Performance Analysis of Compression Ignition Engine Using Waste Cooking Oil

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Abstarct: Biodiesel is one of the biodegradable and renewable fuels, which is originated from vegetable oil or animal fats. Waste cooking oil biodiesel is a kind of biofuel which is gaining acceptance in the market due to many environmental and economic benefits. It can be used alone or in a blend with Diesel fuel, directly in compression ignition engines, without any modifications. This review collects and analyses published papers concerning the usage of waste cooking oil biodiesel as an alternative fuel in Diesel engines. It covers engine combustion, performance and emissions characteristics. Research results reveal that rapeseed biodiesel, either pure or blended with Diesel, has lower heat release rate, reduced ignition delay, lower thermal efficiency and higher brake specific fuel consumption. Carbon monoxide (CO) and particulate matter (PM) exhaust emissions are up to 60% lower, while carbon dioxide (CO_2) and nitrogen oxides (NOx) are higher in comparison to Diesel fuel. This behaviour is explained by the shorter ignition delay and advanced fuel injection when using waste cooking oil.

I.INTRODUCTION

Increased environmental concerns, depletion of petroleum resources and increasing industrialization and modernization of the world have caused researchers around the world to look for alternative fuels from renewable resources. These fuels should be available, economically viable and environmentally acceptable. Biodiesel is one of a few promising alternative fuels. Biodiesel is composed of fatty acids produced via chemical processes from vegetable oil such as rapeseed oil, soybean, palm oil, etc. or animal fat. Appropriate utilization of renewable straight vegetable oil (SVO) as fuel, replacing fossil fuel, contributes to climate, water and soil protection and enables a reduction of greenhouse gas emissions. Biodiesel has a lower aromatic compound content, and is free of Sulphur content. These characteristics contribute to the reduction in carbon dioxide, carbon monoxide, unburned hydrocarbons and soot emissions. Since biodiesel has a high flash point and lower volatility it is safe to store and handle. Biodiesel has a higher bulk modulus, higher sound velocity, higher viscosity, and higher certain number than Diesel fuel. These features of biodiesel lead to an advance in the start of fuel injection (SOI). The major disadvantage of biodiesel is its viscosity. Higher biodiesel viscosity can lead to reduced atomization quality, lower spray cone angle, increased average droplet diameter, and longer tip penetration of the sprayed injected fuel. Numerous studies have been conducted on the ignition delay of Diesel engines fueled with biodiesel at different engine operation conditions, such as; engine speed, fuel injection timing, injection pressure, engine load, compression ratio etc. The results of these studies revealed that biodiesel has shorter ignition delay (ID).

II. Engine

A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. It is classified into two types-

    (a) External combustion engine
    (b) Internal combustion engine

2.1.1. External combustion engine

In this engine, the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle. In the steam engine or a steam turbine plant, the heat of combustion is employed to generate steam which is used in a piston engine (reciprocating type engine) or a turbine (rotary type engine) for useful work. In a closed cycle gas turbine, the heat of combustion in an external furnace is transferred to gas, usually air which the working fluid of the cycle.

2.1.2. Internal combustion engine

In this engine, the combustion of air and fuels take place inside the cylinder and are used as the direct motive force.

2.2. Components of engine

The main components of engine are listed below as follows on

1) Cylinder
2) Cylinder head
3) Piston
4) Piston rings
5) Connecting rod
6) Crankshaft
7) Crank case
8) Flywheel

2.2.1. Cylinder

It is the main part of the engine inside which piston reciprocates to and fro. It should have high strength to withstand high pressure above 50 bar and temperature above 2000 ^{0}C. The ordinary engine is made of cast iron and heavy duty engines are made of steel alloys or aluminum alloys. In the multi-cylinder engine, the cylinders are cast in one block known as cylinder block.

