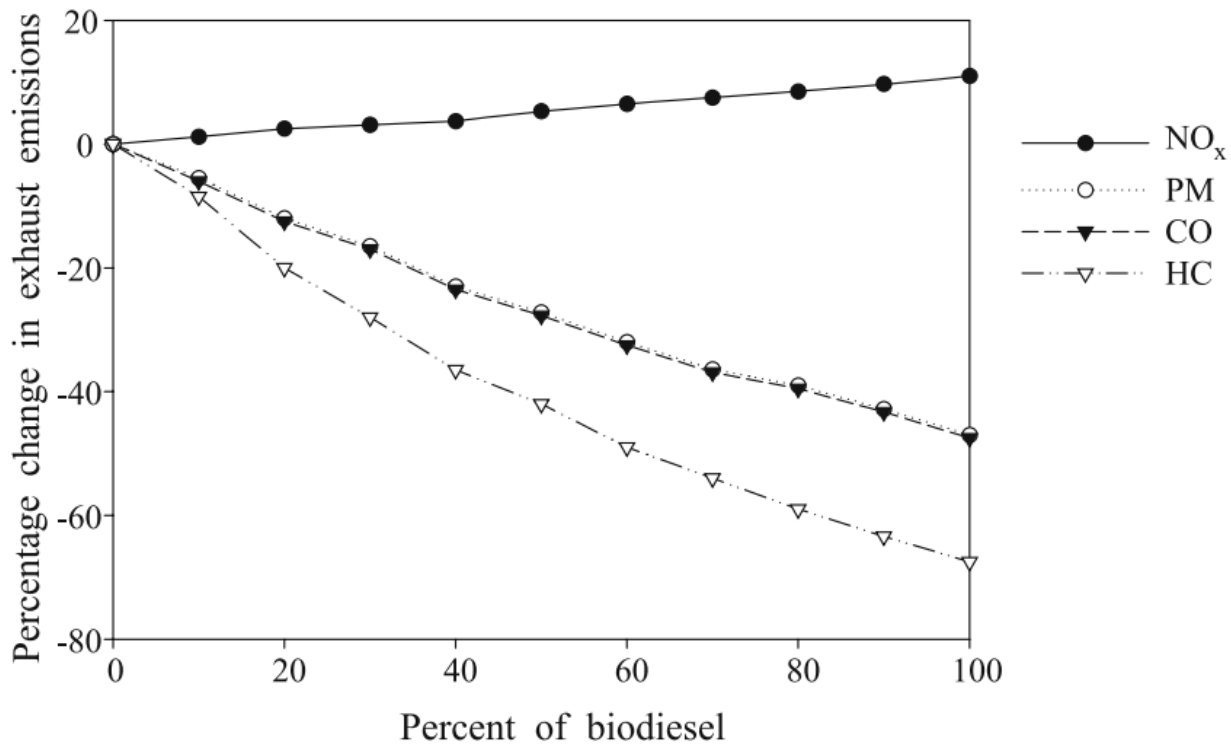


Figure 1.1: Average emission impacts of vegetable-oil-based biodiesel for CIEs [4]

The use of biodiesel in a conventional diesel engine dramatically reduces the emissions of unburned hydrocarbons, carbon dioxide, carbon monoxide, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, ozone-forming hydrocarbons, and particulate matter. The net contribution of carbon dioxide from biomass combustion is small [5]. Reductions in net carbon dioxide emissions are estimated at 77 to 104 g/MJ of diesel displaced by

biodiesel [4]. These reductions increase as the amount of biodiesel blended into the diesel fuel increases. The greatest emissions reductions are seen with biodiesel.

1.6.3 Biodegradability of biodiesel

Biodiesel fuels can be used as a renewable energy source to replace conventional petroleum diesel in CIEs. When degradation is caused by biological activity, especially by enzymatic action, it is called biodegradation. Biodegradability of biodiesel has been proposed as a solution for the waste problem. Biodegradable fuels such as biodiesels have an expanding range of potential applications and they are environmentally friendly. Therefore, there is growing interest in degradable diesel fuels that degrade more rapidly than conventional disposable fuels.

In recent years biodiesel has become more attractive because of its environmental benefits and the fact that it is made from renewable resources [4].

Biodiesel is non-toxic and degrades about four times faster than petrodiesel. Its oxygen content improves the biodegradation process, leading to a decreased level of quick biodegradation. In comparison with petrodiesel, biodiesel shows better emission parameters. It improves the environmental performance of road transport and reduces greenhouse emissions (mainly of carbon dioxide).

As biodiesel fuels are becoming commercialized, their existence in the environment is an area of concern since petroleum oil spills constitute a major source of contamination of the ecosystem [1]. Among these concerns, water quality is one of the most important issues for living systems. It is important to examine the biodegradability of biodiesel fuels and their biodegradation rates in natural waterways in case they enter the aquatic environment in the course of their use or disposal. Chemicals from biodegradation of biodiesel can be released into the environment. With the increasing interest in biodiesel, the health and safety aspects are of utmost importance, including determination of their environmental impacts in transport, storage, or processing [4].

Biodegradation is degradation caused by biological activity, particularly by enzyme action, leading to significant changes in a material's chemical structure. There are many methods of biodegradation. Among them, the carbon dioxide (CO_2) evolution method is relatively simple,

economical, and environmentally safe. Another method is to measure the biochemical oxygen demand (BOD) with a respirometer [1].

1.7 Disadvantages of biodiesel as diesel fuel

The major disadvantages of biodiesel are its higher viscosity, lower energy content, higher cloud point and pour point, higher nitrogen oxide (NO_x) emissions, injector choking, engine compatibility, high price, and higher engine wear.

Important operating disadvantages of biodiesel in comparison with petrodiesel are cold start problems, lower energy content, higher copper strip corrosion, and fuel pumping difficulty from higher viscosity. This increases fuel consumption when biodiesel is used instead of pure petrodiesel, in proportion to the share of the biodiesel content. Taking into account the higher production cost of biodiesel as compared to petrodiesel, this increase in fuel consumption raises in addition the overall cost of application of biodiesel as an alternative to petrodiesel.

Biodiesel has a higher cloud point and pour point compared to conventional diesel [5]. Neat biodiesel and biodiesel blends increase nitrogen oxide (NO_x) emissions compared with petroleum-based diesel fuel used in an unmodified diesel engine. Peak torque is lower for biodiesel than petroleum diesel but occurs at lower engine speed and generally the torque curves are flatter. Biodiesels on average decrease power by 5% compared to diesel at rated loads [3].

2. LITERATURE REVIEW

In the course of this project topic, “A comparative study between the biodiesels of jatropha and palm oils based on their performance and emissions in a four stroke diesel engine”, many journals and books were consulted, which are reviewed here.

2.1 Review of literature

Gerhard Knothe et al. [1] in their book described the technical concept of using vegetable oils or animal fats or even used oils as a renewable diesel fuel. Biodiesel is the form in which these oils and fats are being used as neat diesel fuel or in blends with petroleum- based diesel fuels. The concept itself may appear simple, but that appearance is deceiving since the use of biodiesel is fraught with numerous technical issues. Accordingly, many researchers around the world have dealt with these issues and in many cases devised unique solutions. This book was an attempt to summarize these issues, to explain how they have been dealt with, and to present data and technical information. Countless legislative and regulatory efforts around the world have helped pave the way toward the widespread application of the concept. This book addressed these issues also. To complete the picture, chapters on the history of vegetable oil-based diesel fuels, the basic concept of the diesel engine, and glycerol, a valuable byproduct of biodiesel production, were included.

Report of the committee on development of bio-fuel, Planning Commission India [2] discussed the problems in using petroleum derived high speed diesel, characteristics of biodiesel, rationale, feasibility of producing bio-diesel as petro-diesel substitute, target of bio-diesel production, specifications and quality standards for bio-fuels, R&D issues needing attention (raw material, production technology, utilization as fuel, plants in operation under construction, blending of esters & diesel, storage & handling of bio-diesel, engine development & modifications).

The work of **Alamu O. J. et al. [6]**, “Optimal Tranesterification Duration for Biodiesel Production from Nigerian Palm Kernel Oil”, investigated the effect of variation of mixing time on palm kernel oil (PKO) biodiesel yield. Three replicated transesterification experimental runs were carried out for each of the mixing duration 30, 45, 60, 75, 90, 105, and 120 minutes under identical typical transesterification reaction conditions of 100 g PKO, 60 °C temperature, 1.0 % potassium hydroxide (KOH) concentration and 20 % ethanol (wt % PKO). His results showed PKO biodiesel fuel properties (viscosity, cloud point, specific gravity, pour point and flash point) to be within international biodiesel standard specifications while average PKO biodiesel yield of 87.4, 90.1, 92.5, 94.2, 96.0 and 96.0 % were obtained for the respective mixing duration. Optimal yield of the PKO biodiesel, within the constraint of the typical transesterification process parameters used, was found to be 90 minutes.

Chongkhong S. et al. [7], in his research work, “Biodiesel Production by Esterification of Palm Fatty Acid Distillate”, used the following procedure. The production was carried out in 250 cm³ screw capped bottle. Preheated palm fatty acid distillate (PFAD) was first measured into the bottle, followed by methanol and tetraoxosulphate (VI) acid as catalyst. Operating parameters for efficient esterification include reaction temperatures in the range of 70-100 °C, molar ratios of methanol to PFAD in the range of 0.4:1- 8:1, quantity of tetraoxosulphate (VI) acid catalyst in the range of 0.0- 3.5 weight percent of PFAD, and reaction times in the range of 15-90 minutes were investigated. The production mixture was poured in a separating funnel and then allowed to settle into two phases. The bottom fatty acid methyl ester (FAME) layer was separated and purified by washing with water before being analyzed. According to his results, the final FAME product met with the Thai biodiesel quality standard, and ASTM D6751-02.

Donato A. G. A. et al. [8] deals with esterification of palm fatty acids to produce biodiesel in a batch reactor in his work “Acid-Catalyzed Homogeneous Esterification Reaction for Biodiesel Production from Palm Fatty Acids”. The reactions were performed in a stainless steel 600 ml batch reactor, maximum pressure of 10,000 psi and equipped with a sample withdrawal, stirring velocity was kept constant (500 rpm). Reaction mixture consisted of 307 g of fatty acid mixture, 149 ml methanol or 215 ml ethanol, providing an alcohol/fatty acid molar ratio (A/FA) of 3. Reactants were introduced together with the appropriated catalyst mass (generally 0.1% w/w)

and time of reaction was considered when desired temperature (generally 130 °C) was reached. Sample was withdrawn at 5, 10, 15, 20, 25, 30, 45, and 60 minutes. Reaction conversion was estimated from the free fatty acid (FFA) content of the medium by NaOH titration. They evaluated the effects of alcohol used, presence of water, type and concentration of catalysts. In their results, methanesulfonic and sulfuric acid were the best catalyst. Reaction with methanol showed greater yields. It was shown very clearly that the presence of water in the reaction medium showed a negative effect in the reaction velocity. Kinetic parameters were estimated and molecular modeling was performed.

Alamu O. J. et al. [9], in their work, “Characterization of palm-kernel oil (PKO) biodiesel produced through NaOH-catalyzed transesterification process”, biodiesel was produced from palm kernel oil with ethanol using sodium hydroxide (NaOH) catalyst. The biodiesel was characterized as alternative fuel for diesel engine through ASTM standard fuel tests. The transesterification process using 100 g PKO, 20.0 % ethanol (wt % PKO), 1.0 % NaOH, 60 °C reaction temperature and 90 minutes reaction time yielded average 95.80 % PKO biodiesel for three replications. From their results, fuel tests conducted on the biodiesel showed an 85.06 % reduction of viscosity over its raw PKO at 40 °C. Also higher specific gravity, cloud and pour points were obtained compared to that of petroleum diesel.

In the research work, “Production of Biodiesel from Palm Fatty Acid Distillate”, **Boonnoun P. et al., [10]** produced biodiesel by esterifying PFAD and maintaining it at the reaction temperature in a refluxed batch reactor. The mixture of the methanol and concentrated sulfuric acid were added to the molten PFAD with continuous stirring for 120 minutes. In their study, the variables investigated in the esterification step were the molar ratio of methanol to PFAD (varied from 16:1 to 24:1) and reaction temperatures (60 and 70 °C) by using concentrated sulfuric acid catalyst (1 % v/w of PFAD). From their experimental results, the esterification processes reduce the acid value of the raw material down from 183 mg/g KOH to less than 0.50 mg/g KOH. The purities of biodiesel were between 80-90 % and viscosities were between 4-6 mm²/s. Transesterification post-treatment after esterification process was also studied. In the transesterification step, the reactions were carried out with 0.6 % of KOH catalysts, methanol to PFAD ratio of 8:1 and reaction time of 40 minutes. After transesterification post-treatment, the

acid value of the biodiesel was found to reduce below 0.80 % with the purity of biodiesel higher than 98 %.

Halek F. et al. [11], in their work, “Biodiesel as an Alternative Fuel for Diesel Engines” said that diesel engines operated on biodiesel have lower emissions of carbon monoxide, unburnt hydrocarbons, particulate matter, and air toxics than when operated on petroleum-based diesel fuel. Production of fatty acid methyl ester (FAME) from rapeseed (non-edible oil) fatty acid distillate having high free fatty acids (FFA) was investigated in this work. Conditions for esterification process of rapeseed oil were 1.8 % H_2SO_4 as catalyst, methanol/oil of molar ratio 2: 0.1 and reaction temperature 65 °C, for a period of 3 hours. The yield of methyl ester was > 90 % in 1 hour. The amount of FFA was reduced from 93 wt % to less than 2 wt % at the end of the esterification process. The FAME was purified by neutralization with 1 M sodium hydroxide in water solution at a reaction temperature of 62 °C. The final FAME product met with the biodiesel quality standard, and ASTM D 6751.

From the work of **Hsiao C. C. et al. [12]** which was distributed under the Creative Commons Attribution License, which permits unrestricted use of the article “ Continuous Production of Lipase-Catalyzed Biodiesel in a Packed-Bed Reactor: Optimization and Enzyme Reuse Study”. An optimal continuous production of biodiesel by methanolysis of soybean oil in a packed-bed reactor was developed using immobilized lipase (Novozym 435) as a catalyst in a tert-butanol solvent system. Response surface methodology (RSM) and Box-Behnken design were employed to evaluate the effects of reaction temperature, flow rate, and substrate molar ratio on the molar conversion of biodiesel. The results showed that flow rate and temperature have significant effects on the percentage of molar conversion. On the basis of ridge max analysis, the optimum conditions were as follows: flow rate 0.1 ml/min, temperature 52.10 °C, and substrate molar ratio 1:4. The predicted and experimental values of molar conversion were 83.31 ± 2.07 % and 82.81 ± 0.98 %, respectively. Furthermore, the continuous process over 30 days showed no appreciable decrease in the molar conversion. The paper demonstrated the applicability of using immobilized lipase and a packed-bed reactor for continuous biodiesel synthesis.

Ayhan Demirbas [13] reported the progress and recent trends in biodiesel fuels. Fossil fuel resources are decreasing daily. Biodiesel fuels are attracting increasing attention worldwide as blending components or direct replacements for diesel fuel in vehicle engines. Biodiesel fuel typically comprises lower alkyl fatty acid (chain length C14–C22), esters of short-chain alcohols, primarily, methanol or ethanol. Various methods have been reported for the production of biodiesel from vegetable oil, such as direct use and blending, micro emulsification, pyrolysis, and transesterification. Among these, transesterification is an attractive and widely accepted technique. The purpose of the transesterification process is to lower the viscosity of the oil. The most important variables affecting methyl ester yield during the transesterification reaction are the molar ratio of alcohol to vegetable oil and the reaction temperature. Methanol is the commonly used alcohol in this process, due in part to its low cost. Methyl esters of vegetable oils have several outstanding advantages over other new-renewable and clean engine fuel alternatives. Biodiesel fuel is a renewable substitute fuel for petroleum diesel or petrodiesel fuel made from vegetable or animal fats; it can be used in any mixture with petrodiesel fuel, as it has very similar characteristics, but it has lower exhaust emissions. Biodiesel fuel has better properties than petrodiesel fuel; it is renewable, biodegradable, non-toxic, and essentially free of sulfur and aromatics. Biodiesel seems to be a realistic fuel for future; it has become more attractive recently because of its environmental benefits. Biodiesel is an environmentally friendly fuel that can be used in any diesel engine without modification.

