

# CHARACTERIZATION OF BIO-OIL AND BIODIESEL BLENDS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

**Bachelor of Technology**  
**in**

**Mechanical Engineering**

By

**PENUMATSA LOKESH VARMA**

**108ME055**



**Department of Mechanical Engineering**  
**National Institute of Technology**  
**ROURKELA**

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Under the Guidance of

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## **CERTIFICATE**

This is to certify that the thesis entitled “**CHARACTERIZATION OF BIO-OIL AND BIODIESEL BLENDS**” submitted by Mr. **PENUMATSA LOKESH VARMA (108ME055)** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any University /Institute for the award of any Degree or Diploma.

Date:

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# ABSTRACT

Raising oil prices, depletion of oil reserves and imports burden of petroleum products on developing countries like India, makes the world look for alternatives. Extensive research has been going on alternative fuels like biodiesel, bio-alcohol and other biomass sources. Pyrolysis oil from wood is considered as an alternative fuel for diesel engine. However it cannot be used directly in a diesel engine due to high viscosity, low calorific value and corrosion of components. In order to mitigate these problems it has to be blended with diesel or biodiesel. In the present study, bio-oil from waste package wood is extracted by fixed bed or vacuum pyrolysis process. It is blended with jatropha biodiesel with 2% mixed surfactant of Triton x100 and Span 80. The performance, emission and combustion characteristics of emulsions are analyzed and compared with diesel and biodiesel.

It was observed from results that the brake thermal efficiency for JOE 15 is 2% more than diesel and for JOE5 it is 6% less than diesel. At full load specific energy consumption decreases as WPO concentration increases. The HC and CO emissions of JME and emulsions are lower than that of diesel. The NO emissions compared to diesel increases by 8.29%, 5.5% for JOE5, JOE10 and decreases by 1.3% for JOE15. NO emission decreases with increase in WPO concentration.

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# **CHAPTER 1**

## **INTRODUCTION**

# **1. INTRODUCTION**

Many experts believe that by the year 2070, the world will be exhausted of fossil fuels. So, there is an urgent need of replacing these fossil fuels with alternative fuels. Basically the major part of energy consumed worldwide comes from the fossil fuels (petroleum, coal, natural gas) which are not only non-renewable but also major cause atmospheric pollution. Meanwhile alternative fuels are renewable and also addresses many issues like global warming and air pollution.

## **1.1 ALTERNATIVE FUELS**

Some well known alternative fuels are bioalcohols, biodiesel, chemically stored electricity i.e. batteries and fuel cells, hydrogen, vegetable oil and other biomass sources.

Bioalcohols include methanol, ethanol, propanol, and butanol. Biobutanol can be used directly in a gasoline engine and is often claimed as a direct replacement for gasoline. Ethanol and Methanol are most commonly used biofuels worldwide. Alcohol fuels are produced by fermentation of sugars derived from wheat, corn, sugarcane, potato etc. The most common mixtures used in engines are E85 (85% ethanol and 15% gasoline) and E10 (10% ethanol and 90% gasoline).

The 15% gasoline addition is to eliminate problems like cold starting, tank flammability etc. while E10 reduces the use of gasoline by 10%. The advantages of using alcohols are it can be obtained from many sources both natural and manufactured , high octane rating , less overall emissions and sulphur content. However it suffers from having low energy content, poor cold weather starting and ignition characteristics, corrosion of copper, aluminium, rubber and other plastics [1].

## **1.2 VEGETABLE OILS**

Vegetable oils are a renewable and potentially inexhaustible source of energy with energy content close to diesel fuel. Previously vegetable oils were not acceptable because they were more expensive than petroleum fuels but due to the recent increase in petroleum prices and uncertainties concerning petroleum availability renewed the interest in vegetable oil fuels for diesel engines. There are about 340 oil-bearing crops like cotton seeds, sunflower, soyabean, rapeseed and peanut oils are identified as potential replacement for diesel fuel. The direct use of vegetable oils is problematic due to their high viscosity (11-17 times more viscous than diesel) low volatility, incomplete combustion and formation of deposits in fuel injectors. Pre-heating is one of the widely used techniques for reducing the high viscosity as well as addresses problems like coking and trumpet formation on fuel injectors which prevents fuel atomization. But preheating has its own problems. So, another vegetable oil which is more popular is biodiesel.

## **1.3 BIODIESEL**

Biodiesel refers to vegetable oil or animal fat based diesel fuel consisting of long chain alkyl esters. The National Biodiesel Board gives the definition of “biodiesel” as a mono-alkyl ester.

Biodiesel is commonly produced by transesterification of triglycerides (which are present in vegetable oils and animal fat) with methanol or ethanol to give methyl or ethyl esters and glycerol as a byproduct. Biodiesel is biodegradable and produces less air pollution than diesel. It can be used directly or blended with diesel. Blends of less than 20% biodiesel require no or less minor modifications in diesel equipment. 100% Biodiesel (B100) may require certain engine modifications to avoid maintenance and performance problems.

A few notable properties of biodiesel are it has better lubricating properties, high cetane rating than diesel fuel, calorific value of biodiesel is little lower than diesel. Depending on feed stock the colour of biodiesel varies between golden and dark brown. It is immiscible with water, has a high boiling point and density and has low vapour pressure.

## **1.4 BIOMASS SOURCES**

Biomass, a renewable energy source, is biological material derived from living, or recently living organisms. Biomass generally means energy from plant based material, but biomass can equally apply to both plant and animal derived material. Biomass can either be directly used as energy source to generate electricity with steam turbines and gasifiers by direct combustion or it can be converted into other energy sources such as biofuel. Biomass energy is derived mainly from garbage, waste, wood, landfill gases and alcohol fuels. Wood contributes to largest portion of biomass energy worldwide. Landfill gas, municipal solid waste and manufacturing waste are the also major contributors of energy from waste products.

The various methods used to convert biomass into other forms like liquid biofuel or combustible biogas are thermal conversion (pyrolysis, gasification which are mainly controlled by availability of oxygen and conversion temperature), chemical conversion (transesterification of vegetable oils into biodiesel) and biochemical conversion (break down of molecules). However, considering the problems associated with transportation and storing, a liquid form is more suitable. One of the most promising techniques for the conversion of biomass to liquid is flash pyrolysis process which produces bio-oil (pyrolysis oil) and char at temperatures between 350-550°C.

## **1.5 WOOD PYROLYSIS**

Pyrolysis is thermal decomposition of materials in the absence of oxygen or when significantly less oxygen is present than required for complete combustion. Pyrolysis is different from gasification in which biomass is decomposed into syngas by carefully controlling the amount of oxygen present, however in pyrolysis oils are preferred products. The bio-oil produced by wood pyrolysis is very viscous, highly acidic and does not ignite easily as it contains a substantial amount of water. In addition bio-oil usually has a lower calorific value than biodiesel because of high levels of water content and oxygenates originating from trees. Bio-oil corrodes the fuel delivery system. If stable emulsion of bio-oil and biodiesel is formed, it mitigates viscosity problems to a certain extent. Further, physical properties of emulsions would be more similar to biodiesel than that of bio-oil itself and the negative effects of ash and char in bio-oil would be less because of dilution with biodiesel.

