

“DESIGN & DEVELOPMENT OF A PYROLYSIS REACTOR”

*A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF*

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

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CERTIFICATE

This is to certify that the project entitled, “**Design & Development of a Pyrolysis Reactor**” submitted by Mr. Rahul in partial fulfillments for 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 supervision and guidance.

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

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ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude to my supervisor, **Prof. S Murugan**, for his excellent guidance, suggestions and constructive criticisms and valuable suggestion throughout this project work.

I would like to express my gratitude to **Prof. R.K. Sahoo** (Head of the Department) and **Prof. K.P. Maity** (Project Coordinator) for their valuable suggestions and encouragements at various stages of the work. I am also thankful to all staff & members of Department of Mechanical Engineering, NIT Rourkela.

I greatly appreciate & convey my heartfelt thanks to my colleagues' flow of ideas, dear ones & all those who helped me in completion of this work.

NIT Rourkela

RAHUL

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ABSTRACT

Researchers led by rise in energy demand, stricter emission norms & exhausting oil resources are in search for an alternative fuel for IC engines. Some alternative fuels such as Alcohols, Biodiesel, LPG, CNG etc have been in the transport sector on a commercial scale. A renewed interest has been currently received for the pyrolysis of solid wastes. Simplification of the disposal of many wastes can be done by pyrolysis to some extent. Analysis of the properties of the oil derived from wastes was done & compared with the petroleum products. In this paper, description of the study of using waste pyrolysis oil is being done. The oil has been obtained from waste substances by the method of vacuum pyrolysis.

1. INTRODUCTION

The study of fuels for IC engines has been carried out ever since these engines came into existence. The engine converts heat energy which is obtained from the chemical combination of the fuel with oxygen, into mechanical energy. Since the heat energy is derived from the fuel, a fundamental knowledge of types of fuels & their characteristics is essential in order to understand the combustion phenomenon. The characteristics of the fuel used have considerable influence on the design, efficiency, output & particularly, the reliability & durability of the engine. Further, the fuel characteristics play a vital role in the atmospheric pollution caused by the engines used in automobiles.

The energy sources available can be divided into 3 types:

1. Primary energy sources:

Primary energy sources can be defined as sources which provide a net supply of energy. Coal, oil, uranium etc are examples. The energy required to obtain these fuels is much less than what they can produce by combustion or nuclear reaction. Their energy yield ratio, which is the energy fed back by the material to the energy received from the environment is very high. The primary fuels only can accelerate growth but their supply is limited. It becomes very essential to use these fuels sparingly. Primary fuels contribute considerably to the energy supply.

2. Secondary fuels:

They produce no net energy. Though it may be necessary for the economy, these may not yield net energy. Intensive agriculture is an example wherein terms of energy the yield is less than input.

3. Supplementary sources:

These are defined as those whose net energy yield is zero & those requiring highest investment in terms of energy. Insulation (thermal) is an example for this source.

Coal, natural gas, oil & nuclear energy using breeder reactor are net energy yielders & are primary sources of energy. Secondary sources are like solar energy, wind energy, water energy etc.

ENERGY CONSUMPTION AS A MEASURE OF PROSPERITY :

Energy is an important input in all sectors of any country's economy. The standard of living of a given country can be directly related to per capita energy consumption. Energy crisis is due to the two reasons: firstly that the population of world has increased rapidly & secondly the standard of living of human beings has increased. If we take the annual per capita income of various countries & plot them against per head energy consumption, it will appear that the per capita energy consumption is a measure of the per capita income or is a measure of the prosperity of the nation. The per capita income of developed countries like USA is about 50 times more than per capita income of India & so also is the per capita energy consumption. The per capita energy consumption in USA is 8000 kWh per year, whereas the same in India is 150 kWh. USA with 7 % of world's population consumes 32 % of the total energy consumed in the world, whereas India, a developing country with 20 % of world's population consumes only 1 %.

Developing countries, at present export primary products such as food, coffee, tea, jute, & ores etc. This does not give them the full value of their resources. To get better value, the primary products should be processed to products for export. This needs energy.

Conclusions of the study on alternate energy strategies are:

1. The supply of fossil oil will soon fail to meet increasing demand, even if energy prices rise 50% above current levels in real terms. Additional constraints on oil production will hasten this shortage, thereby reducing the time available for action on alternatives.
2. Demand for energy will continue to grow even if governments adopt vigorous policies to conserve energy. This growth must increasingly be satisfied by energy resources other than oil, which will be progressively reserved for uses that fossil oil can satisfy.
3. The continued growth of energy demand requires that energy resources be developed with the utmost vigor. The change from a world economy dominated by fossil oil must start now. The alternatives require 5 to 15 years to develop & the need for replacement fuels will increase rapidly.

It has been concluded that world fossil oil production is likely to level-off very shortly & that alternative fuels will have to meet growing energy demand. Large investments & long lead times are required to produce these fuels on a scale large enough to fill the prospective shortage of fossil oil, the fuel that now furnishes most of the world's energy. The task for the world will be to manage a transition from dependence on fossil oil to greater reliance on other alternative fuels.

ENERGY SOURCES & THEIR AVAILABILITY

Today, every country draws its energy needs from a variety of sources. We can broadly categorize these sources as commercial & non-commercial. The commercial ones include fossil fuels-coal, oil, natural gas, hydroelectric power, & nuclear power, while the non-commercial sources include wood, animal waste & agricultural wastes. In an industrialized country like USA, most of the energy requirements are met from commercial sources, while in an industrially less developed country like India, the use of commercial & non-commercial sources are about equal.

Wood was dominant source of energy in pre-industrialization era. It gave way to coal & coke. Use of coal reached a peak in the early part of twentieth century. Fossil oil got introduced at that

time & has taken a substantial share from wood * coal. Wood is no more regarded as a conventional source. Hydroelectricity has already grown to a stable level in most of the developed countries. A brief account of the various important sources of energy & their future possibilities is as:-

The percent use of various sources for the total energy consumption in the world is:

Coal	32.5 %
Oil	38.3 %
Gas	19 %
Uranium	0.13 %
Hydro	2 %
Wood	6.6 %
Dung	1.2 %
Waste	0.3 %

Coal, oil, gas, uranium & hydro are **commercial** or **conventional energy** sources. Looking at the percent distribution, one finds that world's energy supply comes mainly from fossil fuels. The heavy dependence on fossil fuels stands out clearly. One of the so most significant aspects of the current energy consumption pattern in many developing countries is that non-commercial sources such as firewood, animal dung & agricultural waste represent a significant 8 % of the total energy used in the world. They constitute about 4 times the energy produced by the hydro & 60 times the energy produced by nuclear sources. In some developing countries non-commercial energy sources are a significant fraction of the total resources. This dependence of the developing countries is likely to continue unless replaced by other alternative sources of energy.