Alternative fuels for diesel engines have been becoming increasingly important due to diminishing petroleum reserves and the growing environmental concerns have made renewable fuels an exceptionally attractive alternative as a fuel for the future. Biodiesel is derived from a varied range of edible and inedible vegetable oil, animal fats, used frying oil and waste cooking oil. The edible oil in use at present is soyabean, sunflower, rapeseed and palm. The inedible oil used as feedstock for biodiesel production includes *J. curcas*, *M. indica*, *F. elastica*, *A. indica*, *C. inophyllum* *jatropha*, neem, *P. pinnata*, rubber seed, mahua, silk cotton tree, waste cooking, microalgae, etc. Transesterification is a chemical reaction between triglyceride and alcohol in the presence of catalyst or without catalyst. The purpose of the transesterification process is to lower the viscosity of the oil. Methanol being cheaper is the commonly used alcohol during transesterification reaction. Homogeneous catalysts such as sulphuric acid, sodium hydroxide, potassium hydroxide and heterogeneous catalysts such as calcium oxide, magnesium oxide and

others can be used in transesterification reaction. Noncatalyzed transesterification processes are the BIOX process and the supercritical alcohol (methanol) process. The advantage in its usage is attributed to lesser exhaust emissions in terms of carbon monoxide, hydrocarbons, particulate matter, polycyclic aromatic hydrocarbon compounds and nitrated polycyclic aromatic hydrocarbon compounds. The main advantages of biodiesel given in the literature include its domestic origin, its potential for reducing a given economy's dependency on imported petroleum, biodegradability, high flash point, and inherent lubricity in the neat form. The biodiesel policy will help reducing of petroleum imports and saving of foreign exchange. The biodiesel high flash point makes it possible for its easy storage and transportation. The main disadvantages of biodiesel are its higher viscosity, lower energy content, higher cloud point and pour point, higher nitrogen oxide emissions, lower engine speed and power, injector coking, engine compatibility, and high price. Blends of up to 20% biodiesel mixed with petroleum diesel fuels can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment. Biodiesel can be used directly or as blends with diesel fuel in a diesel engine. Biodiesel is a biodegradable and renewable fuel. It contributes no net carbon dioxide or sulfur to the atmosphere and emits less gaseous pollutants than normal diesel. Carbon monoxide, aromatics, polycyclic aromatic hydrocarbons (PAHs) and partially burned or unburned hydrocarbon emissions are all reduced in vehicles operating on biodiesel. Recently, biodiesel has been receiving increasing attention due to its less polluting nature and because it is a renewable energy resource as against the conventional diesel, which is a fossil fuel leading to a potential exhaustion. Biodiesel has become more attractive recently because of its environmental benefits. Biodiesel is an environmentally friendly fuel that can be used in any diesel engine without modification. Biodiesel fuels have generally been found to be nontoxic and are biodegradable, which may promote their use in applications where biodegradability is desired. Neat biodiesel and biodiesel blends reduce particulate matter (PM), hydrocarbons (HC) and carbon monoxide (CO) emissions and slightly increase nitrogen oxides (NO_x) emissions compared with petroleum-based diesel fuel used in an unmodified diesel engine. The brake power of biodiesel was nearly the same as with petrodiesel, while the specific fuel consumption was higher than that of petrodiesel. Carbon deposits inside the engine were normal, with the exception of intake valve deposits. Biodiesel fuels can be performance improving additives in compression ignition engines. Performance testing showed that while the power decreased and the brake specific fuel

consumption increased for all of the biodiesel samples, compared with diesel fuel, the amount of the changes were in direct proportion to the lower energy content of the biodiesel.

Ayhan Demirbas [14] reported study on importance of biodiesel as transportation fuel. The scarcity of known petroleum reserves will make renewable energy resources more attractive. The most feasible way to meet this growing demand is by utilizing alternative fuels. Biodiesel is defined as the monoalkyl esters of vegetable oils or animal fats. Biodiesel is the best candidate for diesel fuels in diesel engines. The biggest advantage that biodiesel has over gasoline and petroleum diesel is its environmental friendliness. Biodiesel burns similar to petroleum diesel as it concerns regulated pollutants. On the other hand, biodiesel probably has better efficiency than gasoline. One such fuel for compression-ignition engines that exhibit great potential is biodiesel. Diesel fuel can also be replaced by biodiesel made from vegetable oils. Biodiesel is now mainly being produced from soybean, rapeseed and palm oils. The higher heating values of biodiesels are relatively high. The higher heating values of biodiesels (39–41 MJ/kg) are slightly lower than that of gasoline (46 MJ/kg), petrodiesel (43 MJ/kg) or petroleum (42 MJ/kg), but higher than coal (32–37 MJ/kg). Biodiesel has over double the price of petrodiesel. The major economic factor to consider for input costs of biodiesel production is the feedstock, which is about 80% of the total operating cost. The high price of biodiesel is in large part due to the high price of the feedstock. Economic benefits of a biodiesel industry would include value added to the feedstock, an increased number of rural manufacturing jobs, an increased income taxes and investments in plant and equipment.

Amarnath H. K. et al. [15], in his research work, objective was comparison of performance and emissions of a 4-stroke diesel engine run on three different biodiesels viz. Karanja, Jatropha and Palm separately. Short-term engine performance tests are conducted on a single-cylinder, four-stroke, direct-injection, variable compression ratio, compression ignition engine using the three biodiesels mentioned above at torques of 0, 5, 10, 15, 20 Nm, compression ratios of 14, 15, 16, 17, 17.5, 18 and injection pressures of 150, 200, 250 bar. The performance of the three biodiesels is compared on the basis of brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature and the emissions compared are hydrocarbons and oxides of nitrogen. It is found from the results that biodiesels differ very little from diesel in performance and are

better than diesel with regard to hydrocarbon emissions. However oxides of nitrogen are found to be higher for biodiesels but not significantly higher when compared with diesel.

Liaquat A. M. et al. [16] investigated the effects of using different types of fuel samples in terms of emission characteristics and feasibility of using alternative fuels. A total of five fuel samples, such as 100% diesel fuel (FS1); 5% palmdiesel (palm biodiesel) and 95% diesel fuel (FS2); 5% jatropha oil and 95% diesel fuel (FS3); 5% jatropha oil, 5% palmdiesel and 90% diesel fuel (FS4); and 10% jatropha oil, 10% palmdiesel and 80% diesel fuel (FS5) respectively were used to analyze the exhaust emissions referring to carbon monoxide, carbon dioxide, nitrogen oxide and also exhaust gas temperature. All tests were carried out on a one-cylinder, four-stroke, direct injection (DI), naturally aspirated diesel engine at constant speed of 2000 rpm at varied load conditions between 5 Nm and 17.5 Nm with intervals of 2.5 Nm. The results showed that the FS2 and FS3 have a potential to reduce emissions compared to diesel fuel (FS1). Therefore, in conclusion the FS2 and FS3 can be considered as feasible alternative fuels for diesel engine without any engine modification.

Sahoo P. K. et al. [17] in his research work Non-edible filtered Jatropha (*Jatropha curcas*), Karanja (*Pongamia pinnata*) and Polanga (*Calophyllum inophyllum*) oil based mono esters (biodiesel) produced and blended with diesel were tested for their use as substitute fuels of diesel engines. Diesel; neat biodiesel from Jatropha, Karanja and Polanga; and their blends (20 and 50 by v%) were used for conducting combustion tests at varying loads (0, 50 and 100%). The engine combustion parameters such as peak pressure, time of occurrence of peak pressure, heat release rate and ignition delay were computed. Combustion analysis revealed that neat Polanga biodiesel that results in maximum peak cylinder pressure was the optimum fuel blend as far as the peak cylinder pressure was concerned. The ignition delays were consistently shorter for neat Jatropha biodiesel, varying between 5.9 and 4.2 crank angles lower than diesel with the difference increasing with the load. Similarly, ignition delays were shorter for neat Karanja and Polanga biodiesel when compared with diesel.

Senthil K. M. et al. [18] in his research work various methods of using vegetable oil (Jatropha oil) and methanol such as blending, transesterification and dual fuel operation were studied

experimentally. A single cylinder direct injection diesel engine was used for this work. Tests were done at constant speed of 1500 rev min at varying power outputs. In dual fuel operation the methanol to Jatropha-1 oil ratio was maintained at 3:7 on the volume basis. This is close to the fraction of methanol used to prepare the ester with Jatropha oil. Brake thermal efficiency was better in the dual fuel operation and with the methyl ester of Jatropha oil as compared to the blend. It increased from 27.4% with neat Jatropha oil to a maximum of 29% with the methyl ester and 28.7% in the dual fuel operation. Smoke was reduced with all methods compared to neat vegetable oil operation. The values of smoke emission are 4.4 Bosch Smoke Units (BSU) with neat Jatropha oil, 4:1 BSU with the blend, 4 BSU with methyl ester of Jatropha oil and 3:5 BSU in the dual fuel operation. The Nitric Oxide (NO) level was lower with Jatropha oil compared to diesel. It was further reduced in dual fuel operation and the blend with methanol. Dual fuel operation showed higher hydrocarbon (HC) and carbon monoxide (CO) emissions than the ester and the blend. Ignition delay was higher with neat Jatropha oil. It increased further with the blend and in dual fuel operation. It was reduced with the ester. Peak pressure and rate of pressure rise were higher with all the methods compared to neat Jatropha oil operation. Jatropha oil and methyl ester showed higher diffusion combustion compared to standard diesel operation. However, dual fuel operation resulted in higher premixed combustion. On the whole it is concluded that transesterification of vegetable oils and methanol induction can significantly enhance the performance of a vegetable oil fuelled diesel engine.

Rajneesh Kumar et al. [19] reported technique to produce biodiesel from crude Jatropha curcas seed oil having high free fatty acids (7% FFA) has been developed. The two step process was carried out to produce biodiesel from crude Jatropha curcas oil. The pretreatment process was carried out to reduce the free fatty acid content by (2%) acid catalyzed esterification. The optimum reaction conditions for esterification were reported to be 5 % H_2SO_4 , 20% ethanol and 1 hr. reaction time at temperature of 65°C. The pretreatment process reduced the free fatty acid of oil from 7% to 1.85%. In second process, alkali catalysed transesterification of pretreated oil was carried and the effects of the varying concentrations of KOH and ethanol: oil ratios on percent ester recovery were investigated. The optimum reaction conditions for transesterification were reported to be 3% KOH (w/v of oil) and 30% (v/v) ethanol: oil ratio and reaction time 2 hrs. at 65°C. The maximum percent recovery of ethyl ester was reported to be 60.33%. After that

the experimental work has been carried out to analyze the emission and performance characteristics of a single cylinder 3.73 kW, compression ignition engine fuelled with Jatropa ethyl ester blends with diesel fuel at an compression ratio of 16.5:1. The fuel samples were prepared by blending Jatropa ethyl ester with diesel in the composition of 0:100, 10:90, 20:80, 30:70 and 40:60%. The performance parameters evaluated were brake thermal efficiency, brake specific energy consumption (BSEC), exhaust gas temperature and the emissions measured were carbon monoxide (CO) and oxides of nitrogen (NO_x). The results of experimental investigation with biodiesel blends were compared with that of baseline diesel. The results indicate that the Brake thermal efficiency increased with increase in load on the engine for all blends and also increased with increase in proportion of biodiesel in diesel fuel. Brake specific fuel consumption decreased with increase in load on the engine for all fuel blends. Brake specific fuel consumption increased with increase in concentration of blends in diesel fuel. NO_x emissions increased with increase in percentage of ester in blend as compared to diesel fuel and also increased with increase in load. CO emissions were lower for all the blends at all loads. CI engine could be operated without affecting the performance of the engine with 40 % blending of jatropa ethyl ester biodiesel with diesel.

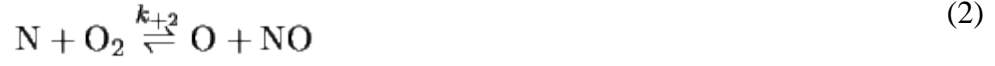
2.2 Kinetics of NO_x formation

In the diesel engines, the emission of nitrogen oxides and particulate matter are of main concern although all the emission regulations also limit the unburned hydrocarbon and carbon monoxide.

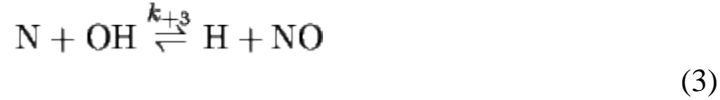
2.2.1 Thermal NO_x formation

The formation of thermal NO_x is determined by a set of highly temperature-dependent chemical reactions known as the extended Zeldovich mechanism. The principal reactions governing the formation of thermal NO_x from molecular nitrogen are as follows:





A third reaction has been shown to contribute, particularly at near-stoichiometric conditions and in fuel-rich mixtures:



Thermal NO_x reaction rates

The rate constants for these reactions have been measured in numerous experimental studies and the data obtained from these studies have been critically evaluated. The expressions for the rate coefficients for Reactions 1-3 used in the NO_x model are given below [20].

$$k_1 = 1.8 \times 10^8 e^{-38370/T} \quad (4)$$

$$k_{-1} = 3.8 \times 10^7 e^{-425/T} \quad (5)$$

$$k_2 = 1.8 \times 10^4 T e^{-4680/T} \quad (6)$$

$$k_{-2} = 3.8 \times 10^3 T e^{-20820/T} \quad (7)$$

$$k_3 = 7.1 \times 10^7 e^{-450/T} \quad (8)$$

$$k_{-3} = 1.7 \times 10^8 e^{-24560/T} \quad (9)$$

In the above expressions K_1 , K_2 and K_3 are the rate constants for the forward reactions 1-3, respectively K_{-1} , K_{-2} and K_{-3} are the corresponding reverse rates. All of these rates have units of $\text{m}^3/\text{gmol}\cdot\text{s}$.

The net rate of formation of NO via Reactions 1-3 is given by

$$\frac{d[\text{NO}]}{dt} = k_1[\text{O}][\text{N}_2] + k_2[\text{N}][\text{O}_2] + k_3[\text{N}][\text{OH}] - k_{-1}[\text{NO}][\text{N}] - k_{-2}[\text{NO}][\text{O}] - k_{-3}[\text{NO}][\text{H}]$$

(10)

where all concentrations have units of gmol/m³.

To calculate the formation rates of NO and N, the concentrations of O, H, and OH are required.

2.2.2 Prompt NO_x formation

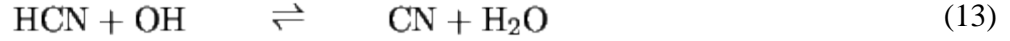
The presence of a second mechanism leading to NO_x formation was first identified by Fenimore and was termed "prompt NO_x". There is good evidence that prompt NO_x can be formed in a significant quantity in some combustion environments, such as in low-temperature, fuel-rich conditions and where residence times are short. Surface burners, staged combustion systems, and gas turbines can create such conditions [20].

At present the prompt NO_x contribution to total NO_x from stationary combustors is small. However, as NO_x emissions are reduced to very low levels by employing new strategies (burner design or furnace geometry modification), the relative importance of the prompt NO_x can be expected to increase.

Prompt NO_x mechanism

The actual formation involves a complex series of reactions and many possible intermediate species. The route now accepted is as follows





Reaction 11 is of primary importance. In this studies [20], comparison of probability density distributions for the location of the peak NO_x with those obtained for the peak CH have shown close correspondence, indicating that the majority of the NO_x at the flame base is prompt NO_x formed by the CH reaction. Assuming that Reaction 11 controls the prompt NO_x formation rate

$$\frac{d[\text{NO}]}{dt} = k_0[\text{CH}][\text{N}_2] \quad (15)$$

There are, however, uncertainties about the rate data for the above reaction. From Reactions 11-14 it can be concluded that the prediction of prompt NO_x formation within the flame requires coupling of the NO_x kinetics to an actual hydrocarbon combustion mechanism. Hydrocarbon combustion mechanisms involve many steps and, as mentioned previously, are extremely complex and costly to compute. In the present NO_x model, a global kinetic parameter derived by De Soete is used. De Soete compared the experimental values of total NO_x formation rate with the rate of formation calculated by numerical integration of the empirical overall reaction rates of NO_x and N_2 formation. He showed that overall prompt formation rate can be predicted from the expression [20].

$$\frac{d[\text{NO}]}{dt} = (\text{overall prompt NOx formation rate}) - (\text{overall prompt N}_2 \text{ formation rate}) \quad (16)$$

2.2.3 Fuel NO_x formation

It is well known that nitrogen-containing organic compounds present in liquid or solid fossil fuel can contribute to the total NO_x formed during the combustion process. This fuel nitrogen is a particularly important source of nitrogen oxide emissions for residual fuel oil and coal, which typically contain 0.3-2% nitrogen by weight. Studies have shown that most of the nitrogen in heavy fuel oils is in the form of heterocycles and it is thought that the nitrogen components of coal are similar. It is believed that pyridine, quinoline, and amine type heterocyclic ring structures are of importance [20].

2.3 Gap in literature

A lot of work has been done on transesterification of edible oils. Limited amount of work is done for the extraction of the biodiesel through transesterification from non-edible oils. In India, the high cost of edible oils prevents their use in biodiesel preparation. But non-edible oils are affordable for biodiesel production. Cost associated with biodiesel is reduced due to the low cost of the non-edible oils. Limited amount of work has been done on comparative experimental study between the biodiesels of jatropha oil and palm oils based on their performance and emissions in a four stroke diesel engine.

3. METHODOLOGY

Objective

The main objective of this work was to do a comparative study of biodiesels of jatropha and palm oils based on their performance and emissions in a four stroke diesel engine. A total of four fuel samples, such as 100% diesel fuel (D100); 20% jatropha biodiesel and 80% diesel fuel (JB20); 20% palm biodiesel and 80% diesel fuel (PB20); and 10% jatropha biodiesel, 10% palm biodiesel and 80% diesel fuel (JPB20) respectively were tested and analyzed at different compression ratios and at different engine loads.

Methodology to be adopted

The proposed work can be divided in following steps:-

1. Production of biodiesel
2. Blending of biodiesel with petro diesel
3. Performance parameters
4. Emission characteristics
5. Comparison of performance and emission characteristics of biodiesels with that of petro diesel

3.1 Biodiesel preparation methodology

First of all sample jatropha oil and palm oil was collected from various sources. This sample was taken to MERADO (Mechanical Engineering Research and Development Organisation)

Laboratory situated at Ludhiana (Punjab). The main parameter for any sample of vegetable oil or animal fat to convert it into biodiesel is its FFA (free fatty acid) value. FFA value should be less than 0.5 for any sample of vegetable oil or animal fat to convert it into biodiesel. If the FFA value of any sample is greater than 0.5 then it cannot be converted into the biodiesel and hence rejected. If the FFA value is 0.5 or less then only it can be converted into biodiesel. Otherwise the free fatty acid value can also be decreased to some extent by the use of some acid like sulphuric acid (H_2SO_4). Now then take the required quantity of the sample of oil and convert that oil sample to Biodiesel by the process known as transesterification. After the biodiesel was prepared from transesterification process, the viscosity was the main parameter to be checked to use it as a fuel for an internal combustion engine. The viscosity of biodiesel should be equal to or less than 5.0 centiStokes(cSt) to use it as a fuel in internal combustion engine. The yield of biodiesel oil should also be checked whether it was appropriate or not.