Studies indicated that a stable emulsion can be achieved between wood pyrolysis oil and biodiesel using appropriate surfactants. Surfactants are compounds that lower the surface tension of a liquid or interfacial tension between two liquids or that between a liquid and a solid. Surfactants act as emulsifiers. Commonly used surfactants for pyrolysis and biodiesel emulsions are Tween 80, Tween20, Span20, Span80, Triton x-100 etc.

In the present study we are making a BIODIESEL and WPO (wood pyrolysis oil) emulsion and we check the stability of emulsion formed. The emulsion is characterized and the properties are studied.

## **CHAPTER 2**

# **LITERATURE SURVEY**

## 2. LITERATURE SURVEY

In 1885, Dr. Rudolf Diesel built the first diesel engine with intention of running it on vegetative oils. In 1912 he also stated that vegetable oils as engine fuels don't seem significant these days, but they would become as important as petroleum and coal tar products of present time [2].

**Scott et al [3]** have reported that through flash pyrolysis high liquid yields from biomass can be produced. An organic liquid yield of 65-70 wt% of dry wood is feasible.

**Yrjo Solantausta et al [4]** have studied the feasibility and economics of using wood pyrolysis oil in a diesel power plant. A typical flash pyrolysis oil have the following common features: high density (1.2), acidity (pH 2.8-3.8), water content (15-30 wt%), low heating value (14-18.5 MJ/kg) and elemental composition close to feed stock composition. They also reported that viscosity of pyrolysis oil increases when kept in storage from 11.5 to 15.3 cSt (20° C) in four months. Pyrolysis oil suffer from ignition problems which could be reduced by adding cetane improver like (nitrated alcohol) to wood pyrolysis oil. Best emission results were obtained with 5% ignition improver.

**Raja S.A et al [5]** have studied the production and characterization of biodiesel produced from jatropha oil. They used the process of transesterification in which alcohol (methanol) reacts with triglycerides present in jatropha oil to convert it to jatropha methyl ester in the presence of NaOH catalyst. They extracted oil from jatropha seeds by crushing them with a yield of 25-30%. They have also studied the use of jatropha oil in various power and heat generation applications. They also stated that viscosity is reduced from 57 to 4.8 centistokes after transesterification and flash point also decreases. The optimum parameters for biodiesel production were found out to be 6:1 methanol to oil molar ratio, Catalyst-NaOH 0.92%, reaction temperature of 60°C.

**Michio Ikura et al [6]** have conducted tests on emulsions of pyrolysis oil and diesel fuel. They reported that stable emulsions are formed with 0.8 to 1.5 wt% surfactant concentrations. The costs of surfactants used were high and could be reduced using a new CANMET surfactant. They also characterized fuel properties like calorific value, viscosity, corrosivity, cetane number. The heating value of emulsion is in between the bio-oil and diesel. Emulsion viscosity is lower than that of bio-oil which means a lot easier to handle. The corrosivity is about half of pyrolysis oil.

It was reported by many that pyrolysis oil quality can be improved by the addition of alcohol which improves storage stability and reduces its viscosity. It was also reported that emulsification with diesel or biodiesel by using suitable surfactants is considered a means of upgrading pyrolysis oil. This process improves stability and decreases viscosity. The main aim is to facilitate the use of pyrolysis oil in already existing equipment for heat and power generation and also the emulsions have improved ignition characteristics compared to pure pyrolysis oil. The pyrolysis oil cannot be used directly for engine operation because of high viscosity, low calorific value, high acidity, low stability, poor lubrication. So, blending with diesel or biodiesel is most suitable alternative to utilize a major fraction of it [7], [12] - [17].