Figure 1. Cylinder

2.2.2. Cylinder head

The top end of the cylinder is covered by cylinder head over which inlet and exhaust valve, spark plug or injectors are mounted. A copper or asbestos gasket is provided between the engine cylinder and cylinder head to make tight joint.

Figure 2. Cylinder Head

2.2.3. Piston

Transmit the force exerted by the burning of charge to the connecting rod. Usually made of aluminum alloy which has good heat conducting property and greater strength at higher temperature.

Figure 3. Piston

2.2.4. Piston rings

These are housed in the circumferential grooves provided on the outer surface of the piston and made of steel alloys which retain elastic properties even at high temperature. 2 types of rings- compression and oil rings. Compression ring is upper ring of the piston which provides air tight seal to prevent leakage of the burnt gases into the lower portion. Oil ring is lower ring which provides effective seal to prevent leakage of the oil into the engine cylinder.

Figure 4. Piston rings

2.2.5. Connecting rod

It converts reciprocating motion of the piston into circular motion of the crank shaft, in the working stroke. The smaller end of the connecting rod is connected with the piston by gudgeon pin and bigger end of the connecting rod is connected with the crank with crank pin. The special steel alloys or aluminum alloys are used for the manufacture of connecting rod.

Figure 5. Connecting Rod

2.2.6. Crank shaft

It converts the reciprocating motion of the piston into the rotary motion with the help of connecting rod. The special steel alloys are used for the manufacturing of the crankshaft. It consists of eccentric portion called crank.

Figure 6. Crank Shaft

2.2.7. Crank case

It houses cylinder and crankshaft of the IC engine and also serves as sump for the lubricating oil.
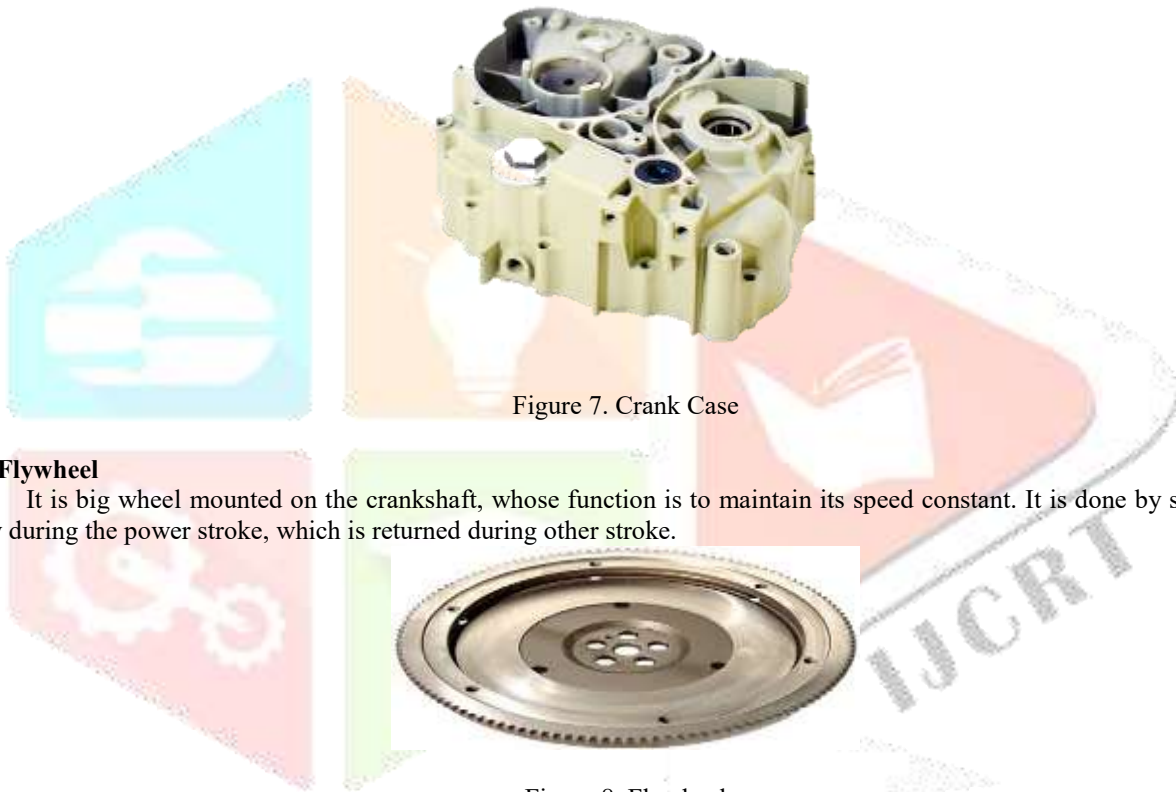