3.1.1 Material

Following materials were used:

1. Jatropha oil
2. Palm oil
3. Methanol (Methyl alcohol)
4. Potassium hydroxide (KOH) as base catalyst
5. Sulphuric acid (H_2SO_4) as acid catalyst

3.1.2 Biodiesel preparation

As two different oils were used for the extraction of biodiesel, thus two different processes were employed. Because of high Free Fatty Acid (FFA) content for Jatropha oil a 2-stage transesterification process which includes an acid catalyzed transesterification followed by a base catalyzed tranesterification was carried out. Whereas for Palm oil a single stage base catalyzed transesterification was carried out.

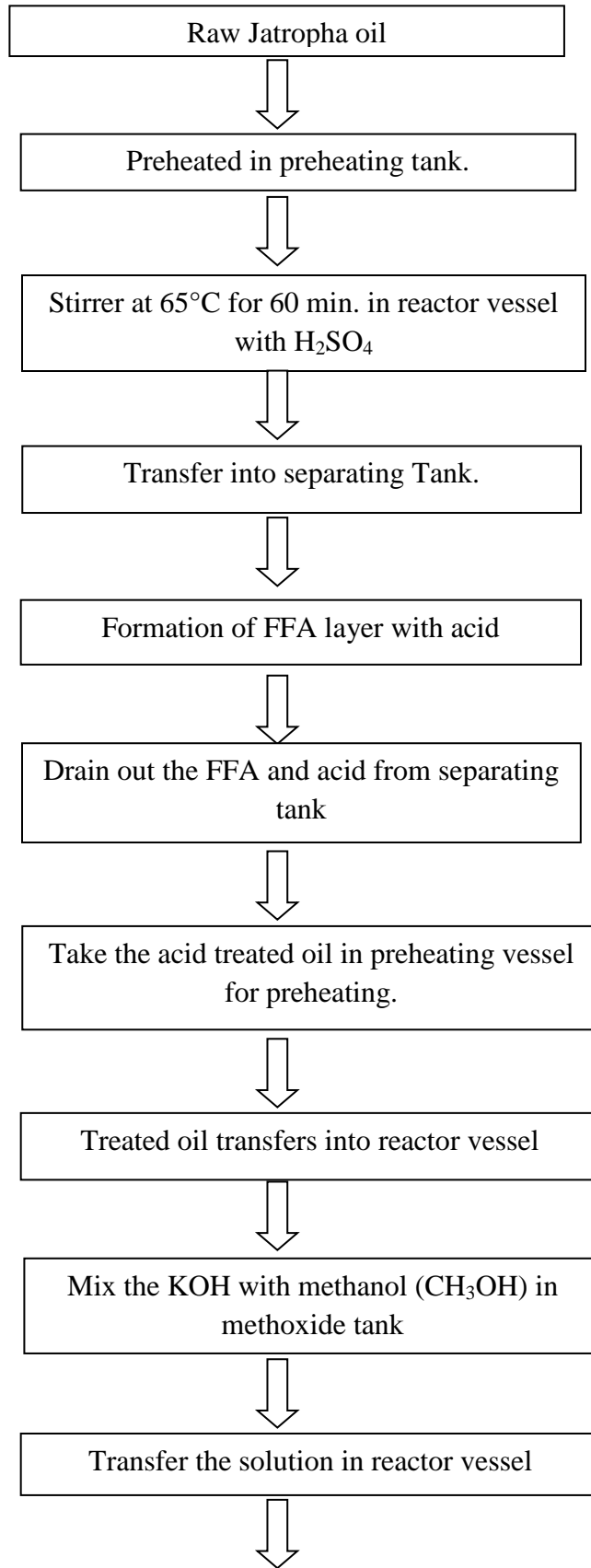
3.1.2.1 Jatropha Biodiesel preparation

First stage (Acid catalyzed transesterification)

1. Some known quantity of crude oil was taken in a conical flask.
2. The oil in the flask was then heated on a heating plate upto a temperature of 60°C.
3. A mixture of known quantity of sulphuric acid (H_2SO_4) as acid catalyst and methanol was then mixed with the preheated crude oil.
4. The preheated oil mixture was then subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker.
5. After 1 hour of constant stirring the mixture was poured into a separating funnel for impurities to settle down.
6. After 4-5 hours the settled down impurities were separated from the remaining oil.

Second Stage (Base catalyzed transesterification)

7. Remaining oil quantity was measured and again heated upto 60°C.
8. A mixture of known quantity of Potassium hydroxide (KOH) as base catalyst and methanol was then mixed with the remaining preheated oil.
9. The preheated oil mixture was then again subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker.
10. After 1 hour of constant stirring the mixture was poured into a separating funnel for glycerol to settle down.
11. After 2-3 hours settled down glycerol is separated and removed.
12. Remaining is methyl ester (biodiesel) of crude jatropha oil (Yield 82%) which was further purified through washing and drying for removal of excess KOH, methanol and water.



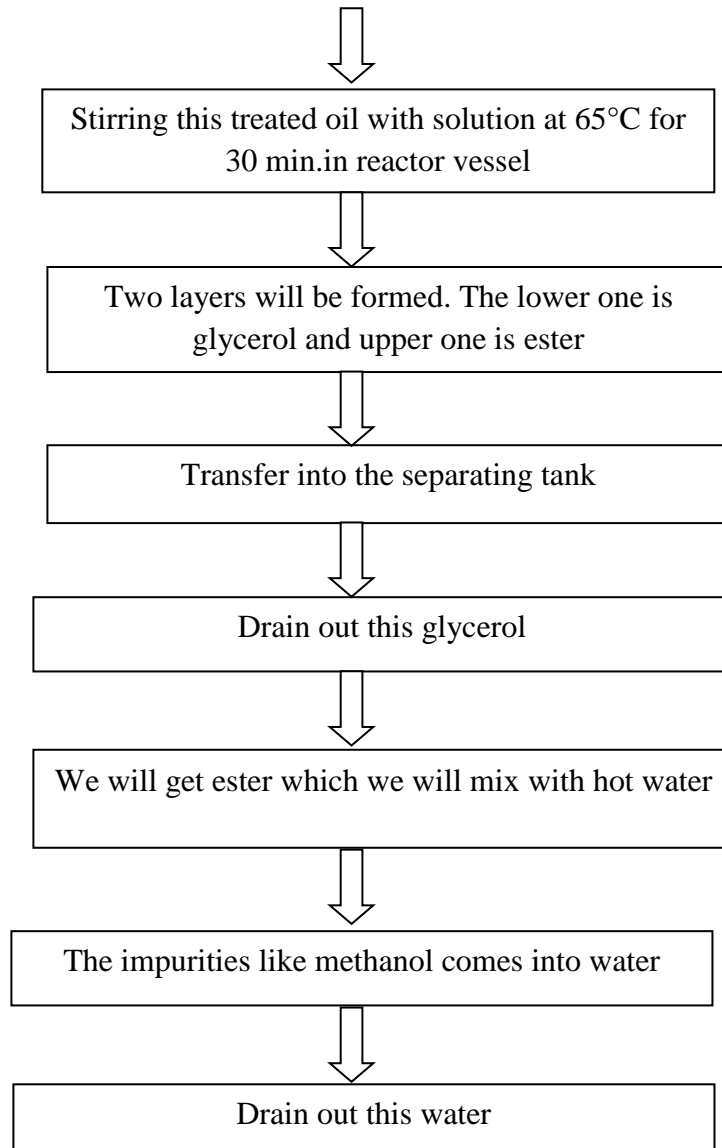


Figure 3.1: Schematic diagram of procedure employed for production of Jatropha biodiesel

3.1.2.2 Palm biodiesel preparation

Single Stage (Base Catalyzed Transesterification)

1. Some known quantity of palm oil was taken in a conical flask.
2. The oil in the flask was then heated on a heating plate upto a temperature of 60°C.

3. A mixture of known quantity of Potassium hydroxide (KOH) as base catalyst and methanol was then mixed with the oil.
4. The preheated oil mixture was then subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker.
5. After 1 hour of constant stirring the mixture was poured into a separating funnel for glycerol to settle down.
6. After 2-3 hours settled down glycerol was separated and removed.
7. Remaining was methyl ester (biodiesel) of refined palm oil (Yield 90%) which was further purified by washing and drying for removal of excess KOH, methanol and water.

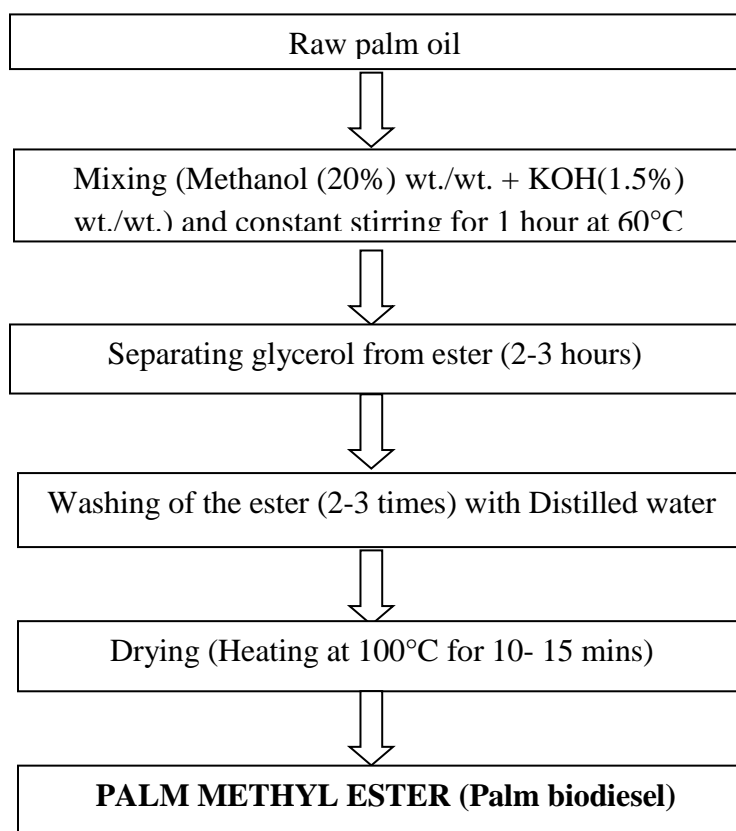


Figure 3.2: Schematic diagram of procedure employed for production of Palm biodiesel

3.2 Fuel characterization

The characteristic fuel properties of Jatropha biodiesel and Palm biodiesel were determined in accordance with standards of Bureau of Indian Standards, New Delhi and the Institute of Petroleum, London.

3.2.1 Relative density and API gravity

The relative density of the selected fuels at 15⁰C was determined as per IS: 1448 [P: 32]: 1992. The empty pyknometers of 50 ml capacity were weighed on an Adair Dutt make, MJ 500 series electronic balance of range 0 - 500g, having readability of 0.001 g. The pyknometers were then filled with fuel samples and weighed. The samples were maintained at 15⁰C by keeping them in a Saveer Biotech make walk-in temperature control chamber. A mercury thermometer of 0 – 100⁰C range was also used to measure the temperature of fuels kept inside the temperature control chamber.

The weights of the empty pyknometers were subtracted from the weights of the filled ones to get the weight of the fuel samples. Three replicates were taken for each sample and their mean was calculated. This value when divided by the volume of the fuel sample gave the density (ρ_F) of the fuel sample at 15⁰C. The density of distilled water (ρ_w) at 15⁰C was also determined.

Equation 3.1 was used to calculate the relative density.

$$\text{Relative density} = \frac{\text{Density of the fuel at } 15^0 \text{ C}}{\text{Density of the water at } 15^0 \text{ C}} \quad \dots (3.1)$$

The API (American Petroleum Institute) gravity, which is an indicator of heat content and lightness of a fuel, was also calculated. The higher the API gravity, the lighter is the fuel. The following relationship was used to determine the API gravity of Palm oil.

$$\text{API Gravity} = \frac{141.5}{\text{Relative density at } 15^{\circ}\text{C}} - 131.5 \quad \dots (3.2)$$

3.2.2 Kinematic viscosity

Viscosity can be defined as the resistance to flow of liquid due the internal friction between the liquid and surface. It plays an important role in the performance of an engine fuel system operating through a wide range of temperature. Kinematic viscosity affects the fuel injection system. Low viscosity can result in an excessive wear in injection pumps and power loss due to pump leakage whereas high viscosity may result in excessive pump resistance, filter blockage, high pressure and coarse atomization and fuel delivery rates.

A Redwood Viscometer No.1 of WISWO was used for measurement of kinematic viscosity of selected fuel samples. The instrument measures the time of gravity flow in seconds of a fixed volume of the fluid (50ml) through specified orifice made in an agate piece as per IS : 1448 [P : 25] 1976. The apparatus could be used for flow time between 30 to 2000 seconds. The fuel was filled in a cup fitted with agate jet at the bottom up to a specified level indicated in the cup. The cup was surrounded by water jacket having an immersion heater. The water was heated to 38⁰C by regulating the rate of heating using a voltage regulator of the instrument. A silver plated metallic ball was used to open and close the agate jet. A standard 50 ml volumetric glass was kept below the agate jet to collect a falling fuel sample. Each test was replicated thrice. Kinematic viscosity in centistokes was then calculated from time units by using the relationships given by Guthrie (1960).

$$v_k = 0.26 t - \frac{179}{t} \quad \dots (3.3)$$

When $34 < t < 100$ and

$$v_k = 0.24 t - \frac{50}{t} \quad \dots (3.4)$$

When $t > 100$

where,

ν_k = Kinematic viscosity in centistokes, cS

t = Time for flow of 50 ml sample, s



Plate 3.1: Redwood Viscometer Used for Measurement of Kinematic Viscosity

3.2.3 Gross heat of combustion

The heat of combustion or calorific value of a fuel is an important measure since it is the heat produced by the fuel within the engine that enables the engine to do the useful work. The gross heat of combustion of fuel samples was determined as per IS: 1448 [P: 6]: 1984 with the help of a Widson Scientific Works make Isothermal Bomb Calorimeter. A fuel sample of 1 ml was burnt in the bomb of calorimeter in the presence of pure oxygen. The sample was ignited electrically. As the heat was produced, the rise in temperature was measured. The water equivalent (effective heat capacity of the calorimeter) was also determined using pure and dry benzoic acid as test fuel. Each sample was replicated three times.

The gross heat of combustion of the fuel samples was calculated using the equation given below:

$$H_c = \frac{W_c \times \Delta T}{M_s} \quad \dots (3.5)$$

where,

- Hc = Heat of combustion of the fuel sample, Cal / g
- Wc = Water equivalent of the calorimeter, Cal / °C
- ΔT = Rise in temperature, °C
- Ms = Mass of sample burnt, g



Plate 3.2: Digital Bomb Calorimeter Used for Measurement of Calorific Value

3.2.4 Cloud and pour point

The Cloud and Pour point is the measure which indicates that the fuel is sufficiently fluid to be pumped or transferred. Hence it holds significance to engines operating in cold climate. The cloud point is defined as the temperature at which a cloud or haze of wax crystal appears at the bottom of a test jar when chilled under prescribed conditions. The pour point is defined as the temperature at which the fuel ceases to flow. Both properties may indicate the tendency towards filter plugging and flow problems in the fuel line.

The Cloud and Pour point of fuel samples were determined as per IS: 1448 [P: 10]: 1970 using the Cloud and Pour point apparatus. The apparatus mainly consists of 12 cm high glass tubes of 3 cm diameter. These tubes are enclosed in an air jacket, which is filled with a freezing mixture of crushed ice and sodium chloride crystals. The glass tube containing fuel sample is taken out from the jacket at every 1°C interval as the temperature falls, and is inspected for cloud formation. The point at which a haze was first seen at the bottom of the sample was taken as the cloud point.

The apparatus and the procedure for the pour point as same as for cloud point only the sample was pre-heated to 48⁰C and then cooled to 35⁰C in air before it was filled in the glass tube. Thereafter, the cooled samples were placed in the apparatus and withdrawn from the cooling bath at 1⁰C interval for checking its flow ability. The pour point was taken to be the temperature 1⁰C above the temperature at which no motion of fuel was observed for five seconds on tilting the tube to a horizontal position. Three replications were made for each fuel type.



Plate 3.3: Cloud & Pour Point Measurement Apparatus

3.2.5 Flash and fire point

Flash point measures the tendency of the sample to form a flammability mixture with air under controlled laboratory conditions. This is the property that must be considered in assessing the overall flammability and hazard of material. Flash point can indicate the possible presence of highly volatile and flammable material in relatively non-volatile material. It is defined as the lowest temperature at which the fuel gives off sufficient vapours and ignites for a moment. The fire point is an extension of flash point in a way that it reflects the condition at which vapour burns continuously for five seconds. The fire point is always higher than flash point by 5 to 8⁰C.

The flash and fire point of the fuel samples were determined as per IS: 1448 [P: 32]: 1992. A Pensky Martin Flash Point (closed) apparatus was used for measuring the flash and fire point of the fuel samples. The sample was filled in the test cup up to the specified level and heated by

heating the air bath with the help of a heater. The fuel sample was stirred at a slow constant rate. The sample was heated in such a way that rate of temperature rise was approximately 5°C per min. The temperature was measured with the help of a thermometer of -10 to 400°C range. At every 1°C temperature rise, flame was introduced for a moment with the help of a shutter. The temperature at which a flash appeared in the form of sound and light was recorded as flash point. The fire point was recorded as the temperature at which fuel vapour catches fire and stays for minimum of five seconds.