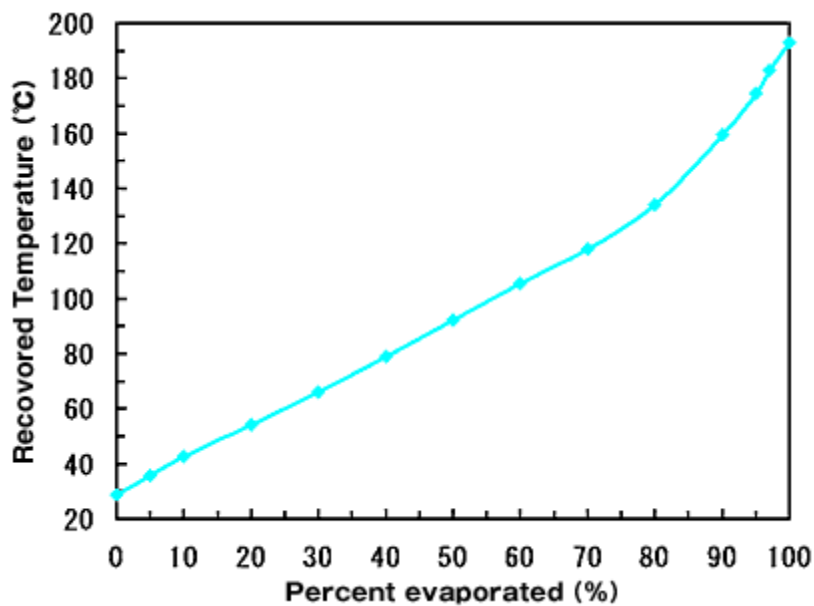
Due to the limited fossil oil reserves, India has to depend on substantial imports for meeting its future requirements. The bulk of the demand for fossil oil is from transport sector, & in order to reduce the pressure from this sector, it is necessary to explore possibilities of developing substitute fuels like bio-mass & pyrolysis oils.

1.1 FUELS FOR SI ENGINES

Fuels used in IC engines should possess certain basic qualities which are important for the smooth running of the engines. Gasoline which is mostly used in the present day SI engines is usually a blend of several low boiling paraffins, naphthalenes & aromatics in varying proportions. Some of the important qualities of gasoline are:-

(i) **Volatility:**

Volatility is one of the main characteristic properties of gasoline which determines its suitability for use in an SI engine. Since gasoline is a mixture of different hydrocarbons, volatility depends on the fractional composition of the fuel. The usual practice of measuring the fuel volatility is the distillation of the fuel in a special device at atmospheric pressure & in the presence of its own vapor. The fraction that boils off at a definite temperature is measured. The characteristic points are the temperatures at which 10, 40, 50 & 90% of the volume evaporates as well as the temperature at which boiling of the fuel terminates. The more important aspects of volatility related to engine fuels are in conjunction with the distillation curve:-



(ii) Starting & Warm up:

A certain part of the gasoline should vaporize at the room temperature for easy starting of the engine. Hence, the portion of the distillation curve between about 0 & 10 % boiled off have relatively low boiling temperatures. As the engine warms up, the temperature will gradually increase to the operating temperature. Low distillation temperatures are desirable throughout the range of the distillation curve for best warm-up.

(iii) Operating Range Performance:

In order to obtain good vaporization of the gasoline, low distillation temperatures are preferable in the engine operating range. Better vaporization tends to produce both more uniform distribution of fuel to the cylinders as well as better acceleration characteristics by reducing the quantity of liquid droplets in the intake manifold.

(iv) Crankcase Dilution:

Liquid fuel in the cylinder causes loss of lubricating oil (by washing away oil from cylinder walls) which deteriorates the quality of lubrication & tends to cause damage to the engine through increased friction. The liquid gasoline may also dilute the lubricating oil & weaken the oil film between rubbing surfaces. To prevent these possibilities, the upper portion of the distillation curve should exhibit sufficiently low distillation temperatures to ensure that all gasoline in the cylinder is vaporized by the time the combustion starts.

(v) Vapor Lock Characteristics:

High rate of vaporization of gasoline can upset the carburetor metering or even stop the fuel flow to the engine by setting up a vapor lock in the fuel passages. This characteristic, demands the presence of relatively high boiling temperature hydrocarbons throughout the distillation range. Since this requirement is not consistent with the other requirements desired, a compromise must be made for the desired distillation temperatures.

(vi) Antiknock Quality:

Abnormal burning or detonation in an SI engine combustion chamber causes a very high rate of energy release, excessive temperature & pressure inside the cylinder adversely affects its thermal efficiency. Therefore, the characteristics of the fuel used should be such that it resists the tendency to produce detonation & this property is called its antiknock property. The antiknock property of a fuel depends on the self-ignition characteristics of its mixture & vary largely with the chemical composition & molecular structure of the fuel. In general, the best SI engine fuel will be that having highest antiknock property, since this permits use of higher compression ratios & thus the engine thermal efficiency & the power output can be greatly increased.

(vii) Gum Deposits:

Reactive hydrocarbons & impurities in the fuel have a tendency to oxidize upon storage & form liquid & solid gummy substances. The gasoline containing hydrocarbons of the paraffin, naphthalene & aromatic families forms little gum while cracked gasoline containing unsaturated hydrocarbons is the worst offender. A gasoline with high gum content will cause operating difficulties such as sticking valves & piston rings carbon deposits in the engine, gum deposits in the manifold, clogging of carburetor jets & enlarging of the valve stems, cylinders & pistons. The amount of gum increases with increased concentrations of oxygen, with rise in temperature, with exposure to sunlight & also on contact with metals. Gasoline specifications therefore limit both the gum content of the fuel & its tendency to form gum during storage.

(viii) Sulphur Content:

Hydrocarbon fuels may contain free sulphur, hydrogen sulphide & other sulphur compounds which are objectionable for several reasons. The sulphur is a corrosive element of the fuel that can corrode fuel lines, carburetors & injection pumps & it will unite with oxygen to form sulphur dioxide that, in the presence of water at low temperatures, may form sulphurous acid. Since sulphur has a low ignition temperature, the presence of sulphur can reduce the self-ignition temperature, then promoting knock in the SI engine.

