# COMPARATIVE STUDY OF NON EDIBLE BIO DIESEL FUEL

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

Of

**Master of Engineering**

In

**THERMAL ENGINEERING**

Submitted By

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# CERTIFICATE

I hereby declare that the seminar report entitled "**COMPARATIVE STUDY OF NON EDIBLE BIO DIESEL FUEL**" submitted by me , in the partial fulfillment of the requirement for award of degree of Master of Engineering Mechanical (Thermal Engineering) to Thapar University, Patiala is a record of my own work carried out under supervision and guidance of Professor S.K. Mohapatra. This report has not been submitted in any other University or Institute for the award of any degree.

Dated: 10.07.2013

Place: Patiala

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

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# ABSTRACT

Biodiesel derived from nonedible feed stocks such as Jatropha, neem and hemp are reported to be feasible choices for many countries including India. The main advantages of using this alternative fuel are its renewability, biodegradability and lesser exhaust emission. It is environmentally friendly alternative to conventional petro diesel fuel for use in existing CI engines. The use of biodiesel reduces the demand of importing fossil fuels which have become costlier day by day. The non-edible Jatropha oils for biodiesel production widely used, because the properties of Jatropha biodiesel favorably with the characteristics required for CI fuel. The experimental work presented in this thesis is divided into three main parts. In the first part the properties of the three biodiesel (Jatropha, neem and hemp) are evaluated and compared with the petro diesel. The calorific values are lesser than the petro diesel fuel. In the second part the evaluating the engine performance of non-edible oil at various compression ratio and find the optimum compression ratio, which is to be find 17.5:1. An experimental investigation has been carried out to evaluate the performance and emission characteristics of a diesel engine fuelled with Jatropha, neem and hemp biodiesel and their blends (10%, 15% and 20%). The performance parameters analyzed include thermal efficiency, brake specific fuel consumption and exhaust gas temperature whereas exhaust emission include oxides of nitrogen, HC, $CO_2$ and CO. The experimental results are comparing with each other and also with baseline data of diesel fuel. The objective of the present study was to find the effect of different fuel and their blends on the performance and emission of CI engine. The study also shows the comparative study of different fuel with diesel.

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| | |
|---|---|
| BP | Brake Power |
| IP | Indicated Power |
| BMEP | Brake Mean Effective Pressure |
| BTHE | Brake Thermal Efficiency |
| EGT | Exhaust Gas Temperature |
| BSFC | Brake Specific Fuel Consumption |
| NOx | Oxides of Nitrogen |
| HC | Hydrocarbon |
| $CO_2$ | Carbon Dioxide |
| CO | Carbon Monoxide |
| ASTM | American Society of Testing and Petroleum |
| ISO | International standard organization |
| EU | European Union |
| $H2SO_4$ | Sulphuric Acid |
| NaOH | Sodium Hydroxide |
| KOH | Potassium Hydroxide |
| DI | Direct Injection |
| CI | Compression Ignition |
| FFA | Free Fatty Acids |
| Vol | Volume |
| wt. | Weight |
| ppm | Parts per million |
| kcal/kg | Kilo Calorie per Kilogram |
| kW | Kilowatt |
| PH | Pre-heat |
| EGR | Exhaust gas regulator |
| JB | Blend of jatropha biodiesel |
| NB | Blend of neem biodiesel |
| HB | Blend of hemp biodiesel |

# CHAPTER 1
# INTRODUCTION

## 1 INTRODUCTION

Fuel represent a combustible substance which, once raised to ignition temperature, continues to burn without any external support provided a sufficient quantity of oxygen is available for combustion wood, coal, kerosene, petrol, diesel, producer gas, oil gas etc. are some of the fuels.

## 1.1 FUELS

Fuel is a substance which, when burnt, on coming in contact and reacting with oxygen or air, produces heat. Thus, the substances classified as fuel must necessarily contain one or several of the combustible elements i.e. carbon, hydrogen, sulphur, etc. In the process of combustion, the chemical energy of fuel is converted into heat energy. To utilize the energy of fuel in most usable form, it is required to transform the fuel from its one state to another. In this way, the energy of fuels can be utilized more effectively and efficiently for various purposes. Fuels may broadly be classified in two ways as per the following.

(a) According to the physical state in which they exist in nature i.e. solid, liquid and gaseous.

(b) According to the mode of their procurement i.e. natural and manufactured.

**Table 1.1: Natural and Manufactured Fuels**

| | **Solid Fuels** | **Liquid Fuels** | **Gaseous Fuels** |
|---|---|---|---|
| **Natural Fuels** | Wood<br>Coal<br>Oil shale | Petroleum | Natural gas |
| **Manufactured Fuels** | Tanbark,<br>Bagasse, Straw<br>Charcoal<br>Coke<br>Briquettes | Oils from distillation of petroleum<br>Coal tar<br>Shale-oil<br>Alcohols, etc. | Coal gas<br>Producer gas<br>Water gas<br>Hydrogen<br>Acetylene<br>Blast furnace gas<br>Oil gas |

### 1.1.1 SOLID FUELS

**Coal:** Its main constituents are carbon, hydrogen; oxygen, nitrogen, sulphur, moisture and ash. Coal passes through different stages during its formation from vegetation. The stages are enumerated and discussed below:

**Peat.** It is the first stage in the formation of coal from wood. It contains huge amount of moisture and therefore it is dried for about 1 to 2 months before it is put to use. It is used as a domestic fuel in Europe and for power generation in Russia. In India it does not come in the categories of good fuels.

**Lignites and brown coals.** These are intermediate stages between peat and coal. They have a woody or often clay like appearance associated with high moisture, high ash and low heat contents. Lignites are usually amorphous in character and impose transport difficulties as they break easily. They burn with a smoky flame. Some of this type are suitable for local use only.

**Bituminous coal**. It burns with long yellow and smoky flames and has high percentages of volatile matter. The average calorific value of bituminous coal is about 31350 kJ/kg. It may be of two types, namely caking or non-caking.

**Semi-bituminous coal.** It is softer than the anthracite. It bums with a very small amount of smoke. It contains 15 to 20 per cent volatile matter and has a tendency to break into small sizes during storage transportation.

**Semi-anthracite.** It has less fixed carbon and less lusture as compared to true anthracite and gives out longer and more luminous flames when burnt.

**Anthracite.** It is very hard coal and has a shining black lusture. It ignites slowly unless the furnace temperature is high. It is noncaking and has high percentage of fixed carbon. It burns either with very short blue flames or without flames. The calorific value of this fuel is high to the tune of 35500 kJ/kg and as such is very suitable for steam generation.

**Wood charcoal.** It is obtained by destructive distillation of wood. During the process the volatile matter and water are expelled. The physical properties of the residue (charcoal) however depends upon the rate of heating and temperature.

**Coke.** It consists of carbon, mineral matter with about 2% sulphur and small quantities of hydrogen, nitrogen and phosphorus. It is solid residue left after the destructive distillation of certain kinds of coals. It is smokeless and clear fuel and can be produced by several processes. It is mainly used in blast furnace to produce heat and at the same time to reduce the iron ore.

**Briquettes.** These are prepared from fine coal or coke by compressing the material under high pressure.

### 1.1.2 LIQUID FUELS

The chief source of liquid fuels is petroleum which is obtained from wells under the earth's crust. These fuels have proved more advantageous in comparison to sold fuels. The liquid fuels can be classified as following.

a) Natural or crude oil.
a) Artificial or manufactured oils.

#### 1.1.2.1 NATURAL LIQUID FUEL

Petroleum is the natural liquid fuel. There are different opinions regarding the origin of petroleum. However, now it is accepted that petroleum has originated probably from organic matter like fish and plant life etc., by bacteria1 action or by their distillation under pressure and heat. It consists of a mixture of gases, liquids and solid hydrocarbons with small amounts of nitrogen and sulphur compounds. In India the main sources of petroleum are Assam and Gujarat.

Heavy fuel oil or crude oil is imported and then refined at different refineries. The refining of crude oil supplies the most important product called petrol. Petrol can also be made by polymerization of refinery gases.

Other liquid fuels are kerosene, fuels oils, colloidal fuels and alcohol.

- **The advantage of liquid fuels**

a) They possess higher calorific value per unit mass than solid fuels.
b) They burn without dust, ash, clinkers, etc.
c) Their firing is easier and also fire can be extinguished easily by stopping liquid fuel supply.

d) They are easy to transport through pipes.

e) They can be stored indefinitely without any loss.

f) They are clean in use and economic to handle.

g) Loss of heat in chimney is very low due to greater cleanliness.

h) They require less excess air for complete combustion.

i) They require less furnace space for combustion.

- **Disadvantages of liquid fuels**

a) The cost of liquid fuel is relatively much higher as compared to solid fuel.

b) Costly special storage tanks are required for storing liquid fuels.

c) There is a greater risk of fire hazards, particularly, in case of highly inflammable and volatile liquid fuels.

d) For efficient burning of liquid fuels, specially constructed burners and spraying apparatus are required.

#### 1.1.2.1.1 The Various Properties of Liquid Fuels

Petroleum is a basic natural fuel. It is a dark greenish brown, viscous mineral oil, found deep in earth's crust. It is mainly composed of various hydrocarbons (like straight chain paraffins, cycloparaffins or napthenes, olefins, and aromatics) together with small amount of organic compounds containing oxygen nitrogen and sulphur. The average composition of crude petroleum is: C = 79.5 to 87.1%; H = 11.5 to 14.8%; S = 0.1 to 3.5%, N and O = 0.1 to 0.5%.

**(a) Density**

Density is defined as the ratio of the mass of the fuel to the volume of the fuel at a reference temperature of 15°C. Density is measured by an instrument called a hydrometer. Its unit of density is $kg/m^3$.

**(b) Specific gravity**

This is defined as the ratio of the weight of a given volume of oil to the weight of the same volume of water at a given temperature. The density of fuel, relative to water, is called specific gravity. The specific gravity of water is defined as 1. Since specific gravity is a ratio, it has no units. The measurement of specific gravity is generally made by a hydrometer. Specific gravity is used in calculations involving weights and volumes. The specific gravity of various fuel oils is given in Table below.

**Table 1.2: Specific gravity of various fuel oils**

| Fuel Oil | Light Diesel Oil | Furnace Oil | Low Sulphur Heavy Stock |
|---|---|---|---|
| Specific Gravity | 0.85 - 0.87 | 0.89 - 0.95 | 0.88 - 0.98 |

### (c) Viscosity

The viscosity of a fluid is a measure of its internal resistance to flow. Viscosity depends on the temperature and decreases as the temperature increases. Any numerical value for viscosity has no meaning unless the temperature is also specified. Viscosity is measured in Stokes / Centistokes. Sometimes viscosity is also quoted in Engler, Saybolt or Redwood. Each type of oil has its own temperature - viscosity relationship. The measurement of viscosity is made with an instrument called a Viscometer. Viscosity is the most important characteristic in the storage and use of fuel oil. It influences the degree of pre- heating required for handling, storage and satisfactory atomization. If the oil is too viscous, it may become difficult to pump, hard to light the burner, and difficult to handle. Poor atomization may result in the formation of carbon deposits on the burner tips or on the walls. Therefore pre-heating is necessary for proper atomization.

### (d) Flash Point

The flash point of a fuel is the lowest temperature at which the fuel can be heated so that the vapour gives off flashes momentarily when an open flame is passed over it. The flash point for furnace oil is $66^0$C.

### (e) Pour Point

The pour point of a fuel is the lowest temperature at which it will pour or flow when cooled under prescribed conditions. It is a very rough indication of the lowest temperature at which fuel oil is ready to be pumped.

### (f) Specific Heat

Specific heat is the amount of kcals needed to raise the temperature of 1 kg of oil by $1^0$C. The unit of specific heat is kcal/kg$^0$C. It varies from 0.22 to 0.28 depending on the oil specific gravity. The specific heat determines how much energy it takes to heat oil to a desired temperature. Light oils have a low specific heat, whereas heavier oils have a higher specific heat.

### (g) Calorific Value

The calorific value is the measurement of heat or energy produced, and is measured either as gross calorific value or net calorific value. The difference is determined by the latent heat of condensation of the water vapour produced during the combustion process. Gross calorific value (GCV) assumes all vapour produced during the combustion process is fully condensed. Net calorific value (NCV) assumes the water leaves with the combustion products without fully being condensed. Fuels should be compared based on the net calorific value. The typical GCVs of some of the commonly used liquid fuels are given below.

**Table 1.3: Gross calorific values for different fuel oils**

| Fuel Oil | Gross Calorific Value (kCal/kg) |
|---|---|
| Kerosene | 11,100 |
| Diesel Oil | 10,800 |
| Light Diesel Oil | 10,700 |
| Furnace Oil | 10,500 |
| Low Sulphur Heavy Stock | 10,600 |

### (h) Sulphur Contents

The amount of sulphur in the fuel oil depends mainly on the source of the crude oil and to a lesser extent on the refining process. The normal sulfur content for the residual fuel oil (furnace oil) is in the order of 2 - 4 %. Typical figures for different fuel oils are shown in Table 3

**Table 1.4: Percentages of sulphur contents for different fuel**

| Fuel oil | Percentage of Sulphur contents |
|---|---|
| Kerosene | 0.05 - 0.2 |
| Diesel Oil | 0.05 - 0.25 |
| Light Diesel Oil | 0.5 - 1.8 |
| Furnace Oil | 2.0 - 4.0 |

| | |
|---|---|
| Low Sulphur Heavy Stock | < 0.5 |

The main disadvantage of sulphur is the risk of corrosion by sulphuric acid formed during and after combustion, and condensation in cool parts of the exhaust pipe line and air pre-heater and economizer.

### (i) Ash Content

The ash value is related to the inorganic material or salts in the fuel oil. The ash levels in distillate fuels are negligible. Residual fuels have higher ash levels. These salts may be compounds of sodium, vanadium, calcium, magnesium, silicon, iron, aluminum, nickel, etc. Typically, the ash value is in the range 0.03 - 0.07 %. Excessive ash in liquid fuels can cause fouling deposits in the combustion equipment.

### (j) Carbon Residue

Carbon residue indicates the tendency of oil to deposit a carbonaceous solid residue on a hot surface, such as a burner or injection nozzle, when its vaporizable constituents evaporate. Residual oil contains carbon residue of 1 percent or more.

### (k) Water Content

The water content of furnace oil when it is supplied is normally very low because the product at refinery site is handled hot. An upper limit of 1% is specified as a standard. Water may be present in free or emulsified form and can cause damage to the inside surfaces of the furnace during combustion especially if it contains dissolved salts. It can also cause spluttering of the flame at the burner tip, possibly extinguishing the flame, reducing the flame temperature or lengthening the flame. Typical specifications of fuel oils are summarized in the Table below.

**Table 1.5: Specifications of Oils used as fuel**

| Fuel Oils | | | |
|---|---|---|---|
| **Properties** | **Furnace Oil** | **Low Sulphur Heavy Stock** | **Light Diesel Oil** |
| Density (Approx. g/cc at $15^0$C) | 0.89 - 0.95 | 0.88 - 0.98 | 0.85 - 0.87 |
| Flash Point ($^0$C) | 66 | 93 | 66 |
| Pour Point ($^0$C) | 20 | 72 | 18 |
| G.C.V. (kCal/kg) | 10500 | 10600 | 10700 |

| | | | |
|---|---|---|---|
| Sediment, % Wt. Max. | 0.25 | 0.25 | 0.10 |
| Sulphur Total, % Wt. Max. | Up to 4.0 | Up to 0.5 | Up to 1.8 |
| Water Content, % Vol. Max. | 1.0 | 1.0 | 0.25 |
| Ash % Wt. Max. | 0.1 | 0.1 | 0.02 |

### (l) Storage of Fuel Oil

It can be potentially hazardous to store furnace oil in barrels. A better practice is to store it in cylindrical tanks, either above or below the ground. Furnace oil that is delivered may contain dust, water and other contaminants. The sizing of the storage tank facility is very important. A recommended storage size estimate is to provide for at least 10 days of normal consumption. Industrial heating fuel storage tanks are generally vertical mild steel tanks mounted above the ground. It is prudent for safety and environmental reasons to build bund walls around tanks to contain accidental spillages. As a certain amount of settlement of solids and sludge will occur in tanks over time, tanks should be cleaned at regular intervals: annually for heavy fuels and every two years for light fuels. Care should be taken when oil is decanted from the tanker to the storage tank. All leaks from joints, flanges and pipelines must be attended to at the earliest. Fuel oil should be free from possible contaminants such as dirt, sludge and water before it is fed to the combustion system.

## 1.1.2.2 MANUFACTURED LIQUID FUELS

Manufactured liquid fuels include gasoline, diesel oil, kerosene, heavy oil, naphtha, lubricating oils, etc. These are obtained mostly by fractional distillation of crude petroleum.

### (a) Gasoline or Petrol and its Characteristics

The straight run gasoline is obtained either from distillation of crude petroleum or by synthesis. It contains some undesirable unsaturated straight chain hydrocarbons and sulphur compounds. It has boiling range of 40-120$^0$C. The unsaturated hydrocarbons get oxidized and polymerized, thereby causing gum and sludge formation on storing. On the other hand, sulphur compounds lead to corrosion of internal combustion engine and at the same time they adversely affect tetraethyl lead, which is generally added to gasoline for better ignition properties. The sulphur compounds from gasoline are generally removed by treating it with an alkaline solution sodium plumbite. Olefins and colouring matter of gasoline are usually removed by percolating through ‘Fuller’s earth’ which absorbs preferentially only the colours and olefin. It is used in air-crafts. It is also used as motor fuel, in dry-cleaning and as a solvent.

### (b) The Characteristics of an ideal Gasoline

a) It must be cheap and readily available.
b) It must burn clean and produce no corrosion, etc. on combustion.
c) It should mix readily with air and should easily vaporize.
d) It must be knock resistant.
e) It should be pre-ignite easily.
f) It must have a high calorific value.

### (c) Diesel Fuel and its Characteristics

Conventional diesel fuels are distillates with a boiling range of about 149°C to 371°C, obtained by the distillation of crude oil. The components of diesel fuels are straight run fractions containing paraffinic and naphthenic hydrocarbons, naphtha and cracked gas oils. The atmospheric gas oils tend to have good ignition quality (cetane number) but many contain some high melting point hydrocarbons (waxes) that can result in high cloud and high pour points. These fractions are blended to produce different seasonal grades of diesel fuels required to meet a wide range of diesel engine uses. Diesel fuel produces power in an engine when it is atomized and mixed with air in the combustion chamber. Pressure caused by the piston rising in the cylinder causes a rapid temperature increase. When fuel is injected, the fuel/air mixture ignites and the energy of the diesel fuel is released forcing the piston downwards and turning the crankshaft.

### (d) Kerosene Oil and its Characteristics

Kerosene oil is obtained between 180-250$^0$C during fractional distillation of crude petroleum. It is used as an illuminant, jet engine fuel, preparing laboratory gas. With the development of jet engine, kerosene has become a material of far greater importance than it is used to be. When kerosene is used in domestic appliances, it is always vaporized before combustion. By using a fair excess of air it burns with a smokeless blue flame.

### (e) Heavy Oil and its Characteristics

It is a fraction obtained between 320-400$^0$C during fractional distillation of crude petroleum. This oil on fractionation gives;

a) Lubricating oils which are used as lubricants.
b) Petroleum-jelly (Vaseline) which is used as lubricants in medicines and in cosmetics.
c) Greases which are used as lubricants.
d) Paraffin wax which is used in candles, boot polishes, wax paper, tarpolin cloth and for electrical insulation purposes.

## 1.1.3 GASEOUS FUELS

Gaseous fuels occur in nature, besides being manufactured from solid and liquid fuels. Gaseous fuels due to erase and flexibility of their applications, possess the following advantages over solid or liquid fuels.

a) They can be conveyed easily through pipelines to the actual place of need, thereby eliminating manual labour in transportation.
b) They can be lighted at ease.
c) They have high heat contents and hence help us in having higher temperatures.
d) They can be pre-heated by the heat of hot waste gases, thereby affecting economy in heat.
e) Their combustion can readily by controlled for change in demand like oxidizing or reducing atmosphere, length flame, temperature, etc.
f) They are clean in use.
g) They do not require any special burner.
h) They burn without any shoot, or smoke and ashes.
i) They are free from impurities found in solid and liquid fuels.

### 1.1.3.1 NATURAL GAS

Natural gas is generally associated with petroleum deposits and is obtained from wells dug in the oil-bearing regions. The approximate composition of natural gas is : $CH_4$ = 70.9%, $C_2 H_6$ = 5.10%, $H_2$ = 3%, CO + $CO_2$ = 22%. The calorific value varies from 12,000 to 14,000 kcal/m$^3$. It is an excellent domestic fuel and is conveyed in pipelines over very large distances. It is a colourless gas and is non-poisonous. Its specific gravity is usually 0.57 to 0.7.

### 1.1.3.2 MANUFACTURED GASES

Manufactured gases are obtained from solid and liquid fuels. Some of the important manufactured gaseous fuels are coal gas, blast furnace gas, water gas, producer gas and oil gas.

#### (a) Coal Gas

Mainly consists of hydrogen, carbon monoxide and hydro-carbons. It is prepared by carbonization of coal. It finds its use in boilers and sometimes used for commercial purposes.

#### (b) Blast Furnace Gas

It is obtained from smelting operation in which air is forced through layers of coke and iron ore, the example being that of pig iron manufacture where this gas is produced as byproduct and contains about 20% carbon monoxide (CO). After filtering it may be blended with richer gas or used in gas engines directly. The heating value of this gas is very low.

#### (c) Water Gas

It is produced by blowing steam into white hot coke or coal. The decomposition of steam takes place liberating free hydrogen and oxygen in the steam combines with carbon to form carbon monoxide according to the reaction:

$$C+H_2O \rightarrow CO + H_2O$$

#### (d) Producer Gas

Producer gas is essentially a mixture of combustible gases carbon monoxide and hydrogen associated with non-combustible gases $N_2$, $CO_2$, etc. It is prepared by passing air mixed with little steam (about 0.35 kg/kg of coal) over a red hot coal or coke bed maintained at about $1100^0C$ in a special reactor called gas producer. It consists of a steel vessel about 3 m in diameter and 4 m in height. The vessel is lined inside with fire bricks. It is provided with a cup and cone feeder at the top and a side opening for the exit of producer gas. At the base it has an inlet for passing air and steam. The producer at the base is also provided with an exit for the ash formed.