Plate 3.4: Flash & Fire Point Measurement Apparatus

3.2.6 Carbon residue

Carbon residue was determined for different fuels by using a carbon residue apparatus. The measurement was made in accordance with the ASTM D189–IP 13 of Institute of Petroleum, London. This procedure determines the amount of carbon residue left after evaporation and pyrolysis of an oil. It was intended to provide some indication of relative coke forming properties. In this method, 10 g weight to the nearest 5 mg of each fuel sample was weighed free of moisture and other suspended matter into an iron crucible of the apparatus. The crucible was then placed in the centre of skidmore crucible of the apparatus and the sand was leveled in the large sheet iron crucible and then the skidmore crucible was set on it in the exact centre of the iron crucible. Thereafter, the covers were applied to both skidmore and iron crucible loosening the latter fitting to allow free exit to the vapours as it formed. The fuel sample was then heated

with a high strong flame from gas burner for 20 min. When the smoke appeared on the chimney, immediately the burner was moved or tilted so that the gas flame plays on the sides of the crucible for the purpose of igniting the vapours. After that the ignited vapour was burnt uniformly with the flame above the chimney for another period of time. When the vapour ceased to burn and no further smoke was observed, the burner was adjusted and the heat was held as at the beginning to make the bottom and the lower part of the sheet iron crucible, a cherry red for about 15 min. Thereafter, the burner was removed and allowed to cool until no smoke appeared. The cover of skidmore was then removed with a tong and it was cooled and weighed. The percentage of carbon residue on the original sample was then calculated using the equation as given below:

$$C_r = \frac{W_c}{W_s} \times 100 \quad \dots (3.6)$$

where,

- Cr = Carbon residue, %
- Wc = Weigh of carbon residue, g
- Ws = Weight of the sample, g



Plate 3.5: Carbon Residue Content Measurement Apparatus

3.2.7 Ash content

Ash in a fuel can result from oil, water soluble material compounds or extraneous solids, such as dirt and rust. The ash content of Palm oil was measured as per the standard ASTM D482-IP 4 of Institute of Petroleum, London. An electric muffle furnace of WISWO make was used in the experiment. In order to measure the ash content, sample was taken in a silica dish. The dish was first weighed empty and then with the fuel sample. The sample weight was obtained from the difference between the initial and final weight of the dish. The sample was then placed in the muffle furnace and heated at $775 \pm 25^{\circ}\text{C}$ for two hours. The dish was then cooled to room temperature in a desiccator. Thereafter, the dish was weighed to the nearest 0.01 mg using an electronic balance described in Section 3.7.1. Each sample was replicated three times. The ash content was obtained using the equation given below

$$A_s = \frac{W_a}{W_s} \times 100 \quad \dots (3.7)$$

where,

A_s = Ash content, percent

W_a = Weight of ash, g

W_s = Weight of sample, g



Plate 3.6: Muffle Furnace Used for Measurement of Ash Content

3.2.8 Acid value

Free fatty acids present in a vegetable oil may be corrosive to some engine parts. At elevated temperatures, free fatty acids may react with many metals producing fatty acid metal salts thus increasing wear. Acid value was, therefore, an important characteristic to be measured. The acid value or number defined as the mg KOH required to neutralize the free fatty acid present in one gram of sample. However, the free fatty acid content is expressed as oleic acid equivalents. The total acid value of different fuel samples was measured as per method describe by Cox and Pearson, 1962. The procedure described below was followed in order to determine total acidity of various fuels selected for the study:

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

Add a few drops of phenolphthalein.

Titrate the contents against 0.1N KOH.

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

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

$$A_v = \frac{56.1 N \times T_v}{W_s} \quad \dots (3.8)$$

where,

A_v = Acid value, mg of KOH/g

T_v = Titrate value, ml

N = Normality of the potassium hydroxide solution

W_s = Weight of sample, g

Table 3.1: Standard methods for calculating the properties [3]

Property	Method used
Kinematic viscosity	IS: 1448 [P: 25] 1976
Flash point and fire point	IS: 1448 [P: 32]: 1992
Ash content	ASTM D482-IP 4 of IIP
Cloud point and pour point	IS: 1448 [P: 10]: 1970
Carbon residue	ASTM D189-IP 13 of IIP
Calorific value	IS: 1350

Table 3.2: Apparatus used for calculating the properties [MERADO, Ludhiana]

Property	Apparatus used
Density	Weighing balance
Kinematic viscosity	Redwood viscometer
Flash point	Flash and fire point apparatus
Fire point	Flash and fire point apparatus
Ash content	Muffle furnace
Cloud point	Cloud and pour point apparatus
Pour point	Cloud and pour point apparatus
Carbon residue	Carbon residue (rams bottom) apparatus
Calorific value	Bomb calorimeter

3.3 Blending of biodiesel with petro diesel

After the biodiesel were prepared, four fuel samples, such as 100% diesel fuel (D100); 20% jatropha biodiesel and 80% diesel fuel (JB20); 20% palm biodiesel and 80% diesel fuel (PB20); and 10% jatropha biodiesel, 10% palm biodiesel and 80% diesel fuel (JPB20) respectively. For a short term time period, up to B20 blend can directly be used in an internal combustion engine without any further modification in the engine [4].

3.4 Experimental methodology

Here a brief description of the apparatus and its method of operation are given. Along with it different performance and exhaust emission parameters were also discussed.

3.4.1 Engine Performance Evaluation

Evaluation of the engine performance was described

- Engine description
- Operation
- Parameters evaluated

3.4.1.1 Engine Description

Pictorial view of variable compression ratio compression ignition engine setup along with the online performance evaluation system is shown in Plate 3.7.



Plate 3.7: Variable compression ratio compression ignition engine experimental setup

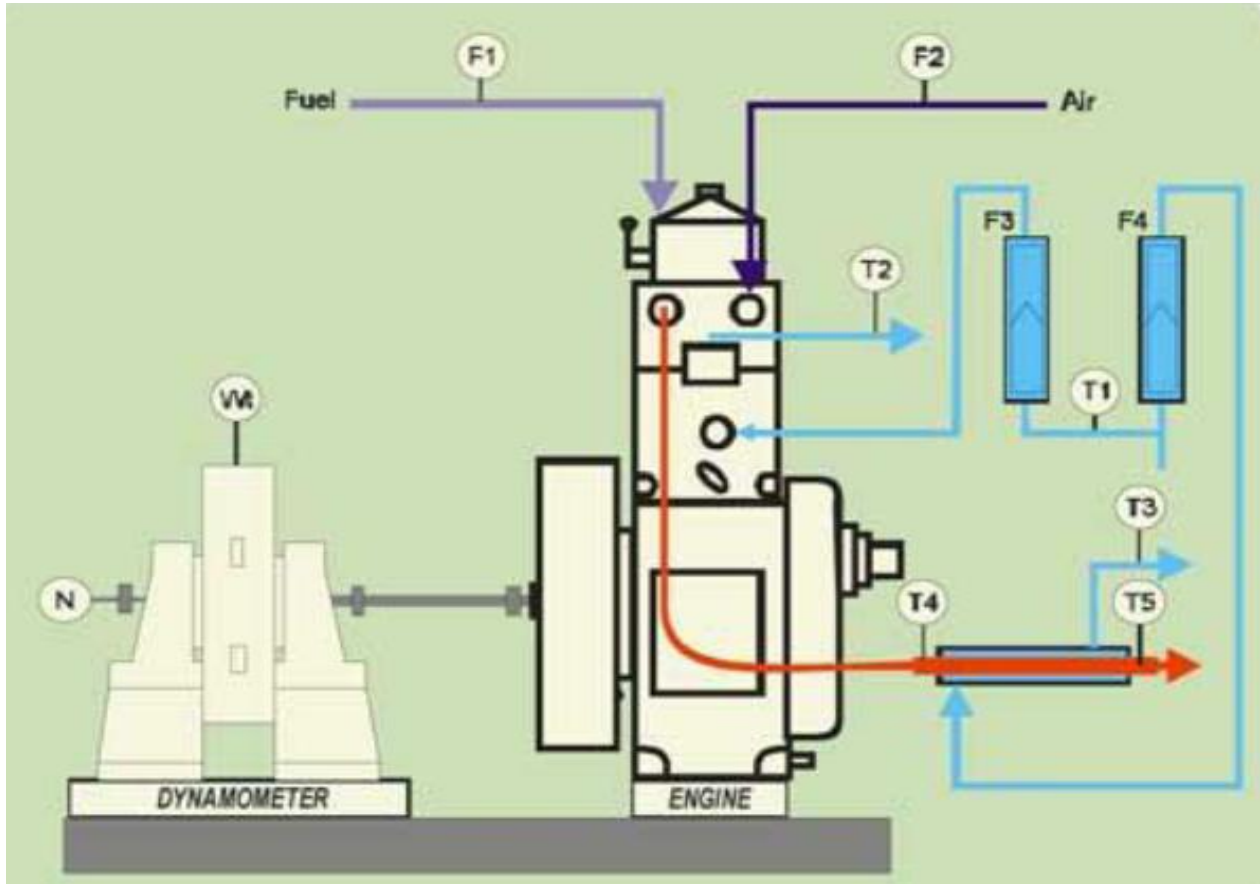


Plate 3.8: Flow line diagram variable compression ratio compression ignition engine setup

T1	Inlet temperature of water into engine jacket and calorimeter
T2	Outlet temperature of water from the engine jacket
T3	Outlet temperature of water from the calorimeter
T4	Inlet temperature of exhaust gases into the calorimeter
T5	Outlet temperature of exhaust gases from the calorimeter
N	Non-contact type speed sensor (Engine shaft speed)
W	Load sensor (Eddy current dynamometer)
F1	Fuel supply to engine cylinder
F2	Air flow to engine cylinder
F3	Water flow to the engine jacket
F4	Water flow to calorimeter

Table 3.3: Detailed specification of engine setup

Components	Specification
Product	VCR Engine test setup 1 cylinder, 4 stroke, Diesel (Computerized)
Product Code	234
Engine	Make Kirloskar, Type 1 cylinder, 4 stroke Diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5, Modified to VCR engine CR range 12 to 18
Dynamometer	Type eddy current, water cooled, with loading unit
Propeller Shaft	With universal joints
Air Box	M S fabricated with orifice meter and manometer
Fuel Tank	Capacity 15 lit with glass fuel metering column
Calorimeter	Type Pipe in pipe
Piezo Sensor	Range 5000 PSI, with low noise cable
Crank Angle Sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
Data Acquisition Device	NI USB-6210, 16-bit, 250kS/s.
Piezo Powering Unit	Make-Cuadra, Model AX-409.
Digital Millivoltmeter	Range 0-200mV, panel mounted
Temperature Sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature Transmitter	Type two wire, Input RTD PT100, Range 0–100 Deg C, Output 4–20 mA and Type two wire, Input Thermocouple, Range 0–1200 Deg C, Output 4–20 mA
Load Indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load Sensor	Load cell, type strain gauge, range 0-50 Kg
Fuel Flow Transmitter	DP transmitter, Range 0-500 mm WC
Air Flow Transmitter	Pressure transmitter, Range (-) 250 mm WC
Software	“EnginesoftLV” Engine performance analysis software
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Pump	Type Monoblock

Overall Dimensions	W 2000 x D 2500 x H 1500 mm
Optional	Computerized Diesel injection pressure measurement

A tilting cylinder block arrangement was used for varying the compression ratio without stopping the engine. Setup was provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through, engine indicator for P –V diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters were provided for cooling water and calorimeter water flow measurement. Lab view based Engine Performance Analysis software package "Enginesoft" was provided for on line performance evaluation.

3.4.1.2 Operation

3.4.1.2.1 Experimental procedure

For getting the base line data of the engine first the experimentation was performed with diesel and then with blends of 20% jatropha biodiesel and 80% diesel fuel (JB20); 20% palm biodiesel and 80% diesel fuel (PB20); and 10% jatropha biodiesel, 10% palm biodiesel and 80% diesel fuel (JPB20).

1. Fill the diesel in fuel tank.
2. Initially adjust the compression ratio of the engine to a ratio of 12:1.
3. Start the water supply. Set cooling water flow for engine at 300 LPH and calorimeter flow at 70 LPH.
4. Also ensure adequate water flow rate for dynamometer cooling and piezo sensor cooling.
5. Check for all electrical connections. Start electric supply to the computer through the UPS.
6. Open the lab view based engine performance analysis software package "Enginesoft" for on screen performance evaluation.
7. Supply the diesel to the engine by opening the valve provided at the burette.
8. Set the value of calorific value and specific gravity of the fuel through configure option in the software.

9. Select run option of the software. Start the engine and let it run for few minutes under no load condition.
10. Choose log option of the software. Turn on the fuel supply knob. After 1 minute, the display changes to input mode then enter the values of water flows in cooling jacket and calorimeter and then the file name (applicable only for the first reading) in the software. The first reading for the engine gets logged for the no load condition. Turn the fuel knob back to regular position.
11. Repeat the experiment for different load.
12. All the readings will be displayed on the monitor.
13. Save the readings for particular compression ratio.
14. Change the compression ratio by adjusting the screw arrangement.
15. Repeat the whole experiment for different compression ratio.
16. Save the readings for each compression ratio.
17. Similarly change the fuel in the fuel tank and the fuel calorific value and specific gravity in the software.
18. Repeat the experiment for particular fuel at different compression ratio.
19. At the end of the experiment bring the engine to no load condition and turn off the engine and computer so as to stop the experiment.
20. After few minutes also turn off the water supply.

3.4.1.3 Performance characteristics

The blends were fuel in C. I. engine to read the performance characteristics. The single cylinder, four stroke, VCR (variable compression engine) diesel engine connected to eddy current type dynamometer for loading. The following four engine performances were determined:

- i. Brake power (BP)
- ii. Brake specific fuel consumption (BSFC)
- iii. Brake thermal efficiency (BTE)
- iv. Exhaust gas temperature (EGT)

3.4.2 Exhaust emission evaluation

3.4.2.1 Emission characteristics

Emission characteristic were estimate with the aid of FGA (Flue Gas Analyzer) and HA (Horiba Analyzer). The following emission characteristics were analyzed:

- i. Carbon monoxide (CO)
- ii. Nitrogen oxides (NO_x)
- iii. Unburned hydrocarbon (HC)

Table 3.4: Exhaust emission parameters

Parameters	Test method
Hydro Carbon as HC (ppm)	Horiba Analyzer
Carbon monoxide as CO (ppm)	Flue Gas Analyzer (KM19106)
Carbon dioxide as CO ₂ (%)	Flue Gas Analyzer (KM19106)
Nitrogen oxides as NO (ppm)	Flue Gas Analyzer (KM19106)
Nitrogen oxides as NO ₂ (ppm)	Flue Gas Analyzer (KM19106)
Nitrogen oxides as NO _x (ppm)	Flue Gas Analyzer (KM19106)



Plate 3.9: Horiba Analyzer



Plate 3.10: Flue Gas Analyzer

3.4.2.2 Operation

3.4.2.2.1 Experimental procedure

1. At particular load condition insert the sensors into the provided outlet for exhaust gases to escape into the environment.
2. Exhaust gases pass through these sensors to the respective analyzer attached with it.
3. After entering into the analyzer the readings were displayed on the digital screen.
4. After 2-3 minutes when the values were stabilized 3 readings are noted down.
5. Mean value of the three readings was evaluated.
6. Sensors were removed for the values on the analyzers to settle down again to zero value.
7. Repeat the above procedure for different fuel and load condition respectively

3.5 Comparative analysis

After the study and analysis of different blends of biodiesel, the one with optimum performance characteristics such as brake power (BP), Brake specific fuel consumption (BSFC), brake mean effective pressure (BMEP), brake thermal efficiency (BTE) and optimum emission characteristics such as carbon monoxide (CO), nitrogen oxides (NO_x), unburned hydrocarbon, was to be chosen and suggest the best blend of biodiesel with petrodiesel.

4. RESULT AND DISCUSSION

The biodiesel was largely produced by methyl transesterification of edible and non-edible oils. The studies were therefore conducted on blends of non-edible biodiesel Jatropha and edible biodiesel palm to compare the properties of these with the petro diesel. The fuel properties such as kinematic viscosity, calorific value flash and fire point, ash content and carbon content of Jatropha, palm oil and diesel were compared.

A 5.2 kW stationary constant speed single cylinder 4 stroke diesel engine having a standard injection timing of 23° BTDC was tested on diesel and blends of Jatropha and palm. The brake thermal efficiency, fuel consumption, brake specific fuel consumption, exhaust gas temperature and emission of carbon monoxide, carbon dioxide, oxygen level, and oxides of nitrogen were measured. The results of parameters measured and their interpretation with discussion are presented in this chapter.

4.1 Fuel characterization

4.1.1. Relative density

The relative density at 15⁰C of diesel, Jatropha biodiesel and Palm biodiesel are shown in Table 4.1. The relative density of diesel used in the experiments was found to be 0.839. The relative density of Jatropha biodiesel and Palm biodiesel were found to be 0.877 and 0.864 respectively. The relative density of Jatropha biodiesel and Palm biodiesel were found to be 4.529 and 2.979 percent higher than that of diesel respectively.

The results obtained during the experiments indicate that the relative density of biodiesel was almost closer to that of diesel.