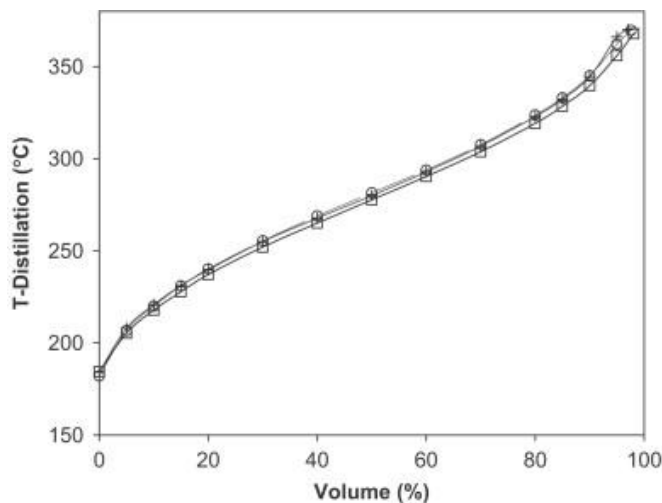
1.2 FUELS FOR CI ENGINES

(i) Knock Characteristics:

Knock in the CI engine occurs because of an ignition lag in the combustion of the fuel between the time of injection & the time of actual burning. As the ignition lag increases, the amount of fuel accumulated in the combustion chamber increases & when combustion actually takes place, abnormal amount of energy is suddenly released causing an excessive rate of pressure rise which results in an audible knock. Hence, a good CI engine fuel should have a short ignition lag & will ignite more readily. Furthermore, ignition lag affects the starting, warm up, & leads to the production of exhaust smoke in CI engines. The present day measure in the cetane rating, the best fuel in general, will have a cetane rating sufficiently high to avoid objectionable knock.

(ii) Volatility:

The fuel should be sufficiently volatile in the operating range of temperature to produce good mixing & combustion.



[Ref 7]

Figure above is a representative distillation curve of a typical diesel fuel.

(iii) Starting Characteristics:

The fuel should help in starting the engine easily. This requirement demands high enough volatility to form a combustible mixture readily & a high cetane rating in order that the self-ignition temperature is low.

(iv) Smoking & Odour:

The fuel should not promote either smoke or odour in the engine exhaust. Generally, good volatility is the first prerequisite to ensure good mixing & therefore complete combustion.

(v) Viscosity:

CI engine fuels should be able to flow through the fuel system & the strainers under the lowest operating temperatures to which engine is subjected to.

(vi) Corrosion & Wear:

The fuel should not cause corrosion & wear of the engine components before or after the combustion. These requirements are directly related to the presence of sulphur, ash & residue in the fuel.

(vii) Handling Ease:

The fuel should be a liquid that will readily flow under all conditions that are encountered in actual use. This requirement is measured by the pour point & the viscosity of the fuel. The fuel should also have a high flash point & a high fire point.

2. VEGETABLE OIL & PYROLYSIS OIL

2.1 VEGETABLE OIL

Bio-diesel, is an alternative for the diesel fuel, that is made from the renewable sources which are biodegradable like the vegetable oil & the animal fats. It is a biodegradable, non-toxic & possesses very low emission profiles. It is environmental friendly too.

One hundred years ago, Rudolf Diesel had first tested the vegetable oil as the fuel for his engine. When cheap petroleum came, crude oil fractions were refined to serve as the fuel & diesel fuels & diesel engines had started evolving together. Then in the 1940's, vegetable oils had been used again as a fuel in emergency times, during the period of World War II. Because of the increase in crude oil prices, limited resources of fossil fuels & the environmental concern, there had been renewed focus on vegetable oils & animal fats for production of bio-diesel fuel. Bio-diesel has potential to reduce level of pollution & level of global warming

Bio-diesel is a mono-alkyl-esters of the long-chain-fatty-acids that are derived from the renewable lipid sources. Bio-diesel is the name for the variety of the ester based oxygenated fuel from the renewable biological sources. It could be used in the compression ignition engines with little or without modifications.

2.2 PYROLYSIS OILS

Pyrolysis oil is a synthetic fuel. It's extracted by biomass conversion to liquid by way of destructive distillation converting dried biomass in the reactor at a temperature of 500°C followed by cooling. Pyrolytic oil is basically resembles tar and contains very high levels of oxygen to be called a hydrocarbon. So, this is the reason it's distinctly different from similar petroleum products.

Fuel oil characteristics:

The oil produced is an acidic one with a pH of 1.5-3.8 (2.8). The acidity is decreased by addition of base compounds. The biomass begins with 10% to 15% moisture & the oil obtained doesn't end up with water content. Water molecules are split during the pyrolysis & held separately in other compounds in the pyrolysis liquid. The density is equal to 1.2-1.3 (1.22) kg/l or 10.01-10.85 (10.18) lbs/gallon, the value of which is much higher than diesel. The oxygen portion is 40-50%, mostly from the water content, & no sulfur is detected normally. The lower heating value is about 16-21 (17.5) MJ/kg. The pour point is -12°C to -33°C, no cloud point can be observed upto -21°C. The carbon residue is 17-23 % wt (0.13% ash). The flash point is 40-100°C, pyrolysis oil isn't an auto-igniting one in a CI engine. The cetane number is 10. The viscosity rises to a max in 12 months owing to polymerization. The pyrolysis oil isn't stable reacting with air and degasing. Pyrolysis oil can't be blended with diesel.

2.3 BIOFUELS

Biofuels are the wide variety of fuels which that are derived from the biomasses. It includes solid biomass, liquid fuels & various biogases. They are gaining more & more public & scientific attention, due to factors like oil price spikes & the need for increasing energy security.

Bioethanol is basically an alcohol that is made by fermenting sugar components of the plant materials & it's made mostly from sugar & starch crops. With the advanced technology under development, cellulosic biomass, like trees & grasses, are used as feedstocks for production of ethanol. Ethanol can be used as fuel for the vehicles in the pure form, but it's used mainly as gasoline additive to increase the octane & improve the vehicle emissions. Bioethanol is applied in the USA and in Brazil.

Biodiesel is manufactured from the vegetable oils, the animal fats or recycled greases. Biodiesel can be used as a fuel for the vehicles in pure form, but it's used as the diesel additive to decrease the levels of particulates, carbon monoxide, and the hydrocarbons from diesel-powered vehicles. Biodiesel is manufactured from the oils or fats by the use of transesterification & is the most used biofuel in Europe.

Biofuels accounted for 1.8% of world's transport fuel in year 2008. Investments into the biofuels production exceeded \$4 billion in the world in year 2007 and is expanding.