Figure 7. Crank Case

2.2.8. Flywheel

It is big wheel mounted on the crankshaft, whose function is to maintain its speed constant. It is done by storing excess energy during the power stroke, which is returned during other stroke.

Figure 8. Flywheel

3.1. Fuel used in internal combustion engine

In IC engines, the chemical energy contained in the fuel is converted into mechanical power by burning (oxidizing) the fuel inside the combustion chamber of the engine. Fuels suitable for fast chemical reaction have to be used in IC engines, they are listed below as follows on

1) Petrol
2) Diesel
3) Hydrogen
4) Natural gas
5) Bio diesel

3.1.1. Petrol

All the carbon bonds are single bonds, they are "saturated" high number of H atoms, high heat content and low density ($620 – 770$ kg/m^3). The carbon atoms can be arranged as a straight chain or as branched chain compounds. Straight chain group (normal paraffin's) shorter the chain, stronger the bond not suitable for SI engines – high tendency for auto ignition according to the value of "n" in the formula, they are in gaseous (1 to 4), liquid (5 to 15) or solid (>16) state.

3.1.2. Diesel

Saturated hydrocarbons which are arranged in a circle have stable structure and low tendency to auto ignite compared to alkanes. Low heat content and high density ($740 – 790$ kg / m^3).

3.1.3. Hydrogen

Clean burning fuel and has the highest energy content per unit mass of any chemical fuels which can reduce the dependency on hydrocarbon based fuels. Most common method of producing hydrogen involves splitting water (H_2O) into its component parts of hydrogen (H_2) and oxygen (O).

3.1.4. Natural gas

Natural gas is present in the earth and is often produced in association with the production of crude oil. Processing is required to separate the gas from petroleum liquids and to remove contaminants. First, the gas is separated from free liquids such as crude oil, hydrocarbon condensate, water and entrained solids. The separated gas is further processed to meet certain pipelines quality specifications with respect to water content, hydrocarbon dew point, heating value and hydrogen sulphide content. Generally, a gas sweetening plant removes hydrogen sulphide and other sulphur compounds.

3.1.5. Biodiesel

It is methyl or ethyl ester of a fatty acid produced from vegetable oil of edible or nonedible types or animal fat or algae, by transesterification process using catalysts. Has better lubricating properties and much higher cetane ratings than today's low sulfur diesel fuels. Its addition reduces the fuel system wear. Can be used in the pure form (B100), or may be blended with petroleum diesel in any concentration in most diesel engines for transportation purpose. But, the engine may face problems, such as low temperature operation, less durability and drop in power. New diesel fuel injection systems, such as common rail systems are equipped with materials that are compatible with biodiesel (B100). Biodiesel offers a substantial reduction in particulate matter (25%-50%) and a marginal increase of NOx (1%-6% when it is used as an alternative fuel in a CI engine. The major problems associated with biodiesel are (i) poor oxidation stability, (ii) higher viscosity and density, (iii) lower calorific value, and (iv) cold flow property. Blends of 20% and lower biodiesel can be used in diesel engines with no, or only minor modifications.