Table 4.1: Relative Density at 15⁰C

S. No.	Fuel Types	Relative Density	Percent higher than Diesel (%)
1	Diesel	0.839	-
2	Jatropha biodiesel	0.877	4.529
3	Palm Biodiesel	0.864	2.979

4.1.2. Kinematic Viscosity

Table 4.2 shows the kinematic viscosity of diesel, Jatropha biodiesel and Palm biodiesel at 38⁰C. The kinematic viscosity of diesel was found to be 3.12 cS. The kinematic viscosity of diesel at 38⁰C may range between 2.0 to 7.5 cS (IS: 1460-1974).

The Jatropha biodiesel had the kinematic viscosity of 3.45 cS at 38⁰C. Palm biodiesel was found to have kinematic viscosity 4.41 cS at 38⁰C. The kinematic viscosity of Jatropha biodiesel and Palm biodiesel were found to be 10.577 and 41.346 percent higher than that of diesel respectively. However, the Jatropha biodiesel and Palm biodiesel possess kinematic viscosity within the range specified for diesel by the Bureau of Indian Standards (IS: 1460-1974).

Table 4.2: Kinematic Viscosity at 38⁰C

S. No.	Fuel Types	Kinematic Viscosity (cS)	Percent higher than Diesel (%)
1.	Diesel	3.12	-
2.	Jatropha biodiesel	3.45	10.577
3.	Palm Biodiesel	4.41	41.346

4.1.3. Cloud Point and Pour Point

The cloud and pour point of diesel, Palm oil and biodiesel are shown in Table 4.3. The table indicates that the cloud and pour point of diesel used for the experiment was 2.6 °C and -2.0 °C respectively. The Jatropha biodiesel had the cloud and pour point as 4 °C and 0 °C respectively. The cloud point of Palm biodiesel was observed as -6 °C and the pour point -12 °C respectively.

Table 4.3: Cloud Point and Pour Point

S. No.	Fuel Types	Cloud Point (°C)	Pour Point (°C)
1.	Diesel	2.6	-2.0
2.	Jatropha biodiesel	4	0
3.	Palm Biodiesel	-6	-12

4.1.4. Flash Points and Fire Point

The flash and fire point of diesel, Palm oil and biodiesel are shown in Table 4.4. The flash and fire point of diesel used for the experiment was observed as 54.3 °C and 59.4 °C respectively. The flash and fire point of Jatropha biodiesel was found to be 160 °C and 165 °C respectively. The table also reveals that Palm biodiesel have flash point 181 °C and fire point 186 °C.

Table 4.4: Flash Points and Fire Point

S. No.	Fuel Types	Flash Point (°C)	Fire Point (°C)
1.	Diesel	54.3	59.4
2.	Jatropha biodiesel	160	165
3.	Palm Biodiesel	181	186

4.1.5. Carbon Residue Content

The observed carbon residue content of diesel, Jatropha biodiesel and Palm biodiesel are shown in Table 4.5. The carbon residue content in diesel was found to be 0.16 percent. The maximum recommended carbon residue level in diesel fuel as per IS: 1460-1974 is 0.2 percent. The Carbon Residue Content of Jatropha biodiesel and Palm biodiesel were found to be 0.03 and 0.07 respectively. The Carbon Residue Content of Jatropha biodiesel and Palm biodiesel were found to be 81.25 and 56.25 percent less than that of diesel respectively.

Table 4.5: Carbon Residue Content

S. No.	Fuel Types	Carbon Residue Content (%)	Percent higher than Diesel (%)
1.	Diesel	0.16	-
2.	Jatropha biodiesel	0.03	-81.25
3.	Palm Biodiesel	0.07	-56.25

4.1.6. Ash Content

Table 4.6: Ash Content

S. No.	Fuel Types	Ash Content (%)	Percent higher than Diesel (%)
1.	Diesel	0.0080	-
2.	Jatropha biodiesel	0.0200	150
3.	Palm Biodiesel	0.0066	-17.5

Table 4.6 shows the observed ash content in diesel, Jatropha biodiesel and Palm biodiesel. The ash content in diesel was observed as 0.008 percent. The IS: 1460-1974 has recommended maximum ash content level of 0.01 percent in diesel fuel. The ash content of Jatropha biodiesel was found to be 0.020 percent which is 150.0 percent more than that of diesel. The ash content of Palm biodiesel is 0.0066 percent which is 17.5 percent less than that of diesel. The above results indicate that the biodiesel had the ash content within the recommended level.

4.2 Performance characterization

Effect of load on brake power for various fuel blends

Graph of the brake power (BP) as a function of load obtained during engine operation on different blends of biodiesel i.e. PB20, JB20 and JPB20 with diesel (D100) at compression ratio of 12:1, 14:1 and 16:1 have been shown in Figure 4.1 to 4.3.

Brake power of the engine increases with increase in the load on the engine. Brake power is the function of calorific value and the torque applied. Diesel has more calorific value than the biodiesel, so diesel has the highest brake power among the different blends of biodiesel. It can also be seen that as we increase the load, torque increases and thus there is an increase in brake power with the load.

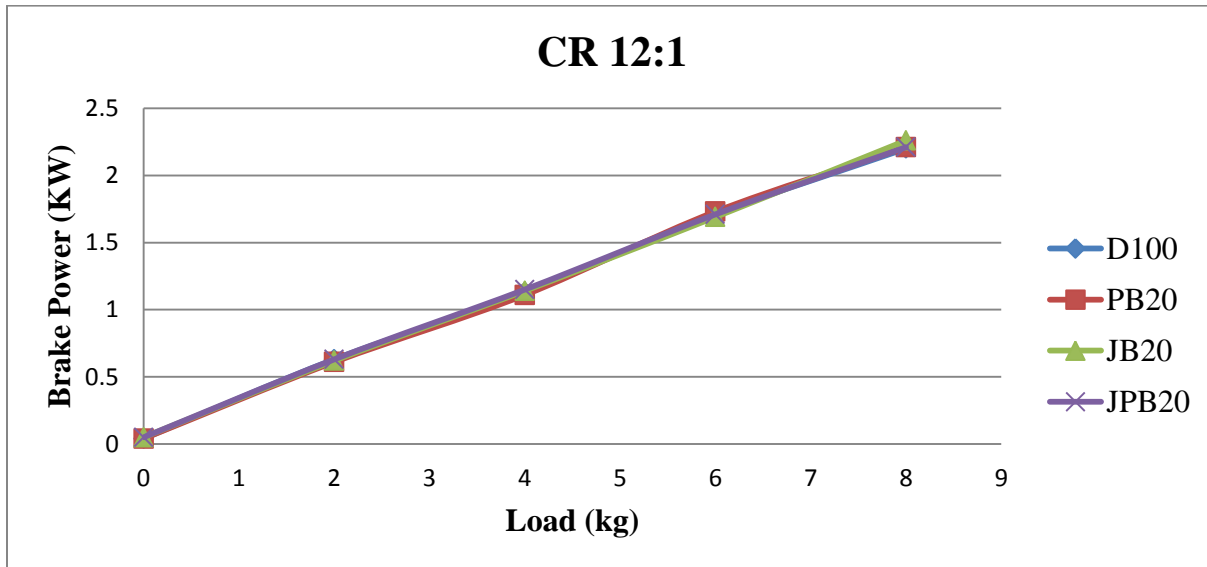


Figure 4.1: Variation of brake power with respect to load for 12 CR

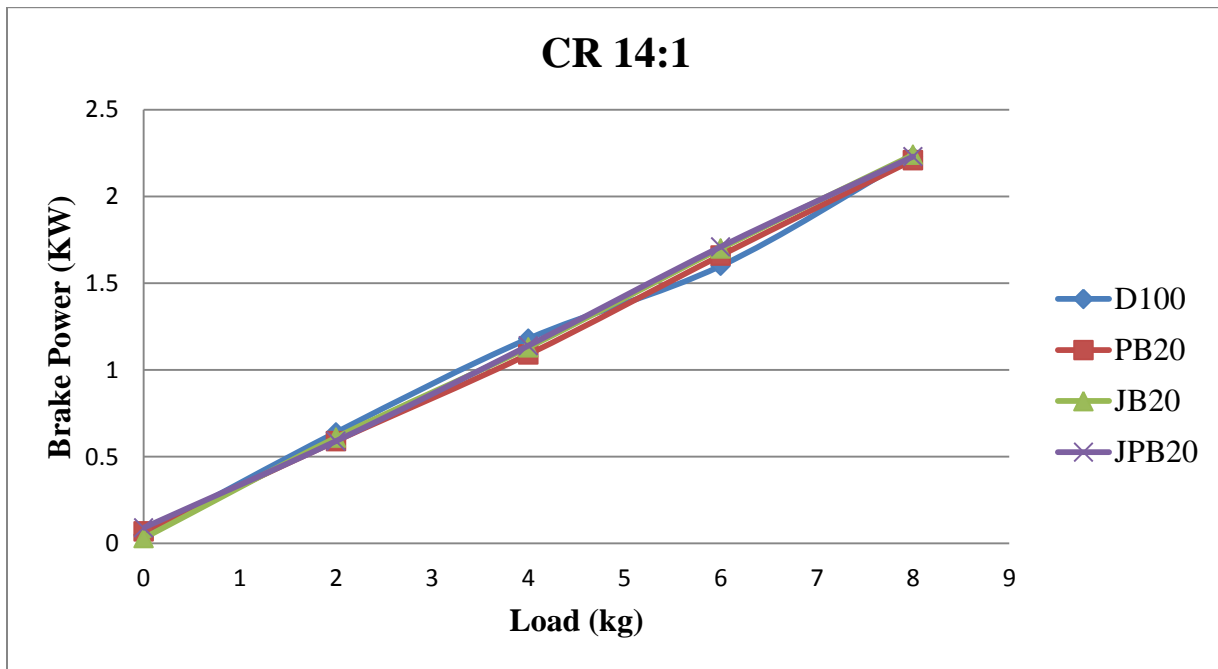


Figure 4.2: Variation of brake power with respect to load for 14 CR

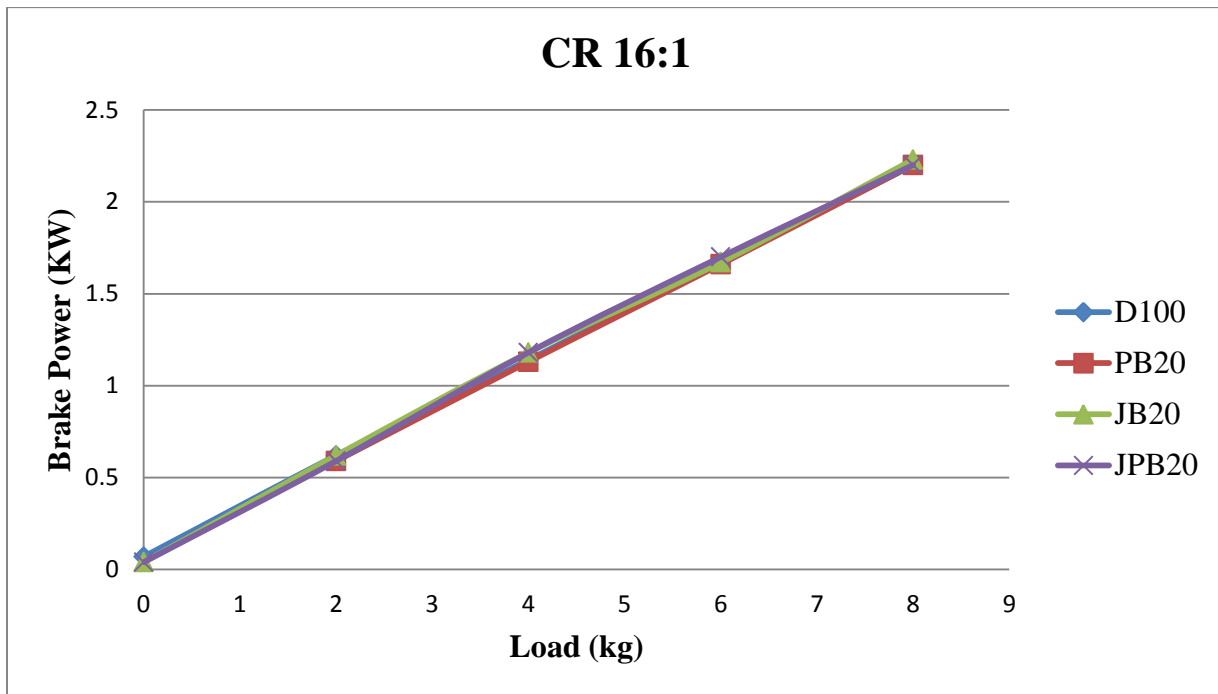


Figure 4.3: Variation of brake power with respect to load for 16 CR

Effect of load on brake thermal efficiency for various fuel blends

The variation of brake thermal efficiency with load of the engine for different fuel blends is shown in Figure 4.4 to 4.6. Brake thermal efficiency increase with increase in load on the engine. This may be due to reduction in heat loss and increase in power with increase in load. Maximum brake thermal efficiency of 25.15 % was obtained for JPB20 at full load condition for CR 12. For D100, PB20, JB20 and JPB20, it is respectively 24.02 %, 23.44 %, 24.04% and 25.15 % at full load for compression ratio of 12. For D100, PB20, JB20 and JPB20, it is respectively 22.81 %, 23.03 %, 23.13 % and 22.72 % at full load for compression ratio of 14. For D100, PB20, JB20 and JPB20, it is respectively 22.17 %, 21.71 %, 22.32 % and 23.01 % at full load for compression ratio of 16. Brake thermal efficiency increase with increase in percentage of ethyl ester in the fuel. Increase efficiency with increase in percentage of ethyl ester in the fuel might be due to increase fuel temperature as blends contain more oxygen. So, higher fuel temperature reduced its viscosity and might have reduced the ignition lag also, resulting in better combustion and hence increase efficiency.