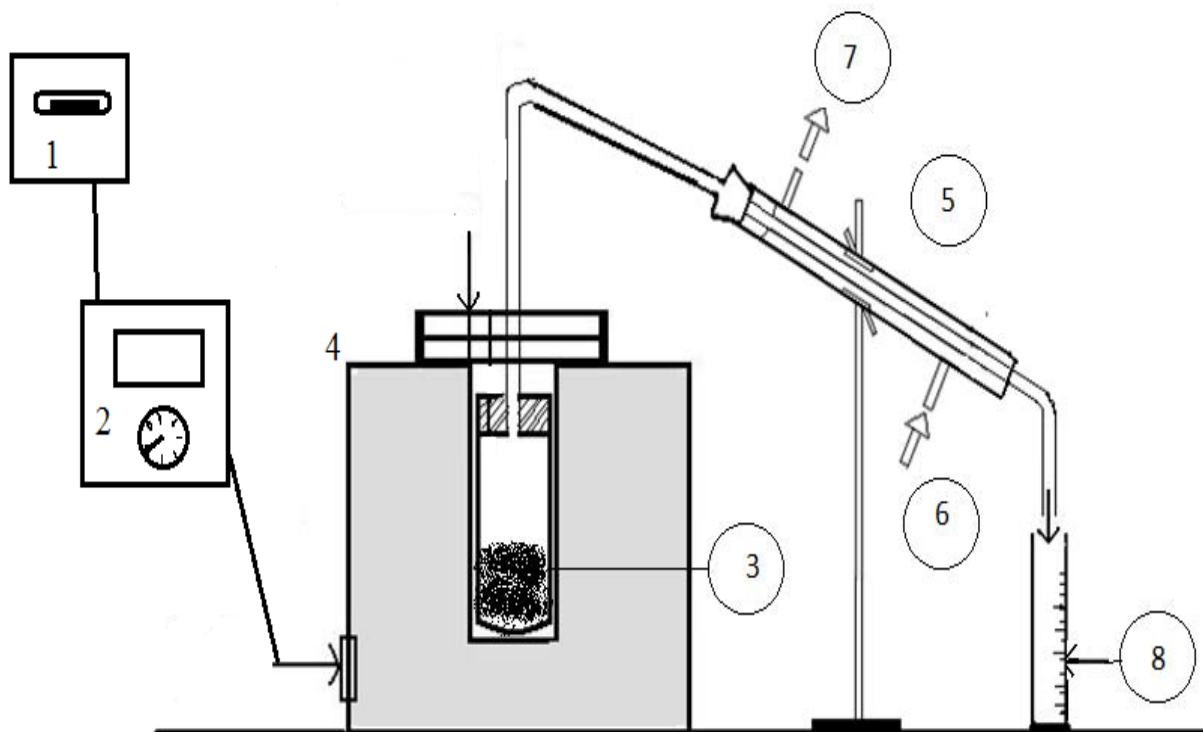
## **CHAPTER 3**

# **MATERIALS AND METHODS**

### **3. MATERIALS AND METHODS**

#### **3.1 EXTRACTION OF PYROLYSIS OIL**

Pyrolysis oil is extracted by flash pyrolysis of waste package wood chips of size 5mm-10mm. This process is done in the pyrolysis reactor which can take a maximum feed of 1kg of wood chips. The pyrolysis reactor is also equipped with temperature sensor, temperature control device to set the optimum temperature of operation, energy meter to measure the power required for the pyrolysis process and also to estimate the economy of the operation. The other accessories include condenser flask for condensing the pyrolytic gases to liquid by circulating water around the condenser flask with the help of a water pump. One end of condenser flask is connected to the tube from pyrolysis reactor and at the other end a conical flask is kept for collecting the condensed liquid. The temperature inside the reactor is raised at the rate of 9<sup>o</sup>C per minute at initial stages and falls to 2<sup>o</sup>C at latter stages. After a number of trails, the optimum to temperature of operation is found out be in the range of 400<sup>o</sup>C to 420<sup>o</sup>C. So, the temperature control device is set for 400<sup>o</sup>C. The average energy meter reading is 3.9 kWh. The Pyrolysis gases from the reactor are of two types, condensable and non-condensable. The moisture present in the wood comes off as water and this generally starts at 220<sup>o</sup>C and continues up to 350<sup>o</sup> C, then a colour change to dark brown in the liquid is visible. This is Pyrolysis oil which starts to come at 350<sup>o</sup>C and continues up to 390<sup>o</sup>C. The reactor used is cylindrical in shape and have outer diameter 250mm, inner diameter 200mm and height of 250mm. The reactor is fully insulated by glass wool and refractory lining. The typical yield for 500 grams of feed is 150 ml of water and 100ml of wood pyrolysis oil. [7]



**Figure 1 Schematic diagram of pyrolysis setup [7]**

1.power meter	2. Temperature controller	3. Wood chips
4. Reactor	5. Condenser	6.Water inlet
7. Water outlet	8. WPO collector	

### **3.2 PRODUCTION OF JATROPHA METHYL ESTER**

The plant from which jatropha oil is extracted is *Jatropha curcas*. Jatropha oil is extracted from the seeds which has an oil content of 25-35%. The oil contains saturated fatty acids (21%) and unsaturated fatty acids (79%). The most potential process to convert vegetable oil into methyl ester is by transesterification. Transesterification is the process of chemically reacting animal and plant fats or oils which contains triglycerides (esters containing three fatty acids and trihydric alcohol and glycerol) with an alcohol in a presence of a catalyst. Alcohol used is methanol. Catalyst used is sodium hydroxide or potassium hydroxide.

In transesterification, *Jatropha* oil is heated to drive off moisture and Methanol of 99.5% purity is used. NaOH Catalyst is dissolved in Methanol in a separate vessel and added to *jatropha* oil and mixture is stirred continuously. The products formed during the transesterification process were *Jatropha* methyl ester and Glycerin. The bottom layer has Glycerin, excess alcohol, catalyst, impurities and the upper layer consists of biodiesel and alcohol. Biodiesel is separated after washing with hot distilled water to remove the unreacted oil, alcohol and catalyst. [5]

### 3.3 COMPARISON OF FUELS

Table showing different fuel properties [8].

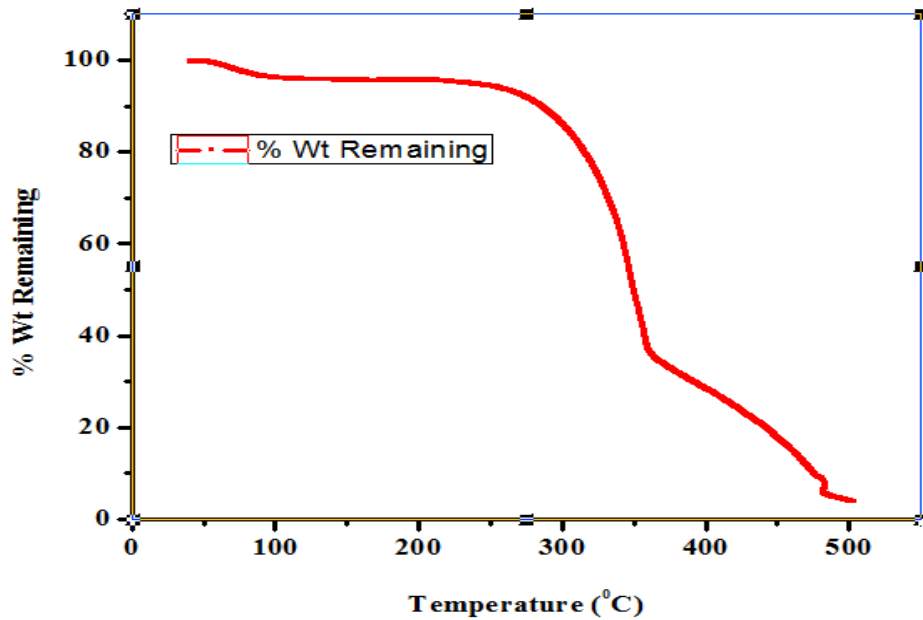
PROPERTIES	DIESEL	JME	WPO
Net calorific value[MJ/kg]	43.8	39	18
Specific gravity at 15 °C	0.83	0.873	1.2
Kinematic viscosity at 40 °C[cSt]	2.58	4.80	13
Flash point[°C]	50	170	66
pH value	-	0.42	2.4
Moisture content (wt %)	0.025	0.36	15-30

It is evident from the table that net calorific value of diesel is greater than JME. Diesel has 12% more calorific value than JME. Specific gravity and Viscosity of WPO are more than diesel and JME. Due to more difference in specific gravities of JME and WPO, they don't mix properly, hence we are using a surfactant. Flash point which is defined as the lowest temperature at which fuel vaporizes in order to form an ignitable mixture in the air is highest in the case of JME biodiesel. Moisture content is high in the case of WPO about nearly 15-30%.

### 3.4 CHARACTERIZATION OF MATERIALS

#### TGA ANALYSIS

**Thermo gravimetric analysis** is a test conducted on samples to determine the changes in weight in relation to a temperature. TGA analysis relies on three measurements i.e. weight, temperature, and temperature change. A derivative weight loss curve is used to note the point where weight loss is most evident. In TGA a mixture is heated to a high a temperature so that one of the components decomposes into a gas, which dissociates into the air. This process uses heat and stoichiometry ratios to compute the percent by mass ratio of a solute. If the compounds present in the mixture that remains are known, then the percentage by mass can be calculated by taking the weight of what's left in the mixture and dividing it by the initial mass.