4.1. Sources of biodiesel

The biodiesel is produced from nonedible oils, which include Jatropha (Jatrophacurcas) oil, Karanja or Honge (Pongamiapinnata/glabra) seed oil, Polanga (Calophylluminophyllum) seed oil, Rubber (Heveabrasiliensis) seed oil, Mahua (Madhucaindica) oil, Tobacco (Nicotianatabacum) seed oil, Bitter almond (Prunusdulcis) oil, Castor (Ricinuscommunis) seed oil, Okra (Hibiscusesculentus) seed oil,Kusum (Schleicheratrijuga) oil, Simarouba (Simaroubaglauca), Milo (Thespesiapopulnea) seed oil , Milk thistle (Silybummarianum) seed oil , and wild safflower (Carthamusoxyacantha Bieb) seed oil. In the production process of biodiesel. The catalyst concentration, reaction time, and reaction temperature has been studied and optimized. The fuel properties of produced biodiesel have been investigated and compared with the standard specifications for assessing their feasibility to substitute the petroleum fuels.

5.1. Production of biodiesel

The present study is based on biodiesel production which consists of reaction where an ester reacts with alcohol to form another ester and another alcohol. Ester here is the vegetable oil (Neem oil) which consist triglyceride. There are four ways to use neat vegetable oils in diesel engine.

   i.   Direct use or blending in diesel fuel
   ii.   Micro emulsions in diesel fuel
   iii. Thermal cracking of vegetable oils
   iv.   Transesterification.

Out of the four methods, transesterification is the most popular and best way to use neat vegetable oils. It was conducted as early as 1853 by scientists E. Duffy and J. Patrick, many years before the first diesel engine became functional. For the purpose of soap production, in the 1940s this process was developed to improve the separation of glycerin. Acid catalyst is used for the esterification and alkali catalyst was (KOH or NaOH) used for the transesterification reaction. The formation of methyl esters by transesterification of vegetable oil requires raw oil, 15% of methanol & 5% of sodium hydroxide on mass basis. On mole basis, one mole glyceride reacts with three mole methanol in presence of a catalyst (KOH or NaOH) to produce methyl esters. For the equilibrium condition of the reaction 55-65°C temperature is needed. In most cases the temperature is kept below the normal boiling point of the methanol (65°C), so that the reactor does not need to be pressurized.

5.1.1. Pyrolysis

Pyrolysis is a method of conversion of one substance into another by mean of heat or by heat with the aid of the catalyst in the absence of air or oxygen. The process is simple, waste less, pollution free and effective compared with other cracking processes.

5.1.2. Dilution

The vegetable oil is diluted with petroleum diesel to run the engine. Caterpillar Brazil, in 1980, used pre-combustion chamber engines with the mixture of 10% vegetable oil to maintain total power without any alteration or adjustment to the engine. At that point it was not practical to substitute 100% vegetable oil for diesel fuel, but a blend of 20% vegetable oil and 80% diesel fuel was successful. Some short-term experiments used up to a 50/50 ratio. 25 part of sunflower oil and 75 parts of diesel were blended as diesel fuel. The low viscosity is good for better performance of engine, which decreases with increasing the percentage of diesel.

5.1.3. Micro emulsion

A micro emulsion defines as a colloidal equilibrium dispersion of optically isotropic fluid microstructure with dimensions generally into 1–150 range formed spontaneously from two normally immiscible liquids and one and more ionic or more ionic amphiphilic. They can improve spray characteristics by explosive vaporization of the low boiling constituents in micelles. The engine performances were the same for a micro emulsion of 53% sunflower oil and the 25% blend of sunflower oil in diesel. A micro emulsion prepared by blending soya bean oil, methanol, and 2-octanol and cetane improver in ratio of 52.7:13.3:33.3:1.0 also passed the 200 h EMA test.