3. LITERATURE SURVEY

I. de Marco Rodriguez et al had studied the behaviour & chemical analysis of the pyrolysis oil. In that work it was reported that Pyrolysis Oil is a complex mixture of organic compounds of 5-20 carbons and with a higher proportion of aromatics. The percentages of aromatics, aliphatic, nitrogenated compounds, benzothiazol were also determined in the pyrolysis oil at various operating temperatures of the pyrolysis process. Roy et al., conducted experiments on the vacuum pyrolysis. In this work, a step-by-step approach has been used, starting from bench-scale batch systems, to a process development unit & lastly a pilot plant, to experiment & develop vacuum pyrolysis of waste wood. It had been reported that the yield is 55% oil, 25% carbon black, 9% steel, 5% fiber and 6% gas. Adrian M. Cunliffe and Paul T. Williams (1998), had studied the composition of oils derived from the batch pyrolysis of wastes in a nitrogen purged static-bed batch reactor, which is used to pyrolyse 3 kg of shredded wastes at temperatures between 450°C and 600°C. It had been reported that the pyrolysis of wastes produced oil similar in properties to a light fuel oil, with similar calorific value, sulphur & nitrogen contents. The oil had been found to contain 1.4 % sulphur and 0.45 % nitrogen on mass basis & have similar fuel properties to those of diesel fuel. These oils contained significant concn. of polycyclic aromatic hydrocarbons some of which had been shown to be either carcinogenic and or mutagenic. A single oil droplet combustion study had been carried out & also the oil was analysed in detail for its content of polycyclic aromatic hydrocarbons (PAH). The derived oil had been combusted in an 18.3 kW ceramic-lined, oil-fired, spray burner furnace, 1.6 m in length and 0.5 m internal diameter. Isabel de Marco Rodriguez et al., (2001) had studied the behavior and chemical analysis of wastes pyrolysis oil. In the same work, an automatic distillation test was carried out at 500 deg. C to analyse the potential use of waste wood pyrolysis oil as petroleum fuels.

4. DESIGN OF A PYROLYSIS SETUP

Desirable parameters for the design:

- a) Melting point of the substance

If mp is high, substance easily vaporizes & more oil is obtained.

- b) Density

If density is lower, substance easily vaporizes & more oil is obtained.

- c) Quality of substance

More is quality, more is the yield of oil.

- d) Moisture content

More is moisture, less is the oil yield.

- e) Reactor Temp

More is the reactor temp, more is the yield

- f) Heating rate

More is the heating rate, more is the yield

- g) Reactor size

There is an optimum for the reactor size to get maximum oil yield.

- h) Feed rate

Feed rate is given according to the demand for the oil.

DESIGN SPECIFICATIONS:

Furnace outer dimensions: 1ft x 1ft x 1ft

Diameter of Central Cylindrical Core Heater: 0.6 ft

Height of Central Cylindrical Core Heater: 1 ft

Distance of the heater from the furnace bottom: 0.05 ft

Height of the heater above the furnace top: 0.05 ft

Total Height of the heater: 1 ft

Length of the condenser pipe from reactor top to inlet of condenser: 2 ft

Diameter of condenser: 1 ft

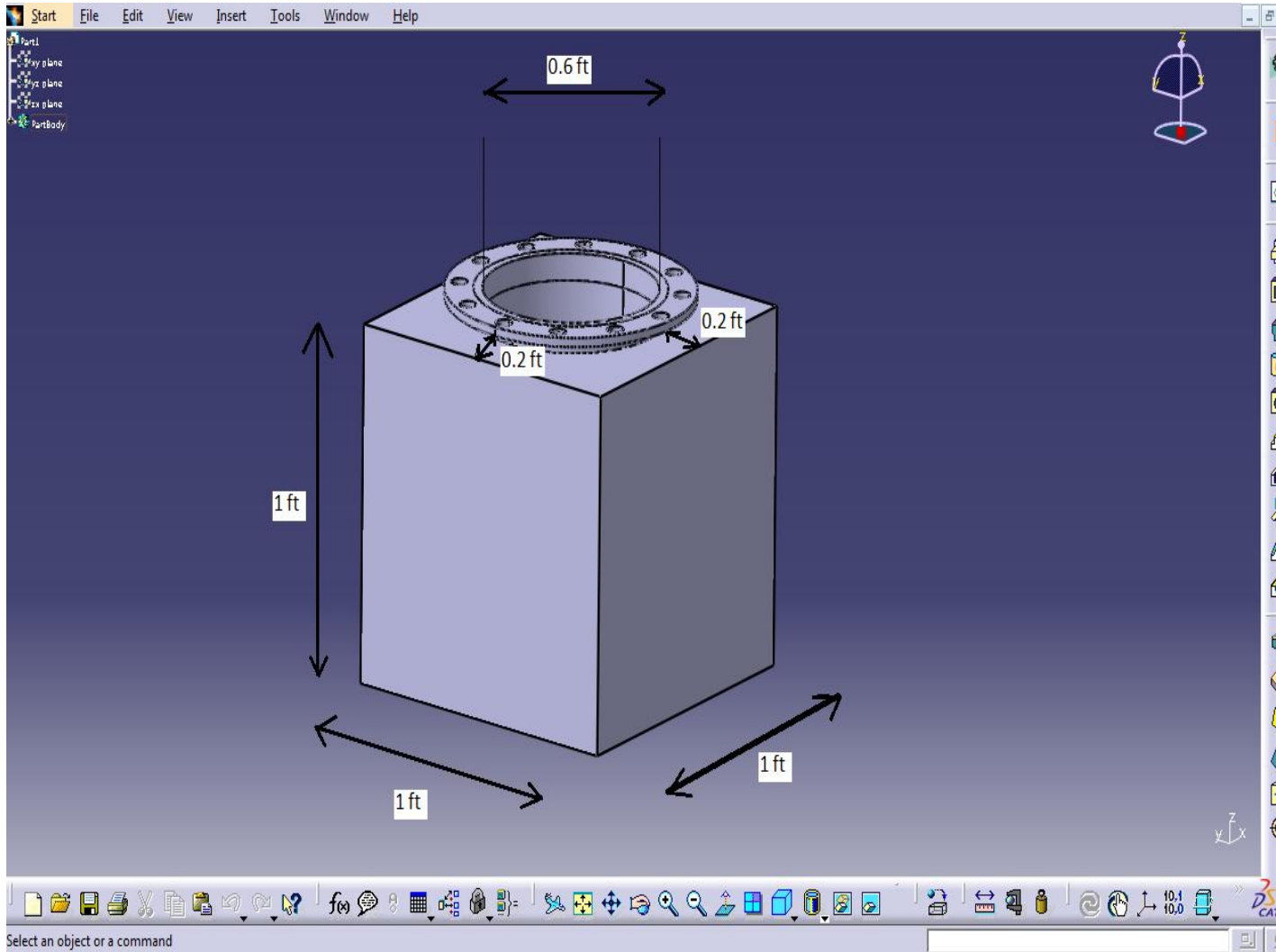
Length of condenser: 1.2 ft

Length of condenser exit to oil collector: 1 ft

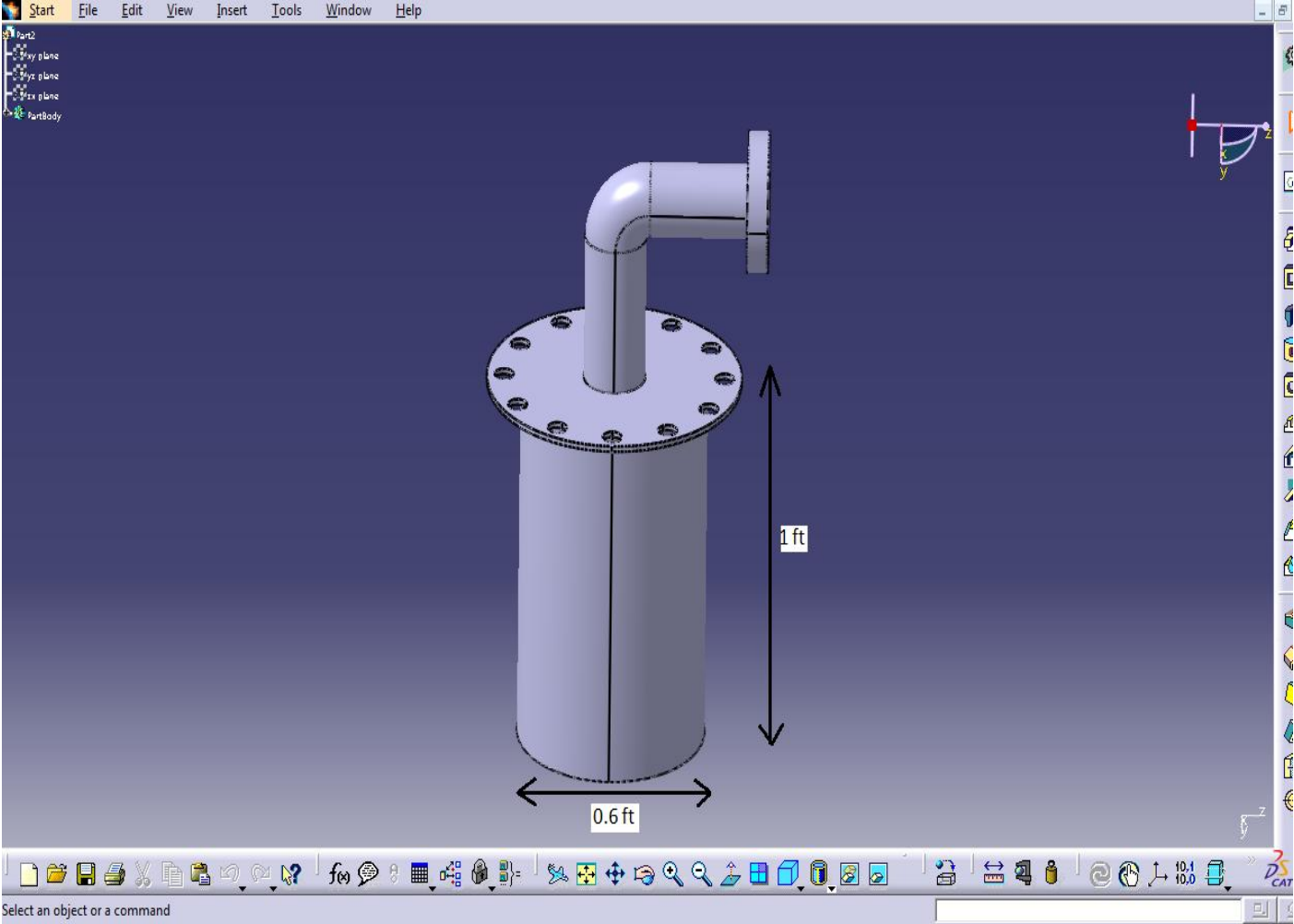
Anticipated Process time, Power input and output

Electrical heater capacity	: 2 kW
Feedstock	: 1 kg
Output -Wood pyrolysis oil	: 45% of 1L Wood Oil
Residence time for 1 kg	: 90-100 minutes
Heat required to convert waste to Wood pyrolysis oil	: 4-6 MJ/kg

PYROLYSIS REACTOR :

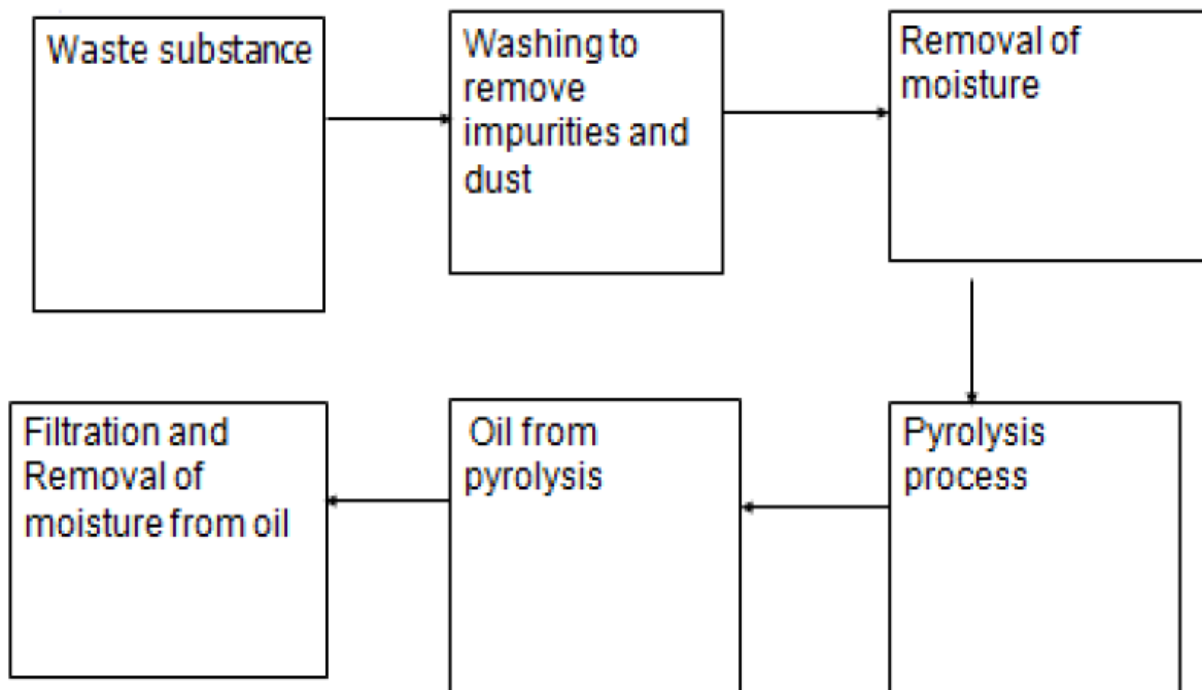


CENTRAL CORE HEATER :



5. PYROLYSIS OF WASTE WOOD

Pyrolysis Flow Diagram



Product Distributions as a Function of Pyrolysis Reactor Temperature:

Outside Reactor Temp (°C)	Gas%	Oil%	Char, %
300	7	41	52
400	11	51	38
500	16	56	28
600	32	42	26

Elemental Composition of Oil:

Elemental composition (wt %)		Proximate analysis (Dry air wt %)	
Carbon	: 85	Volatile matter	: 62
Hydrogen	: 12	Fixed carbon	: 24
Oxygen	: -	Moisture content	: 1%
Nitrogen	: 0.8	Ash content	: 13
Sulphur	: 2.2		
Total	: 100.00		: 100.00