**FIG.2. Variation of percent weight remaining with temperature**

From the graph the temperature at which maximum decomposition of wood takes place is found out to be around 300°C

### 3.5 EMULSIFICATION OF WPO AND BIODIESEL

Generally WPO can be used as an alternative fuel in diesel engine by adopting techniques such as blending, preheating, increasing injection pressure and improving ignition quality. But in case of WPO, pilot ignition, addition of ignition improver and emulsification with diesel or biodiesel has been suggested.

Blending of WPO with biodiesel fuel has a drawback i.e. WPO is not miscible in biodiesel. Hence different emulsions of WPO with biodiesel using various surfactants at varying concentrations have been tried. 100ml samples are prepared with varying WPO blends i.e. 5%, 10%, 15% and varying surfactants composition i.e. 2% and 4 %. Many surfactants such as Span 80, Span 20, Tween 80, Tween 20, and Triton X100 have been tried and stability check has been performed. It was reported by many researchers that a mixture of two surfactants improves the stability of emulsion than a single surfactant. In our present work optimum stability has been achieved with a mixed surfactant of

1. Triton X100 (HLB=13.5) and Span 80 (HLB=4.3) in the proportion of 80% and 20% respectively to get a HLB value of 6.1

The emulsions with 2% mixed surfactant are prepared as follows:

1. The mixed surfactants are prepared first by carefully measuring the surfactants with the help of a fillet and both surfactants are mixed properly
2. The mixed surfactant is mixed with Jatropha biodiesel and is stirred with the help of a mechanical agitator for about 10 minutes.

3. WPO is then added to biodiesel and surfactants mixture and stirred for 20-30 minutes with the mechanical agitator.

A total of 1 liter emulsion is prepared in every case with different concentrations of WPO (5%, 10%, 15%) and 2% of mixed surfactant.

So, in total 3 different emulsions were prepared as follows:

1. JOE 5 –JATROPHA METHYL ESTER 95% or 950 ml, WPO 5% or 50ml ,surfactant 20ml (TritonX100-16ml and Span80-4ml).

2. JOE 10–JATROPHA METHYL ESTER 90% or 900 ml, WPO 10% or 100ml , surfactant 20ml (TritonX100- 16ml and Span80-4ml).

3. JOE 15 –JATROPHA METHYL ESTER 85% or 850 ml, WPO 15% or 150ml ,surfactant 20ml (TritonX100-16ml and Span80-4ml).

The emulsions are found out to be stable for more than 5 hours.



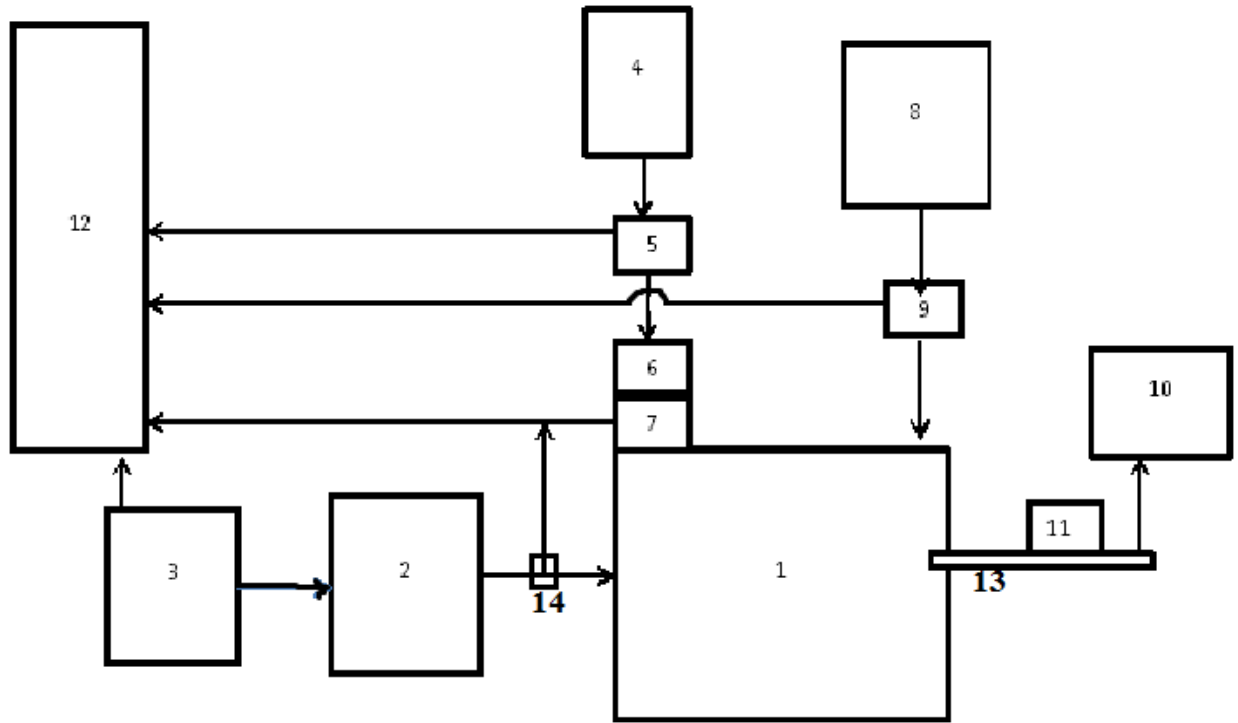
### 3.6 EXPERIMENTAL SETUP

After the completion of forming emulsions, emulsions are tested in the Kirloskar TAF 1 single cylinder, air cooled, 4 stroke, direct injection diesel engine. The specifications of engine are as follows:

**Table 2: Specifications of engine**

<b>Model of engine</b>	<b>Kirloskar TAF 1</b>
Brake power	4.4 kW
Rated speed	1500 rpm
Bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5 :1

The engine set up consists of a single cylinder 4 stroke engine (1), alternator (2). The load is controlled by the load cell which in turn activates the alternator for applying load on the engine. Air is taken by the air box and flows through an air flow sensor which measures the amount of air taken. Fuel readings are measured with the help of a fuel sensor. These measurements are provided as inputs to the data acquisition system. **AVL 444 gas analyzer** is used to measure the emissions from exhaust pipe.