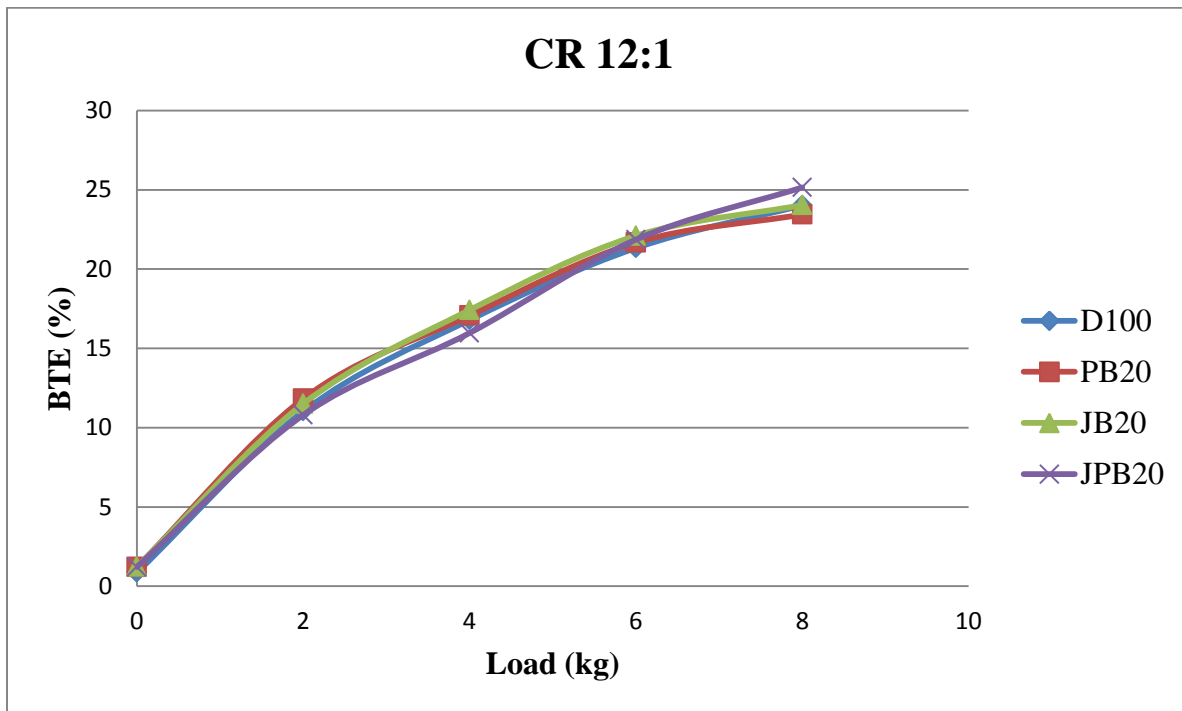


Figure 4.4: Variation of Brake thermal efficiency with respect to load for 12 CR

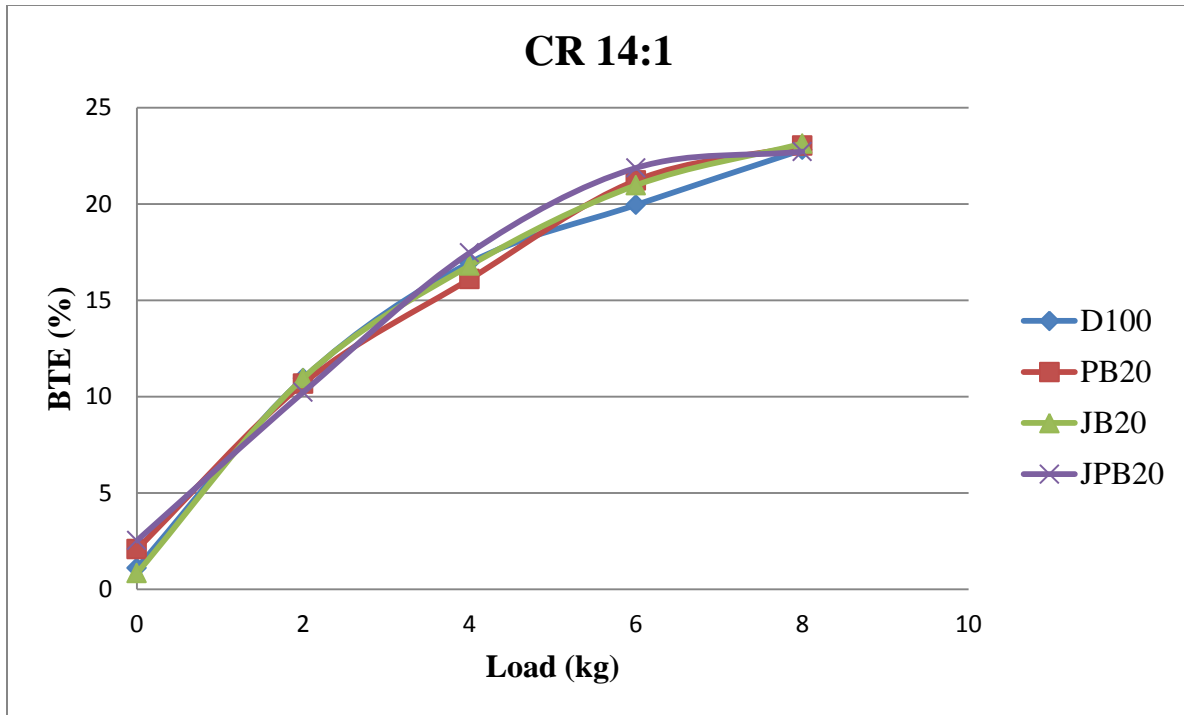


Figure 4.5: Variation of Brake thermal efficiency with respect to load for 14 CR

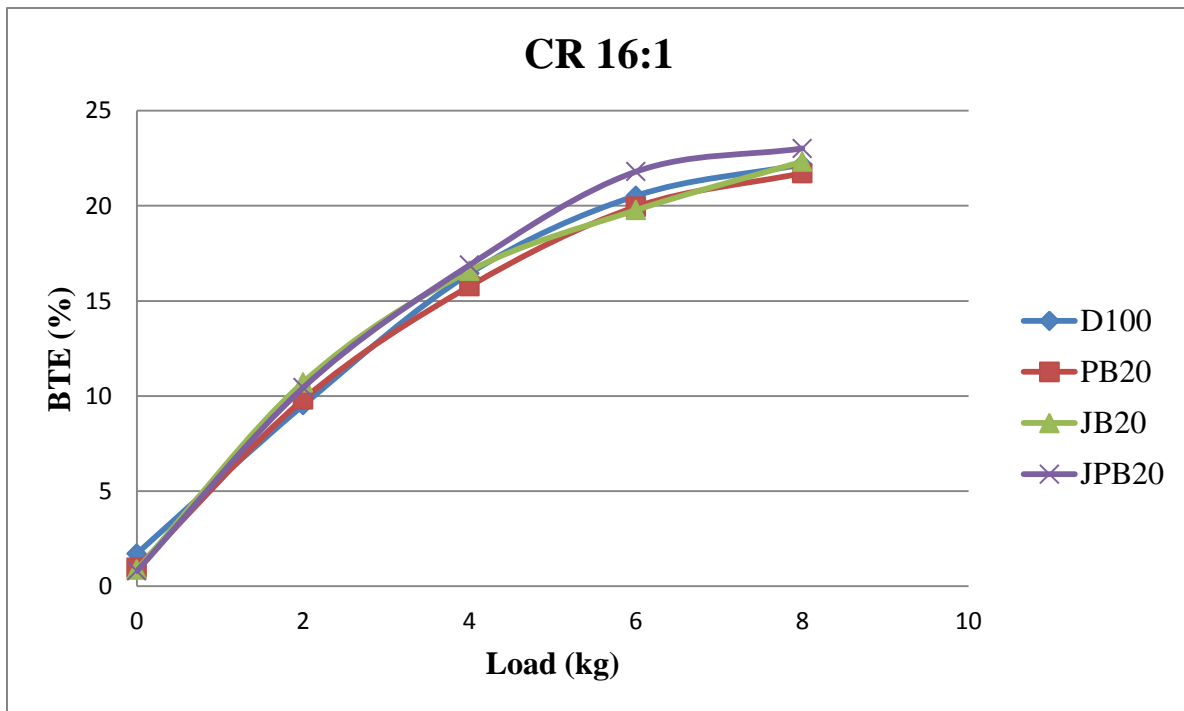


Figure 4.6: Variation of Brake thermal efficiency with respect to load for 16 CR

Effect of load on brake specific fuel consumption for various fuel blends

The variation of brake specific fuel consumption with load of the engine for different fuel blends is shown in Figure 4.7 to 4.9. Brake specific fuel consumption decrease with increase in load on the engine for all fuel blends. This reduction could be due to higher percentage of increase in brake power with load as compared to fuel consumption. Brake specific fuel consumption for D100, PB20, JB20 and JPB20 blends varied from 0.78 to 0.36, 0.72 to 0.37, 0.74 to 0.36 and 0.79 to 0.34 kg/kWh respectively as the load was increased from no load to full load for compression ratio of 12. Brake specific fuel consumption for D100, PB20, JB20 and JPB20 blends varied from 0.78 to 0.38, 0.80 to 0.37, 0.78 to 0.37 and 0.84 to 0.38 kg/kWh respectively as the load was increased from no load to full load for compression ratio of 14. Brake specific fuel consumption for D100, PB20, JB20 and JPB20 blends varied from 0.65 to 0.39, 0.87 to 0.39, 0.80 to 0.38 and 0.82 to 0.38 kg/kWh respectively as the load was increased from no load to full load for compression ratio of 16. The increase in brake specific fuel consumption with increase in concentration of blends in diesel fuel is attributed to lower heat values.

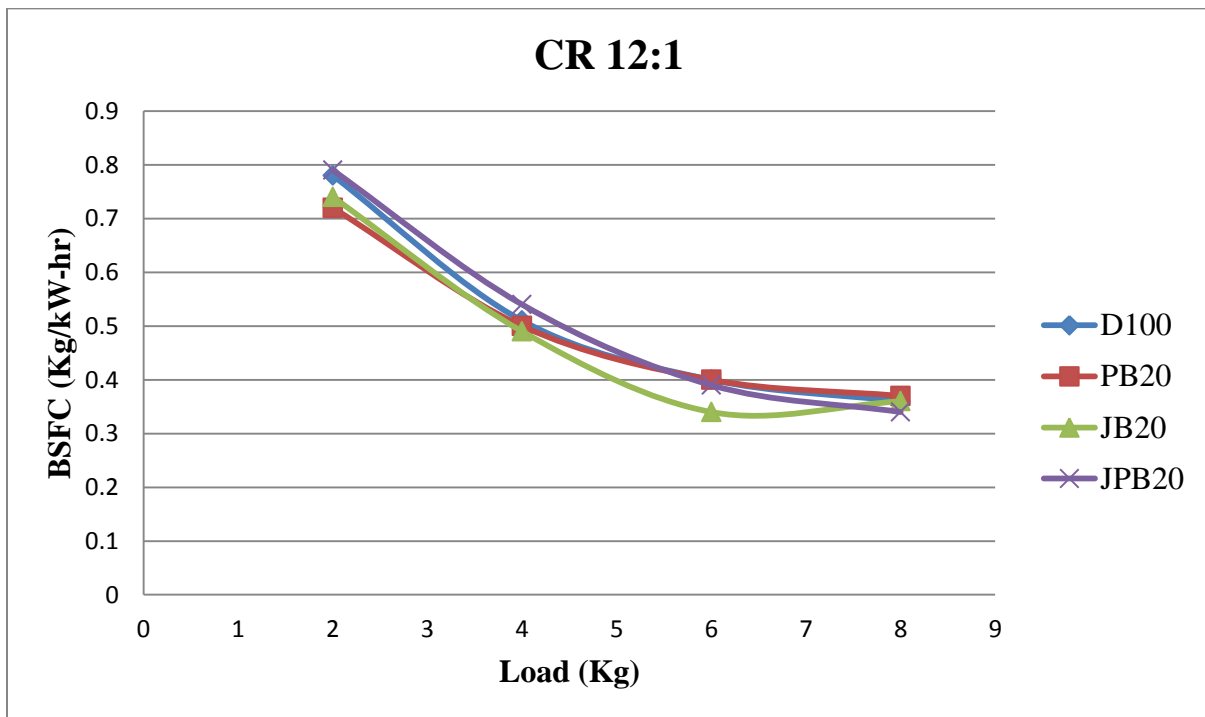


Figure 4.7: Variation of Brake specific fuel consumption with respect to load for 12 CR

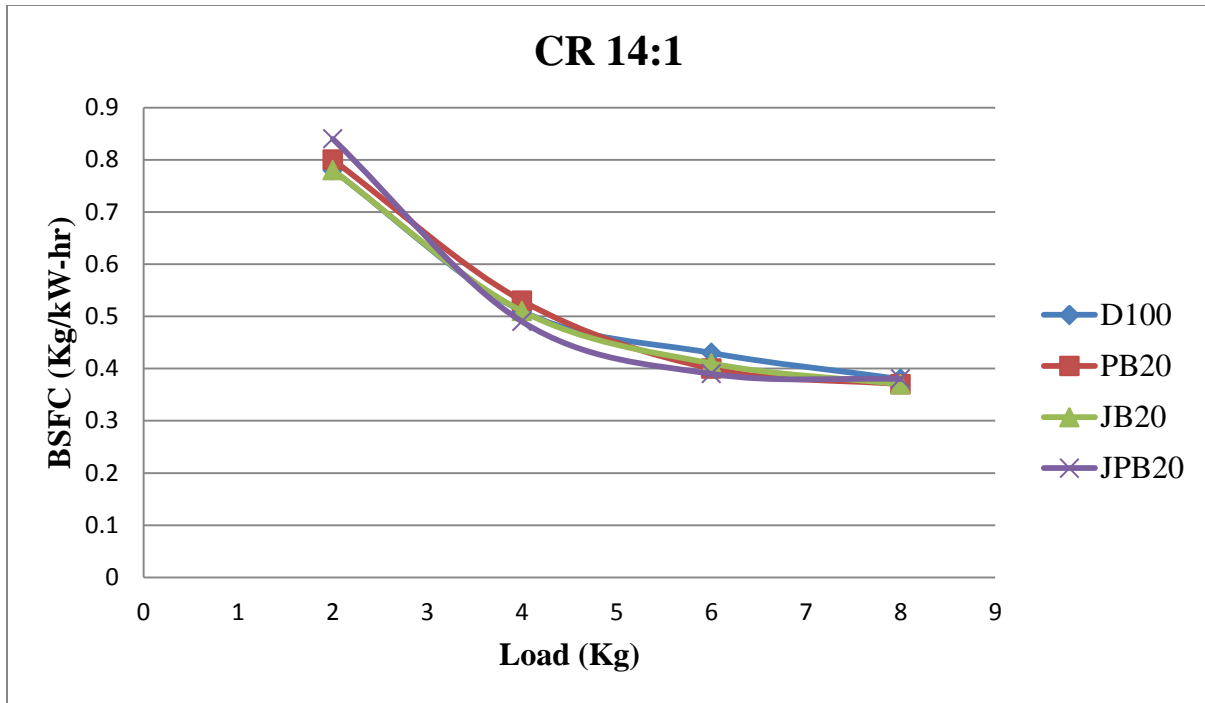


Figure 4.8: Variation of Brake specific fuel consumption with respect to load for 14 CR

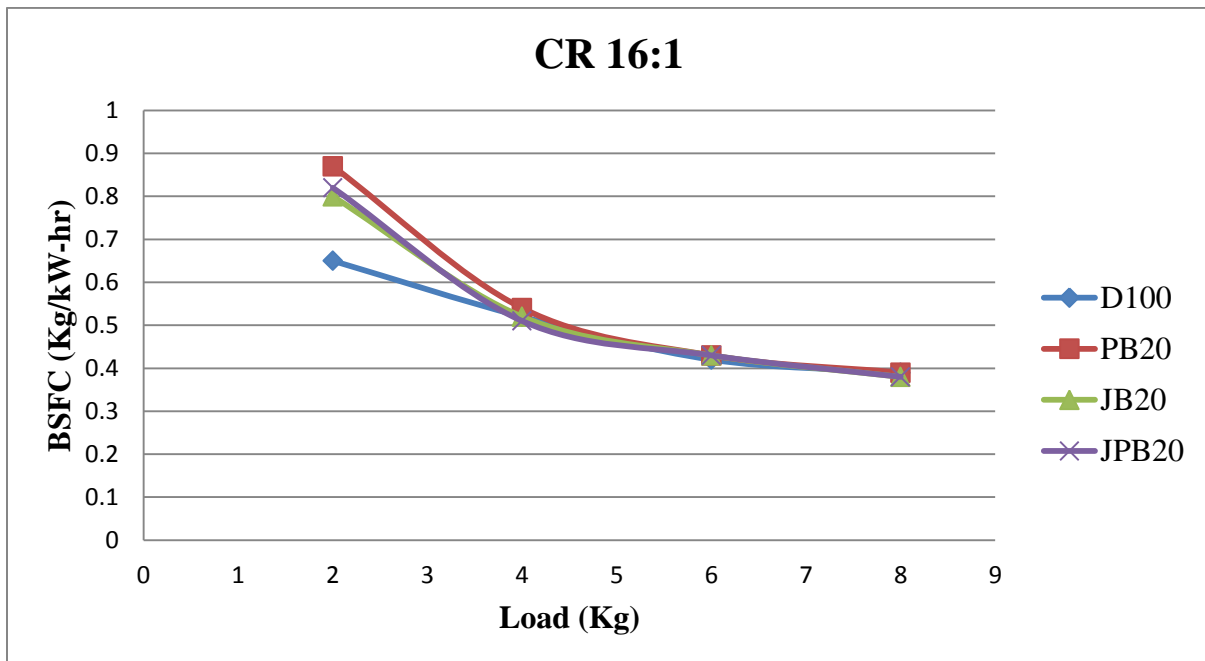


Figure 4.9: Variation of Brake specific fuel consumption with respect to load for 16 CR

Effect of load on exhaust gas temperature for various fuel blends

The variation of exhaust gas temperature with load of the engine for different fuel blends is shown in Figure 4.10 to 4.12. Exhaust gas temperature increased with increase in load on the engine. This may be attributed to increase in quantity of fuel injected with the increase in load. The increased quantity of fuel generated greater heat in combustion chamber. Exhaust gas temperature increased for all fuel types because of pressure rise in combustion chamber and an increase in fuel injection rate with increase in brake load. Secondly, this may be due to better utilization of heat released during combustion of fuels and increase in brake thermal efficiency on blended fuels.

The biodiesel contains some amount of oxygen molecules in the ester form. It is also taking part in combustion. When biodiesel concentration is increased, the exhaust gas temperature increases by small value. The exhaust gas temperature increases with increase in load. Diesel has the least exhaust gas temperature among the PB20, JB20 and JPB20. The reason of EGT being more in the case of biodiesel blends is the presence of more oxygen atoms in the biodiesel. So, the exhaust gas temperature increases and it increases with increase in load. As the load on the engine increases, more fuel is burnt. So exhaust gas temperature increases continuously with rise in load.