5.1.4. Transesterification

Transesterification is the reaction of a fat or oil with an alcohol to form esters and glycerol. A catalyst is usually used to improve the reaction rate and yield. Excess alcohol is used to shift the equilibrium toward the product because of reversible nature of reaction.

6.1. Production of biodiesel from cooking oil

The production of biodiesel from cooking oil is done by the process of transesterification. The process of transesterification is done by the addition of catalyst with the cooking oil.

6.1.1. Effect of methanol to oil molar ratio

The amount of methanol required for transesterification was analyzed in terms of the methanol to oil molar ratio. The stoichiometric methanol to oil molar ratio required for a complete transesterification is 3:1. But, in practice this is not sufficient to complete the transesterification reaction. A higher molar ratio is required to drive the reaction to completion at a faster rate. It was observed that the transesterification reaction with lower molar ratios requires a longer reaction time. The methanol to oil molar ratio affects the yield. It was observed that the yield of the process increases with the increase in the methanol to oil molar ratio. The maximum yield for cooking and cooking oil was obtained at the methanol to oil molar ratio of 9:1. Further increase in molar ratio does not increase the yield noticeably. Hence, the methanol to oil molar ratio of 9:1 was used for the remaining experiments.

6.1.2. Effect of catalyst concentration

The alkali catalyst was studied in the range of 0.5–3 wt.% for cooking oil and cooking oil using KOH as an alkali catalyst. The influence of catalyst amount on yield. The maximum yield was obtained for cooking and cooking oil at 1 wt.% and 2 wt.% catalyst loading, respectively. It was observed that the production yield decreases with an increase in KOH concentration, because of soap formation and excessive amount of catalyst used. However, according to, the methyl ester concentration increases with increased catalyst concentration at a lower methanol to oil mass ratio. During the experiment it was also observed that transesterification could not take place properly with an insufficient amount of alkali catalyst loading.

6.1.3. Effect of reaction temperature

The reaction temperature effect on the yield and was studied in the temperature range of 40–120 ℃ for cooking oil and cooking oil at atmospheric pressure. The maximum yield was obtained at a temperature of 60 ℃ for cooking oil and 80 ℃ for cooking oil. A decrease in the yield was observed when the reaction temperature went beyond 60 ℃ for cooking oil. The reaction temperatures greater than 60 ℃ should be avoided in case of cooking oil, because it tends to accelerate saponification of the glycerides by the alkali catalyst before completion of the alcoholysis and also, excessive loss of methanol tends to lower the yield at the end.

6.1.4. Effect of reaction time

Transesterification experiments cooking oil were carried out at a constant speed for various periods of times between 30 min and 120 min. For cooking oils, about 60 min for alkali transesterification was sufficient for the completion of the reaction with an agitation speed of 1000 rpm.

Figure 9. Experimental setup for production of biodiesel

7.1. Fuel Properties of diesel

The fuel properties are listed below as follows one by one in a special way is listed below

1. Calorific value
2. Flash point
3. Fire point
4. Kinematic viscosity
5. Density

Calorific value

Calorific value is defined as the value of energy emitted for one kilogram of fuel. It is denoted by the unit of KJ/Kg. The calorific value is calculated mathematically by the total energy released by the amount of fuel burnt. The calorific value of diesel is 43500 KJ/Kg.

Flash point

The flash point temperature is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of a material. Flash point is used in shipping and safety regulations to define flammable and combustible materials. One should consult the particular regulation involved for precise definitions of these classifications. The flash point of diesel is 76ºC.

Fire point

The fire point temperature is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of a material. Fire point is used in shipping and safety regulations to define flammable and combustible materials. One should consult the particular regulation involved for precise definitions of these classifications. The fire point of diesel is 82ºC.

Density

Density is defined as the ratio of mass of fuel to the volume of fuel. It is denoted by the symbol Kg/m^3. The density of diesel is $850Kg/m^3$.