**Fig.3 Schematic diagram of engine setup**

1. engine	2.alternator	3. load cell with control panel
4. Fuel tank	5. fuel sensor	6.fuel filter
7.fuel pump	8. Air box and air filter	9. Air flow sensor
10. Gas analyzer	11. Thermocouple	12.Computerised data acquisition system
13. exhaust pipe	14. speed sensor	

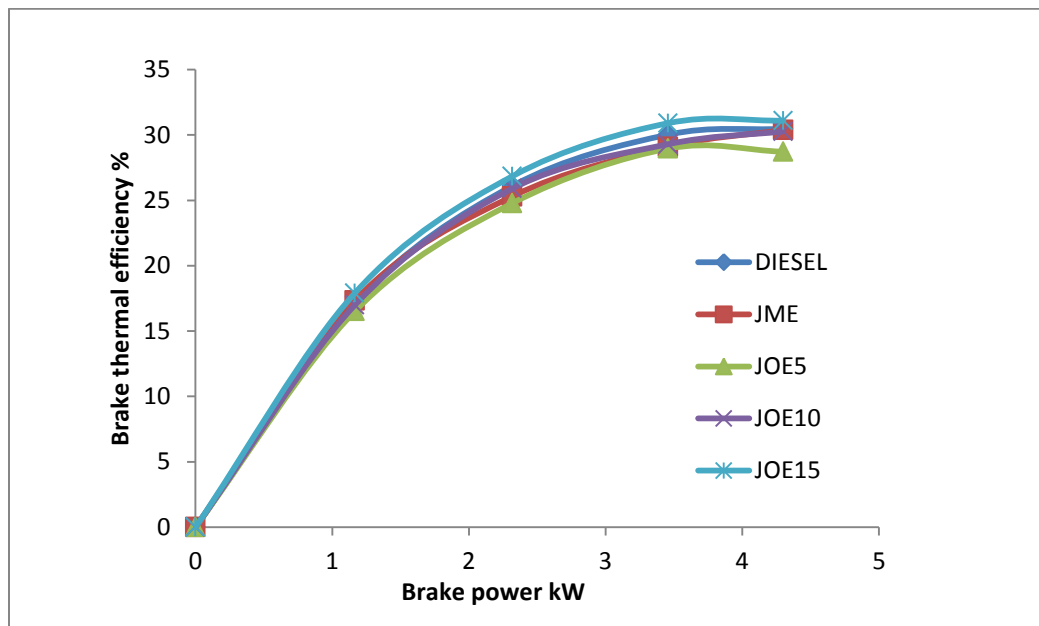
## **CHAPTER 4**

# **RESULTS AND DISCUSSIONS**

## 4. RESULTS AND DISCUSSIONS

### 4.1 PERFORMANCE PARAMETERS

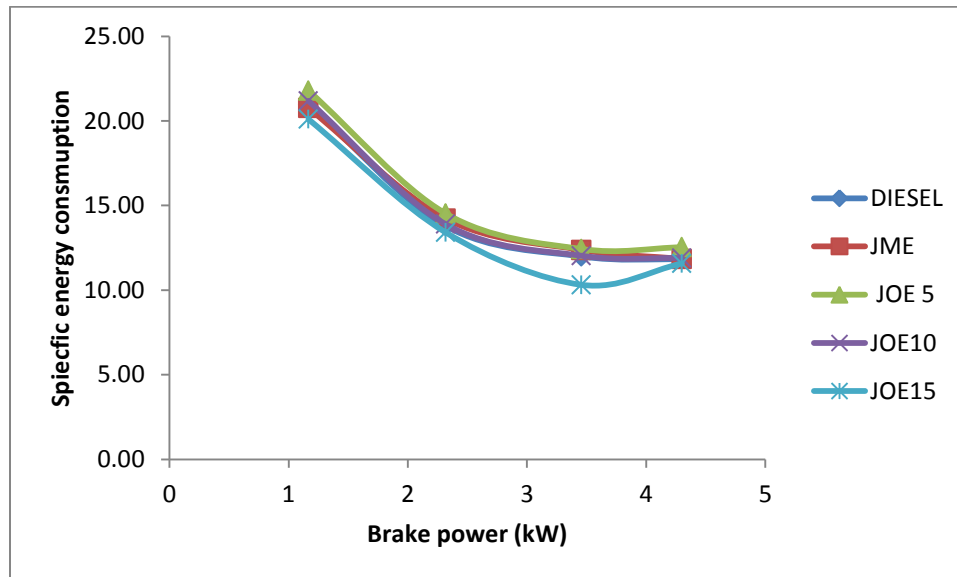
#### 4.1.1 Brake thermal efficiency (%) vs. Brake power (kW)



**Fig.4 Variation of brake thermal efficiency (%) with brake power (kW)**

The brake thermal efficiency for diesel, JME, JOE5, JOE10 and JOE15 at full load is 30.47%, 30.38%, 28.7%, 30.27736% and 31.1% respectively. The BTE for JOE 15 is 2% more than diesel and for JOE5 it is 6% less than diesel. The highest is recorded with JOE15 and lowest with JOE5. The increase in the thermal efficiency is may be due to micro explosion phenomenon which occurs with emulsified fuels combustion. Lower thermal efficiency of JOE5 emulsion may be due to lower calorific value of the emulsion. [9] [11]

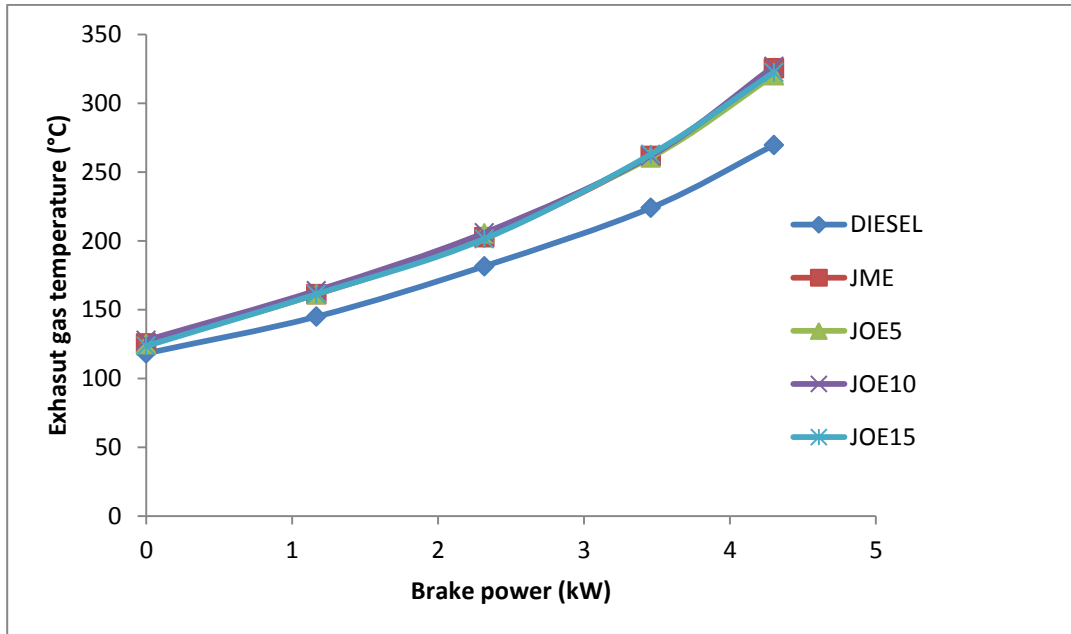
#### 4.1.2 Brake specific energy consumption vs. Brake power (kW)



**Fig.5 Variation of brake specific energy consumption with brake power**

It is found that at full load SEC decreases as WPO concentration increases from 12.534(MJ/kWh) for JOE5 to 11.575 MJ/kWh of JOE15. BSEC of JOE5 is 5.45% more than that of JME and BSEC of JOE15 is 2.3% less than that of JME. Lower calorific value of the emulsions causes higher fuel consumption to produce the same power output.