### (e) Oil Gas

Oil gas is obtained by cracking kerosene oil. Oil in a thin steam is allowed to fall on a stout red hot cast iron retort, which is heated in coal fired furnace. The resulting gaseous mixture passes out through a bonet cover to a hydraulic main, a tank containing water. Here tar gets condensed. Then at the testing cap, the proper cracking of oil is estimated from the colour of the gas produced. A good oil gas should have a golden colour. By proper adjusting the supply of air, gas of required colour can be obtained. The gas is finally stored over water in gas holders.

### (f) Sewer Gas

It is obtained from sewage disposal vats in which fermentation and decay occur. It consists of mainly marsh gas ($CH_4$) and is collected at large disposal plants. It works as a fuel for gas engines which are turn drive the plant pumps and agitators.

**Table 1.6: Typical compositions of some gaseous fuels**

| Fuel | $H_2$ | CO | $CH_4$ | $C_2H_4$ | $C_2H_6$ | $C_4H_8$ | $O_2$ | $CO_2$ | $N_2$ |
|---|---|---|---|---|---|---|---|---|---|
| **Natural gas** | - | 1 | 93 | - | 3 | - | - | - | 3 |
| **Coal gas** | 53.6 | 9 | 25 | - | - | 3 | 0.4 | 3 | 6 |
| **Blast furnace Gas** | 2 | 27 | - | - | - | - | - | 11 | - |

## 1.1.4 BIODIESEL

The concept dates back to 1885 when Dr. Rudolf Diesel built the first diesel engine with the full intention of running it on vegetative source. He first displayed his engine at the Paris show of 1900 and astounded everyone when he ran the patented engine on any hydrocarbon fuel available, which included gasoline and peanut oil. In 1912 he stated "The use of vegetable oils for engine fuels may seem insignificant today. But such oils may in the course of time become as important as petroleum and the coal tar products of present time." Scientists discovered that the viscosity of vegetable oils could be reduced in a simple chemical process, in 1970 and that it could work well as diesel fuel in modern engine.

At present bio-diesel is an eco-friendly, alternative diesel fuel prepared from domestic renewable resources i.e. vegetable oils (edible or non- edible oil) and animal fats. Bio-diesel has been more attractive recently because of it can be prepared locally. Since

India is deficient in edible oils, therefore, the non-edible oil like Karanjia, Jatropha, etc. could be the desirable source for India for production of bio-diesel. These plants could be grown on wasteland, about 80 million hectare of which is available in India. These crops grow in arid and semi-arid region and require almost no post plantation management and care. Since, all most all the wasteland is available in rural and economically underdeveloped region, the large-scale bio-diesel production has an enormous potential for employment and development of these areas. The major application of bio-diesel is in transportation sector as an alternate to mineral diesel. Many automobiles builders like Ford, John Deere, Massey-Ferguson, Mercedes, BMW, Volkswagen, Volvo etc. have accepted Bio-diesel as the fuel suitable for their vehicles in the existing diesel engines. However, mostly Bio-diesel is used in 10% or 20% blends rather than as neat Bio-diesel. This blending approach also avoids the need to build a separate & costly infrastructure for storing Bio-diesel. Thus, Bio-diesel is recommended for use in almost all conventional diesel engines to run vehicles.

**Use of biodiesel in CI engine**

- It is recommended for use as fuel for petroleum based diesel engine because of biodiesel is a renewable, environmentally friendly emission and local production.
- Biodiesel is nontoxic. It produces 80% less harmful pollutants from diesel engine. It does not have sulphur but emission of nitrogen oxides increased.
- Bio diesel has high cetane number. Due to this it is easy for cold starting and low idle noise.
- The use of biodiesel increases the life of diesel engines because it has more lubricating properties.

#### 1.1.4.1 DEVELOPMENT OF BIODIESEL IN INDIA

The policy aims at mainstreaming of biofuels and, therefore, envisions a central role for it in the energy and transportation sectors of the country in coming decades. The Policy will bring about accelerated development and promotion of the cultivation, production and use of biofuels to increasingly substitute petrol and diesel for transport and be used in stationary and other applications, while contributing to energy security, climate change mitigation, apart from creating new employment opportunities and leading to environmentally sustainable development. The goal of the policy is to ensure that a minimum level of biofuels become readily available in the market to meet the demand at any given time. An indicative target of 20% blending of biofuels, both for bio-diesel and bio-ethanol, by 2017 is proposed. Blending levels prescribed in regard to bio-diesel are intended to be recommendatory in the near term. The blending level of bio Page 5 of 18 ethanol has already been made mandatory, effective from October, 2008, and will continue to be mandatory leading up to the indicative target.

### 1.1.4.2 RAILWAYS TO SET UP FOUR BIODIESEL PLANTS

**NEW DELHI** : Is one of the biggest initiatives for bio-fuel production in the country, Indian Railways is poised to set up four bio-diesel plants costing about Rs 120 crore. Biodiesel produced from waste oil, fatty acid and non-edible vegetable oil, bio-diesel will be blended with the mineral diesel oil for running locomotives.

**KOLKATA:** The biotechnology board in West Bengal has taken an initiative to produce bio-diesel from seeds of Jatropha plants. The board has decided to set up a park dedicated to Jatropha plantation at Salt Lake. The park will come up in Salt Lake. This site has been selected because land in this area will be freely available from the state department of planning and development. The park, besides growing Jatropha trees, will also house a pilot processing plant for extraction of crude Jatropha oil and later for its conversion into bio-diesel.

West Bengal pollution board has asked all telecom towers to use at least 30% biodiesel in their generators. Producers of biodiesel, banned from selling the fuel as a transport fuel, are looking to enter long-term supply arrangements with telecom tower operators, who use diesel gen sets for power backup purposes.

The Indian approach to biofuels is based solely on non-food feedstock to be raised on degraded or waste lands that are not suitable for agriculture, thus avoiding a possible conflict of fuel versus food security. Promotion of biofuels could meet India's energy needs in an environmentally-sustainable manner, while reducing its import dependence on fossil fuels. Indian Oil Corporation (IOC), the country's biggest oil marketing company, is looking to acquire 50,000 hectares of wasteland in Uttar Pradesh for plantation of non-edible oilseeds, such as jatropha and karanjia, which are used for biodiesel production. The company has already acquired 30,000 hectares in Chhattisgarh and another 2,000 hectares in Madhya Pradesh. IOC has planted 1,000 hectares so far and aims to plant 10,000 hectares this year. Seeds from the plantations will start coming after three to four years, he added. IOC has also entered into a MoU with Indian Railways for plantation of Jatropha on railway land. The Union Cabinet last month approved a national policy on biofuels that aims to implement 20 per cent blending of biodiesel with diesel and ethanol with petrol (the current rule is 5 per cent) by 2017. The new policy may consider financial incentives such as subsidies and grants for biofuel production. The policy also envisages setting up of a National Biofuel Fund and a National Biofuel Coordination Committee headed by the prime minister.

The research and development division of IOC has perfected a process to produce biodiesel from various non-edible oils, especially from jatropha and karanjia. The biodiesel produced has been tested for its properties and meets the stringent international standards. Extensive field trials have been conducted by IOC using five and 10% biodiesel blends in collaboration with Indian Railways and Haryana Roadways. A reduction of 10-15 per cent in smoke density has been observed with the use of biodiesel blends.

The Indian Railways' Research Design and Standard Organization (RDSO) has successfully developed and tested biodiesel-based locomotive engines, in its bid to scout for renewable and environment friendly fuels. Lucknow-based RDSO is the railway's sole research and development facility in the country, whose executive director (engine development).

### 1.1.4.3 ENERGY SCENARIO IN INDIA

India is the world's fifth largest primary energy consumer and fourth largest petroleum consumer after United States, China and Japan. Despite the recent global economic slowdown, India's economy is expected to continue to grow at 6% to 8% per year in the next term. With an outlook for moderate to strong economic growth and a rising population and growing infrastructural will stimulate an increase in energy consumption across all major sectors of the Indian economy. In the recent past, financial year 2009-2010, imports of gasoline and petroleum products has outgrown total domestic consumption by more than 14%. It is estimated that the proportionate consumption of petroleum products in India is as follows (petroleum consumption):

**Table 1.7: The proportionate consumption of petroleum products in India**

| Fuel | Percentage use |
|---|---|
| Transport (Petrol, Diesel, CNG, Aviation Fuel) | 51 % |
| Industry (Petrol, Diesel, Fuel Oil, Naphtha, Natural Gas) | 14% |
| Commercial and Others | 13% |
| Domestic (LPG and Kerosene) | 18% |
| Agriculture (Diesel) | 4% |

Thus, in terms of end usage, energy demand across the transport sector is greatest. Roads, being one of the dominant infrastructures for transport, carry an estimated 85% to 90% of the country's passenger traffic and 65% of its freight. Traffic on roads is growing at a rate of 7% to 10% percent per year while the vehicle growth is of the order of 8% to 10% per year.

In the profile of energy sources in India, coal has a dominant position. Coal constitutes about 51% of India's primary energy resources followed by Oil (36%), Natural Gas (9%), Nuclear (2%) and Hydro (2%). To address the issue concerning energy consumption, and more particularly, the need for enhancing the energy supply, India has accorded appropriate priority to both - supply side management and demand side management. On the supply side management, while it is essential for India to radically expand the capacities on all the fronts and all the segments of energy, equally important is the need for efficient consumption of energy for which a number of initiatives have been put in place.

Oil constitutes over 35% of the primary energy consumption in India. It is expected that this would rise both in terms of absolute amount and proportion. The demand projection is placed at about 200 million metric ton by the end of the 11th Five Year plan i.e. by 2011-12 and over 250 million metric ton by 2024-25. The present level of demand is about 120 million metric ton of oil equivalent. At present the upstream regulation is by the Director General of Hydro Carbons. They concentrate on the technical aspects and pricing is not under their domain. However, under the NELP contract, the private sector would need to have the price approved by the Government and to that extent, Director General, Hydrocarbons would have a role.

Natural gas constitutes about 9% in the India's energy profile, as compared to about 25% world average. About 45% of natural gas is consumed by power sector and about 40% by the fertilizer sector. The balance 15% goes for various other consumption. At present about 65 million cubic meters of gas per day is being consumed and it has the potential for increase.

### 1.1.4.4 TRANSPORT SCENARIO IN INDIA

The value for Road sector diesel fuel consumption per capita (kt of oil equivalent) in India was 25.98 as of 2009. Over the past 38 years the consumption reached a maximum value of 27.40 in 1995 and a minimum value of 5.80 in 1971.

**Table 1.8: Vehicle Population in India (State-wise - Top 10 in lakh nos.)**

| State/UT | Total Vehicle | 2-Wheelers | 3-Wheelers | Buses | Trucks | Jeeps | Cars | Cars as % of Total |
|---|---|---|---|---|---|---|---|---|
| **Maharashtra** | 45.15 | 29.62 | 3.97 | 0.45 | 1.75 | 1.48 | 4.69 | 10.39 |
| **Gujarat** | 37.77 | 26.39 | 2.23 | 0.35 | 1.89 | 0.66 | 2.86 | 7.57 |
| **UP** | 33.06 | 22.78 | 0.48 | 0.31 | 0.96 | 0.57 | 1.59 | 4.81 |
| **TN** | 31.82 | 24.54 | 0.93 | 0.38 | 1.52 | 0.26 | 3.19 | 10.03 |
| **Delhi** | 28.52 | 18.85 | -- | 0.29 | 1.46 | -- | 6.97 | 24.44 |
| **AP** | 27.99 | 23.01 | 0.78 | 0.28 | 1.65 | 0.40 | 1.42 | 5.03 |
| **MP** | 25.69 | 19.19 | 0.59 | 0.45 | 0.89 | 0.49 | 1.04 | 4.05 |
| **Karnataka** | 25.44 | 17.99 | 1.52 | 0.40 | 0.89 | 0.37 | 2.31 | 9.08 |
| **Punjab** | 20.95 | 14.64 | 0.39 | 0.15 | 0.59 | 0.19 | 1.04 | 4.96 |
| **Rajasthan** | 19.86 | 13.26 | - | 0.36 | 1.08 | 0.75 | 0.92 | 4.63 |
| **TOTAL (all-India)** | **375.81** | **259.15** | **14.89** | **5.12** | **19.43** | **7.51** | **35.25** | **9.38** |

### 1.1.4.5 BIODIESEL DIESEL FUEL QUALITY AND PROPERTIES

The various properties of biodiesel which are essential for fuel used in diesel engine such as viscosity of fuel pour and fire point, calorific value of fuel and ignition quality i.e. cetane number.

**(a) Density/specific gravity**

Biodiesel is slightly heavier than conventional diesel fuel (specific gravity 0.88 compared to 0.84 for diesel fuel). Due to this biodiesel should always be blended at top of diesel fuel.

**(b) Kinematic viscosity**

Viscosity is a measure of a liquid's resistance to flow. High viscosity means the fuel is thick and does not flow easily. Fuel with the wrong viscosity (either too high or too low) can cause engine or fuel system damage. High viscosity fuel will increase pumping losses in injector pump and injectors, as result reduces injection pressure. Low viscosity fuel may not provide adequate lubrication to plungers, barrels and injectors, and its use should be evaluated carefully. The viscosity of the fuel affects atomization and fuel delivery rate. The viscosity of diesel fuel is normally specified at 40°C. Fuels with viscosities over 5.5 centistokes at 40°C are limited to use in slow speed engines, and may require preheating for injection.

**(c) Flash point and fire point**

Flash point is determined by heating the fuel in a small enclosed chamber until the vapours ignite when a small flame is passed over the surface of the liquid. The flash point of biodiesel is higher than the conventional diesel fuel. The flash point of biodiesel blend is dependent on the base diesel fuel used, it increase with percentage of biodiesel in blend. On storage, the biodiesel and its blends are safer than that of diesel fuel. The flash point of biodiesel is around $160^0$C.

**(d) Water content or moisture content**

Biodiesel and its blends are susceptible to growing microbes when water is present in fuel. The solvency properties of the biodiesel can cause microbial slime to clog fuel filters. It effects on quality of biodiesel. High content of water causes blockage of fuel filter and fuel lines.

### (e) Cold filter plugging point

At low operating temperature fuel may thicken and not flow properly affecting the performance of fuel lines, fuel pumps and injectors. Cold filter plugging point of biodiesel reflect its cold weather performance. It defines the fuels limit of filterability. CFPP has better correlation than cloud point for biodiesel as well as diesel fuel.

### (f) Cloud point

Cloud point is defined as the temperature at which a cloud of crystals appear in the fuel under test conditions. The biodiesel fuel has higher cloud point than diesel fuel.

### (g) Pour point

Normally either pour point or CFPP are specified. French and Italian biodiesel specifications specify pour point whereas others specify CFPP. Since CFPP reflect more accurately the cold weather operation of fuel, it is proposed to not specify pour point of biodiesel. Pour point commonly used for diesel fuel not for biodiesel.

### (h) Cetane number

Cetane number is a measure of the ignition delay of a diesel fuel. The shorter the interval between the time the fuel is injected and the time it begins to burn, the higher is its cetane number. It is a measure of the ease with which the fuel can be ignited and is most significant in low temperature starting, warm up, idling and smooth, even combustion. Low cetane number usually causes an ignition delay in the engine. This delay causes starting difficulties and engine knock. Biodiesel has higher cetane number than conventional diesel fuel. As a results, higher combustion efficiency and smoother combustion.

### (i) Acid number/neutralization number

Acid number/neutralization number is specified to ensure proper ageing properties of the fuel or a good manufacturing process. Acid number reflects the presence of free fatty acids or acids used in manufacturing of biodiesel. It also reflects the degradation of biodiesel due to thermal effects.

### (j) Free fatty acid content

If the oil has high water or free fatty acid (FFA) content the reaction will be unsuccessful due to saponification (saponification is defined as the reaction of an ester with a metallic base and water) commonly known as making soap and make separation of the glycerol difficult at the end of the reaction. The FFA content of raw oil determines the quantity of biodiesel as the fuel product. A very low content of FFA (<0.2) can give a full 100% yield.

### (k) Calorific value

The calorific value is the measurement of heat or energy produced, and is measured either as gross calorific value or net calorific value. The difference is determined by the latent heat of condensation of the water vapour produced during the combustion process. Gross calorific value (GCV) assumes all vapour produced during the combustion process is fully condensed. Net calorific value (NCV) assumes water leaves with the combustion products without fully being condensed.

### (l) Ash content

It is described the amount of inorganic contaminants such as abrasive solids, catalyst residues and soluble metal soaps containing in a fuel sample. Abrasive Solids contribute to injector, fuel pump, piston and ring wear, and also engine deposits. Soluble metal soaps have little effect on wear but may contribute to engine deposits.

### (m) Carbon residue content

It is correlates with respective amount of glycerides, free fatty acid, and soap and catalyst residue. These parameters serve as measure of the carbon depositing tendencies of a fuel sample on injector tips and inside the combustion chamber. It is also influenced by high concentration of polyunsaturated fatty acid methyl esters and polymers.

### (n) Oxidation stability

Poor oxidation stability can cause fuel thickening, formation of gums and sediments, which in turn, can cause filter clogging and injector fouling. Iodine number indicates the tendency of a fuel to be unstable as it measures the presence of C=C bonds that are prone to oxidation. Generally instability increase by factor of 1 for every C=C bond on the fatty acid chain. Thus, C18:3 are three times more unstable than C18:0 fatty acids.

### (o) Iodine value

It is important to measure the oxidation stability of oil. It highly depends on parent oil which affects the iodine value of the ester. It is negative affects engine operation. It is correlated with viscosity and cetane number which both decrease with increasing degree of unsaturation. Fuel with high iodine number tends to polymerise and form deposits on injector nozzles, piston rings and piston ring grooves at high temperature.

### (p) Saponification value

It is indication of the amount of fatty acid saponifiable material in compounded oil. It gives information concerning the character of the fatty acid of the fat and in particular concerning the solubility of their soaps in water. The higher the saponification numbers of a fat from moisture and un-saponification matter, the more soluble the soap that can be made from it.

### (q) Free and total glycerol

The degree of conversion completeness of the vegetable oil is indicated by the amount of free and total glycerol present in the biodiesel. If the actual number is higher than the specified values, result in engine fouling, filter clogging etc. can occur. Manufacturing process controls are necessary to ensure low free and total glycerin. Free glycerol if present can build up at the bottom of the storage tanks.

### (r) Copper strip corrosion

It is correlated to acid number.

## 1.1.4.6 ASTM SPECIFICATION OF BIODIESEL

Biodiesel is a legally registered fuel and fuel additive with the U.S. Environmental Protection Agency. Biodiesel fuel has chemical properties that are very similar to conventional diesel fuel, and does not require any engine modifications or new equipment to enable its use as a blend stock or substitute for conventional diesel.

**Table 1.9: ASTM specification (PS121) for B20**

| Property | ASTM Method | Limits | Units |
|---|---|---|---|
| Flash Point | D93 | 130 min | Degrees C |
| Water & Sediment | D2709 | 0.050 max | % Volume |
| Kinematic | D445 | 1.9-6.0 | $mm^2$/sec |

| | | | |
|---|---|---|---|
| Viscosity ($40^0$C) | | | |
| Sulfated Ash | D874 | 0.020 max | % mass |
| Sulphur | D5453 | 0.0015 max | % mass |
| Copper Strip Corrosion | D130 | No. 3 max. | |
| Cetane Number | D613 | 46 min. | |
| Cloud Point | D2500 | Report | Degrees C |
| Carbon Residue (100% Sample) | D4530 | 0.050 max | % mass |
| Carbon Residue (Ramsbottom) | D524 | 0.090 max. | % mass |
| Acid Number | D664 | 0.80 max. | Mg KOH/gm |
| Free Glycerin | D6584 | 0.020 max | % mass |

**Table 1.10: Properties of Jatropha Oil**

| **PROPERTY** | **JATROPHA OIL** |
|---|---|
| Flash point | 240/110 °C |
| Carbon residue | 0.64 |
| Cetane value | 51.0 |
| Distillation point (°C) | 295 °C |
| Kinematics Viscosity | 50.73 cs |
| Sulphur % | 0.13 % |
| Calorific value | 9 470 kcal/kg |
| Pour point | 8 °C |
| Viscosity (cp) (30°C) | 52.6 (5.51)2 |
| Specific gravity (15 °C/4 °C) | 0.917/ 0.923(0.881) |
| Solidfying Point (°C) | 2.0 |
| Saponification Value | 188 , 198 |
| Iodine Value3 | 90.8 -112.5 |
| Refractive Index (30°C) | 1.47 |
| Acid value | 1.0 - 38.2 |

| | |
|---|---|
| Palmitic acid % | 4.2 |
| Stearic acid % | 6.9 |
| Oleic acid % | 43.1 |
| Linoleic acid % | 34.3 |
| Other acids % | 1.4 |

### 1.1.4.7 SPECIFICATIONS OF INDIAN BIO-DIESEL

Table 1.11: below give a list of important fuel properties that have been considered for quality of the biodiesel. Indian Standard for 100% Biodiesel Blend ISO 15607 For Biodiesel.