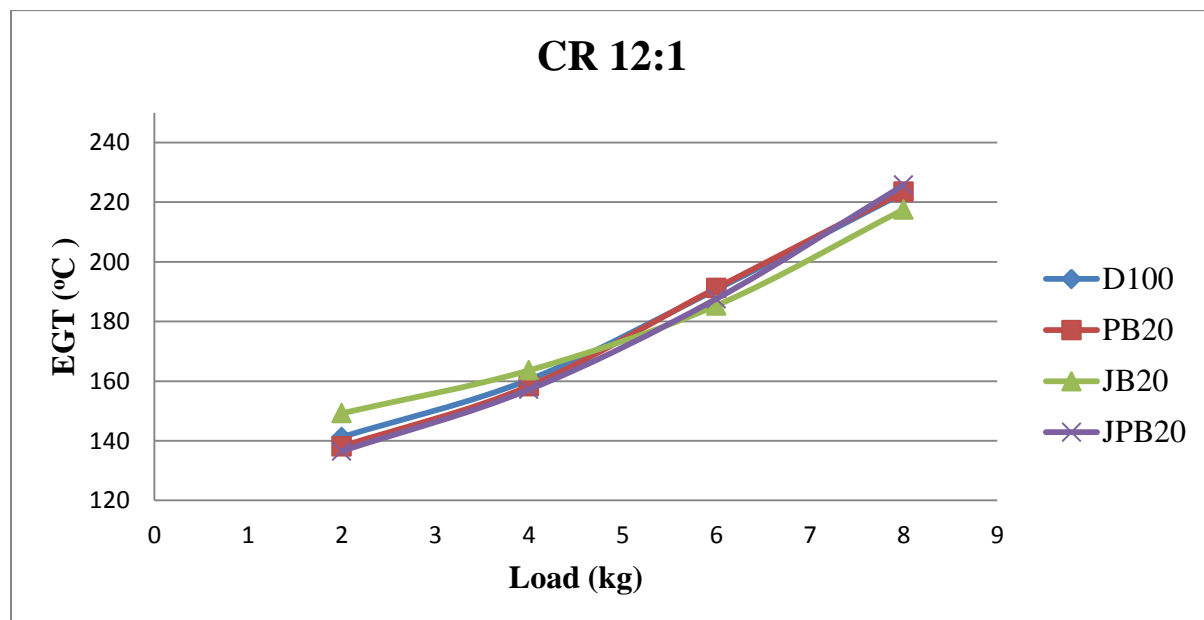


Figure 4.10: Variation of Exhaust gas temperature with respect to load for 12 CR

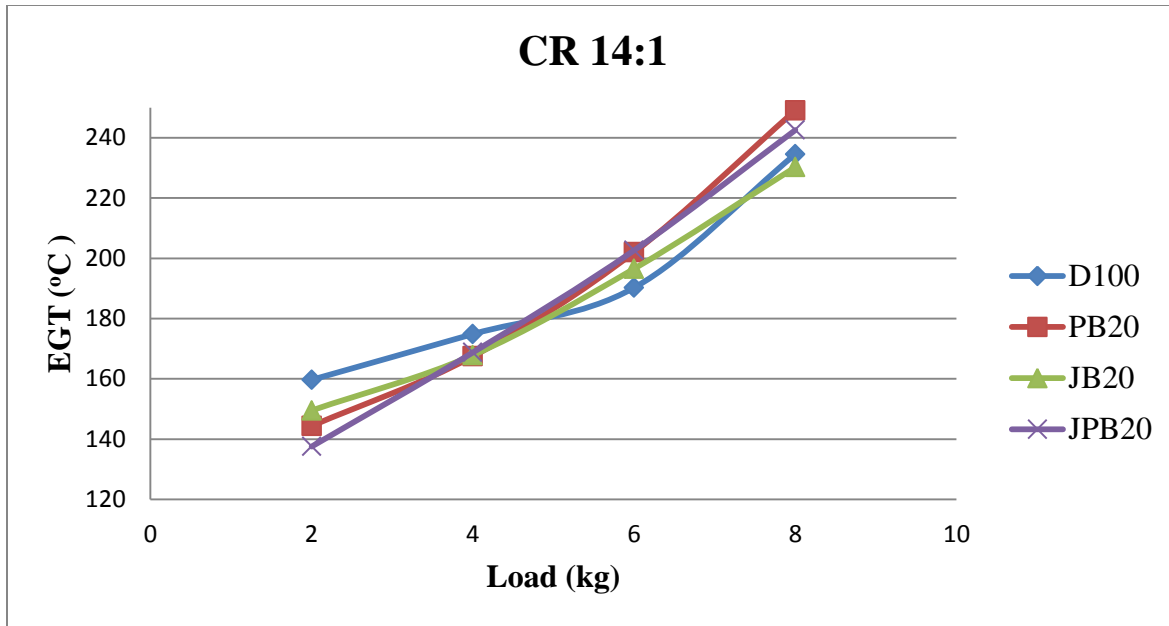


Figure 4.11: Variation of Exhaust gas temperature with respect to load for 14 CR

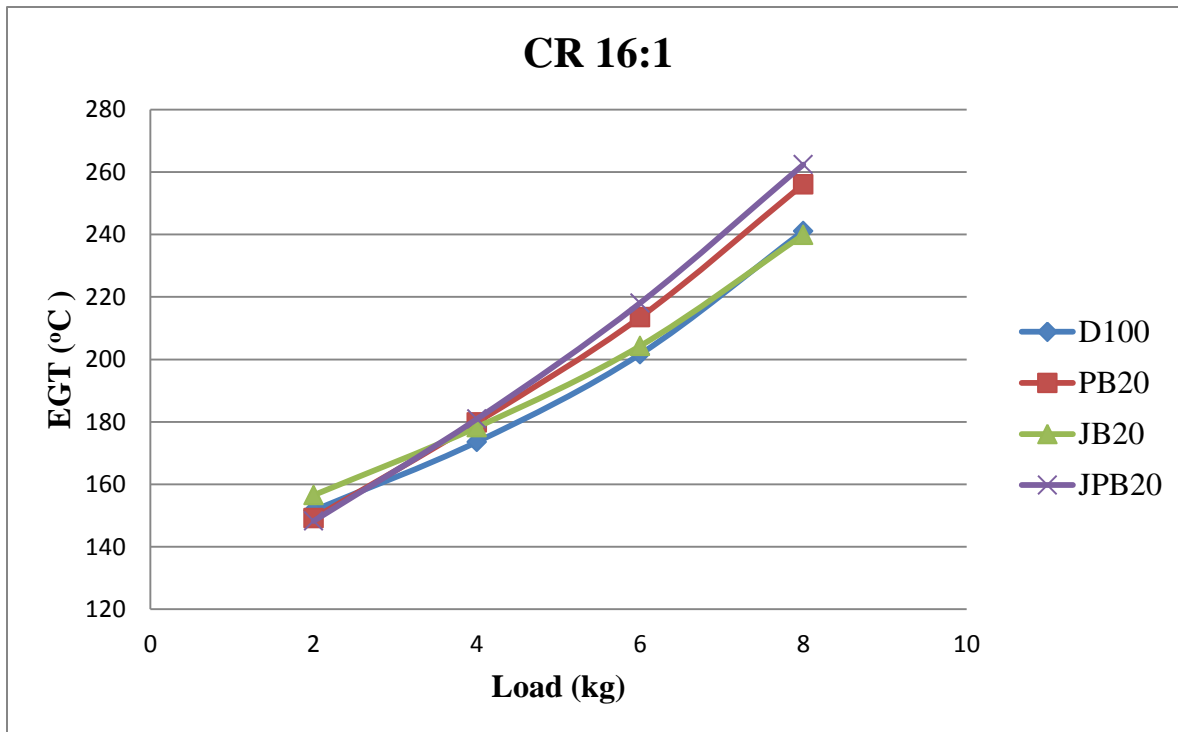


Figure 4.12: Variation of Exhaust gas temperature with respect to load for 16 CR

4.3 Exhaust emission characterization

Effect of load on hydrocarbon (HC) emission for various fuel blends

The variation of hydrocarbon with respect to load for different blends of biodiesel is shown in Figure 4.13 to 4.15. Hydrocarbon emission is mainly due to incomplete combustion. HC concentration in exhaust gas was 30, 20 and 10 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 10 ppm at 75% of rated load for compression ratio of 12. HC concentration in exhaust gas was 40, 30 and 10 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 30 ppm at 75% of rated load for compression ratio of 14. HC concentration in exhaust gas was 40, 40 and 20 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 40 ppm at 75% of rated load for compression ratio of 16.

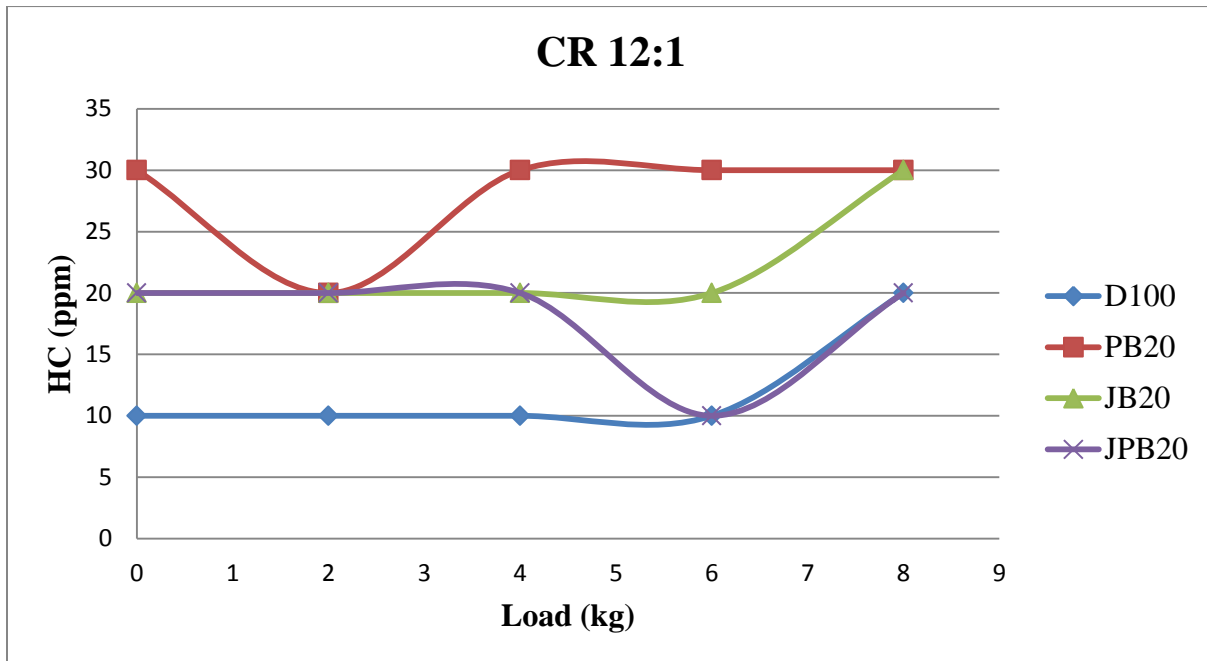


Figure 4.13: Variation of HC with respect to load for 12 CR

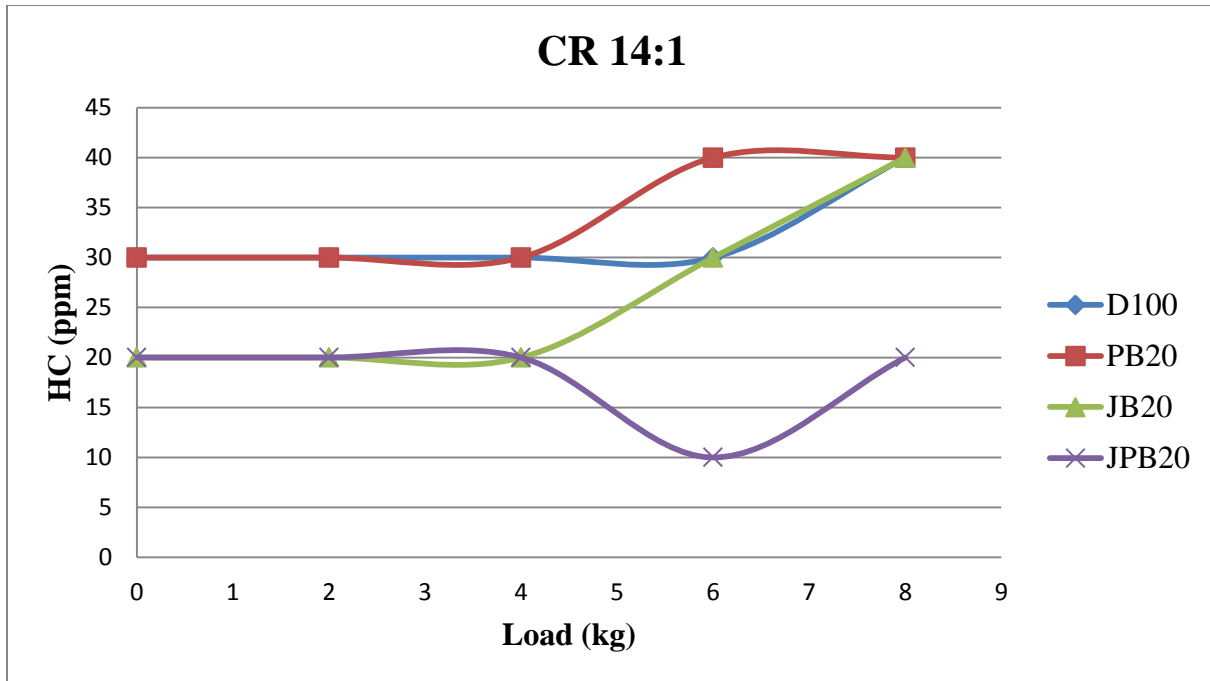


Figure 4.14: Variation of HC with respect to load for 14 CR

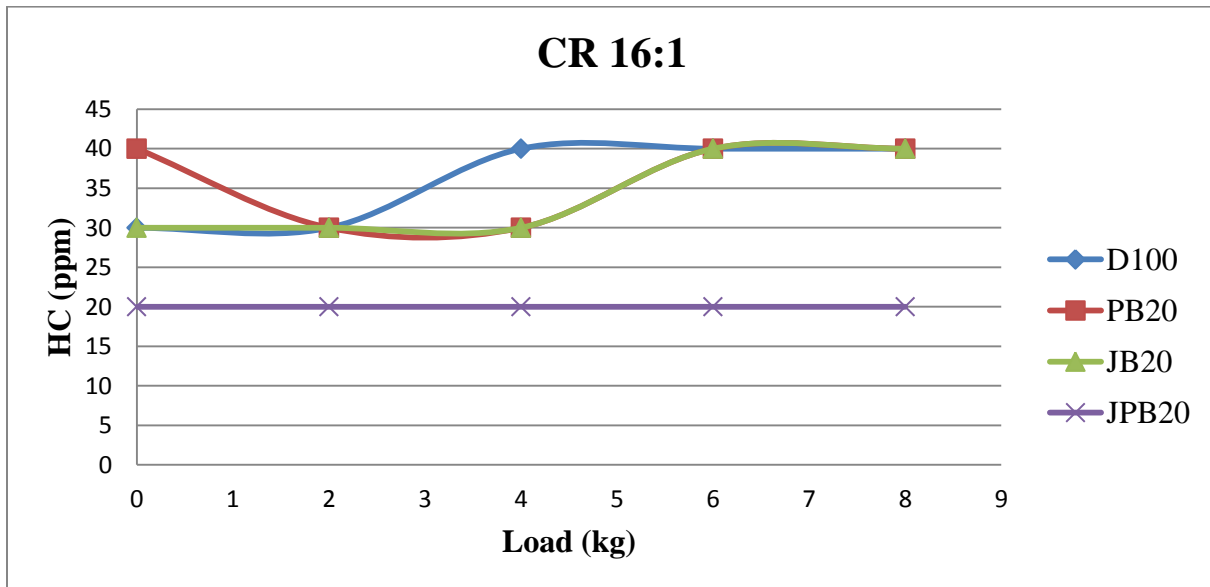


Figure 4.15: Variation of HC with respect to load for 16 CR

Effect of load on carbon monoxide (CO) emission for various fuel blends

The variation of Carbon monoxide (CO) emission with load of the engine for different fuel blends is shown in Figure 4.16 to 4.18. Carbon monoxide (CO) emission increased with increase in load on the engine. This may be due to the fact that as the load is increased, the fuel consumption is also proportionately increased and due to insufficient air in the combustion chamber there may be incomplete combustion of fuel and hence increased CO. It was also observed that Carbon monoxide (CO) emission decreased with increase in percentage of ester in the fuel. This reduced emission of Carbon monoxide (CO) may have resulted due to increase combustion efficiency which is reflected in terms of higher brake thermal efficiency because of presence of the oxygen molecules in blended fuels. CO concentration in exhaust gas was 460, 488 and 392 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 490 ppm at 75% of rated load for compression ratio of 12. CO concentration in exhaust gas was 606, 628 and 617 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 672 ppm at 75% of rated load for compression ratio of 14. CO concentration in exhaust gas was 753, 810 and 782 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 909 ppm at 75% of rated load for compression ratio of 16.