### 4.1.3 Exhaust gas temperature vs. Brake power (kW)

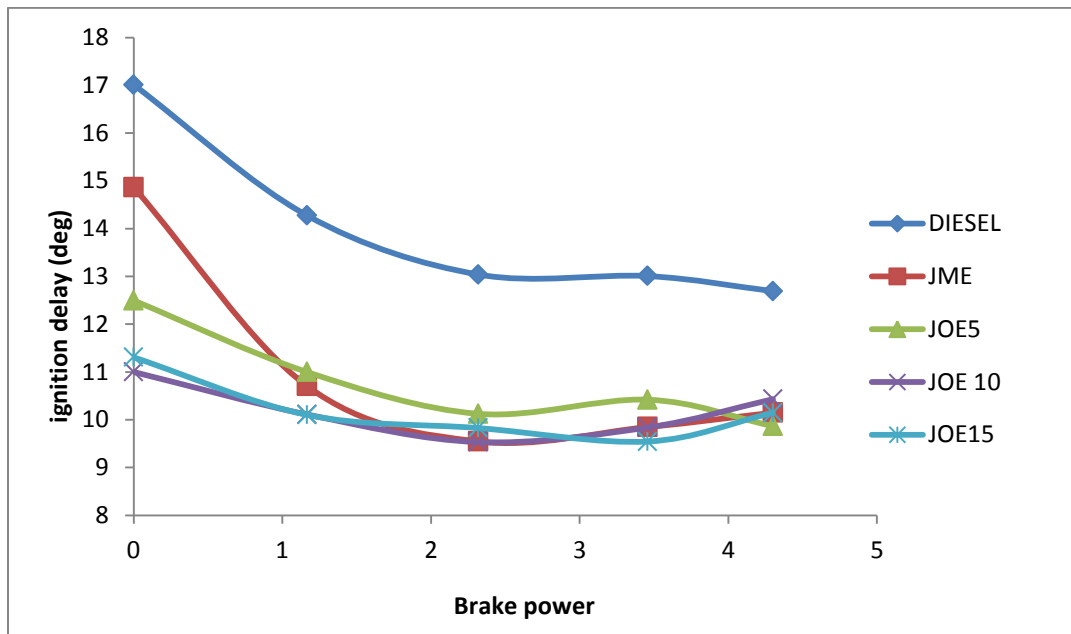


**Fig.6 Variation of exhaust gas temperature with brake power (kW)**

It is found that EGT increase with load for all fuels and EGT of emulsions and JME are more than that of diesel. At full load EGT of JME is 17% more than diesel and for JOE15 it is 16.26% more than diesel. The highest EGT is recorded with JOE10 which is 326.65°C and for diesel it is 270C. It can also be observed that the exhaust gas temperature of the emulsion decreases with increase in the WPO content. The water present in the emulsion gets vaporized during the combustion process and absorbs the heat energy which decreases the local adiabatic flame temperature. This leads to reduction in exhaust gas temperature of WPO-JME emulsions. [10] [11]

## 4.2 COMBUSTION CHARACTERISTICS

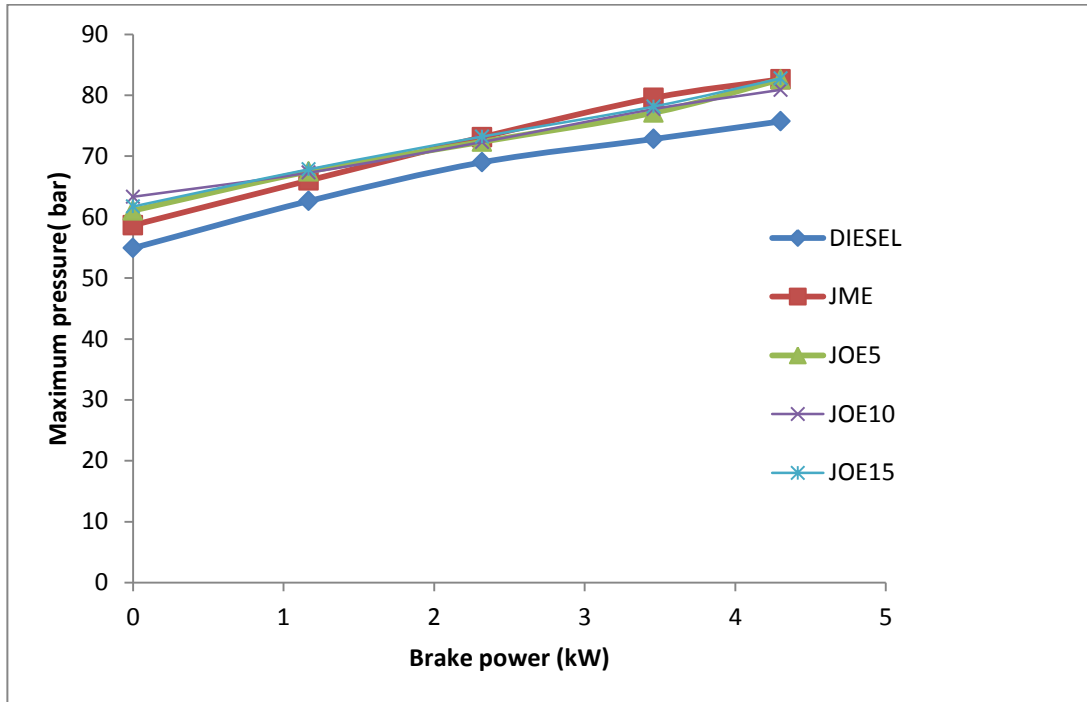
### 4.2.1 Ignition delay vs. Brake power



**Fig.7 Variation of ignition delay with brake power**

The ignition delay is found out to be less for JME and JOE emulsions as compared to diesel. The ignition delay decreases by 20% when using JME as compared to diesel. The lowest ignition delay is for JOE5 which decreases by 22% to that of diesel. Combustion starts earlier in the case of oxygenated fuels and this may be the reason for lower ignition delay.