**Table 1.11: Indian Standard for 100% Biodiesel Blend (ISO 15607 for Biodiesel)**

| Property | Unit | Minimum | Maximum | Test method |
|---|---|---|---|---|
| Ester Content | % (m/m) | 96.5 | | |
| Density @15$^0$C | kg/m$^2$ | 860 | 900 | EN SO3675EN ISO12185 |
| Viscosity @ 40$^0$C | mm$^2$ | 3.5 | 5.0 | EN ISO 310 |
| Flash Point | $^0$C | above 101 | | ISO / CD 3679 |
| Sulfer Content | mg/kg | | 10 | |
| Carbon Residue(1 0% Bottoms) | % (m/m) | | 0.3 | EN ISO 1 037 0 |
| Cetane Number | | 51 .0 | | EN ISO 51 65 |
| Sulphated Ash Content | % (m/m) | | 0.02 | ISO 3987 |
| Water Content | mg/kg | | 500 | EN ISO 1 2937 |
| Total Contamination | mg/kg | | 24 | EN 1 2662 |
| Copper Strip Corrosion(3hr@ 50°C) | rating | Class 1 | Class 1 | EN ISO 21 60 |
| Thermal stability | | | | |

| | | | | |
|---|---|---|---|---|
| Oxidation Stability,110°C | hours | 6 | | pr EN<br>1 41 1 2 |
| Acid Value | mg KOH/g | | 0.5 | pr EN<br>1 41 04 |

### 1.1.4.8 VARIOUS FEEDSTOCK FOR BIODIESEL IN INDIA

1. Jatropha Curcas
2. Pongamia Pinnata
3. Madhucha
4. Rice Bran Oil
5. Neem Oil
6. Rubber Seed Oil
7. Sal Seed Oil
8. Palm Oil
9. Cotton Seed Oil
10. Rape Seed Oil
11. Sunflower Oil
12. Soyabean Oil
13. Castor Oil
14. Used Vegetable Oil
15. Fish Oil
16. Animal Fats/Tallows

### 1.1.4.9 BENEFITS OF BIODIESEL

Biodiesel can be considered as next generation diesel fuel. The major benefits are as following.

1. Biodiesel is an environment friendly fuel produced less amount of harmful gasses during combustion.
2. Biodiesel fuel does not require an existing engine modification. It can be blended with diesel to improve the efficiency of the engine.
3. Biodiesel can even be prepared in workshop if used as biodiesel fuel.
4. Biodiesel has a cetane number of over 100. Cetane number is used to measure the quality of the fuel’s ignition as a results easy cold starting.
5. Biodiesel is cost effective if it is produced locally.

#### 1.1.4.10 PRODUCTION PROCESS OF BIODIESEL

It is reported [1] that a dry seed of Jatropha curcas contains about 55% of oil.

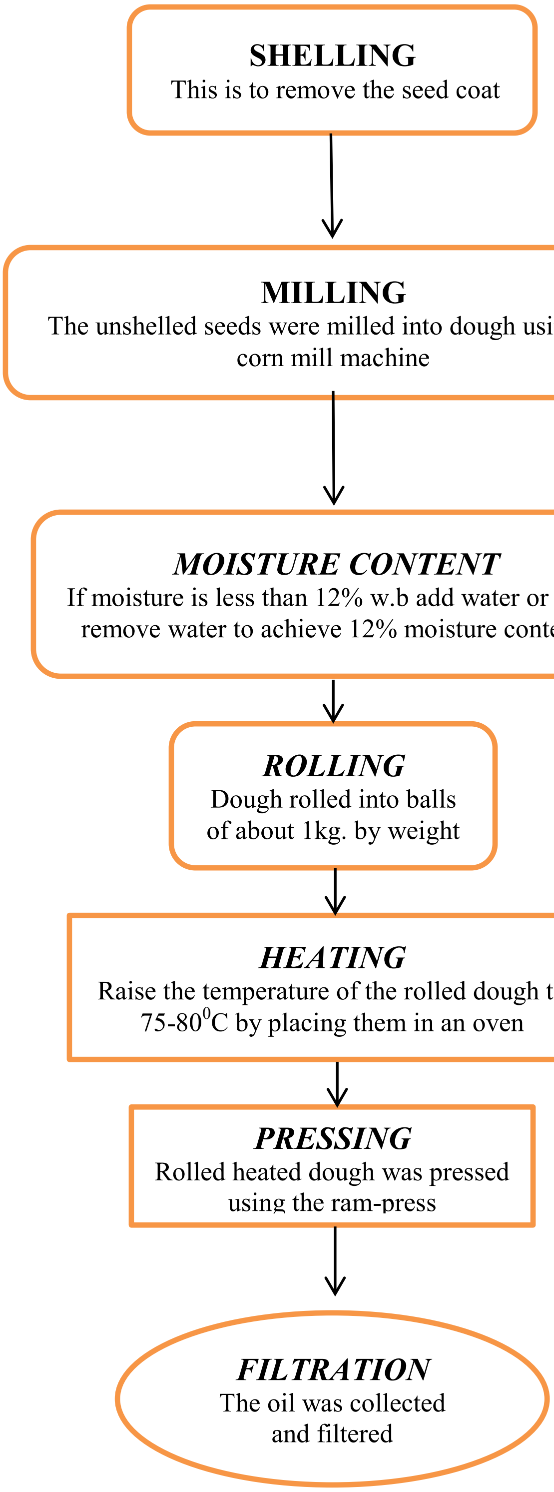

**Figure 1.1: Flow chart of the Jatropha oil extraction process using the mechanical ram-press.**

However, the maximum amount of oil that can be extracted from a given sample of the seed depends on the method of extraction and perhaps the quality of the feedstock. Two main methods of extracting the oil have been identified. They are the chemical extraction method using solvent extraction with n-hexane and the mechanical extraction method using either a manual ram-press or an engine driven-expeller. The process of converting vegetable oil into biodiesel fuel is called transesterification. Chemically, transesterification means taking a triglyceride molecule or a complex fatty acid, neutralizing the free fatty acids, removing the glycerin, and creating an alcohol ester. This is accomplished by mixing methanol with sodium hydroxide to make sodium methoxide. This liquid is then mixed into the vegetable oil. After the mixture has settled, Glycerin is left on the bottom and methyl esters, or biodiesel is left on top and is washed and filtered. The final product bio diesel fuel, when used directly in a diesel engine will burn up to 75% cleaner than mineral diesel fuel.

**Transesterification process**

**Table1.12: Trans-esterification Process.**

| Vegetable Oil | Alcohol | Catalyst(Sodium or Potassium Hydroxide) | Glycerin(Used for medicinal value) | Biodiesel |
|---|---|---|---|---|
| 100 gm | 12 gm | 1 gm | 11 gm | 95 gm |

It is the displacement of alcohol from an ester by another alcohol in a similar process to hydrolysis. Vegetable oil i.e. the triglyceride can be easily trans-esterified in the presence of alkaline catalyst at atmospheric pressure and at temperature of approximately 60 to $70^0$C with an excess of methanol. If 100 gm of vegetable oil is taken, 1 gm of the alkaline catalyst (Potassium Hydroxide), and 12 gm of methanol would be required.  As a first step, the alkaline catalyst is mixed with methanol and the mixture is stirred for half an hour for its homogenization. This mixture is mixed with vegetable oil and the resultant mixture is made to pass through reflux condensation at $65^0$C. The mixture at the end is allowed to settle. The lower layer will be of glycerin and it is drained off. The upper layer of bio-diesel (a methyl ester) is washed to remove entrained glycerin. The excess methanol recycled by distillation. This reaction works well with high quality oil. If the oil contains 1% Free Fatty Acid (FFA), then difficulty arises because of soap formation. If FFA content is more than

2% the reaction becomes unworkable. Methanol is inflammable and potassium hydroxide is caustic, hence proper and safe handling of these chemicals is must.

### 1.1.4.11 PERFORMANCE PARAMETERS OF IC ENGINE

The engine performance is an indication of the degree of success with which it does its assigned job i.e. conversion of chemical energy contained in the fuel into use full mechanical work.

In evaluation of engine performance basic parameters are following.

### 1.1.4.12 POWER AND MECHANICAL EFFICIENCY

(a) **Indicated power**. The power developed by fuel in the combustion chamber is called indicated power.

$$IP = \frac{\mathrm{n}p_m\mathrm{LANk\ x\ 10}}{6} kW$$

Where n = number of cylinders

$P_m$ = indicated mean effective pressure

L = Length of stroke, m

A = Area of piston, $m^2$

K = ½ for four stroke engine and 1 for two stroke engine.

N = Speed in r.p.m.

(b) **Brake power (BP)** the power developed by an engine at the output shaft is called the brake power.

$$BP = \frac{2\pi \mathrm{NT}}{60x1000} kW$$

Where N = Speed in r.p.m.

T= Torque in N-m.

(c) Mechanical efficiency

$$\eta_{mech} = \frac{\mathrm{BP}}{IP}$$

(d) **Mean effective pressure:** Mean effective pressure is defined as hypothetical pressure which is thought to be acting on the piston throughout the power stroke. If it is based on IP then it is called indicated mean effective pressure and if on the based on BP it is called brake mean effective pressure.

(e) **Specific output:** It is defined as the brake output per unit of piston displacement and is given by.

$$Specific\ output. = \frac{\mathrm{BP}}{AxL}$$

(f) Volumetric efficiency: It is defined as the ratio of actual volume (reduced to N.T.P.) of the charge drawn in during the suction stroke to the swept volume of the piston.

(g) Fuel air ratio: It is the ratio of the mass of fuel to the mass of air in the fuel air mixture.

(h) Specific fuel consumption: It is the mass of fuel consumed per kW developed per hour.

(i) Thermal efficiency: It is the ratio of indicated work done to the energy supplied by the fuel.

mf = mass of fuel used in kg/sec.

C = calorific value of fuel (Lower)

Then indicated thermal efficiency (Based on IP)

$$\eta th. = \frac{\mathrm{IP}}{mfxC}$$

And brake thermal efficiency (based on BP)

$$\eta th. = \frac{\mathrm{BP}}{mfxC}$$

### 1.1.5 CURRENT USAGES OF BIO-DIESEL / TRIALS & TESTING IN INDIA

Usages of bio-diesel are similar to that of petro-diesel. With the help of petroleum conservation research association (PCR) (National Bio Fuel Centre).

a) Shatabdi Express was run on 5% blend of bio-diesel from Delhi to Amritsar on 31st Dec. 2002 in association with IOC.
b) Field trials of 10% bio-diesel blend were also done on Lucknow-Allahabad Jan Shatabdi Express also through association with IOC.
c) HPCL is also carrying out field trials in association with BEST bio-diesel blend from IOC (R&D) is being used in buses in Mumbai as well as in Rewari, in Haryana on trial basis .
d) CSIR and Daimler Chrysler have jointly undertaken a successful 5000 km trial run of Mercedes cars using bio-diesel as fuel.
e) NOVOD has initiated test run by blending 10% bio diesel in collaboration with IIT, Delhi in Tata Sumo & Swaraj Mazda vehicles.

# 2 LITERATURE REVIEW

In the literature review extensive literature on chemical structure of biodiesel and transesterification, fuel characteristic, C.I. engine performance and emission of tested fuel are reviewed.

## 2.1 BIODIESEL PRODUCTION METHODS

**Fangrui et al. [2]** defined factors affecting transesterification are molar ratio of glycerides to alcohol, catalysts, reaction temperature and time and the contents of free fatty acids and water in oil and fats. The commonly accepted molar ratio of alcohol to glycerides is 6:1. Base catalysts are more effective than acid catalysts and enzymes. The recommended amount of base used to use is between 0.10 and 1% w/w of oils and fats. The continuous transesterification process is one which can reduce the production cost of biodiesel.

**Gemma et al. [3]** studied the integral biodiesel production by comparing the four basic catalysts (sodium methoxide, potassium methoxide, sodium hydroxide and potassium hydroxide) for methanolysis of sunflower oil and found that biodiesel purity was near 100wt. % for all catalysts. The obtained biodiesel met the measured specifications, except for the iodine value, according to the German and EU draft standards. It is found that the transesterification reaction using sodium hydroxide was the fastest achieving nearly 100 wt. % methyl ester concentration in the biodiesel phase at 30 min.

**Shakinaz et al. [4]** studied the production of biodiesel from Jatropha oil using the microwave technology and found that the application of radio frequency microwave energy offers a fast, easy route to produce biodiesel (from high free fatty acid content feed stock like Jatropha oil etc.) with advantage of exchanging the reaction rate (2 min instead of 150 min, 90 min for pretreatment process and 60 min for transesterification) and also improve the separation process.

**Joon et al. [5]** studied the process of production of biodiesel from Jatropha oil by catalytic and non-catalytic approaches and found that an alkaline catalyst is more suitable for biodiesel production if the FFA content in the Jatropha oil is lower than 1%. If the FFA content is more than 1%, a two-step transesterification process is a better choice. However, an extra step is required that would increase the production cost of biodiesel.

**Feng et al. [6]** studied the one step production of biodiesel from Jatropha oil with high acid value in ionic liquids and found that max biodiesel yield of 99.7% was achieved by trivalent metallic ions than bivalent ones. It was also found that catalytic activity with bivalent metallic ions increased with atomic radius, thus mixture of these and $FeCl_2$ was easily separate from products for reuse to avoid production pollutants.

**Forson et al. [7]** studied the performance and emission characteristics of Jatropha oil and its blends with diesel in a direct-injection single cylinder diesel engine. It is concluded that pure Jatropha, pure diesel and blends of Jatropha oil exhibited similar performance and similar emission levels under comparable operating conditions. Introduction of Jatropha oil into diesel fuel appears to be effecting in reducing the exhaust gas temperatures. They have found that the 2.6% by volume of Jatropha introduced into diesel fuel enhances the performance of the engine and therefore Jatropha oil can be used as fuel enhancement additive for diesel oil

**Tippayawong et al. [8]** studied continuous flow transesterification of crude Jatropha oil with microwave irradiation and concluded that microwave irradiation can enhance transesterification of the vegetable oil. High yield of over 96% can be obtained in relative short reaction time and that at a small amount of catalyst. It also concluded that microwave heating gave efficient heating for rapid conversion of Jatropha oil to biodiesel. The optimal transesterification conditions were found to be reaction time of 30s, a molar ratio of oil to methanol 1:6, and 1.0% $NaOCH_3$ as catalyst to give a conversion yield higher that 96%. This process can be used for continuous production of Jatropha biodiesel.

**Ali et al. [9]** studied the optimization of production process from Jatropha oil using supported hetropolyacid catalyst and assisted by ultrasonic energy and concluded that the maximum yield of 91% was achieved in just 40 min at a molar ratio of 25:1. It is also concluded that reaction time and reactants’ molar ratio affected the reaction response. The ultrasonic irradiation significantly decreased the reaction time as compare to conventional mixing process under same conditions. The low reaction time and low reaction temperature would help in improving the overall economy of the biodiesel production process. The catalytic activity was mainly contributed by heterogeneous reaction.

**Kian et al. [10]** studied the biodiesel production from low quality crude Jatropha (acid value >4mgKOH/g & water content >1000ppm) oil using heterogeneous catalyst shows that modified natural zeolite catalyst had excellent catalytic activity and stability in the transesterification of low quality Jatropha oil to biodiesel with methanol. The optimum conditions are 20:1 molar ratio of methanol to oil, addition of 5wt% catalyst, $70^0$C and 6 hours of reaction time. It has a tremendous potential to provide a friendly low cost method in biodiesel production from low quality raw feed stocks with high FFA and high water content.

**Ragit et al. [11]** studied brown hemp methyl ester transesterification process and evaluation of fuel properties. They found that maximum recoveries of esters were observed at different preheating temperature ($55^0$C, $60^0$C and $65^0$C) i.e. 93.89%, 88.68% and 89.80%. The lowest viscosity observed at $55^0$C were 1.13cSt of hemp methyl ester. The maximum conversion efficiency is achieved very close to the molar ratio of 4:1. It also shows that with lowest molar ratio of alcohol to oil, lesser amount of KOH can be used. The relative densities of hemp oil and hemp methyl ester were observed to be 6.99 and 3.37% higher than that of diesel. The kinematic viscosity of hemp oil was more than that of diesel whereas hemp methyl ester with the kinematic viscosity of 56.54% less than that of diesel. The hemp methyl ester was found to have lower flash point and fire point than the diesel. The flash and fire point of hemp oil was to be higher than diesel. The pour point of hemp methyl ester was higher whereas cloud point of hemp methyl ester was lower than that of diesel. Also the cloud and pour point of hemp oil was lower than those of diesel. The calorific value of hemp oil was increased by 1.21% than that of diesel whereas calorific value of hemp methyl ester was decreased by 0.19% than diesel. The properties of hemp biodiesel were found to be closer to ASTM biodiesel standards.

**Amish et al. [12]** studied the production of biodiesel through transesterification of Jatropha oil using $KNO_3/Al_2O_3$ Solid catalyst and concluded that alumina loaded with potassium was found to be strong solid base catalyst for transesterification of Jatropha oil with methanol. The highest conversion reached 84% with molar ratio of methanol to Jatropha oil of 12:1, a reaction time 6 hours, catalyst amount 6% and agitation speed of 600 rpm. The catalyst is recycled at least three times. It also concluded that kinetic study of transesterification process that at $70^0$C, order of the reaction is 0.5239 and reaction rate constant is 0.00309 $ml^{0.25}mol^{-0.25}h^{-1}$. Activation energy is 26.957cal and frequency factor is 4.67.

## 2.2 CHARACTERISTICS OF BIODIESEL

**Jincheng et al. [13]** studied comparative performance and emission of CI engine using Chinese pistache and Jatropha biodiesel and concluded that the engine performance and thermal efficiency run by Chinese pistache biodiesel and Jatropha biodiesel are comparable to that by pure diesel fuel. The fuel consumptions of engine are slightly higher when the engine is fuelled with two biodiesels compared to diesel. The CO emissions from the biodiesels are lower than that of diesel fuel at the engine high loads, at engine lower loads the CO emission are almost same as that of diesel. The CO emissions of both the biodiesel fuel are same. The HC emission from biodiesels are lower than that of diesel fuel at engine high loads, at engine lower loads, the HC emission are similar as that of diesel. The NOx emissions from biodiesels are lower than that of diesel fuel at engine high loads. The NOx emissions are similar for two biodiesel. The smoke emission from the biodiesel are mostly lower than that of diesel in whole range of engine tested, and lower than that of diesel fuel at engine high loads. The engine performance and emissions run by chinese pistache biodiesel are comparable to that run by Jatropha biodiesel.

**Agarwal et al. [1]** studied the economic analysis of biodiesel and found that the use of vegetable oils and its biomass material as diesel fuel almost same cost as that of mineral diesel. It investigates the performance and emission characteristics of linseed oil, mahua oil, rice bran oil and linseed oil methyl ester in stationary single cylinder, four stroke diesel engine and compares it with mineral diesel. The performance and emission parameters for different fuel blends were found to be closer to diesel. The smoke density and BSFC were slightly higher for vegetable oil blends compared to

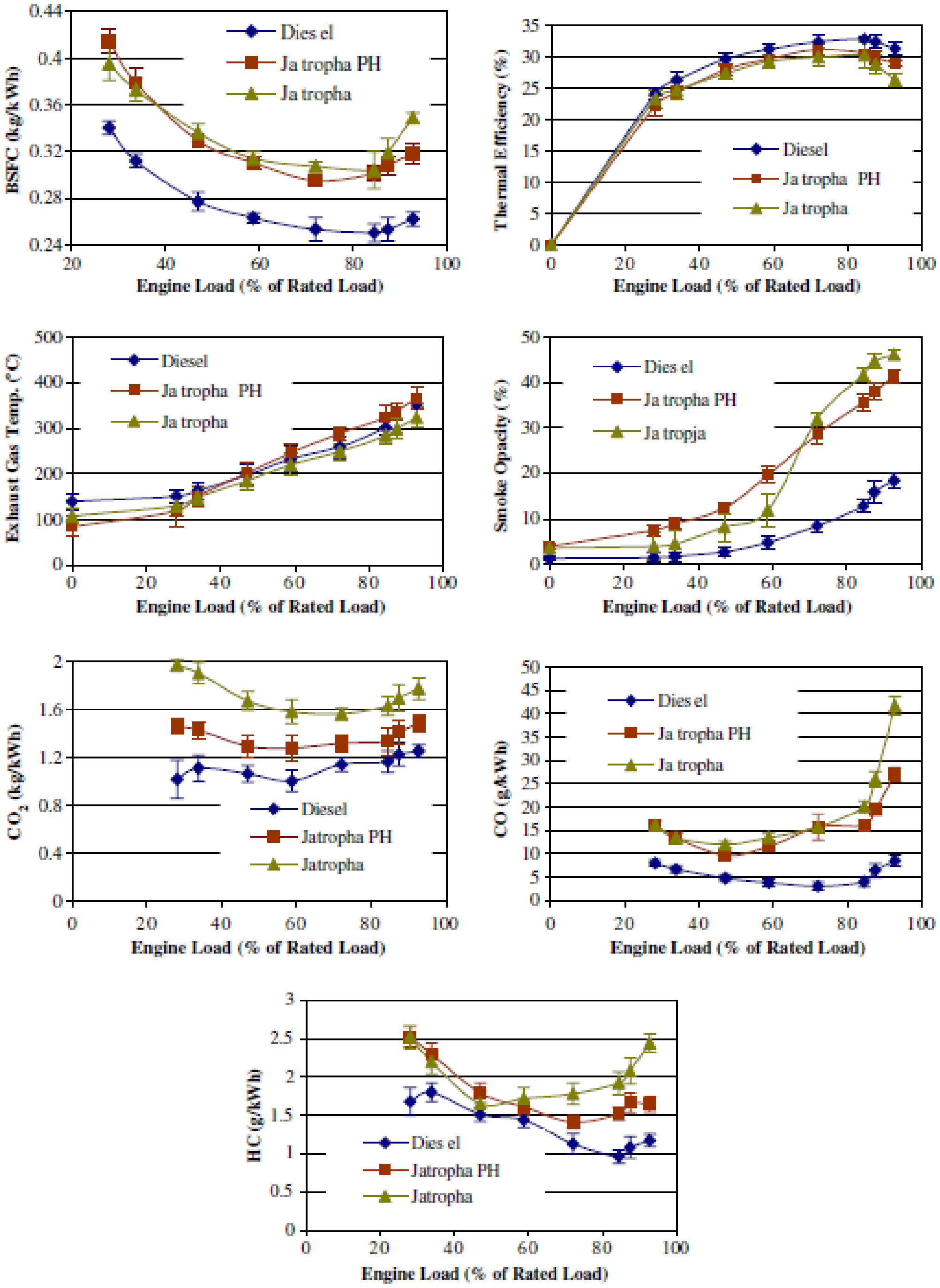

**Figure 2.1: Engine performance and emission parameters for Jatropha (unheated and preheated) [1].**

diesel. However, BSEC for all oil blends was found to be lower than diesel. Vegetable oil blends showed performance characteristics close to diesel. Economic analysis was also conducted to find out cost for different vegetable oils, biodiesel and mineral diesel. It that cost per unit energy produced is almost similar for all fuels.