Properties:

Property	Diesel	Crude WPO	DWPO10	DWPO20
Density@15 deg C (kg/m ³)	830	920	839	848
Kinematic Viscosity@40 deg C(cSt)	3.2	6.8	3.56	3.92
Calorific Value (MJ/kg)	46.5	36	45.5	44.4
Flash Point (deg C)	50	55	50.5	51
Fire Point (deg C)	56	62	56.6	57.2
Sulphur Content, %	0.045	0.1	0.05	0.056
Ash Content,%	0.01	-	-	-
Carbon Residue,%	0.35	-	-	-
Aromatic Content,%	26	-	-	-

PROCESS TIME, POWER INPUT & OUTPUT

Electrical heater capacity : 2 kW

Feedstock : 1 kg

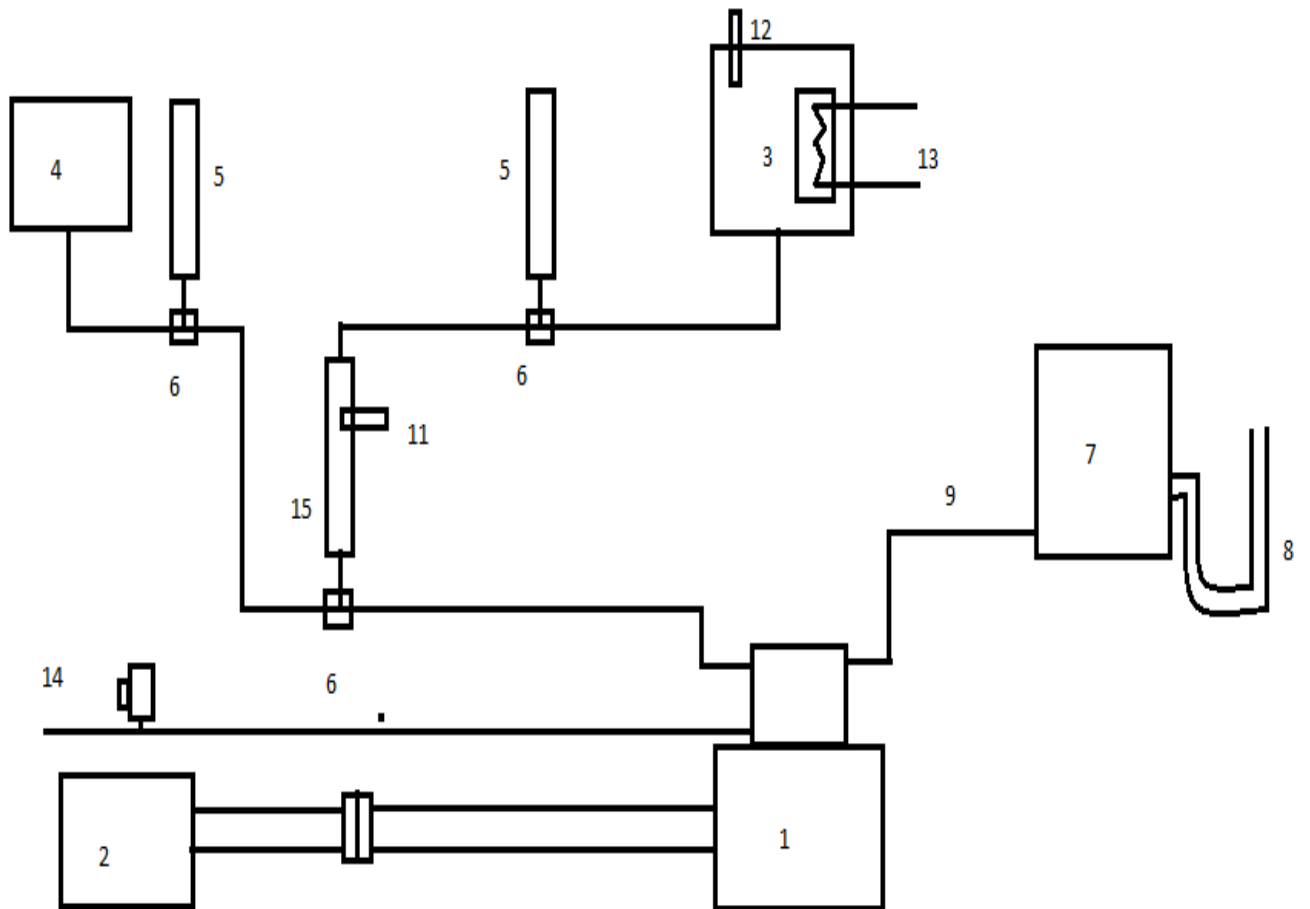
Output -Wood pyrolysis oil : 0.414 litres

Residence time for 1 kg : 95 minutes

**Heat required to convert waste
to Wood pyrolysis oil : 5.3 MJ/kg**

EXPERIMENTAL SETUP AND PROCEDURE

DIAGRAM



- 1.ENGINE
- 4.DIESEL TANK
- 7.AIR BOX
- 10.EXHAUST ANALYZER
- 13.OIL HEATER

- 2.DYNAMOMETER
- 5.BURETTES
- 8.MANOMETER
- 11.THERMOCOUPLE
- 14.EXHAUST FLOW

- 3.FUEL TANK
- 6.THREE WAY VALVE
- 9.AIR FLOW DIRECTION
- 12.THERMOMETER
- 15.SECONDARY HEATER

ENGINE SPECIFICATION

ENGINE	4S TWIN CYLINDER,WATER COOLED,DIRECT INJECTING,VERTICAL,3.7 KW POWER
MAKE/MODEL	KIRLOSKAR TV 1
BHP AND RPM	10 BHP @ 1500 RPM
BORE*STROKE	80mm*110mm
COMPRESSION RATIO	17.5:1

4.3 PROCEDURE

The wood waste pyrolysis oil & diesel are blended together to prepare a blend.10% of the pyrolysis oil is taken and 90% of diesel is taken to prepare the blend. This is the first fuel to be tested. Then 20% of the pyrolysis oil is taken and 80% diesel is mixed to prepare the second blending.

The blend oil is put in the fuel tank, the engine is started first we have to take the reading for 0 load and time taken to consume 20ml of oil is noted down.