#### 4.2.2 Maximum pressure vs. Brake power

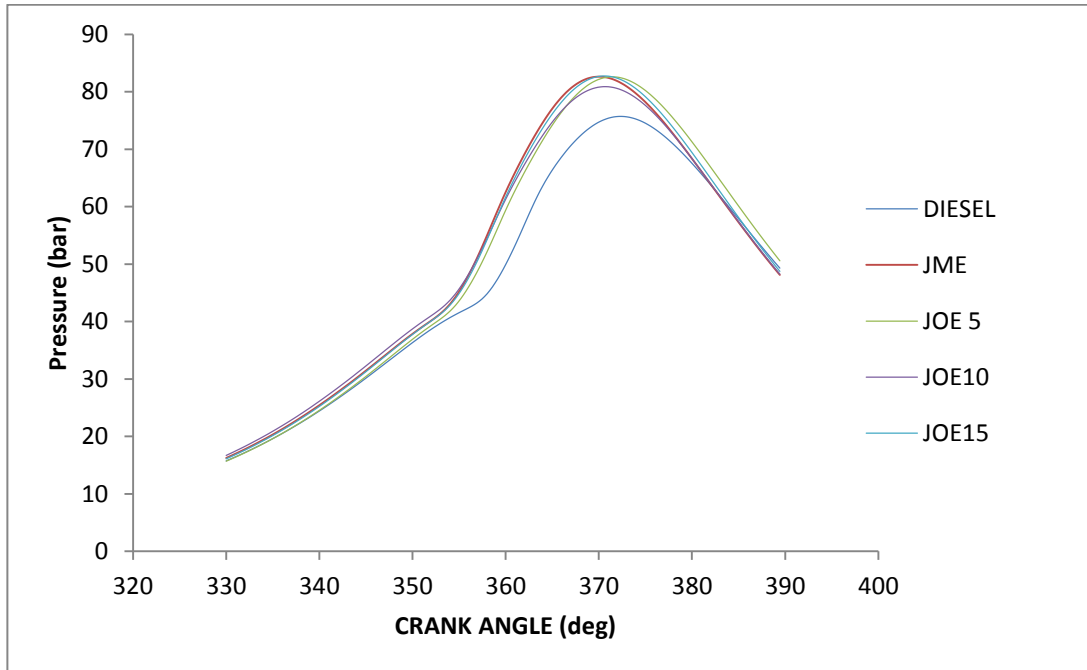


**Fig.8 Variation of max pressure with brake power**

The max pressure for JME, and WPO emulsions are more than that of diesel. The max pressure increases with load for each fuel. At full load the maximum pressure for JME is 9.1% more than that of diesel. The highest max pressure is recorded with JOE15 emulsion. Peak pressure is maximum in the case of emulsions due to shorter ignition delay and rapid combustion.



### 4.3.3 Pressure vs. Crank angle (deg)

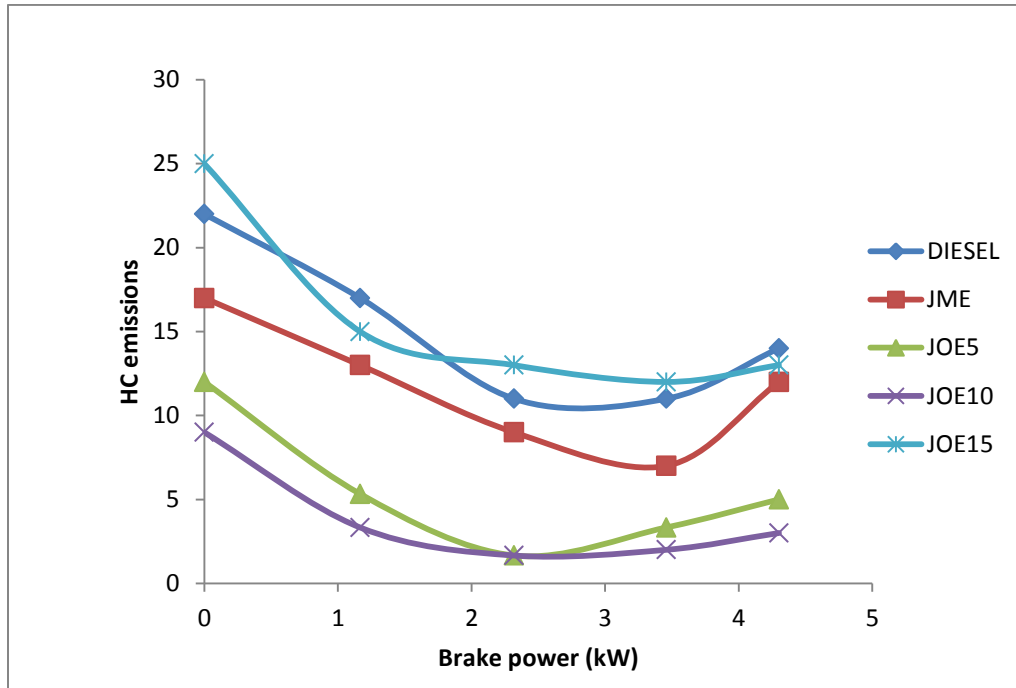


**Fig.9 Variation of pressure with Crank angle**

The maximum pressure of 75.7 bar is found at 372 degrees crank angle for diesel, for JME 82.61 bar is noted at 370°CA, and for JOE5, JOE10, JOE15 pressures of 82.58, 80.8, and 82.7 are noted at 371°CA, 370°CA, and 370° CA respectively. It is observed from the graph that the combustion of emulsions starts earlier than diesel fuel. For all the fuels tested the peak pressure occurs after the TDC which will reduce the expansion stroke.