**Ramadhas et al. [14]** investigated that rubber seed oil, non-edible vegetable oil is used for producing biodiesel and used as fuel in CI engine. The properties of this biodiesel are closely matched with those of diesel fuel. The various blends of biodiesel with diesel are used as fuel in CI engine and its performance emission characteristics are analyzed. The lower concentration of biodiesel blends found to improve the thermal efficiency.

**Ganpathy et al. [15]** studied the performance of single cylinder vertical direct injection water cooled diesel engine with Jatropha biodiesel as fuel by using Taguchi method, they have considered different design parameters such as cylinder bore diameter, stroke length, cut-off ratio, connecting rod length, compression ratio, engine speed etc. They found that compression ratio does not depend with injection timing. It is also observed that brake thermal efficiency increases with stroke length; cylinder bore and decreases with combustion duration. The brake thermal efficiency does not change with the variation of cut off ratio and relative air fuel ratio.

**Mallikappa et al. [16]** studied performance and emission characteristics of double cylinder CI engine operated with cardanol bio fuel. The cardnol obtained by pyrolysis from dr-csnl oil was utilized for testing purposes. They found that brake specific energy consumption decreased by 25-30% approximately with increases in brake power. This reverse trend was observed due to lower calorific value with increase in bio fuel percentage in the blends. They have also observed that variation of brake thermal efficiency with brake power increased with increase in brake power for all the blends this was due to reduction in heat losses and increase in load. The brake thermal efficiency obtained from biodiesel was less than that of diesel. They found that the NOx emission (ppm) increases with increased proportion of blends and this trend is mainly because of presence of oxygen in bio fuel, more oxidation at higher temperature and responsible for more NOx emissions. The carbon monoxide emissions increased with higher blends, and increases slightly after 20% blends. There was reduction in smoke density at higher brake power, this trend due to oxygen presence in the bio-fuel.

**Jindal et al. [17]** studied effect of compression ratio and injection pressure in CI engine with Jatropha methyl ester and found that brake specific fuel consumption decreases with load significantly for both the fuels as the power output per unit fuel consumption increases at higher loads. It was found that the BSFC is always higher for B100 than B0 by about 25-34% at standard rated engine parameters. This is due to the ester have lower heating value when compared to diesel and therefore more biodiesel is needed to maintain the power output. The BSFC for B100 decreases (improves) as the compression ratio of the engine increased. This is due to at higher compression ratio, brake power increases. The effect of change in injection pressure on BSFC is also found significant with lowest BSFC at 200 bar up to 50% load and 250 bar for higher loads. The decrease in BSFC can be attributed to the more efficient utilization of the fuel at higher injection pressure because of better atomization associated with slight delay in admission due to high needle lift pressure with same time lesser fuel going into cylinder. The brake thermal efficiency also improves as increase in compression ratio (18) by 5.5%. Similarly improvement is found with higher injection pressure of 250 bar by 2.3%.

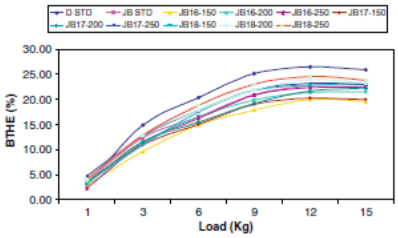

**Figure 2.2: BTHE vs. load for all combinations of compression ratio and injection pressures [17].**

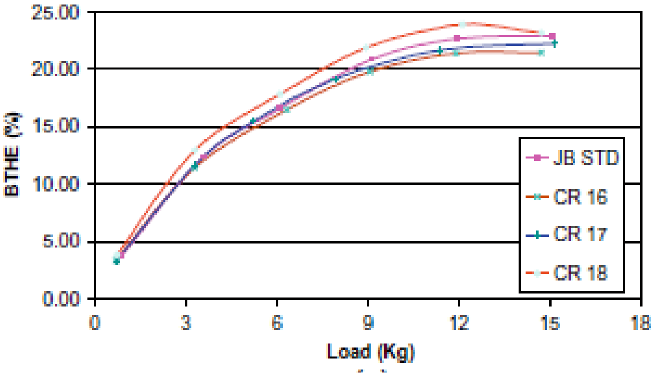

**Figure 2.3: BSFC vs. load for different compression ratios [17].**

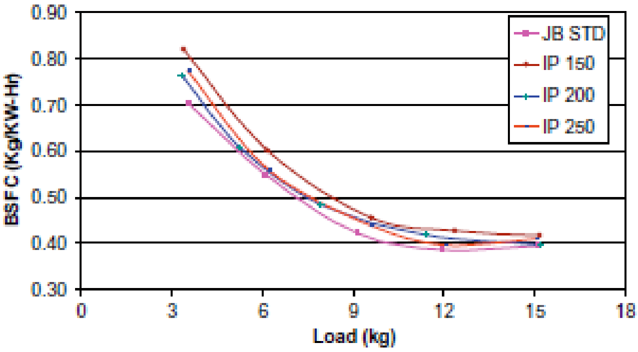

**Figure 2.4: BSFC vs. load for different injection pressures [17].**

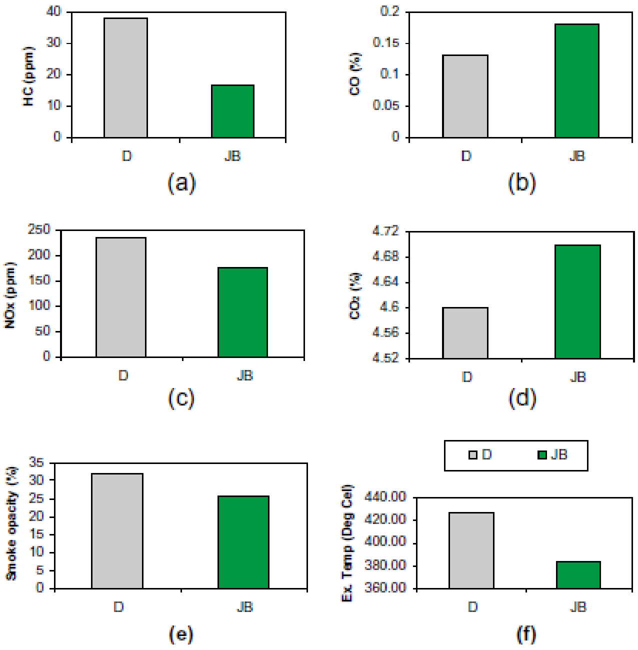

**Figure 2.5: Emissions at standard settings for both fuel [17].**

The emission of engine found at full load, unburned hydrocarbons (HC), oxides of nitrogen (NOx), exhaust temperature and smoke opacity of exhaust are found lower for B100 as compared to diesel at standard setting of the engine whereas $CO_2$ and carbon monoxide emissions are higher. HC emissions tend to increase with increase in compression ratio and also on reduction in injection pressure. Lowest HC emissions (16ppm) were found for compression ratio 17 with injection pressure of 200 bar. The un-burnt HC emissionsare higher for low injection pressure (150 bar) at all compression ratio. The emission of NOx is more sensitive to compression ratio at lower injection pressures as compared to higher compression ratio.

**Narayana et al. [18]** studied the performance and emission characteristics of a single cylinder constant speed direct injection diesel engine using neat Jatropha oil as fuel by changing the injection timing and injection rate. They concluded that on changing the advancing injection timing from base diesel value and increasing the injector opening pressure increase the BTE and reduce HC and smoke emission significantly. When injection timing is retarded and enhanced injection rate then emission with Jatropha oil lower than diesel. At full output HC emission are also lower than diesel.

**Varatharajan et al. [19]** studied mitigation of NOx emission from Jatropha biodiesel fuelled CI engine using antioxidant additives (0.005%) and tested the engine performance. The results show that optimum reduction were found at 0.025%-m concentration of additives (p-phenylenediamine). Biodiesel presented best emission results and mean NOx reduction of 43.55% was observed with this additive the minimum and maximum NOx produced were 1.57 and 2.05 g/kWhr respectively And also meets III B Euro emission standards. Ethylenediamine is most common lubricanting oil additive that control deposits in the fuel system and also effectively reduces the friction between engine cylinder and piston rings. It gave 32.73% mean NOx reduction relative to biodiesel at 0.025%-m and observed specific NOx emissions range was 1.79 to 2.60 g/kW-hr. the CO emission at full load, highest CO emission were observed with p-phenylenediamine (11.12 g/kW-hr). The result show that addition of antioxidants led to some increase in HC emissions at all the loads. At full load the specific fuel consumption with ethylenediamine and p-phenylenediamine additive were 0.133 and 0.136 kg/kW-hr respectively while neat biodiesel was 0.145kg/kW-hr. This reduction in specific fuel consumption might have been due to friction reduction properties of the amines.

**Arakshita et al. [20]** studied blending optimization of hempel distilled bio oil with diesel and concluded that IBP (Initial Boiling point) <140$^0$C fraction of bio oil has been made by Hempel distillation for separating polar compounds from the bio oil. The different blending ratio of higher fraction of bio oil (IBP<140$^0$C) with diesel has been made to seeing their compatibility. It is also concluded that 10% blend is meeting all the specification of the commercial diesel.

**Grimsby et al. [21]** studied human energy requirements in Jatropha oil production for rural electrification in Tanzania and found the energy output: input ratio of production of Jatropha oil where human energy input is included and calculated to be 3.8. 55% of energy harvested as fruits is in the form of seed cake, 21% of the energy is found in the fruit coats and 24% of the energy contained in the Jatropha fruits is recovered in the Jatropha oil. The time required to harvest 36 liter Jatropha fruit was 4.1±0.8 h. Time required to de-hull Jatropha fruits to equal to 5 kg of Jatropha seeds was found to be 3.4±1.0 h. The economy in rural electrification the minimum cost 507 TZS/kWh.

**Pradeep et al. [22]** studied the performance and emission characteristics with Jatropha biodiesel using single cylinder four stroke water cooled direct injection diesel engine. It is concluded that BTE was found to be comparable with diesel, at all loads with and without EGR. The NOx emission with Jatropha biodiesel found to be higher than the diesel fuel. The use of hot EGR of 15% effectively reduced NOx without much adverse effect on the performance, smoke and other emissions. It is also found that at full load NOx emission from Jatropha with 15% EGR was found to be lower than diesel.

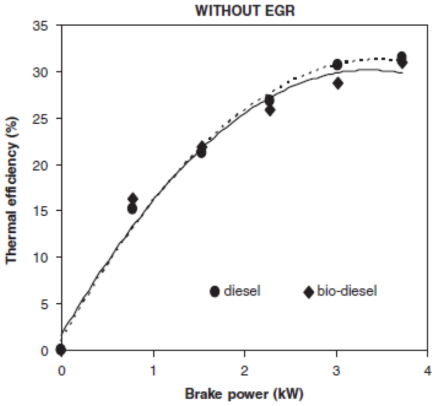

**Figure 2.6: Comparison of brake thermal efficiency (No EGR) [22].**

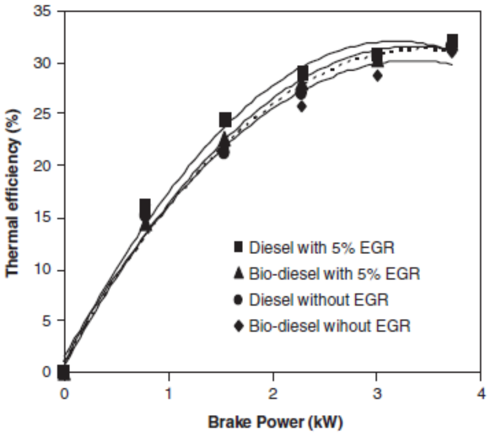

Figure 2.7: Comparison of brake thermal efficiency (5% EGR) [22].

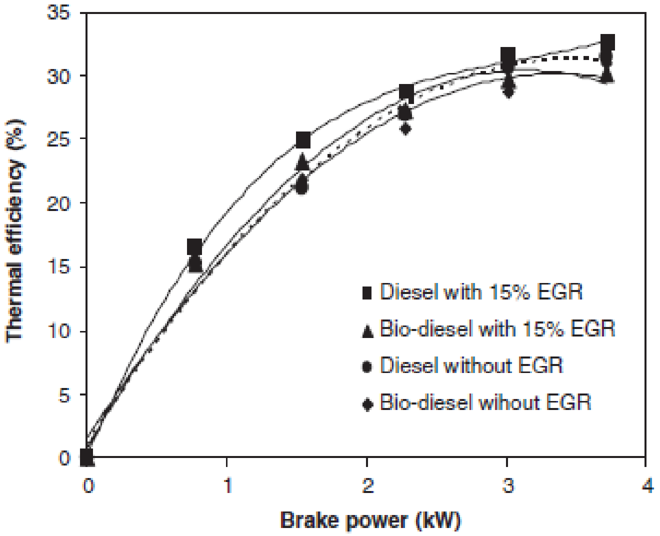

Figure 2.8: Effect of 15% EGR on brake thermal efficiency [22].

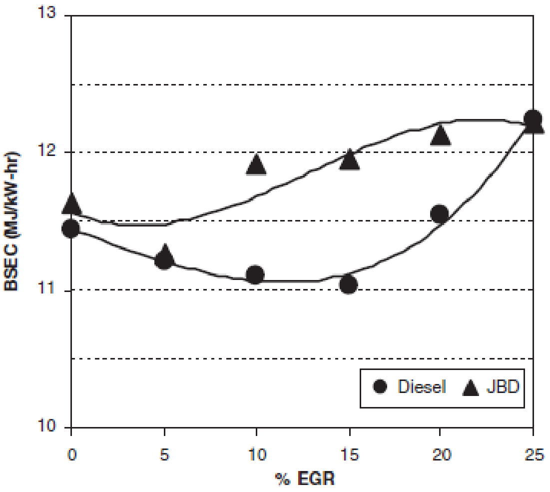

Figure 2.9: Comparison of BSEC with EGR (full load) [22].

The smoke emission with Jatropha was found to be lower than diesel at peak loads with and without EGR. The smoke emission of Jatropha biodiesel was higher in the lower load region.

**Rajesh et al. [23]** studied analysis of combustion of Jatropha biodiesel and found flame shape obtained from the porous sphere experiment at both flames are highly sooty in nature, exhibiting a bright yellow color. It shows that for a given particle size the transition from envelope to wake flame has been observed to take place approximately at 20% lower free stream velocity for bio diesel as compared to that of diesel, because of lower volatility of bio diesel. The mass burning rate for bio diesel is slightly less than that of diesel under similar burning conditions. This is because of the low volatility and higher flash point of the bio diesel.

**Rakesh et al. [24]** studied Jatropha-palm bio diesel blends and studied stability parameters such as oxidation etc. of Jatropha bio diesel. The oxidation stability of Jatropha biodiesel has been found to increase with increase in dosage of antioxidant (ditertiarybutyl hydroxytoluene). It is found that dosing of 200ppm of antioxidant is the minimum requirement to meet EN 14112 specification for biodiesel oxidative stability. Secondly another set of study was undertaken to blend Jatropha oil methyl ester with 60% palm oil methyl ester, which having good oxidation stability. Third study was to blend Jatropha biodiesel with palm biodiesel (80:20), along with antioxidant. Optimum combination for oxidation stability of biodiesel we need 40% palm oil in Jatropha oil and usage of 25 ppm of antioxidant. The blending of palm biodiesel in Jatropha biodiesel exhibits additive response in cloud and pour point properties. The blending of palm biodiesel with Jatropha biodiesel worsens the low temperature properties of Jatropha biodiesel, these results are limited concern in the temperature climate of Asia.

**Singh et al. [25]** studied on holistic approach to 100% utilization of Jatropha fruit for energy purposes. It is concluded that diesel engine can be run satisfactory without any change in engine up to 10% blending of de-waxed and de-gummed Jatropha oil directly without preheat the diesel. The blend of de-wax, degummed Jatropha oil with diesel could also be done up to 50:50 ratio but preheating of mixture was required at $60^0$C to reduce viscosity, when blending of oil with diesel was more in proportion than 20:80. The biodiesel from Jatropha oil offer higher brake thermal efficiency than blended de waxed de gummed Jatropha oil or even from diesel. It is also found that seed husk could be successfully used as feedstock for gasifier and shell could be used for combustion for industrial use. It is concluded that the energy value remaining portion of Jatropha fruit is twice that of biodiesel.

**Sahoo et al. [26]** been studied on combustion analysis of Jatropha, karanja and polanga based biodiesel as fuel in CI engine, found that the methyl esters of Jatropha, karnja and polanga oil have relatively closer fuel property value to that of diesel. The addition of a small quantity of biodiesel with diesel increase the flash point of diesel, hence safer to store biodiesel blends as compared to diesel alone. The heat release rate has maximum value for biodiesel and their blends in comparison with neat diesel. The ignition delays are short for Jatropha biodiesel (100), varying between $5.9^0$ and $4.2^0$ lower than diesel with the difference increasing the load. Similarly delays are shorter for karanja biodiesel (100) varying between $6.3^0$ and $4.5^0$ CA and polanga biodiesel (100) varying between $5.7^0$ and $4.2^0$ CA lower than diesel.

## THE SUMMARY OF LITERATURE SURVEY

### Biodiesel Production Methods

**Annexure-I**

| Author | Type Biodiesel | Production Method | Properties/Performance | Comparison with diesel | Remarks |
|---|---|---|---|---|---|
| Fangrui et al.[2] | Soybean oil | Transesterification | The commonly accepted molar ratio of alcohol to glycerides is 6:1. Base catalysts are more effective than acid catalysts and enzymes. The recommended amount of base used to use is between 0.10 and 1% w/w of oils and fats. | Heating value has lower whereas viscosity has higher value. | The continuous transesterification process is one which can reduce the production cost of biodiesel. |
| Gemma et al.[3] | Sunflower oil | Integrated biodiesel production | The transesterification reaction using sodium hydroxide was the fastest achieving nearly 100 wt. % methyl ester concentration in the biodiesel phase at 30 min. | The obtained biodiesel met the measured specifications, except for the iodine value, according to the German and EU draft standards. | Sodium hydroxide was the fastest achieving nearly 100 wt. % methyl ester concentration in the biodiesel |

| Author | Type Biodiesel | Production Method | Properties/Performance | Comparison with diesel | Remarks |
|---|---|---|---|---|---|
| | | | | | phase at 30 min. |
| Shakinaz et al.[4] | Non edible jatropha oil | Microwave technique | The application of radio frequency microwave energy offers a fast, easy route to produce biodiesel (from high free fatty acid content feed stock like Jatropha oil etc.) and also improve the separation process. | Higher viscosity and flash point. | Reduce the reaction rate (2 min instead of 150 min, 90 min for pretreatment process and 60 min for transesterification ) |
| Joon et al.[5] | Jatropha oil | Catalytic and non- catalytic approaches. | An alkaline catalyst is more suitable for biodiesel production if the FFA content in the Jatropha oil is lower than 1%. | | It would increase the production cost of biodiesel. |
| Feng et.al.[6] | Jatropha oil | Transesterification | Jatropha oil with high acid value in ionic liquids and found that max biodiesel yield of 99.7% was achieved by trivalent metallic ions than bivalent ones. | | Metal chlorides have potential to be used for the commercial |

| Author | Type Biodiesel | Production Method | Properties/Performance | Comparison with diesel | Remarks |
|---|---|---|---|---|---|
| | | | | | production of biodiesel from high acid value crude oil. |
| Forson et al.[7] | Jatropha oil | JB20 and JB50 | Pure Jatropha, diesel and blends of Jatropha oil exhibited similar performance, the 2.6% by volume of Jatropha introduced into diesel fuel enhances the performance of the engine | Emission levels under comparable with diesel. | Jatropha oil can be used as fuel enhancement additive for diesel fuel. |
| Tippayawong et al.[8] | Jatropha oil, cotton seed oil, soybean oil, sunflower oil, used vegetable oil, rapeseed oil and maize oil. | Continuous flow transesterification with microwave irradiation. | High yield of over 96% can be obtained in relative short reaction time and that at a small amount of catalyst. It also concluded that microwave heating gave efficient heating for rapid conversion of Jatropha oil to biodiesel. The optimal transesterification conditions were found to be reaction time of 30s, a molar ratio of oil to methanol 1:6, | | This process can be used for continuous production of Jatropha biodiesel. |

| Author | Type Biodiesel | Production Method | Properties/Performance | Comparison with diesel | Remarks |
|---|---|---|---|---|---|
| | | | and 1.0% NaOCH3 as catalyst to give a conversion yield higher than 96%. | | |
| Ali et al.[9] | Jatropha oil | Ultrasonic energy | Jatropha oil using supported hetropolyacid catalyst and assisted by ultrasonic energy and concluded that the maximum yield of 91% was achieved in just 40 min at a molar ratio of 25:1. The low reaction time and low reaction temperature would help in improving the overall economy of the biodiesel production process. | | The maximum yield of 91% was achieved in just 40 min at a molar ratio of 25:1. |
| Kian et al.[10] | Crude Jatropha oil | Heterogeneous catalyst | The optimum conditions are 20:1 molar ratio of methanol to oil, addition of 5wt% catalyst, $700^0$C and 6 hours of reaction time. | | The optimum conditions are 20:1 molar ratio of methanol to oil, addition of 5wt% catalyst, 700C and 6 hours |

| **Author** | **Type Biodiesel** | **Production Method** | **Properties/Performance** | **Comparison with diesel** | **Remarks** |
|---|---|---|---|---|---|
|  |  |  |  |  | of reaction time. |
| Ragit et al.[11] | brown hemp | Transesterification process | Maximum recoveries of esters were observed at different preheating temperature (550C, 600C and 650C) i.e. 93.89%, 88.68% and 89.80%. The maximum conversion efficiency is achieved very close to the molar ratio of 4:1. The relative densities of hemp oil and hemp methyl ester were observed to be 6.99 and 3.37% higher than that of diesel. The kinematic viscosity of hemp oil was more than that of diesel whereas hemp methyl ester with the kinematic viscosity of 56.54% less than that of diesel. | The properties of hemp biodiesel were found to be closer to ASTM biodiesel standards. | The maximum conversion efficiency is achieved very close to the molar ratio of 4:1. |
| Amish et al.[12] | Jetropha oil |  | The highest conversion reached 84% with molar ratio of methanol to Jatropha oil of 12:1, a reaction time 6 hours, catalyst |  | In this the catalyst is recycled at least three times. |

| Author | Type Biodiesel | Production Method | Properties/Performance | Comparison with diesel | Remarks |
|---|---|---|---|---|---|
| | | | amount 6% and agitation speed of 600 rpm. | | |