Kinematic viscosity

Kinematic viscosity is defined as the ratio of surface tension to the unit area acting on the fluid. It is denoted by the symbol cs. The kinematic viscosity of diesel is 0.287cs.

7.2. Fuel Properties of biodiesel

The fuel properties are listed below as follows one by one in a special way is listed below

1. Calorific value
2. Flash point
3. Fire point
4. Kinematic viscosity
5. Density

Calorific value

Calorific value is defined as the value of energy emitted for one kilogram of fuel. It is denoted by the unit of KJ/Kg. The calorific value is calculated mathematically by the total energy released by the amount of fuel burnt. The calorific value of biodiesel is 37320 KJ/Kg.

Flash point

The flash point temperature is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of a material. Flash point is used in shipping and safety regulations to define flammable and combustible materials. One should consult the particular regulation involved for precise definitions of these classifications. The flash point of biodiesel is 183ºC.

Fire point

The fire point temperature is one measure of the tendency of the test specimen to form a flammable mixture with air under controlled laboratory conditions. It is only one of a number of properties which must be considered in assessing the overall flammability hazard of a material. Fire point is used in shipping and safety regulations to define flammable and combustible materials. One should consult the particular regulation involved for precise definitions of these classifications. The fire point of biodiesel is 194ºC.

Density

Density is defined as the ratio of mass of fuel to the volume of fuel. It is denoted by the symbol Kg/m^3. The density of biodiesel is $920Kg/m^3$.

Kinematic viscosity

Kinematic viscosity is defined as the ratio of surface tension to the unit area acting on the fluid. It is denoted by the symbol cs. The kinematic viscosity of biodiesel is 5.65cs.

7.3. Comparison of biodiesel with diesel

Table 1 Comparison of biodiesel with diesel

S. No	Properties	Diesel	Biodiesel
1.	Calorific value (KJ/Kg)	43500	37320
2.	Flash point (ºC)	76	183
3.	Fire point (ºC)	82	194
4.	Density (Kg/m^3)	850	920
5.	Kinematic viscosity (cs)	0.287	5.65

III. RESULT AND DISSCUSION

8.1. Comparison of biodiesel performance
The comparison of biodiesel performance is listed below as follows on
1) Brake power Vs Brake thermal efficiency
2) Brake power Vs Mechanical efficiency
3) Brake power Vs Indicated thermal efficiency

8.1.1. Brake power Vs Brake thermal efficiency
Brake thermal efficiency for B_{20} increases as the brake power increases. The Brake thermal efficiency of B_{20} is greater than thermal efficiency of B_{10} and B_{100} for the given fuel sample at a specific load capacity.
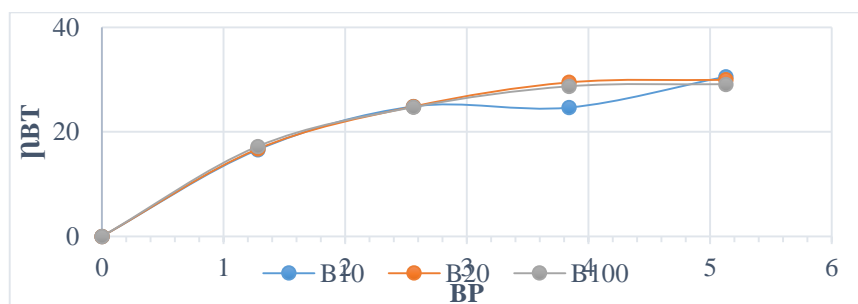