DIESEL

Load (Kgf)	Engine speed (rpm)	Time (sec.)	Ex. temp. (°c)	Fuel consumption (Kg/hr.)	Brake power (Kw)	Brake sp. Fuel consumption (Kg/Kw hr.)	Indicated power (Kw)	$\eta_{\text{mechanical}}$ (BP/IP) (%)	η_{thermal} (%)	brake sp energy consumption bsec
0	1500	74	290	0.81	0	0	4.7	0	0	
5	1500	54	340	1.11	1.34	0.828	6.04	22.2	9.3	10.7
10	1500	45	420	1.33	2.7	0.492	7.4	36.5	15.7	6.35
15	1500	39	440	1.53	4.04	0.379	8.74	46.2	20.4	4.9
20	1500	33	450	1.81	5.39	0.336	10.1	53.4	23	4.34
25	1500	27	470	2.21	6.74	0.328	11.4	58.9	23.6	4.24

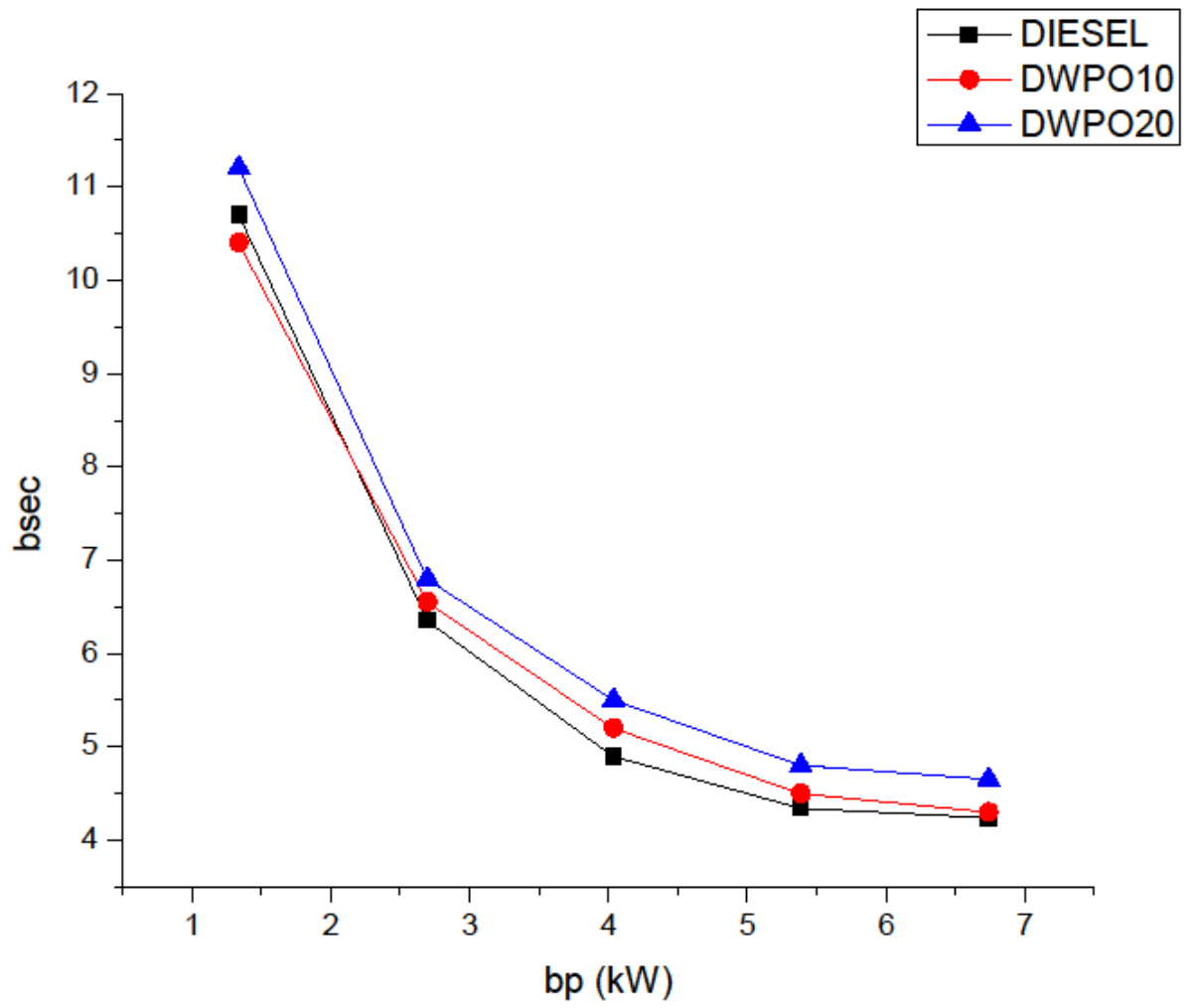
10DWPO-10% Blended Distilled Wood Pyrolysis Oil

Load (Kgf)	Engine speed (rpm)	Time (sec.)	Ex. temp. (°c)	Fuel consumption (Kg/hr.)	Brake power (Kw)	Brake sp. Fuel consumption (Kg/Kw hr.)	Indicated power (Kw)	$\eta_{\text{mechanical}}$ (BP/IP) (%)	η_{thermal} (%)	brake sp energy consumption bsec
0	1500	71	340	0.85	0	0	4.5	0	0	
5	1500	52	380	1.16	1.34	0.823	5.84	22.9	9.15	10.4
10	1500	43	420	1.4	2.7	0.519	7.2	37.5	15.28	6.55
15	1500	37	440	1.65	4.04	0.408	8.54	47.3	19.39	5.16
20	1500	31	470	1.92	5.39	0.356	9.9	54.4	22.23	4.5
25	1500	26	490	2.29	6.74	0.34	11.24	59.96	23.31	4.3