## CHARACTERISTICS OF BIODIESEL

| Author | Type Biodiesel | Blending | Performance | Emission | Remarks |
|---|---|---|---|---|---|
| Jincheng et al.[13] | Jatropha oil and chinese pistache | | The thermal efficiency and performance are comparable with diesel. The fuel consumption higher than diesel. The fuel consumptions of engine are slightly higher when the engine is fuelled with two biodiesels compared to diesel. | CO, HC emission is lower at low load as compared to diesel and at higher loads same as diesel. NOx are lower at high load. | The smoke emission from the biodiesel are mostly lower than that of diesel in whole range of engine tested, and lower than that of diesel fuel at engine high |

| Author | Type Biodiesel | Blending | Performance | Emission | Remarks |
|---|---|---|---|---|---|
| | | | | | loads. |
| Agarwal et al.[1] | Linseed oil, mahua oil, rice bran oil and linseed. | 10%, 20% and 30% rice bran 10%, 20%, 30%, 50% and 100% linseed. | The performance parameters for different fuel blends were found to be closer to diesel. The BSFC were slightly higher for vegetable oil blends compared to diesel. However, BSEC for all oil blends was found to be lower than diesel. Vegetable oil blends showed performance characteristics close to diesel. Economic analysis was also conducted to find out cost for different vegetable oils, biodiesel and mineral diesel | The emission parameters for different fuel blends were found to be closer to diesel and Smoke density is higher for vegetable oil blends. | Vegetable oil blends showed performance characteristics closer to diesel. |
| Ramadhas et al.[14] | Rubber seed oil | 20% and 100% | Lower concentration of biodiesel improved the thermal efficiency. | | With increase in compression ratio brake thermal efficiency increase. |

| Author | Type Biodiesel | Blending | Performance | Emission | Remarks |
|---|---|---|---|---|---|
| Ganpathy et al.[15] | Jatropha biodiesel | 100% | Brake thermal efficiency increases with stroke length; cylinder bore and decreases with combustion duration. The brake thermal efficiency does not change with the variation of cut off ratio and relative air fuel ratio. | | |
| Mallikappa et al.[16] | Cardanol bio fuel | 10%, 15%, 20% and 25% | BSEC decreased by 25-30% with increase in brake power. Brake thermal efficiency increase with increase brake power. The brake thermal efficiency obtained from biodiesel is less than diesel. | NOx, CO emission increases with increased proportion of blends. | The carbon monoxide emissions increased with higher blends, and increases slightly after 20% blends. |
| Jindal et al.[17] | Jatropha methyl ester | JB100 | The BSFC is always higher for B100 than B0 by about 25-34%. At higher compression ratio, brake power increases. | At full load, HC, NOx, exhaust temperature and | Compression ratio 17:1 and injection pressure |

| Author | Type Biodiesel | Blending | Performance | Emission | Remarks |
|---|---|---|---|---|---|
|  |  |  | The brake thermal efficiency also improves as increase in compression ratio (18:1) by 5.5%. Similarly improvement is found with higher injection pressure of 250 bar by 2.3%. | smoke opacity of exhaust are found lower for B100 as compared to diesel. Whereas at compression ratio 17:1 and injection pressure of 200 bar the HC emissions (16ppm) were found lowest. | of 200 bar were found optimum parameters. |
| Narayana etal.[18] | Jatropha oil | jatropha oil and biodiesel | Increasing the injector pressure increase the BTE. When injection timing is retarded and enhanced injection rate then emission with Jatropha oil lower than diesel. | The advancing injection timing from base diesel value and increasing the injector opening pressure reduce HC and smoke | Enhanced injection rate then emission with Jatropha oil lower than diesel. |

| Author | Type Biodiesel | Blending | Performance | Emission | Remarks |
|---|---|---|---|---|---|
|  |  |  |  | emission significantly |  |
| Varatharajan et al.[19] | Jatropha biodiesel with antioxidant additive | 100% | Slightly increase in BSFC was observed with L-ascorbic acid whereas ethylenediamine slight reduction in BSFC as compared to diesel. | NOx reduction of 43.55% was observed with this additive the minimum and maximum NOx produced were 1.57 and 2.05 g/kWhr respectively, And also meets III B Euro emission standards. | Slight reduction in specific fuel consumption compared to diesel. |
| Arakshita et al.[20] | Hempel distilled bio oil | 5%,7.5%, 10% and 15% | 10% blend is meeting all the specification of the commercial diesel. | 10% blend meet the BS-II specification | Used up to 10% blend |
| Grimsby et al.[21] | Jatropha oil | 100% | 3.8. 55% of energy harvested as fruits is in the form of seed cake, 21% of the energy is found in the fruit coats and |  | 24% of the energy contained in the Jatropha |

| Author | Type Biodiesel | Blending | Performance | Emission | Remarks |
|---|---|---|---|---|---|
| | | | | | fruits is recovered in the Jatropha oil. |
| Pradeep et al.[22] | Jatropha oil | 100% | BTE was found to be comparable with diesel, at all loads with and without EGR. | The NOx emission with Jatropha biodiesel found to be higher than the diesel fuel whereas at full load NOx emission from Jatropha with 15% EGR was found to be lower than diesel. | With 15% EGR the NOx emission from Jatropha oil found lower than diesel. |
| Rajesh et al.[23] | Jatropha biodiesel | JB100 | 20% lower free stream velocity for bio diesel as compared to that of diesel. | | Low volatility and higher flash point of the bio diesel. |

| Author | Type Biodiesel | Blending | Performance | Emission | Remarks |
|---|---|---|---|---|---|
| Rakesh et al.[24] | Jatropha, Palm biodiesel | 20-40% Palm biodiesel blend with Jatropha biodiesel | The oxidation stability of Jatropha biodiesel has been found to increase with increase in dosage of antioxidant. |  | Combination of Jatropha and palm biodiesel has optimum mix for Asia. |
| Singh et al.[25] | Jatropha | 25%, 50%, 75% and 100% | Diesel engine can be run satisfactory without any change in engine up to 10% blending of de-waxed and de-gummed Jatropha oil directly without preheat the diesel. The biodiesel from Jatropha oil offer higher brake thermal efficiency than blended de waxed de gummed Jatropha oil or even from diesel |  | More than 10% Jatropha oil can be used in engine with $60^0$C preheating the Jatropha oil. It is concluded that the energy value remaining portion of Jatropha fruit is twice that of biodiesel |

| Author | Type Biodiesel | Blending | Performance | Emission | Remarks |
|---|---|---|---|---|---|
| Sahoo et al.[26] | Jatropha, Karanja and Polanga | JB20, JB50, JB100, KB20, KB50, KB100 | The methyl esters of Jatropha, karnja and polanga oil have relatively closer fuel property value to that of diesel and also the blends of biodiesel. Blends of biodiesel increase the flash point of diesel, hence safer to store biodiesel blends. | | The blends of biodiesel increase the flash point of diesel. |

## 2.3 LIMITATIONS FROM LITERATURE

Literature survey showed that the work has done on the transesterification of edible oils but limited work done on transesterification of non-edible oils production. Testing of available methyl ester and compares these results with ASTM standards fuel test for edible oil such as Soya-bean, Sun-flower and Mustard oil etc.

- Limited comparisons of properties of non-edible biodiesel oil.
- Limited data are available for optimization of transesterification process for non-edible oils for large scale production.
- Only up to 20% blends of biodiesel oil is accepted for use in diesel engine.

## 3 METHODOLOGY

The performance and emission characteristics of diesel engine are reduced by using biodiesel blends as fuel up to 20%. Most of biodiesels are made from edible seeds. But in India edible seeds can't be used for bio-diesel production, as its indigenous production does not meet our current demand. The main non edible oils are Jatropha Curcas, Pongamia Pinnata, Neem and hemp etc. Among these non-edibles tree borne oilseed (TBO), Jatropha Curcas has been identified as the most suitable seed for India. It grows practically all over India under a variety of agro climatic conditions. It can be grown in arid zones (20 cm rainfall) as well as in higher rainfall zones and even on the land with thin soil cover.

### 3.1 OBJECTIVE OF RESEARCH

1. To determine the properties of non-edible (Jatropha, hemp and Neem oil) biodiesel.
2. To compare the performance and emission characteristics of these non-edible biodiesel.
3. To perform experiments by using these nonedible biodiesels blends as fuel on single cylinder constant speed four stroke direct ignition diesel engine and optimize the compression ratio.

### 3.2 DETERMINATION OF FUEL PROPERTIES

The following equipment was used to determine the fuel properties which are shown in table 3.1. The fuel properties of Jatropha, neem and hemp ester were determined and shown in table 3.2 along with the relevant specifications from the biodiesel standards ASTM D6751 and EN 14214.

The fuel properties of non-edible biodiesel oil as following.

1. Density
2. Kinematic viscosity
3. Free fatty acids (FFA)
4. Carbon residue

5. Cloud point
6. Pour point
7. Flash point
8. Fire point
9. Calorific value

**Table 3.1: Different apparatus and standards used for fuel**

| Name of fuel Properties | Methods | Standards |
|---|---|---|
| Kinematic Viscosity | Redwood Viscometer | IS:1448[P:25]:1976 |
| Flash point and fire point | Closed cup flash and fire point apparatus | IS:1448[P:32]:1992 |
| Cloud point and pour point | Cloud and pour point apparatus | IS:1448[P:10]:1970 |
| Calorific value (MJ/Kg) | Bomb Calorimeter | IS:1448[P:6]:1984 |
| Carbon Residues | Carbon Residue Apparatus | ASTM D189-IP 13 OF IIP |
| Ash content | Electric Muffle Furnace | ASTM D482-IP 4 OF IIP |

### 3.2.1 APPARATUS USED

The properties of the biodiesel were determined by following apparatus.

**(a) Red wood viscometer**

The Redwood viscometer measures the kinematic viscosity of fluid. The instrument measures the time of gravity flow in seconds of a fixed volume of the fluid (50 ml) through specified orifice made in an agate piece as per IS:1448[P:25] 1876. 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 specified level indicated in the cup. The cup was surrounded by water jacket having an immersion heater. The kinematic viscosity in centistokes was calculated from time units by using the following relationship given by Guthrie (1960).

When $34<t<100$ then

$$vk = 0.26t - \frac{179}{t}$$

When t>100

$$vk = 0.24t - \frac{50}{t}$$

$vk$ = Kinematic viscousty

$t$ = Time for flow of 50ml sample

**(b) Calorific value**

The heat of combustion or calorific value of a fuel is an important property. It is the heat produced by the fuel within the engine to produce use full work. The gross heat of combustion of fuel samples was determined as per IS: 1448 [P: 6]:1984 with the help of Isothermal Bomb Calorimeter. A fuel sample of 1ml 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 was also determined using pure and dry benzoic acid as test fuel.

$$Hc = \frac{W_c \ X \ \ \Delta T}{M_s}$$

Where

$H_c$ = Heat of combustion of the fuel sample Cal/g

$W_c$ = Water equivalent of the calorimeter Cal/$^0$C

$M_s$ = Mass of sample burnt g

**(c) Cloud and pour point**

The cloud point is defined as the temperature at which a cloud or haze of was 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. The 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 consists of 12cm vertical tubes 3cm diameter. The tubes are covered in an air jacket, which is filled with a freezing mixture of crushed ice and sodium chloride crystals. The sample tube is taken out from cold jacket at every $1^0$C interval as temperature falls and inspect for cloud formation. The point at which a haze was first seen at the bottom of the sample which is taken as the cloud point.

The procedure for the pour point was same as for cloud point the only different is that the sample was pre-heated to $48^0$C and cool to $35^0$C in air before it was put in tube. The pour point was taken as $1^0$C above the temperature at which there was no motion of fuel over five seconds on tilting the tube to the horizontal position.

### (d) Flash and fire point

The flash point is the property of the fuel in which the fuel form a flammability mixture with air under controlled conditions. 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. The flash and fire point of the fuel was determined as per IS: 1448 [P: 32]:1992. The sample was filled in the test cup and heated by heating the air bath with the help of heater at slow and constant rate with continuously stirring. The temperature was measured with the help of a thermometer (-10 to $400^0$C range). For every $1^o$C interval the flame was introduced for a moment with the help of shutter. The temperature at which a flash appeared in the form of sound and light was read as flash point. The fire point was recorded as the temperature at which fuel vapours catches fire and stays for minimum of five seconds.

### (e) Ash content

Ash in a fuel can result from oil, the water soluble material compounds or external solids, such as dirt and dust. The ash content of Jatropha, neem and hemp oil were measured as per the standard ASTM D482-IP 4 of institute of petroleum USA. An electric muffle furnace was used in the experiment as shown in figure 3.4. In order to measure the ash content the sample was taken in a silica dish. The weight of empty dish was measured first and then measured with the sample. The weight of sample can be determined by taking difference of initial and final weight of the dish. The sample was placed in the muffle furnace and heated at $775 \pm 25^0$C for two hours. The ash content was obtained using following equation.

$$A_s = \frac{W_a}{W_s} X\ 100$$

Where

$A_s$ = Ash Content present in the sample

$W_a$ =Weight of ash in g

$W_s$ = Weight of sample in g

**(f) Carbone residue**

The carbon residue was determined by using a carbon residue apparatus. The measurement was taken according to the ASTM D189-IP 13 of institute of petroleum London. By this procedure the amount of carbon residue left after evaporation and pyrolysis of oil. In this method 10g weight to nearest 5mg of each fuel sample was weight free of moisture and other suspending matter into an iron crucible of the apparatus. The crucible was then placed in the centre of skid more crucible of the apparatus and the sand was leveled in the large sheet iron crucible and then the skid more crucible was set on it in the exact center of the iron crucible. Thereafter, the covers were applied to both skid more 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 tilled so that the gas flame plays on the sides of the crucible for the purpose of igniting the vapours. After that the ignited vapours was burnt uniformly with the flame above the chimney for another period of time. When the vapours 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 skid more was then removed with a tong and it was cooled and weighed. The percentage of carbon residue on the original sample was then calculated by following as given below.

$$C_r = \frac{W_c}{W_s} X\ 100$$

Where

$C_r$ = Carbon residue in percentage

$W_c$ = Weight of carbon residue in g

$W_s$ = Weight of sample in g

## 3.3 PERFORMANCE AND EXHAUST EMISSION

The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. Setup is provided with instrumentation for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for $P\,\theta - PV$ diagrams. Rota meters are provided for cooling water and calorimeter water flow measurement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio. Labview based Engine Performance Analysis software package “Enginesoft” is provided for on line performance evaluation.

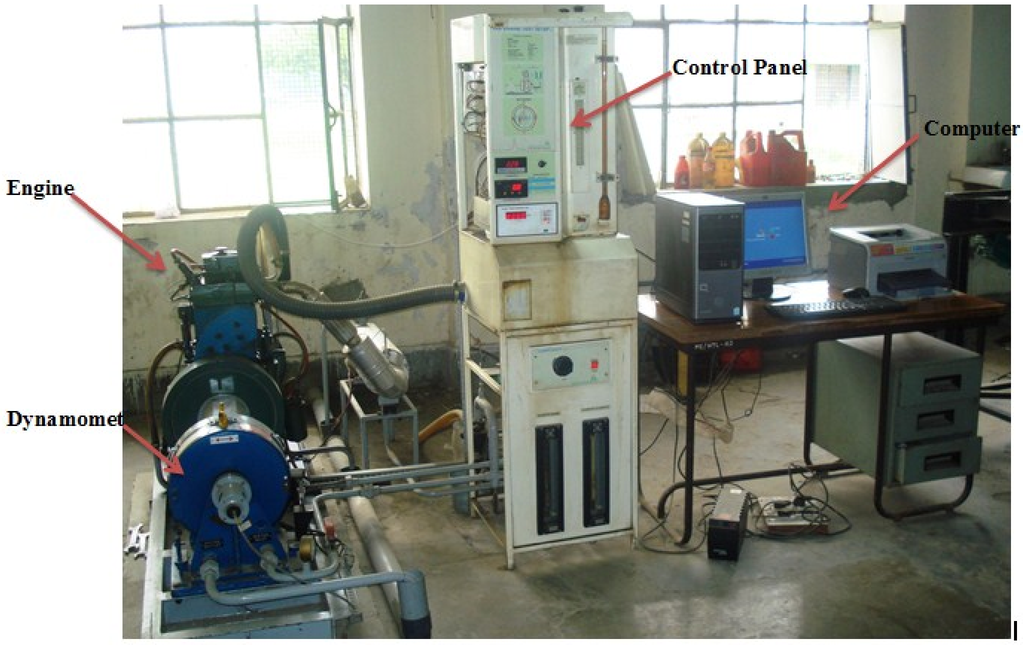

Figure 3.1: Engine Experimental Setup

The fuel tank was fabricated with appropriate valves for fuel supply. Fuel consumption was measured through graduated fuel metering tube controlled through the metering/regular option of the fuel metering cock. Air box with U tube manometer measures air flow rate. The software package used was complete in all aspects for calculations. The readings were taken under stabilized condition of the engine.

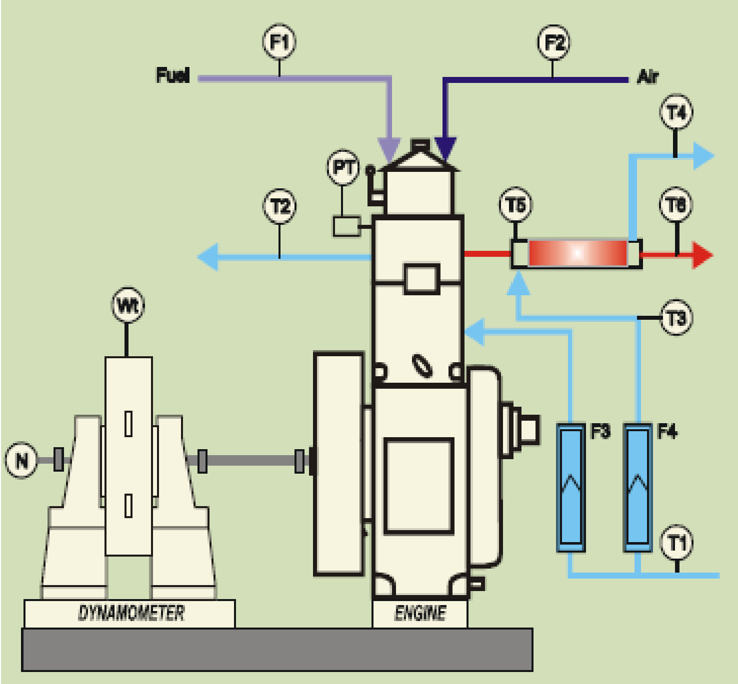

Figure 3.1: Engine Parameters

**Table 3.2 :The detailed specification of the engine setup[27]**

| Sr. No. | Items | Specifications |
|---|---|---|
| 1. | Engine | Make Kirloskar, Type 1 cylinder, 4 stroke Diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110mm, bore 87.5 mm. 661 cc, CR 17.5, Modified to VCR engine CR range 12 to 18 |
| 2. | Dynamometer | Make Saj test plant Pvt. Ltd., Model AG10, Type Eddy current |
| 3. | Dynamometer Loading unit | Make Apex, Model AX-155. Type constant speed, Supply 230V AC. |
| 4. | Manometer | Make Apex, Model MX-104, Range 100-0-100 mm, Type U tube, Conn. 1/4`` BSP hose back side, Mounting panel |
| 5. | Piezo sensor | Make PCB Piezotronics, Model HSM111A22, Range 5000 psi, Diaphragm stainless steel type & hermetic sealed |
| 6. | Crank angle sensor | Make Kubler-Germany Model 8.3700.1321.0360 Dia: |

|  |  |  |
|---|---|---|
|  |  | 37mm Shaft Size: Size 6mmxLength 12.5mm, Supply Voltage 5-30V DC, Output Push Pull (AA,BB,OO), PPR: 360, Outlet cable type axial with flange 37 mm to 58 mm |
| 7. | Temperature sensor | Make Radix Type K, Ungrounded, Sheath Dia.6mmX110mmL, SS316, Connection 1/4"BSP (M) adjustable compression fitting |
| 8. | Load sensor | Make Sensotronics Sanmar Ltd., Model 60001,Type S beam, Universal, Capacity 0-50 kg |
| 9. | Fuel flow transmitter | Make Yokogawa, Model EJA110-EMS-5A-92NN, Calibration range 0-500 mm H2O, Output linear |
| 10. | Air flow transmitter | Range (-) 250 mm WC |
| 11. | Rotameter | Make Eureka Model PG 5, Range 25-250 lph, Connection ¾” BSP vertical, screwed, Packing neoprene |
| 12. |  | Make Eureka Model PG 6, Range 40-400 lph, Connection ¾” BSP vertical, screwed, Packing neoprene |
| 13. | Pump | Make Kirloskar, Model Mini 18SM, HP 0.5, Size 1” x 1”, Single phase 230 V AC |

## 3.4 ENGINE TEST PROCEDURE

A four stroke single cylinder water cooled diesel engine was employed for the study. The detailed specification of the engine setup is given in the table 3.2. The experiment setup is shown in the Figure 3.2. The smoke meter was used to measure the smoke opacity of exhaust gas. The gas analyzer was used to measure the concentration of gaseous emissions such as oxides of nitrogen, unburned hydrocarbon, smoke opacity, carbon monoxide, carbon dioxide and oxygen level. The performance and emission tests are carried out on the CI engine by using various blends of biodiesel and diesel as fuel. The tests are conducted at the constant speed of 1500rpm at varies load condition. The experimental data presented here using various graphs. The test are aim to find the comparative study of different non edible biodiesel. In the each experiment engine parameters related to thermal performance of engine such as brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature and BMEP are measured. Also the engine emission parameters like oxides of nitrogen, unburned hydrocarbon, smoke opacity, carbon monoxide, carbon dioxide and oxygen level.