## 4.3 EMISSION CHARACTERISTICS

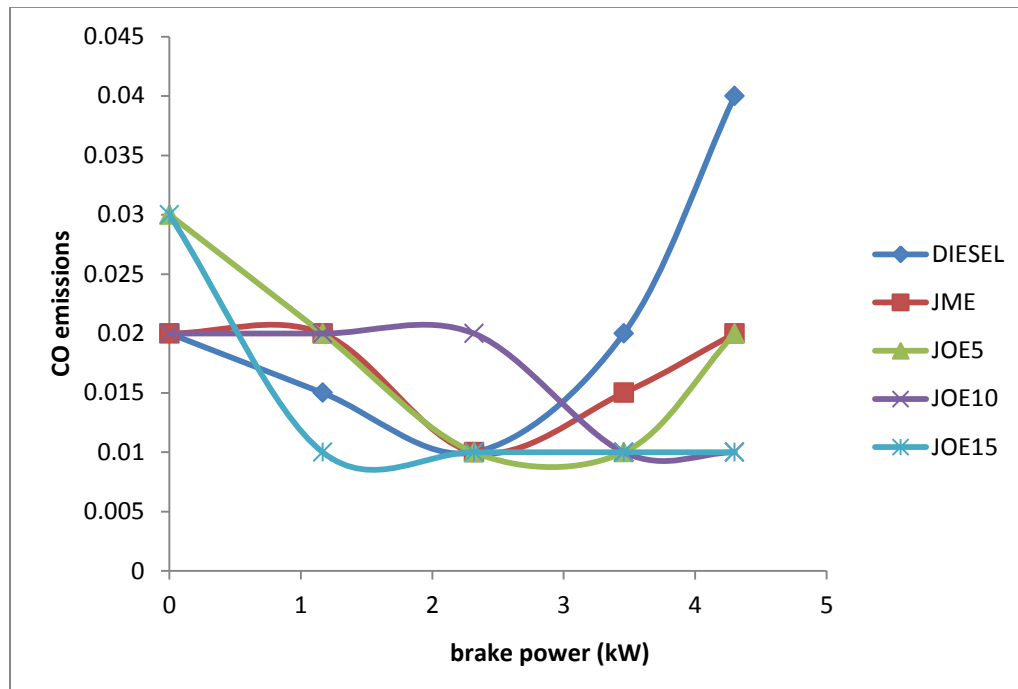
### 4.3.1 HC emissions with Brake power



**Fig.10 Variation of HC emissions with Brake power**

HC emissions decrease by 14% when using JME as compared to diesel. HC emissions seem to decrease with addition of WPO (JOE5 & JOE10) but increases in the case of JOE15. HC emissions are lowest in the case of JOE10. At full load HC emissions for JOE15 is 7% less than diesel. The HC emissions of JME are found to be lower than that of diesel fuel since, the higher oxygen content of the JME leads to more complete burning than diesel fuel. For JOE5, JOE10 and JOE15, the HC emissions were found to be lower than that of JME.

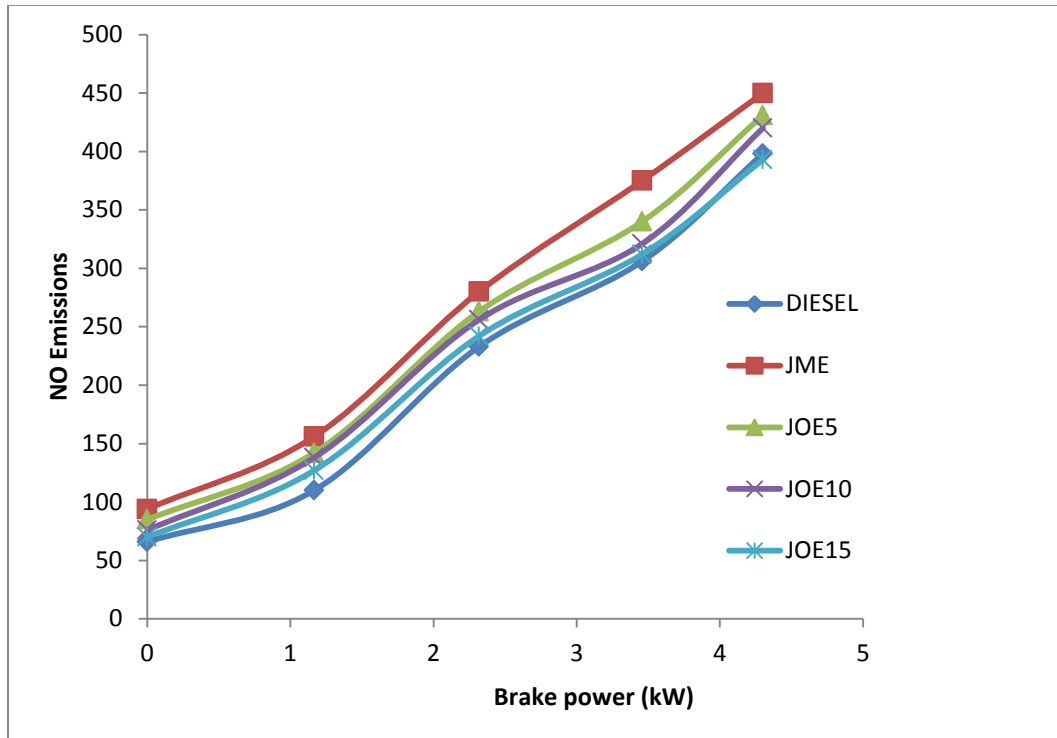
### 4.3.2 CO emissions with Brake power (kW)



**Fig 11 Variation of CO emissions vs. Brake power (kW)**

CO emissions decreases by 50 % with the use of JME and JOE5, it further decreases in the case of JOE10 and JOE15. The CO emissions of emulsions are found to be lower than diesel fuel at full load condition. This may be due improved combustion which occurs with the help of micro explosion phenomenon.

### 4.3.3 NO emissions with Brake power



**Fig .11 Variation of NO emissions with Brake power**

NO emission decreases with increase in WPO concentration, however the values are greater than diesel. NO emissions increase by 13% when using JME as compared to diesel.

The NO emissions compared to diesel increases by 8.29%, 5.5% for JOE5, JOE10 and decreases by 1.3% for JOE15. The NO emissions for emulsions are lower than JME. This may be due to the water content present in the WPO which will reduce the combustion temperature.

## 5. CONCLUSIONS

Pyrolysis oil is extracted from waste package wood chips by flash pyrolysis process and its properties are studied. Three emulsions of WPO and biodiesel are prepared and characterization of the emulsions are conducted as follows:

- The BTE for JOE 15 is 2% more than diesel and for JOE5 it is 6% less than diesel. The increase in the thermal efficiency is may be due to microexplosion phenomenon which occurs with emulsified fuels combustion. Lower thermal efficiency of JOE5 emulsion may be due to lower calorific value of the emulsion.
- At full load SEC decreases as WPO concentration increases. Lower calorific value of the emulsions causes higher fuel consumption to produce the same power output.
- EGT increase with load for all fuels and EGT of emulsions and JME are more than that of diesel. The exhaust gas temperature of the emulsion decreases with increase in the WPO content. The lower molecular weight components present in the emulsion gets vaporized during the combustion process and absorbs the heat energy which decreases the local adiabatic flame temperature. This leads to reduction in exhaust gas temperature of WPO-JME emulsions
- The ignition delay is found out to be less for JME and JOE emulsions as compared to diesel. The lowest ignition delay is for JOE5 which decreases by 22% to that of diesel. Combustion starts earlier in the case of oxygenated fuels and this may be the reason for lower ignition delay.

- The max pressure for JME, and WPO emulsions are more than that of diesel. Peak pressure is maximum in the case of emulsions due to shorter ignition delay and rapid combustion.
- The HC emissions of JME are found to be lower than that of diesel fuel since, the higher oxygen content of the JME leads to more complete burning than diesel fuel. For JOE5, JOE10 and JOE15, the HC emissions were found to be lower than that of JME.
- The CO emissions of emulsions are found to be lower than diesel fuel at full load condition. This may be due improved combustion which occurs with the help of micro explosion phenomenon
- The NO emissions compared to diesel increases by 8.29%, 5.5% for JOE5, JOE10 and decreases by 1.3% for JOE15. The NO emissions for emulsions are lower than JME. This may be due to the water content present in the WPO which will reduce the combustion temperature. NO emission decreases with increase in WPO concentration

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