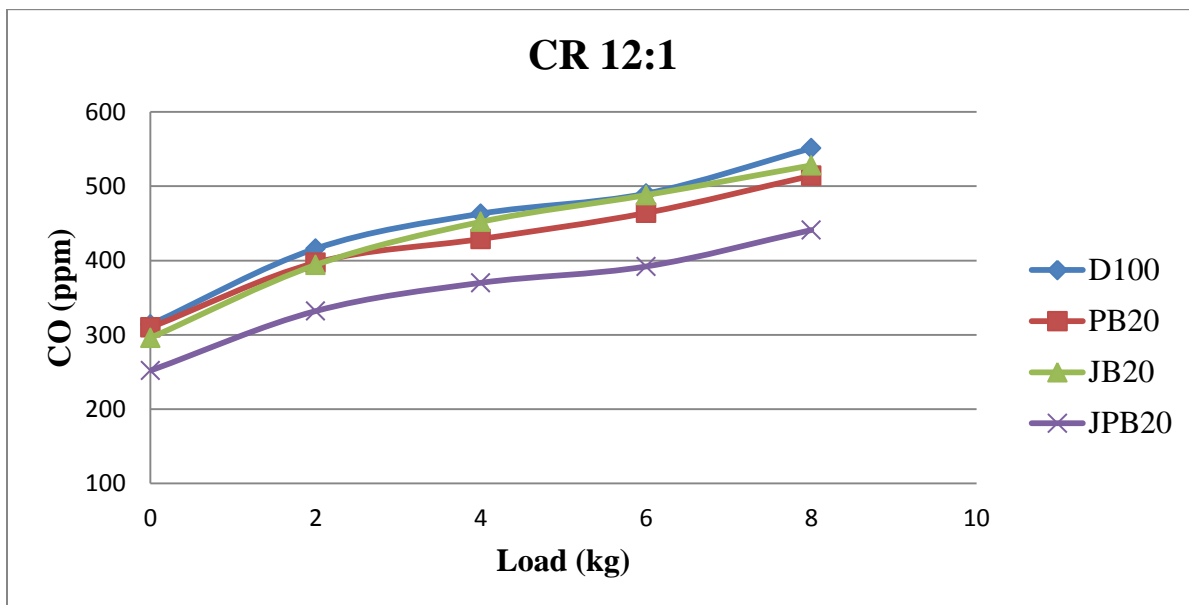


Figure 4.16: Variation of CO with respect to load for 12 CR

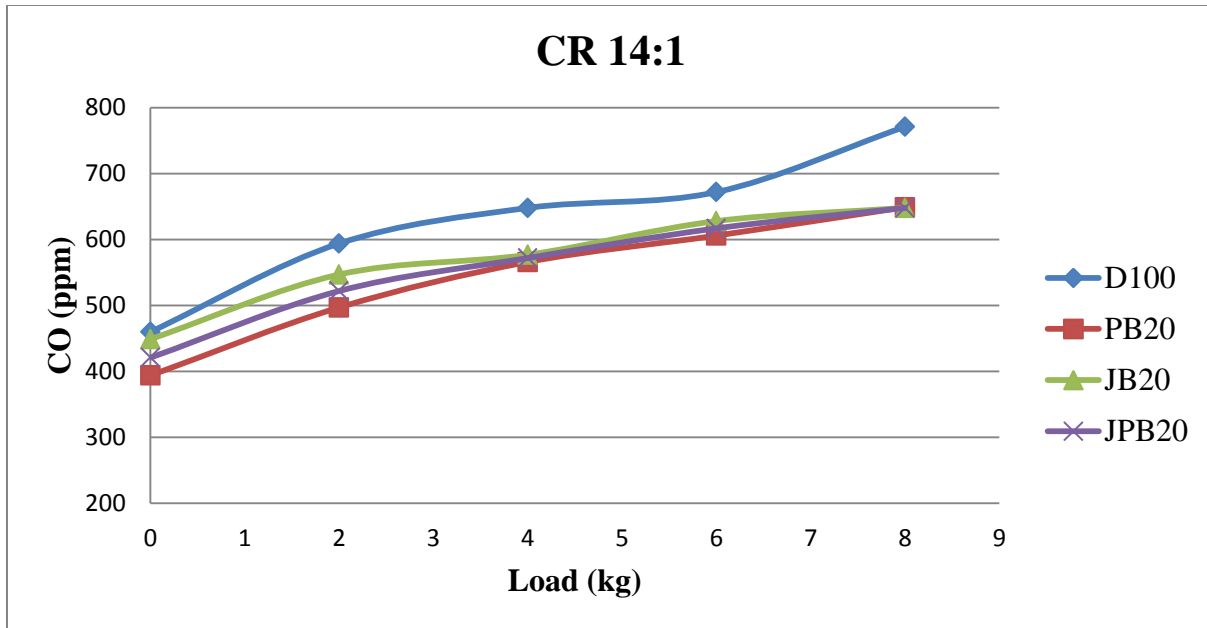


Figure 4.17: Variation of CO with respect to load for 14 CR

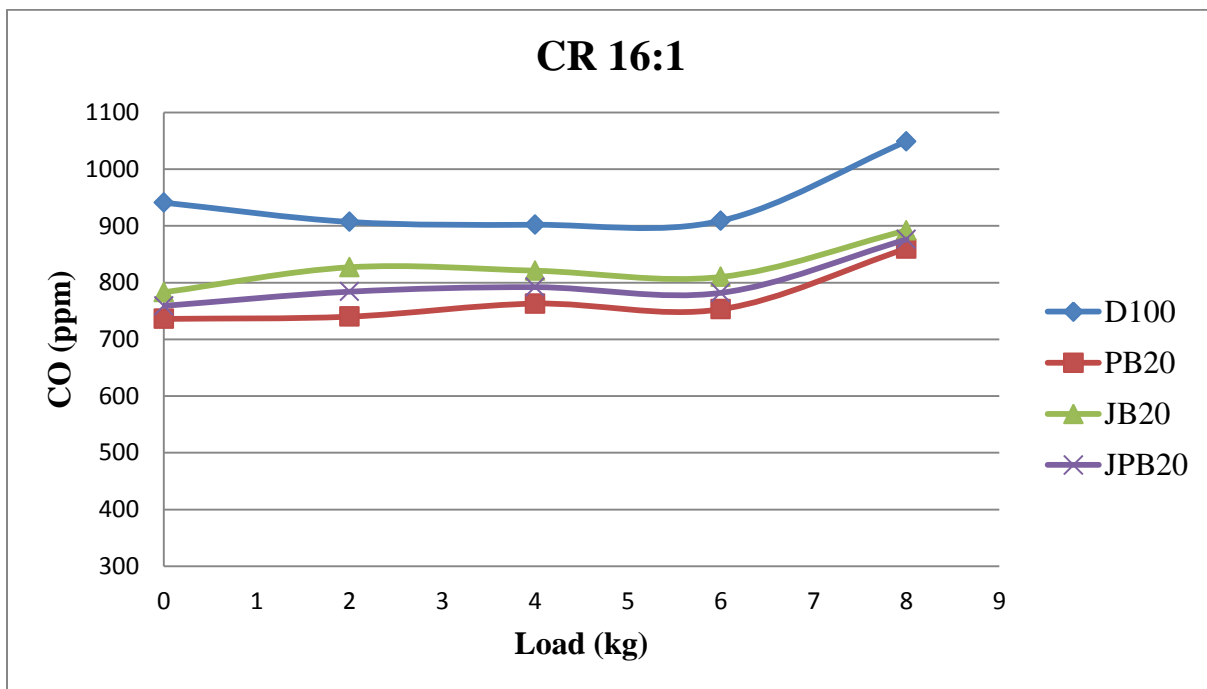


Figure 4.18: Variation of CO with respect to load for 16 CR

Effect of load on nitric oxide (NO_x) emission for various fuel blends

The variation of Nitric oxide (NO_x) emission with load of the engine for different fuel blends is shown in Figure 4.19 to 4.21. Nitric oxide (NO_x) emission increased with increase in load on the engine. It was also observed that there was gradual increase in the emission of Nitric oxide (NO_x) with increase in percentage of esters in the fuel. Nitric oxide (NO_x) formation was higher in ethyl ester blended fuels due to higher temperature during combustion phase and better access to oxygen. Another factor causing the increase in Nitric oxide (NO_x) could be the possibility of higher combustion temperature arising from improved combustion because larger part of the combustion is completed before TDC for ester blends compared to diesel due to their lower ignition delay. So it is higher peak cycle temperatures are reached for ester blends compared to diesel. NO_x concentration in exhaust gas was 289, 303 and 293 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 139 ppm at 75% of rated load for compression ratio of 12. NO_x concentration in exhaust gas was 265, 294 and 282 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 138 ppm at 75% of rated load for compression ratio of 14. NO_x concentration in exhaust gas was 252, 308 and 302 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 132 ppm at 75% of rated load for compression ratio of 16.

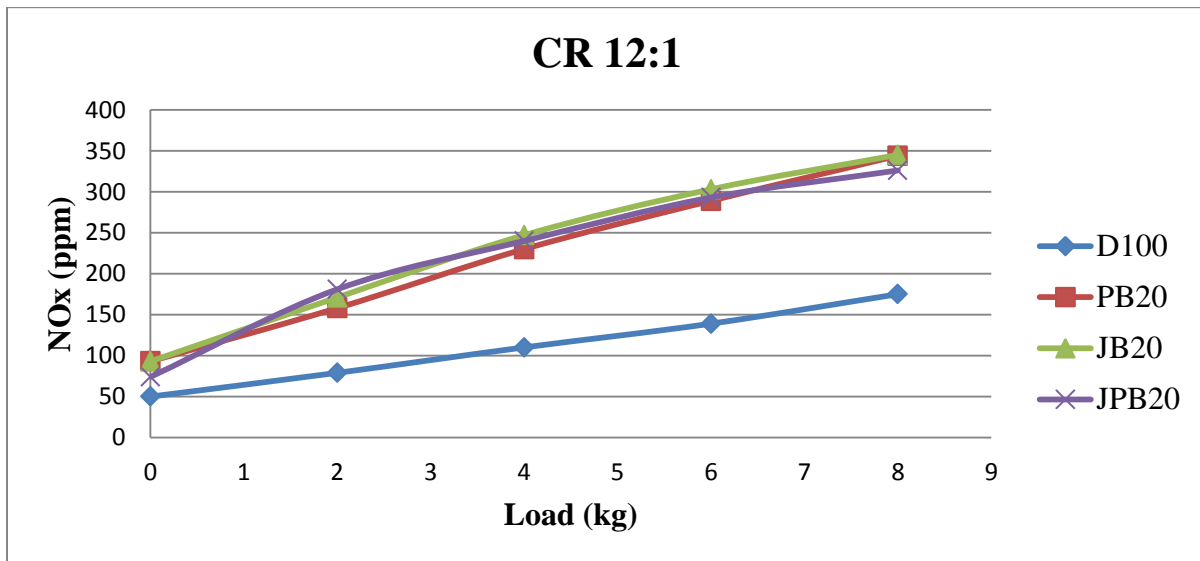


Figure 4.19: Variation of NO_x with respect to load for 12 CR

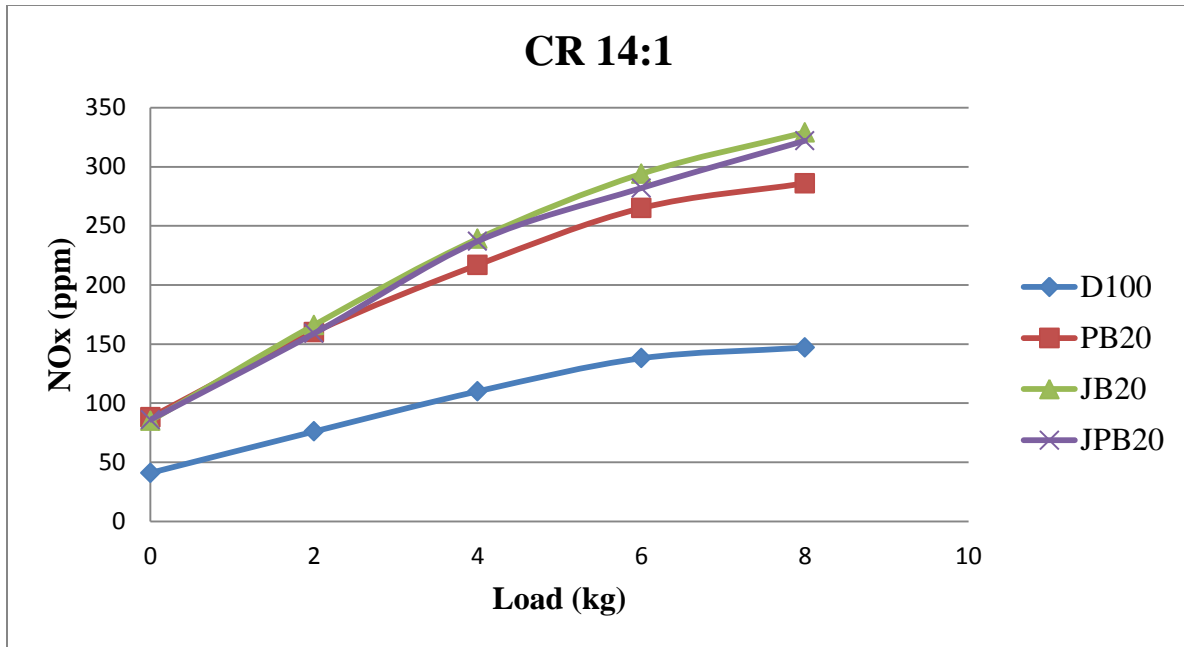


Figure 4.20: Variation of NO_x with respect to load for 14 CR

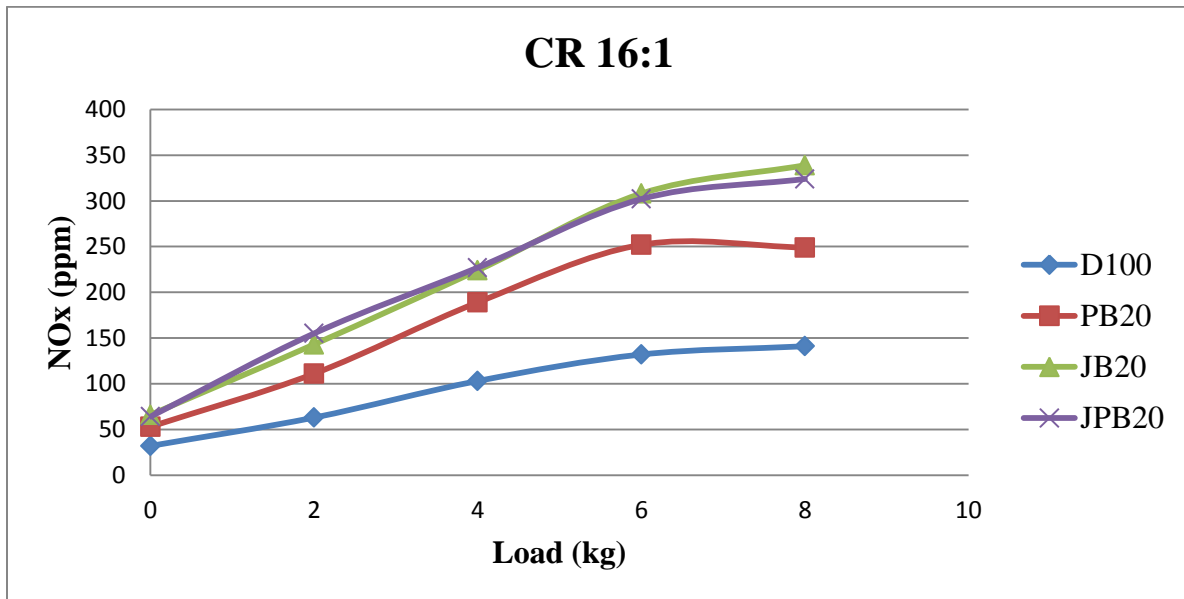


Figure 4.21: Variation of NO_x with respect to load for 16 CR

5. CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The production of biodiesel and fuel characterization was done in the present study. Jatropha oil and Palm oil was esterified with methyl alcohol to obtain Jatropha biodiesel and Palm biodiesel (methyl ester) having lowest possible kinematic viscosity. The characteristic fuel properties such as kinematic viscosity, relative density, gross heat of combustion, cloud and pour point, flash and fire point, carbon and ash content of diesel, Jatropha biodiesel and Palm biodiesel were compared. On the basis of the results obtained from the whole experiment the following conclusions were drawn:

- The relative density of Jatropha biodiesel and Palm biodiesel were found to be 0.877 and 0.864 respectively. The relative density of Jatropha biodiesel and Palm biodiesel were found to be 4.597 and 2.979 percent higher than that of diesel respectively.
- The Jatropha biodiesel had the kinematic viscosity of 3.45 cS at 38⁰C. Palm biodiesel was found to have kinematic viscosity 4.41 cS at 38⁰C. The kinematic viscosity of Jatropha biodiesel and Palm biodiesel were found to be 10.577 and 41.346 percent higher than that of diesel respectively.
- The Jatropha biodiesel had the cloud and pour point as 4 ⁰C and 0 ⁰C respectively. The cloud point of Palm biodiesel was observed as -6⁰C and the pour point -12⁰C respectively.
- The flash and fire point of Jatropha biodiesel was found to be 160⁰C and 165⁰C respectively. The table also reveals that Palm biodiesel have flash point 181⁰C and fire point 186⁰C.
- The Carbon Residue Content of Jatropha biodiesel and Palm biodiesel were found to be 0.03 and 0.07 respectively. The Carbon Residue Content of Jatropha biodiesel and Palm biodiesel were found to be 81.25 and 56.25 percent less than that of diesel respectively.

- The ash content of Jatropha biodiesel was found to be 0.020 percent which is 150.0 percent more than that of diesel. The ash content of Palm biodiesel is 0.0066 percent which is 17.5 percent less than that of diesel.
- Brake thermal efficiency increase with increase in load on the engine. Brake thermal efficiency increase with increase in percentage of ethyl ester in the fuel. Brake thermal efficiency of JPB20 were found to be 2.48%, 9.62% and 6.18% higher than that of D100 at 75% of rated load for compression ratio of 12, 14 and 16 respectively.
- Brake specific fuel consumption decrease with increase in load on the engine for all fuel blends. The increase in brake specific fuel consumption with increase in concentration of blends in diesel fuel is attributed to lower heat values. Brake specific fuel consumption of JPB20 were found to be 2.5% and 9.30% lower than that of D100 at 75% of rated load for compression ratio of 12 and 14 respectively. But for compression ratio of 16 Brake specific fuel consumption of JPB20 were found to be 2.38% higher than that of D100 at 75% of rated load.
- The EGT was higher for JPB20 compared to that of D100 at full load.
- Nitric oxide (NO_x) emission increased with increase in load on the engine. It was also observed that there was gradual increase in the emission of Nitric oxide (NO_x) with increase in percentage of esters in the fuel. The Nitric oxide (NO_x) emission was higher for JPB20 compared to that of D100 at full load.
- Carbon monoxide (CO) emission increased with increase in load on the engine. It was also observed that Carbon monoxide (CO) emission decreased with increase in percentage of ester in the fuel. Carbon monoxide (CO) emission of JPB20 were found to be 20%, 8.18% and 13.97% lower than that of D100 at 75% of rated load for compression ratio of 12, 14 and 16 respectively.

5.2 Future scope

Worldwide energy demands are increasing day-by-day. Major part of it is contributed by fossil fuels. Petroleum diesel being cheaper in cost has attracted the minds of people to use it as fuel in diesel engine which has increased the number of diesel fuelled vehicles. For a petroleum

importing country like India it is a major concern. Due to this rapidly increasing demand of petroleum diesel biodiesel as an alternative fuel comes into consideration. Selection of inexpensive and available feedstock for biodiesel production within the country is the major concern. Crude rice bran oil is relatively an inexpensive and available raw material for biodiesel production as India is the second largest producer of rice in the world.

- Further studies can be carried out for making proper use of the by-products from Jatropha oil and Palm oil and prepared biodiesel.
- Study on the long term stability of the studied biodiesel blends in cars, tractors, trucks etc. should be done.
- Further investigation can be carried out for the production of ester of Jatropha oil and Palm oil from different alcoholic groups to conduct various engine tests.
- Further investigation can be done on the long term storage and utilization of product from biodiesels.
- Performance and emission studies may be done on multi cylinder, variable speed engine.

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