### 3.4.1 ENGINE

The diesel engine with pressure transducer for sensing cylinder gas pressure and thermocouple for sensing exhaust gas temperature is shown in figure 3.5. The engine has open type combustion chamber in an aluminum alloy piston in combination with long stem nozzle. The fuel is supplied to the fuel pump by gravity feed through the fuel tank and paper element filter. The engine lubrication is done by forced feed to main and large end bearings and camshaft bush. The engine can be started by hand cranking using decomposition lever.

### 3.4.2 EDDY CURRENT DYNAMOMETER

It consists of a stator on which are fitted a number of electromagnets and a rotor disc and coupled to the output shaft of the engine. When rotor rotates eddy currents are produced in the stator due to magnetic flux set up by the passage of field current in the electromagnets. These eddy currents oppose the rotor motion, thus loading the engine. These eddy currents are dissipated in producing heat, hence required cooling arrangement. A moment arm measures the torque with the help of force sensor. The load controlled by regulating the current in electromagnets. The SAJ make AG20 eddy current dynamometer was used for present investigation. Dynamometer load measurement was from a strain gauge load cell.

### 3.4.3 CONTROL PANEL

The control panel was equipped with rotameter, inlet water temperature indicator from engine, outlet water temperature indicator from engine, outlet water temperature indicator from calorimeter, loading switch and speed indicator. The setup control panel is shown in figure 3.1.

### 3.4.4 SOFTWARE

The software is designed by M/s Apex Innovations Pvt. Ltd. Sangali for testing IC engine and finds the effect of various parameters on the performance of engine. The software is configurable for different parameters of an engine as shown in table 3.3 below.

**Table 3.3 : Enginesoft Configuration data[27]**

| Sr.NO. | Parameter | Value |
|---|---|---|
| **Set up constants** | | |
| 1. | No of PO cycles | 5 |
| 2. | Cylinder pressure plot ref | 2010 |
| 3. | Fuel read time | 60 sec |
| 4. | Fuel factor | 0.012 kg/Volt |
| 5. | Orifice diameter | 20 mm |
| 6. | Dynamometer arm length | 185 mm |
| **Engine and set up details** | | |
| 7. | Engine power | 5.2 kW |
| 8. | Engine max speed | 1500 RPM |
| 9. | Cylinder bore | 87.5mm |
| 10. | Stroke length | 110mm |
| 11. | Connecting rod length | 234mm |
| 12. | Compression ratio | 16.87 |
| 13. | Compression type | VCR |
| 14. | Stoke type | Four |
| 15. | No. of cylinders | One |
| 16. | Speed type | Constant |
| 17. | Cooling type | Water |
| 18. | Dynamometer type | Eddy current |
| 19. | Indicator used type | Cylinder pressure |
| 20. | Interface type used | PCI-1050 |
| 21. | Calorimeter used | Pipe in pipe |
| **Theoretical constants** | | |
| 22 | Fuel density | 830 kg/m$^3$ |
| 23 | Calorific value | 42000 kJ/kg |
| 24 | Orifice coefficient of discharge | 0.60 |
| 25 | Sp heat of exhaust gas | 1.1 kJ/kg-K |
| 26 | Max sp heat of exhaust gas | 1.25 kJ/kg-K |
| 27 | Min sp heat of exhaust gas | 1.1 kJ/kg-K |

| | | |
|---|---|---|
| 28 | Specific heat of water | 4.186 kJ/kg-K |
| 29 | Water density | 1000 kg/m$^3$ |
| 30 | Ambient temperature | 30$^0$C |

## 3.5 EXPERIMENTATION METHODOLOGY

First of all the test was performed with petro diesel for getting the base line data of the engine and then blends of Jatropha, neem and hemp. The performance of the engine was evaluated in terms of brake thermal efficiency, brake specific energy consumption, exhaust gas temperature, HC, CO, $CO_2$, $O_2$ and $NO_x$. The evaluated results have been comparing with petro diesel and blends of biodiesel.

### 3.5.1 EXPERIMENTE PROCEDURE

1. Ensure all electrical connections are properly connected.
2. Check water supply stop valves.
3. Check selected fuel about 2 liters in quantity in the fuel tank and fuel supply knob on regular position.
4. Star water supply pump and set cooling water flow rate for engine at 300 LPH and calorimeter flow rate at 80 LPH. Maintained this flow rate throughout the experiment. Ensure cooling water flow rate for dynamometer cooling.
5. Switch on electric supply of computer through UPS and open the engine software.
6. Now start engine by cranking handle. Let the engine run on no load for warmed up. The switch on gas analyzer for warmed up.
7. Change the fuel properties (Calorific value and specific gravity) in the configure option.
8. Click RUN button to run the engine for fifteen minutes so that engine gets stabilized. After stabilize engine turn the fuel knob to metering position. Also click log button. After 1 minute the display changes to input mode for file name. Also input the value of compression ratio, water flow rate in cooling jacket and calorimeter and then the file name for data storage to hard disk. Now turn the fuel knob to regular position.

9. Insert the gas analyzer probe of analyzer in exhaust pipe. Choose appropriate mode for reading of instrument from display. After reading is stabilized get the print out.
10. Change the load on engine by increasing electric supply to dynamometer from knob and allow engine to run for 15 minutes for stabilization at new load. After stabilization again turn the fuel knob to metering position and click log button. After 60 seconds logging is over and enters the value cooling water and calorimeter water flow rate. Turn back the knob to regular position and take the gas analyzer reading and smoke meter reading.
11. Repeat the procedure for loads of 3, 5, 7 and 10.
12. Reduce the load to minimum position gradually ensuring that the RPM maintained at 1500 rpm.
13. Save the files with name.
14. Turn off engine and shut down computer.
15. Water flow rate for engine and calorimeter should be on for 15 minutes.
16. Turn off the water pump and close the water supply valves.

### 3.5.2 PERFORMANCE PARAMETER OF ENGINE AND EXHAUST EMISSION

The engine performance setup with high speed data acquisition system was used for study the results. The following parameters were performed on engine experimental setup.

1. Brake power
2. Fuel consumption
3. Air consumption
4. Exhaust gas temperature
5. Cooling water temperature (inlet and outlet)
6. Speed of engine
7. Exhaust gas analysis ($NO_x$ , $CO_2$, HC, CO and $O_2$)

#### 3.5.2.1 PERFORMANCE MEASUREMENT

The brake power is one of the most important parameter in the engine experiment. The eddy current dynamometer was used for loading the engine. The fuel consumption is measured by determining the time required for consumption of given volume of fuel using glass burette. The mass of fuel was calculated by multiplying it by the specific gravity of fuel. An air box method was used to find air consumption. In this method orifice meter and manometer was used for accurate volumetric measurement of air consumption and finally mass flow rate was determined. The digital temperature sensor was used for temperature measurement.

#### 3.5.2.1.1 Brake specific fuel consumption

It is defined as the fuel flow rate per unit power output. It is a measure of efficiency of the engine consuming fuel to produce work. It is desirable to be low BSFC meaning engine used less fuel to produce same work output. It is most important parameter to compares the different fuel.

#### 3.5.2.1.2 Brake mean effective pressure

The brake mean effective pressure is an important for improving different fuel. It is the average pressure of gas inside engine cylinder based on neat power. BMEP is important because it is independent of RPM and the size of the engine.

#### 3.5.2.1.3 Brake thermal efficiency

It is the ratio of the thermal power available in the fuel to the power deliver to shaft. It is depends on how the energy converted. It is also depends on fuel heating value.

#### 3.5.2.1.4 Exhaust gas temperature

The exhaust gas temperature of the IC engine is containing unburned combustion product and some heat. When the air fuel ratio is high then the amount of incomplete combustion products is low because there is excess oxygen for complete combustion. It is also relate to the engine efficiency.

### 3.5.2.2 GAS ANALYZER

Gas analyzer is used to measure emissions of CO, HC, $CO_2$, O2 and NO. It measures CO, HC and $CO_2$ using infrared measurement and $O_2$ and NO using electrochemical measurement technique. The following are the precaution for using gas analyzer.

1. Do not allow the exhaust gas for long time. Insert the probe into exhaust pipe only when readings are taken.

2. Before switch off the instrument unit should be purged with clean ambient air for few minutes.
3. Instrument must be switched on once every month to charge the battery.
4. Pre filter, particulate filter and condensate filter must be changed as per schedule.
5. Check the calibrations of instrument time to time.
6. Insert the probe at least 30 cm into exhaust pipe.

# 4 RESULT AND DISCUSSION

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

A 5.2 kW stationary constant speed single cylinder 4 stroke diesel engine having a standard injection timing of $23^0$ BTDC was tested on diesel and blends of Jatropha, neem and hemp. 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 analytical interpretation with discussion are presented in this chapter.

## 4.1 PROPERTIES OF JATROPHA, NEEM AND HEMP

### 4.1.1 KINEMATIC VISCOSITY

The kinematic viscosity of diesel, neem, Jatropha and hemp were found as 3.7, 2.7, 4.82 and 3.83cSt. at $40^0$C. The result indicated that Jatropha biodiesel have more kinematic viscosity.

### 4.1.2 FLASH AND FIRE POINT

The Jatropha biodiesel was found to have higher flash point and fire point as compare to neem, hemp biodiesel and petro diesel. The hemp biodiesel was found to have lower flash and fire point than that of diesel.

### 4.1.3 DENSITY

The density of diesel, Jatropha, neem and hemp were found as 830, 871,868 and 858 at $15^0$C. The results indicated that the density of biodiesel oil have more than the petro diesel. The results show that Jatropha biodiesel have higher and hemp biodiesel have low density.

### 4.1.4 CALORIFIC VALUE

The calorific value of diesel, Jatropha, neem and hemp were found as 43, 42.80, 39.80 and 42.92 MJ/Kg respectively. The calorific value of Jatropha biodiesel is decreased by 0.5% than diesel. The result shows that the caloric value of neem biodiesel is 7.40% lower than diesel and hemp biodiesel have 0.2% lower.

### 4.1.5 CLOUD POINT AND POUR POINT

The results show that the cloud point and pour point of Jatropha, neem biodiesel have higher than petro diesel and that of hemp biodiesel have cloud point has higher and cloud point has lower than diesel.

**Table 4.1: Fuel properties of Jatropha, neem and hemp biodiesel compare to Diesel**

| Properties | Units | Diesel | Jatropha | Neem | Hemp | ASTM D6751 | EN14214 |
|---|---|---|---|---|---|---|---|
| Density (at $15^0$C ) | kg/$m^3$ | 830 | 871 | 868 | 858 | - | 860-900 |
| Kinematic viscosity (at $40^0$C) | cSt | 3.7 | 4.82 | 2.7 | 1.13 | 1.9-6.0 | 3.5-5.0 |
| Flash point | $^0$C | 60 | 128 | 76 | 47 | >130 | >101 |
| Fire Point | $^0$C | 65 | 136 | 81 | 55 | - | Min 120 |
| Cloud point | $^0$C | -12 | 8 | 9 | -4 | 10 | -1 |
| Pour point | $^0$C | -16 | -2 | 2 | -17 | -15 | - |
| Calorific value | MJ/kg | 43 | 42.80 | 39.81 | 42.92 | - | - |

## 4.2 ENGINE PERFORMANCE AND EXHAUST EMISSION ANALYSIS

### 4.2.1 PERFORMANCE CHARACTERISTICS

#### 4.2.1.1 OPTIMUM COMPRESSION RATIO

The brake thermal efficiency with respect to compression ratio for the different blends of Jatropha biodiesel consider for the optimization of compression ratio. The results show that the break thermal efficiencies at no load are lower for all blends of Jatropha as shown in figure 4.1. The efficiencies have maximum at the compression ratio between 17:1 to 18:1. Hence, the further studies for comparison between Jatropha, neem and hemp with diesel have been done at 17.5:1.

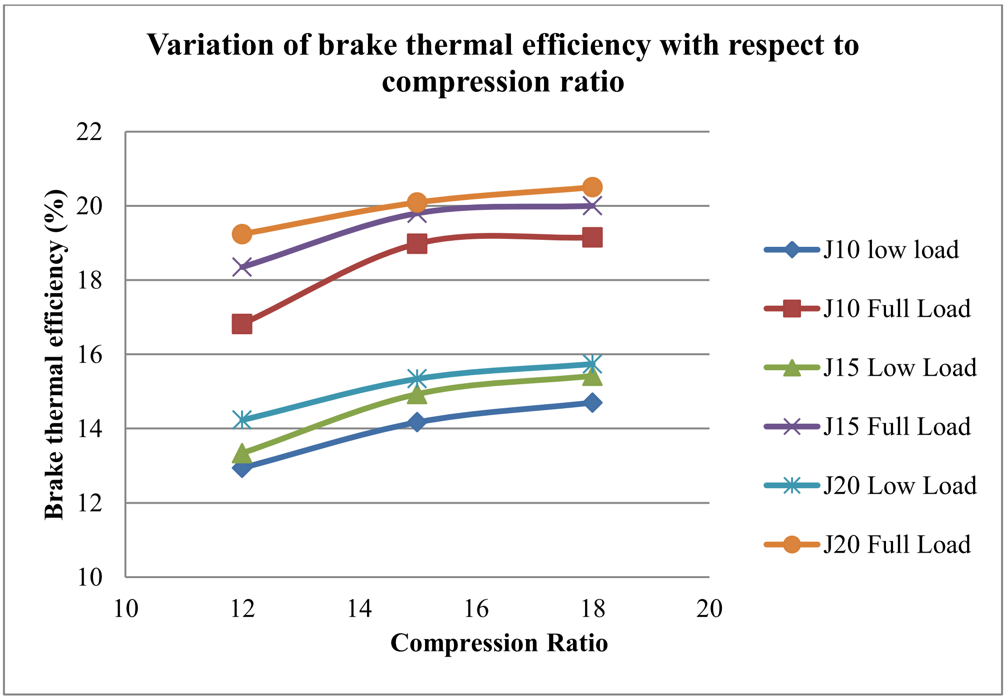

**Figure 4.1: Variation of brake thermal efficiency with respect to compression ratio**

#### 4.2.1.2 BRAKE THERMAL EFFICIENCY

The variation of brake thermal efficiency with respect to brake power for different biodiesel at 10% blends consider for the analysis as shown in figure 4.2. At no load the brake thermal efficiency for all biodiesel blends found nearly same as diesel. The brake thermal efficiency of Jatropha biodiesel is same as diesel up to 30% load.

Whereas the brake thermal efficiency of neem and hemp blends are 9.8% lower than diesel. The brake thermal efficiency of Jatropha and neem blends are nearly same at 75% load but 6.4% lower than diesel. The hemp blend is lower brake thermal efficiency after 50% load.

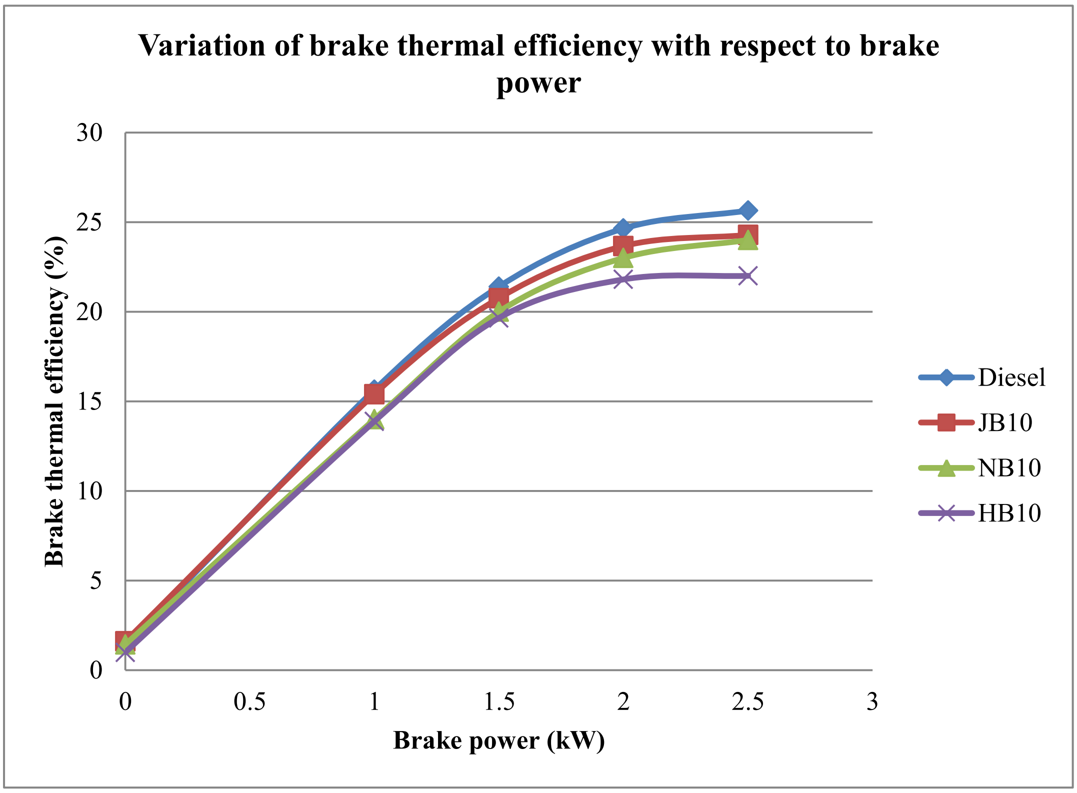

**Figure 4.2: Variation of break thermal efficiency with respect to break power**

The variation of brake thermal efficiency with respect to brake power for different biodiesel at 15% blends consider for the analysis as shown in figure 4.3. The brake thermal efficiency at 15% blend at no load JB15 slightly more than diesel whereas it reduces 6% up to 30% load. The brake thermal efficiency of NB15 is same trend as diesel. The brake thermal efficiency of HB15 reduces to 11.5% at 75% load.

The variation of brake thermal efficiency with respect to brake power for different biodiesel at 20% blends consider for the analysis as shown in figure 4.4. The brake thermal efficiency of all blends are same up to 33% load and it reduces 8.8% for HB20 and 5.5% for JB20. The brake thermal efficiency trend same for NB20 as compares to diesel.