Figure 13.1 Brake power Vs Brake thermal efficiency

8.1.2. Brake power Vs Mechanical efficiency

The mechanical efficiency for B_{20} is increases as the brake power increases. The mechanical efficiency of B_{20} is greater than mechanical efficiency of B_{10} and B_{100} for the given sample of fuel at a specific load capacity.
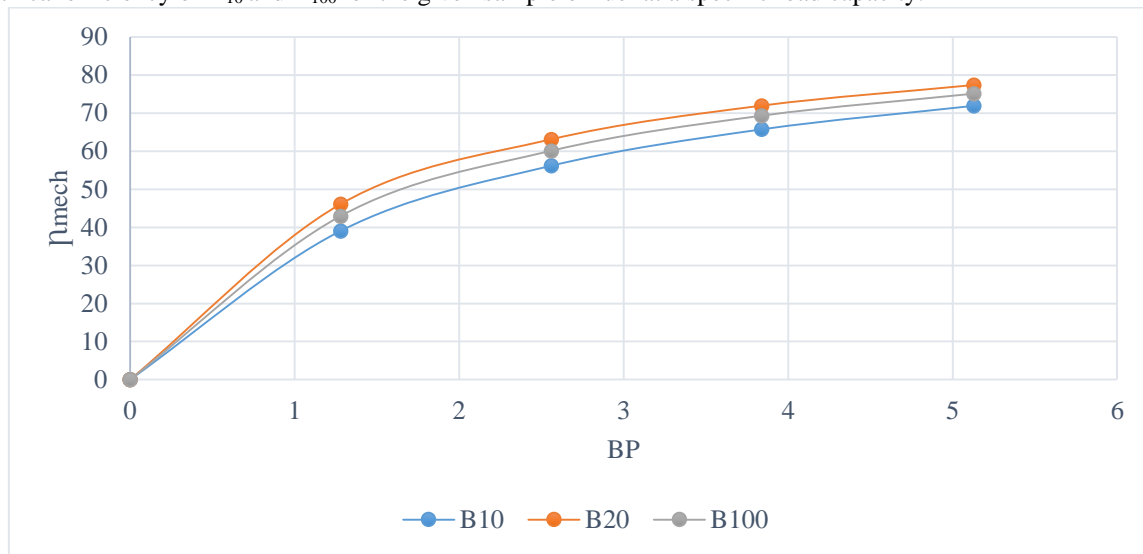

Figure13.2 Brake power Vs Mechanical efficiency

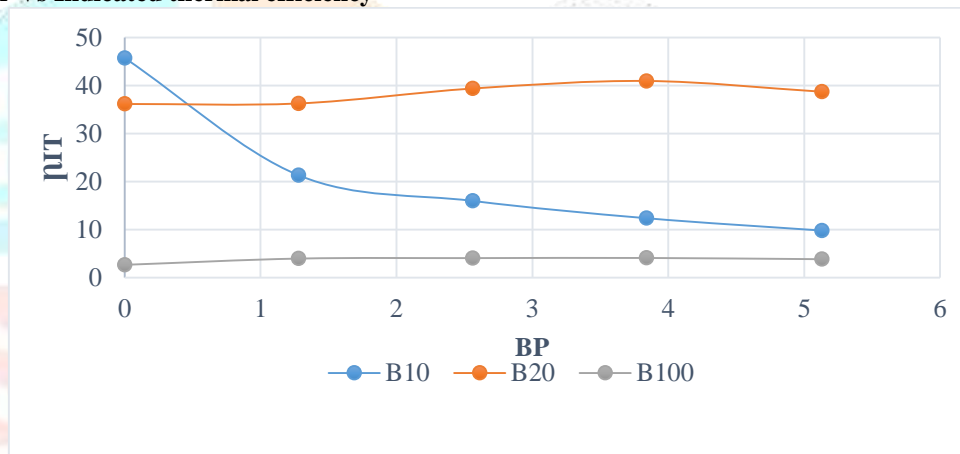### 8.1.3. Brake power Vs Indicated thermal efficiency

Figure 13.3 Brake power Vs Indicated thermal efficiency

The indicated thermal efficiency for B_{20} is increases as the brake power increases. The indicated thermal efficiency of B_{20} is greater than indicated thermal efficiency of B_{10} and B_{100} for the given sample of fuel at a specific load capacity.

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