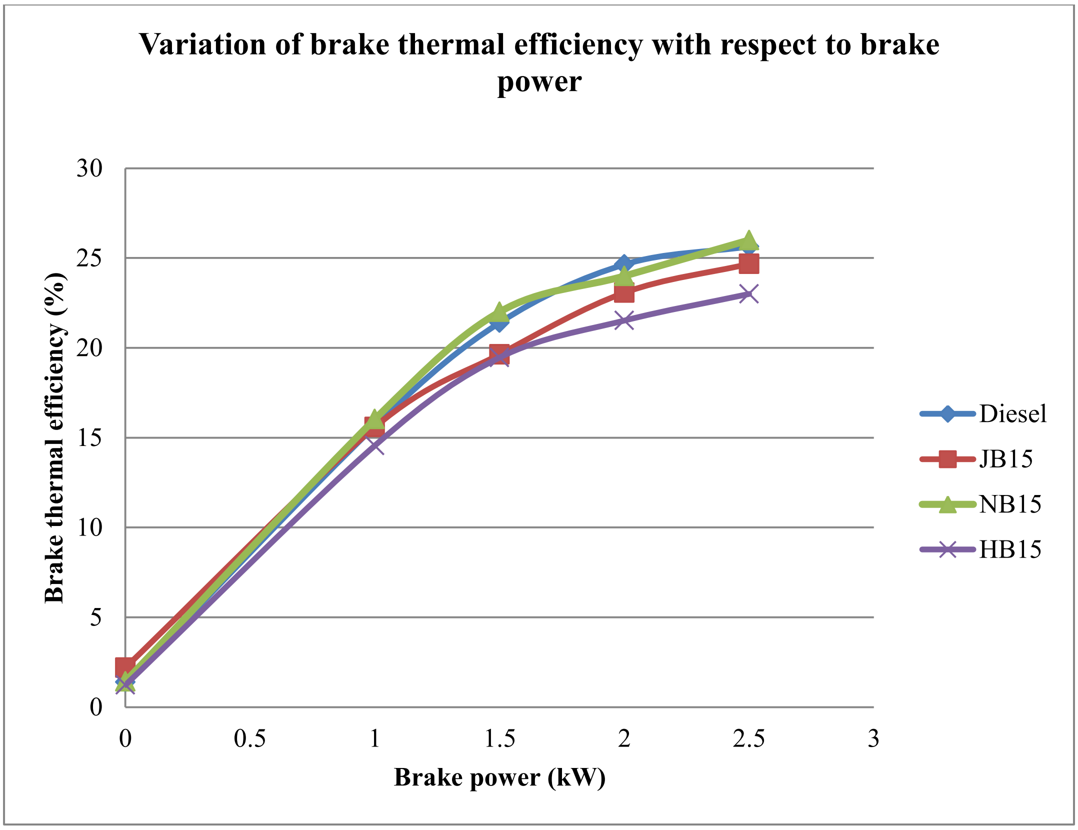

Figure 4.3: Variation of brake thermal efficiency with respect to brake power

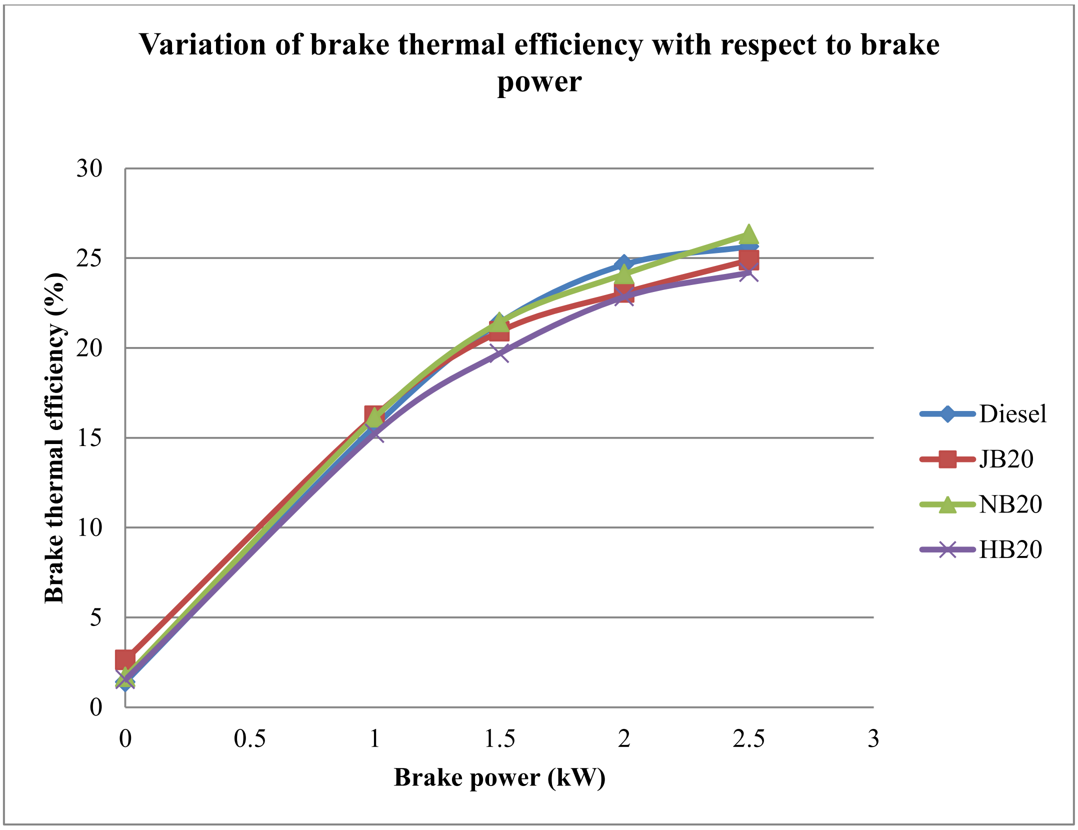

Figure 4.4: Variation of brake thermal efficiency with respect to brake power

The variation of brake thermal efficiency of different biodiesel blends are shown in the following figure 4.5. The brake thermal efficiency trends are same for all blends up to 33% load and after the 33% load the brake thermal efficiency reduces for biodiesel blends. The brake thermal efficiency of all blends of neem biodiesel found 5.5% higher as compares to Jatropha and hemp biodiesel blends. The brake thermal efficiency of all blends of hemp biodiesel HB20 gives higher than HB15 and HB10. The brake thermal efficiency of blends of jatropha biodiesel JB15 reduces 3.8% whereas JB20 reduces 3% and JB10 reduces 5.3% as compare to diesel at 75% load.

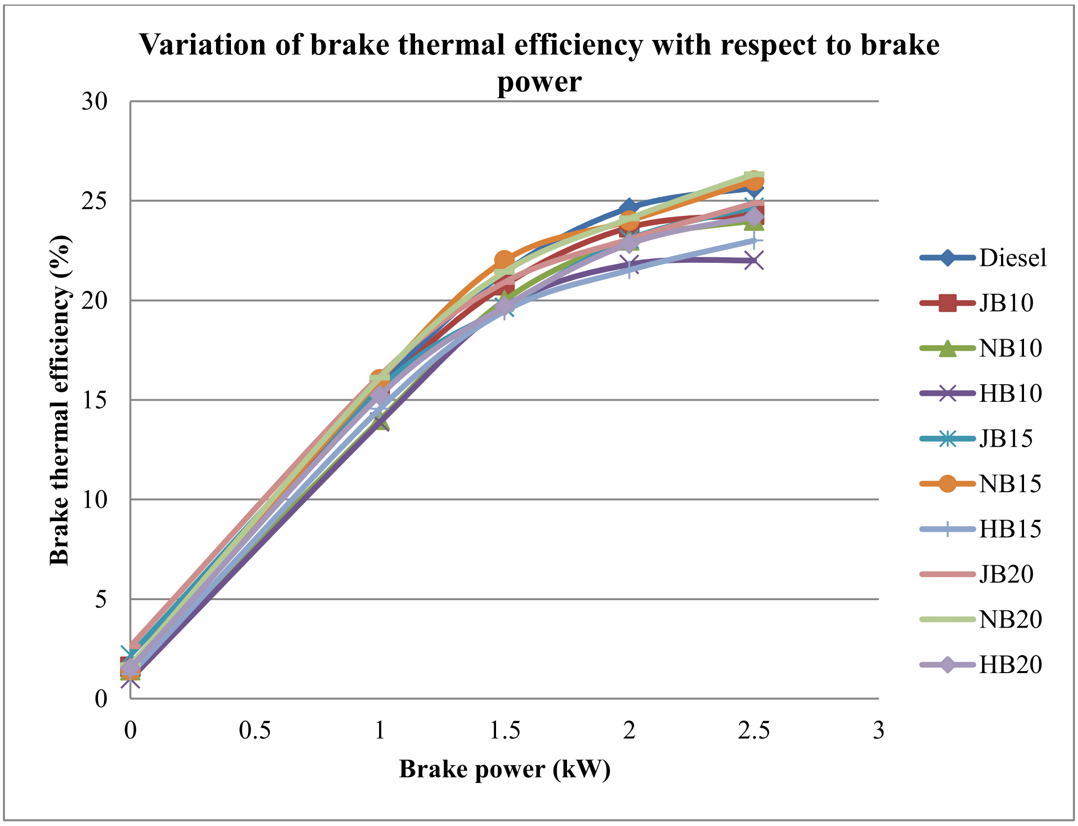

**Figure 4.5: Variation of brake thermal efficiency with respect to brake power**

### 4.2.1.3 BRAKE SPECIFIC FUEL CONSUMPTION

The variation of brake specific fuel consumption with brake power for 10% blends of biodiesel and diesel is shown in figure 4.6. The brake specific fuel consumption for all blends of biodiesel shows the same trend as diesel fuel whereas the BSFC for hemp blend HB10 41% more than diesel at no load. The JB10 is 13% lower BSFC as compare to diesel and BSFC for NB10 is 0.05% higher than diesel. The NB10 is lower BSFC among the three biodiesel blends and diesel. The brake specific fuel consumption for 15% blends of biodiesel and diesel as shown in figure 4.7. The BSFC for HB15 is 13% higher than diesel whereas JB15 is 48% lower than diesel. The BSFC for all blends of biodiesel and diesel are same after 43% load. The HB15 and NB15 trend same as diesel. The JB gives lowest BSFC as compare to NB15, HB15 and diesel.

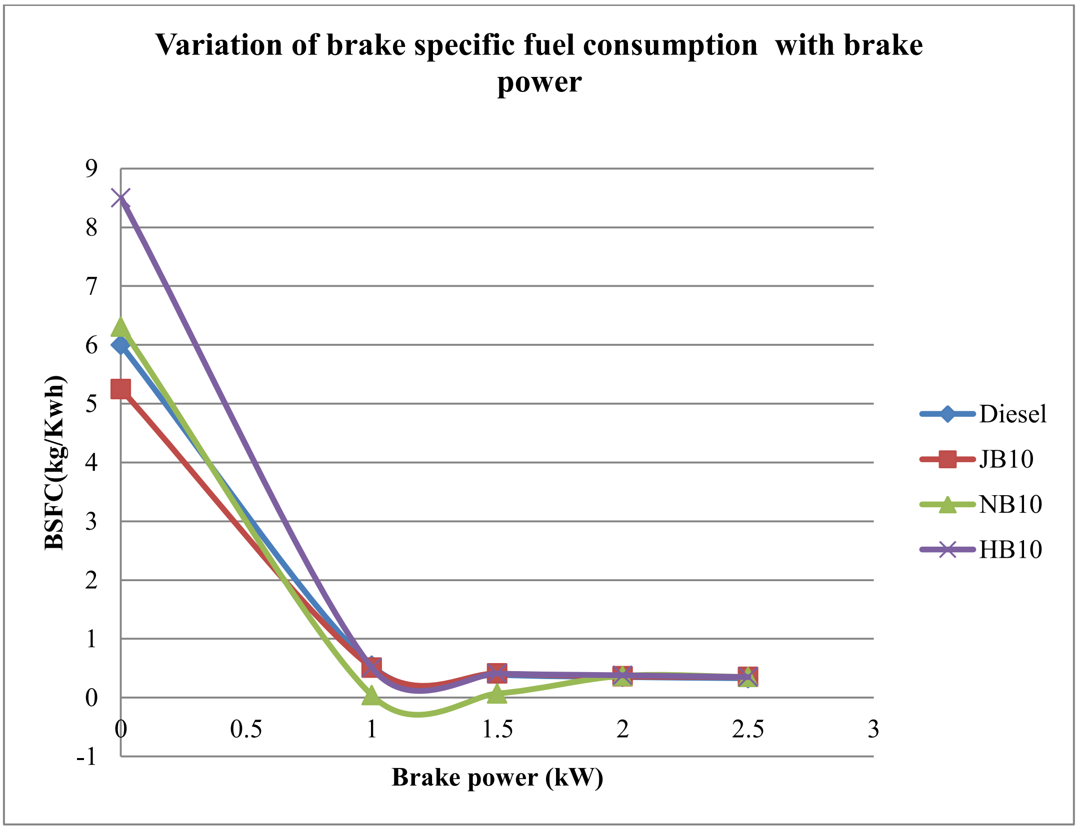

**Figure 4.6: Variation of brake specific fuel consumption with respect to brake power**

The variation of BSFC and brake power for 20% blends of different biodiesel and diesel shown in figure 4.8. The brake specific fuel consumption is lower with the blends JB20, NB20 and HB20 than diesel. The BSFC for JB20 is same as JB15 which is 46% less than diesel at no load. The BSFC for HB20 is 8.6% and NB20 is 4.3% lower than diesel. Jb20 finds the lowest BSFC as compare to NB20, HB20 and diesel.

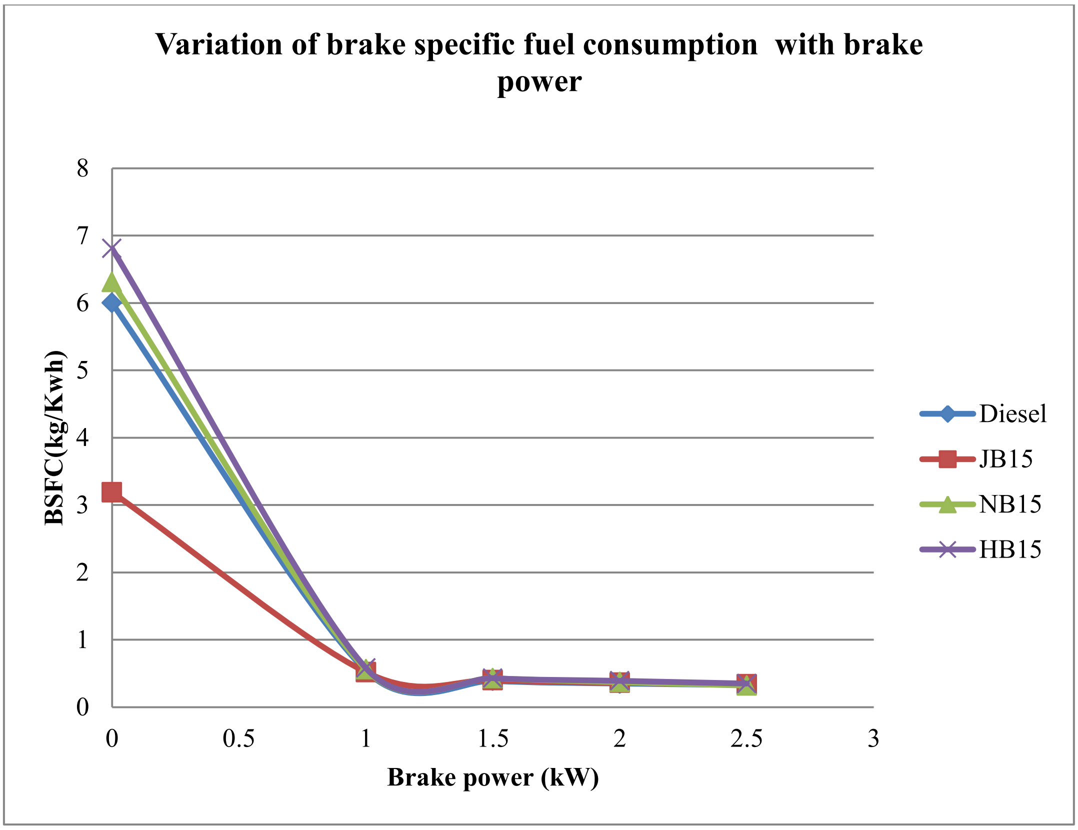

Figure 4.7: Variation of brake specific fuel consumption with respect to brake power

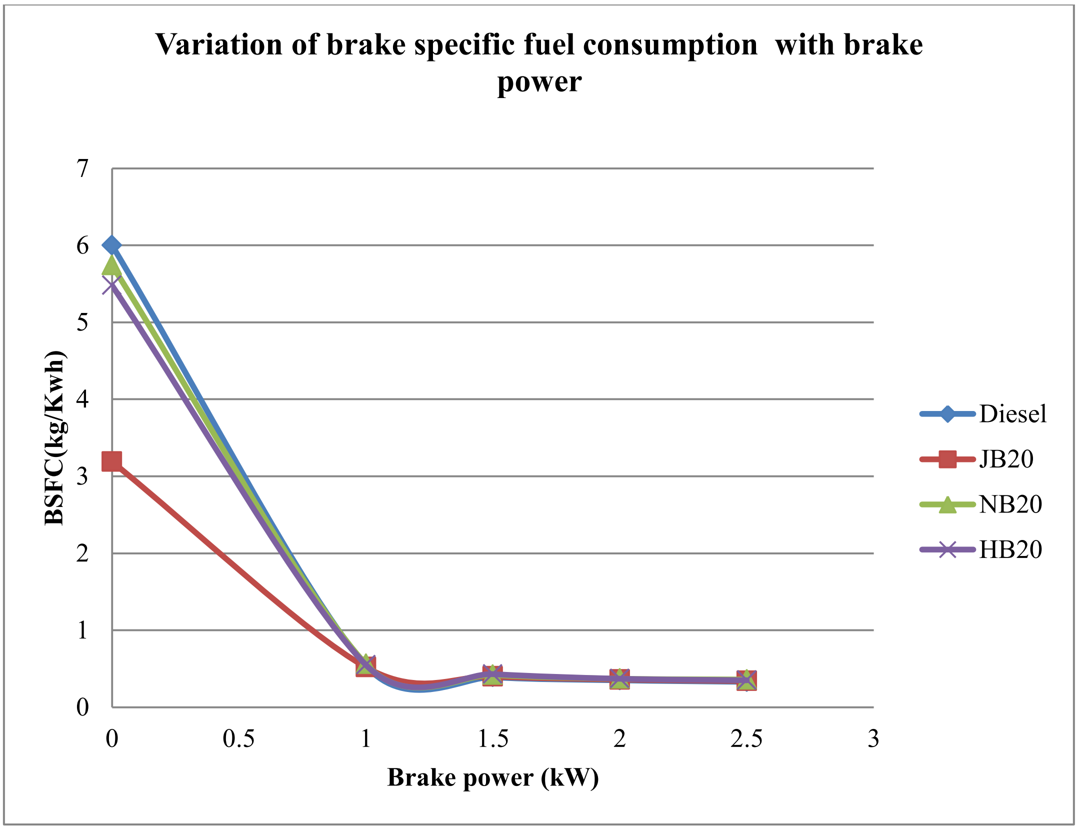

Figure 4.8: Variation of brake specific fuel consumption with respect to brake power

The variation of brake specific fuel consumption with respect to brake power for different blends of biodiesel and diesel are shown in figure 4.9. The hemp biodiesel (HB10 and HB15) shows the higher whereas HB20 gives 8.6% lower BSFC as compare to diesel up to 30% load. The blends of jatropha JB20 and JB10 give lowest BSFC as compares to diesel. The blends of neem biodiesel are nearly same trend as the diesel. The jatropha JB20 is 46% lower BSFC at no load and lower among the three blends of biodiesel and diesel.

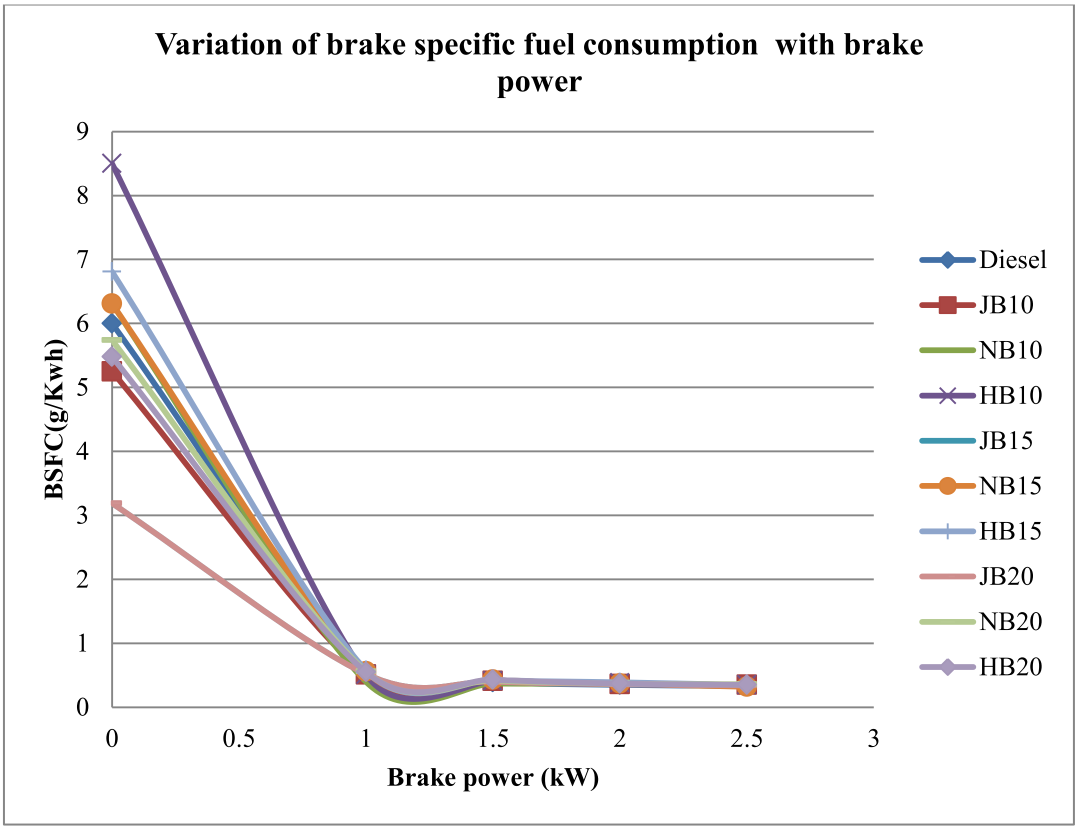

**Figure 4.9: Variation of brake specific fuel consumption with respect to brake power**

#### 4.2.1.4 EXHAUST GAS TEMPERATURE

The variation of exhaust gas temperature with respect to brake power for 10% blends of different biodiesel and diesel are shown in figure 4.10. The exhaust gas temperature increases with increase in brake power at full load only. The exhaust gas temperature of neem biodiesel blend at no load is 6% and at part load 15% higher than diesel. The exhaust gas temperature of jatropha biodiesel blend reduces 4.2% at no load and 4.9% at part load. The exhaust gas temperature of hemp biodiesel blend reduces 39% at no load and increases with brake power.

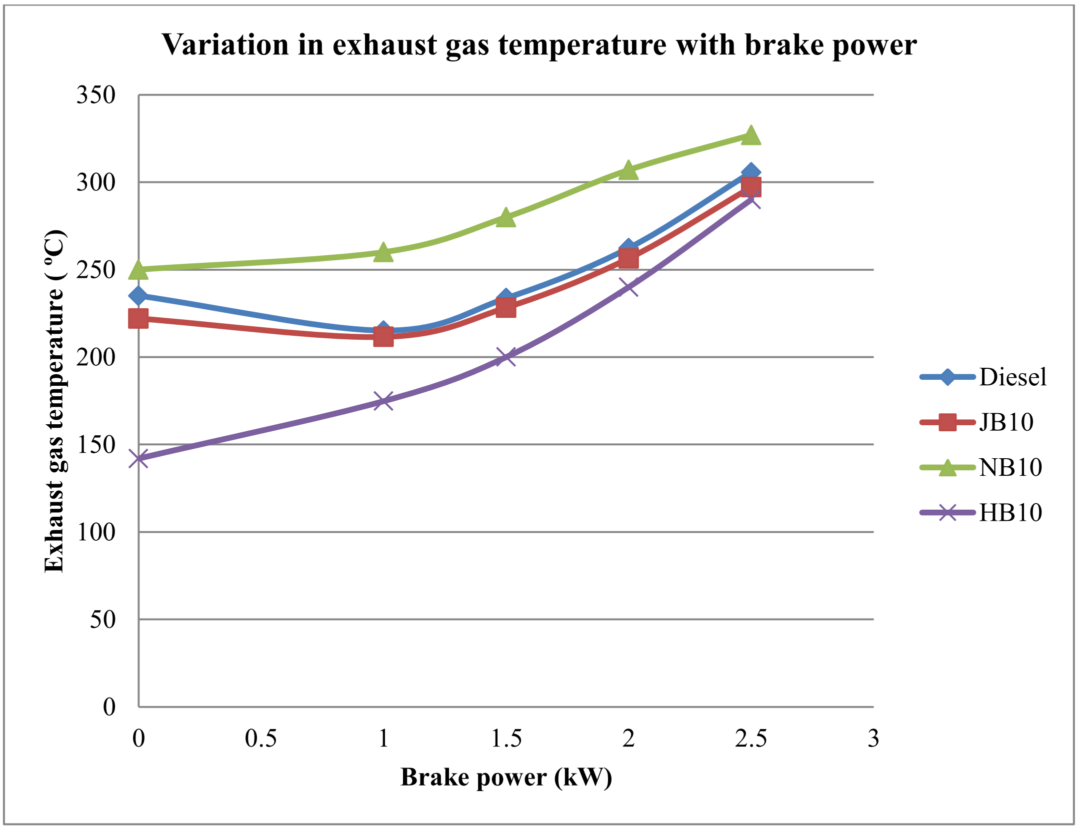

**Figure 4.10: Variation of exhaust gas temperature with respect to brake power**

The variation of exhaust gas temperature with respect to brake power for 15% blends of different biodiesel and diesel are shown in figure 4.11. The exhaust gas temperature of Jatropha biodiesel JB15 is same as the diesel. The exhaust gas temperature of JB15 reduces 29.8% at no load as compares to diesel and increases with brake power whereas it is same at full load. The exhaust gas temperature of hemp biodiesel blend HB15 reduces 39% at no load and increases with brake power up to full load.

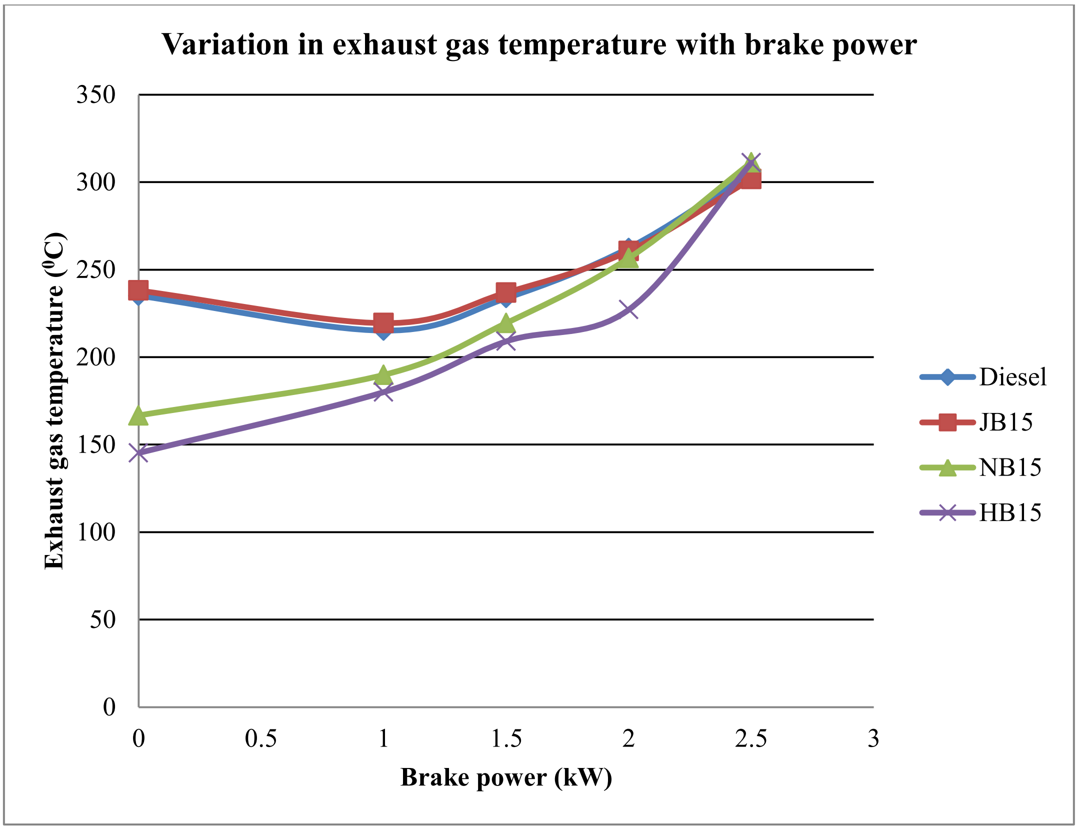

**Figure 4.11: Variation of exhaust gas temperature with respect to brake power**

The variation of exhaust gas temperature with respect to brake power for 15% blends of different biodiesel and diesel are shown in figure 4.12. The exhaust gas temperature of JB20, NB20 and HB20 are lower than diesel 16%, 17% and 27.6% respectively at no load. The exhaust gas temperature of 20% blends of biodiesel increases with brake power. At 50% load the EGT of JB20 and NB20 reduces 6% than diesel whereas it increases 9.8% for HB20. As the brake power increases the exhaust gas temperature difference with diesel reduces.

The variation of exhaust gas temperature with respect to brake power of all blends of different biodiesel and diesel are shown in figure 4.13. The exhaust gas temperature of NB10 is higher as compared to all blends of biodiesel and diesel whereas the HB10 is lower. The exhaust gas temperature of HB20, NB20, NB15, HB15 and HB10 increases with the increase of brake power. More than 75% load the EGT closer to the diesel.

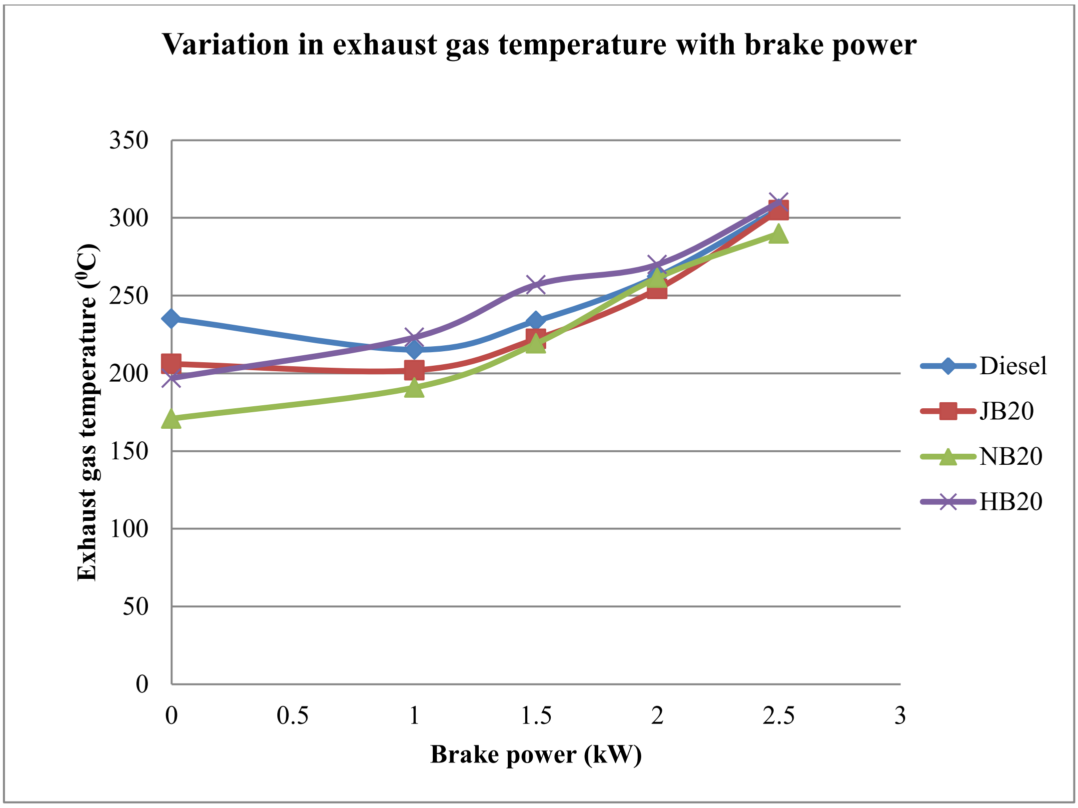

Figure 4.12: Variation of exhaust gas temperature with respect to brake power

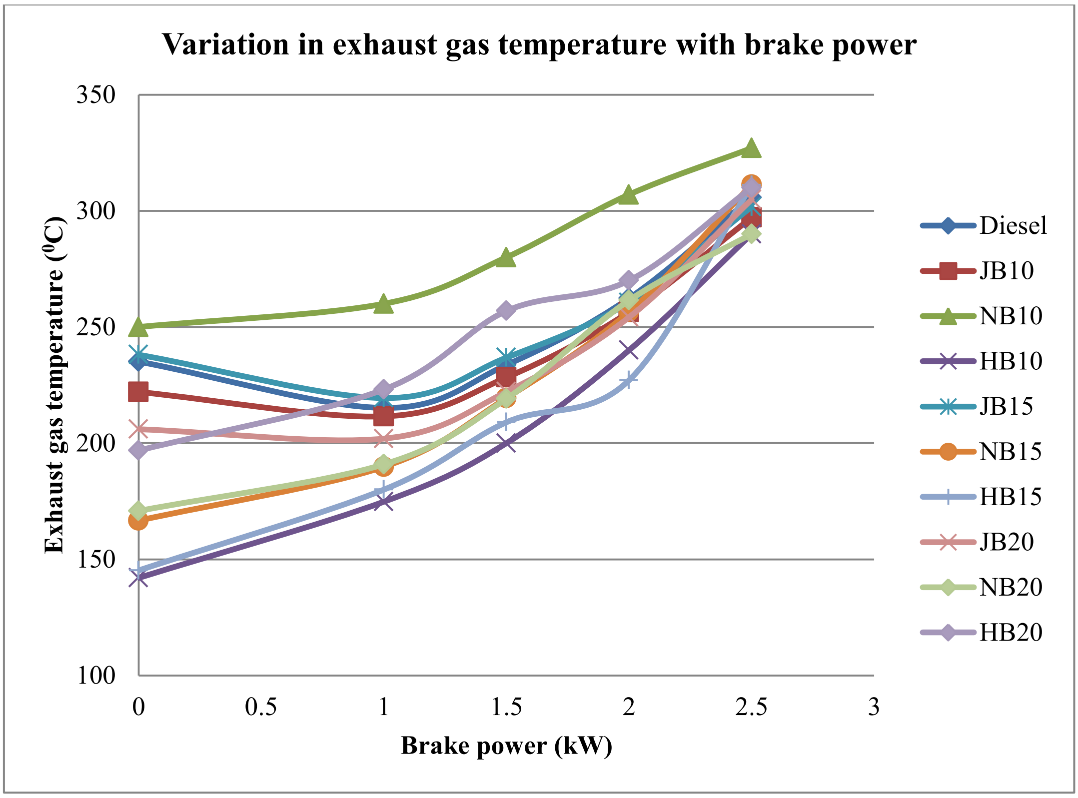

Figure 4.13: Variation of exhaust gas temperature with respect to brake power

### 4.2.2 EXHAUST EMISSION CHARACTERISTICS

#### 4.2.2.1 UNBURNED HYDROCABON

The variation of unburned hydrocarbon with respect to brake power for different blends of biodiesel is shown in figure 4.14. The neem biodiesel NB20 and JB20 biodiesel blends observed lower value than diesel. For load more than 75% the trend of graph closer to diesel.

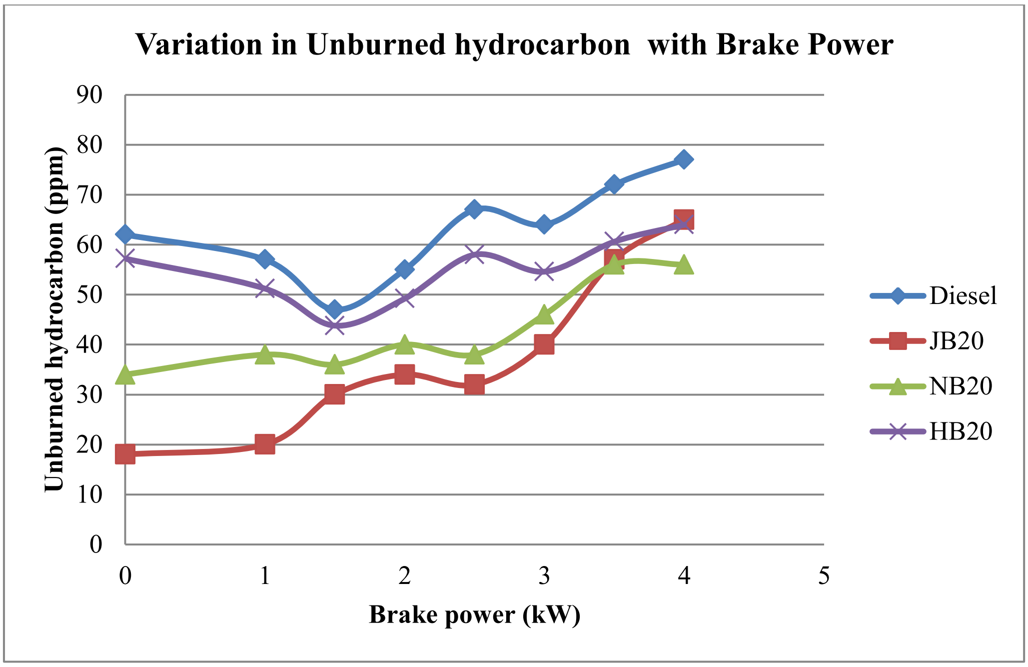

**Figure 4.14: Variation of unburned hydrocarbon with respect to break power**

#### 4.2.2.2 CARBON MONOXIDE

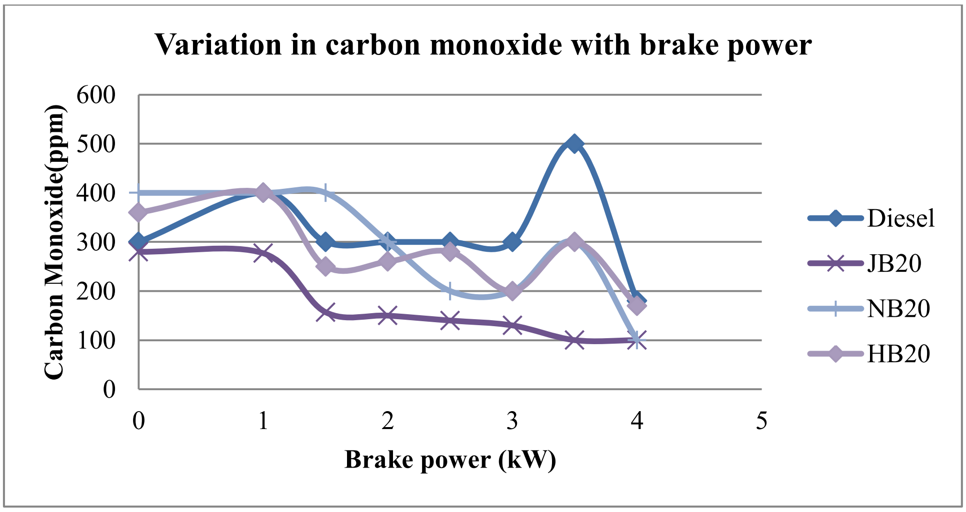

**Figure 4.15: Variation of carbon monoxide with respect to break power**

The variation of carbon monoxide with respect to brake power for different blends of biodiesel is as shown in figure 4.15. The variation was observed after the 40% engine load for all blends and diesel. The blends of jatropha and neem were found almost same whereas the blend of hemp was observed same trend as diesel. The CO emission of biodiesel blends were found lower than diesel.

#### 4.2.2.3 CARBON DIOXIDE

The variation of carbon dioxide with respect to brake power for different blends of biodiesel is as shown in figure 4.16. The $CO_2$ emission of diesel and hemp biodiesel blend was the same whereas blend of neem and jatropha were found higher value than diesel.

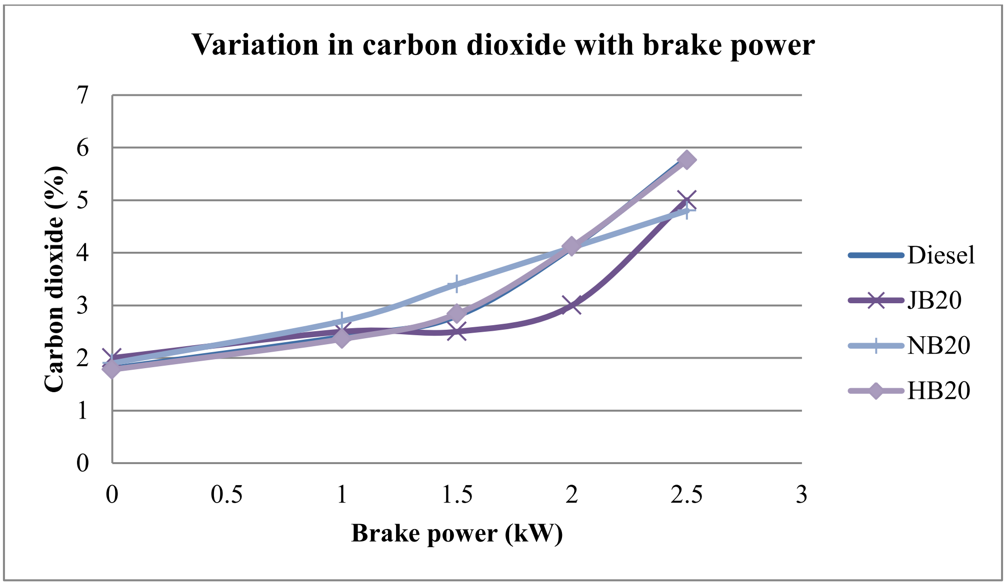

Figure 4.16: Variation of carbon dioxide with respect to break power

#### 4.2.2.4 OXIDES OF NITROGEN

The variation of oxides nitrogen with respect to brake power for different blends of biodiesel is as shown in figure 4.17. The blend of JB20 was observed as lowest as compared to diesel as well as neem and hemp biodiesel blends. The blends of neem and hemp biodiesel were observed closer to diesel. The oxide of nitrogen was increased with increase of brake power of an engine.

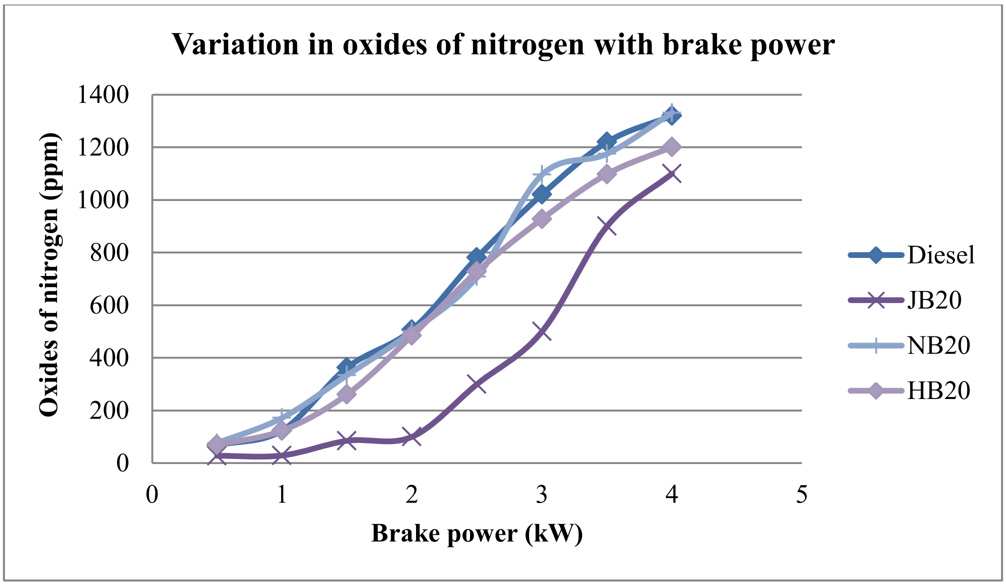

Figure 4.17: Variation of oxides of nitrogen with respect to break power

# CHAPATER 5
# CONCLUSIONS AND FUTURE SCOPE OF WORK

## 5 CONCLUSIONS

The finding of the studies is based on the fuel properties, engine performance and exhaust emission of blends of Jatropha, neem and hemp biodiesel. The following conclusions have been concluded.

- The kinematic viscosity value of Jatropha biodiesel has found 23.2% higher whereas hemp biodiesel has 227.43% less than diesel fuel.
- The calorific value of jatropha, neem and hemp biodiesel decreased by 0.46%, 7.42% and 0.23% than that of diesel fuel.
- The brake thermal efficiency of Engine with all blends of biodiesel observed lower than diesel. It is also observed that with neem biodiesel, brake thermal efficiency 5.5% higher as compare to Jatropha and hemp biodiesel blends.
- The brake specific fuel consumption HB20 was found 8.6% lower than diesel up to 30% load whereas blends of neem biodiesel have same trend as diesel.
- The CO emission for all blends of biodiesel found less than diesel. The $CO_2$ and HC emission were increase with increase of brake power.
- The jatropha biodiesel blend was observed the lowest oxides of nitrogen.

**SCOPE OF FUTURE WORK**

- The biodiesel may be used as diesel fuel for trucks and tractor up to 20% blends.
- Endurance test on engine may be done to find the wear rate of metal part and chemical reaction with the seals and gaskets of an engine.
- On the bases of the thermal efficiencies of blends various biodiesels may be studied and optimum parameter of blends may be found.
- The further studies can be done on the long term storage and utilization of the by products from biodiesel.
- Performance and emission studies may be done on multi cylinder, variable speed engine.
- The performance on blends of three biodiesels may be done to find the optimum mix.

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