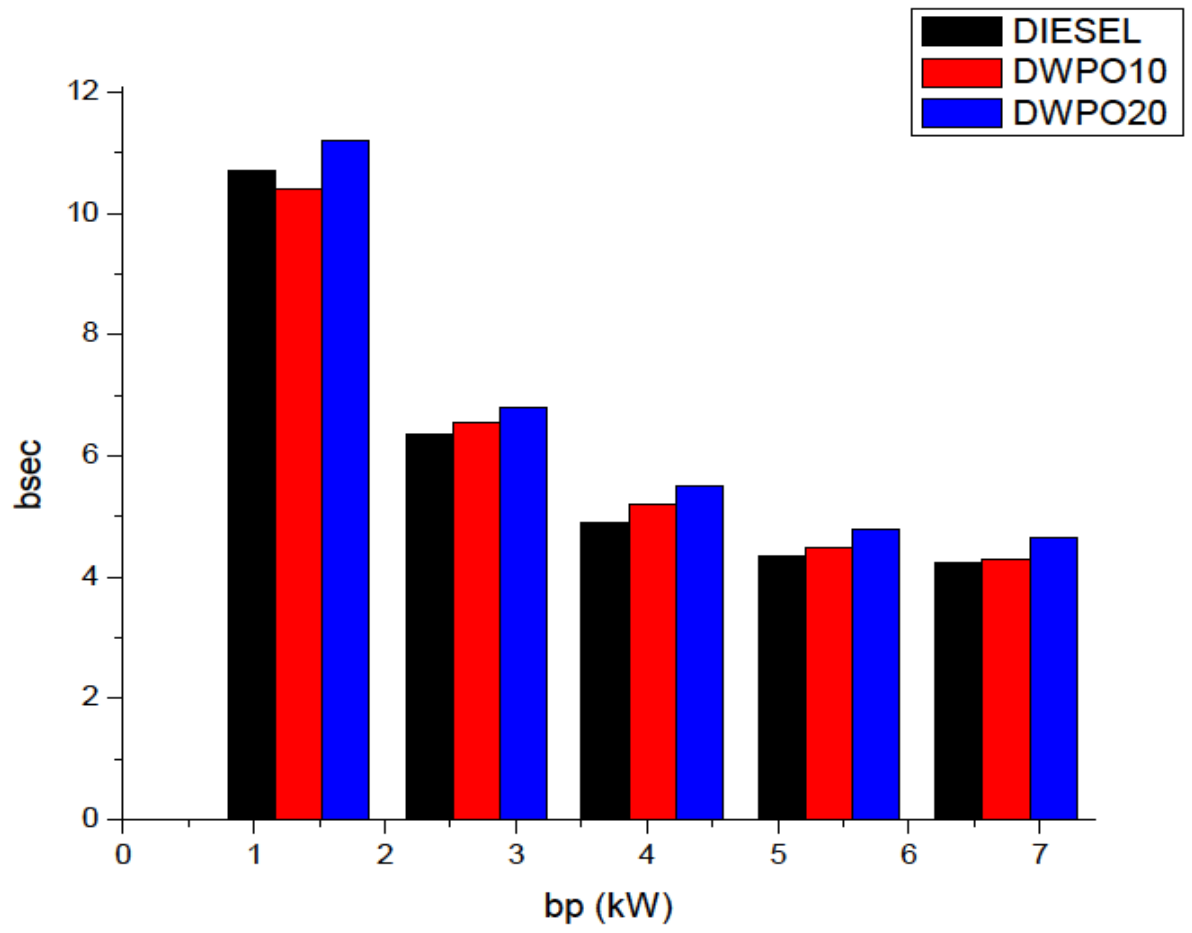
20DWPO-20% Blended Distilled Wood Pyrolysis Oil

Load (Kgf)	Engine speed (rpm)	Time (sec.)	Ex. temp. (°c)	Fuel consumption (Kg/hr.)	Brake power (Kw)	Brake sp. Fuel consumption (Kg/Kw hr.)	Indicated power (Kw)	$\eta_{\text{mechanical}}$ (BP/IP) (%)	η_{thermal} (%)	brake sp energy consumption bsec
0	1500	69	340	0.88	0	0	4.4	0	0	
5	1500	50	400	1.22	1.34	0.91	5.74	23.34	8.9	11.22
10	1500	41	440	1.49	2.7	0.552	7.1	38.03	14.69	6.81
15	1500	34	460	1.8	4.04	0.445	8.44	47.87	18.24	5.49
20	1500	29	480	2.1	5.39	0.39	9.79	55.06	20.81	4.81
25	1500	24	520	2.54	6.74	0.377	11.14	60	21.51	4.65

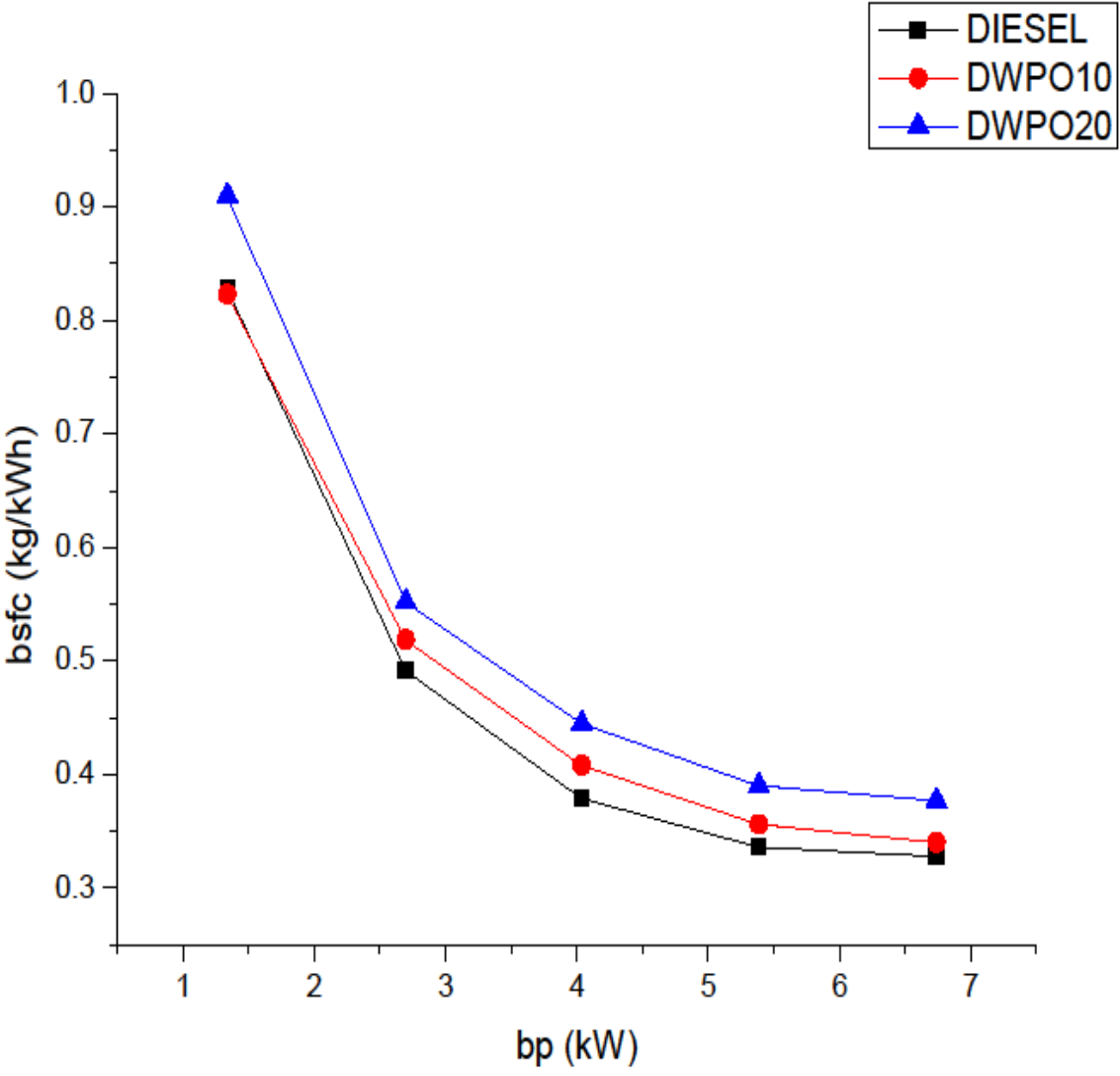
BSEC Vs BP



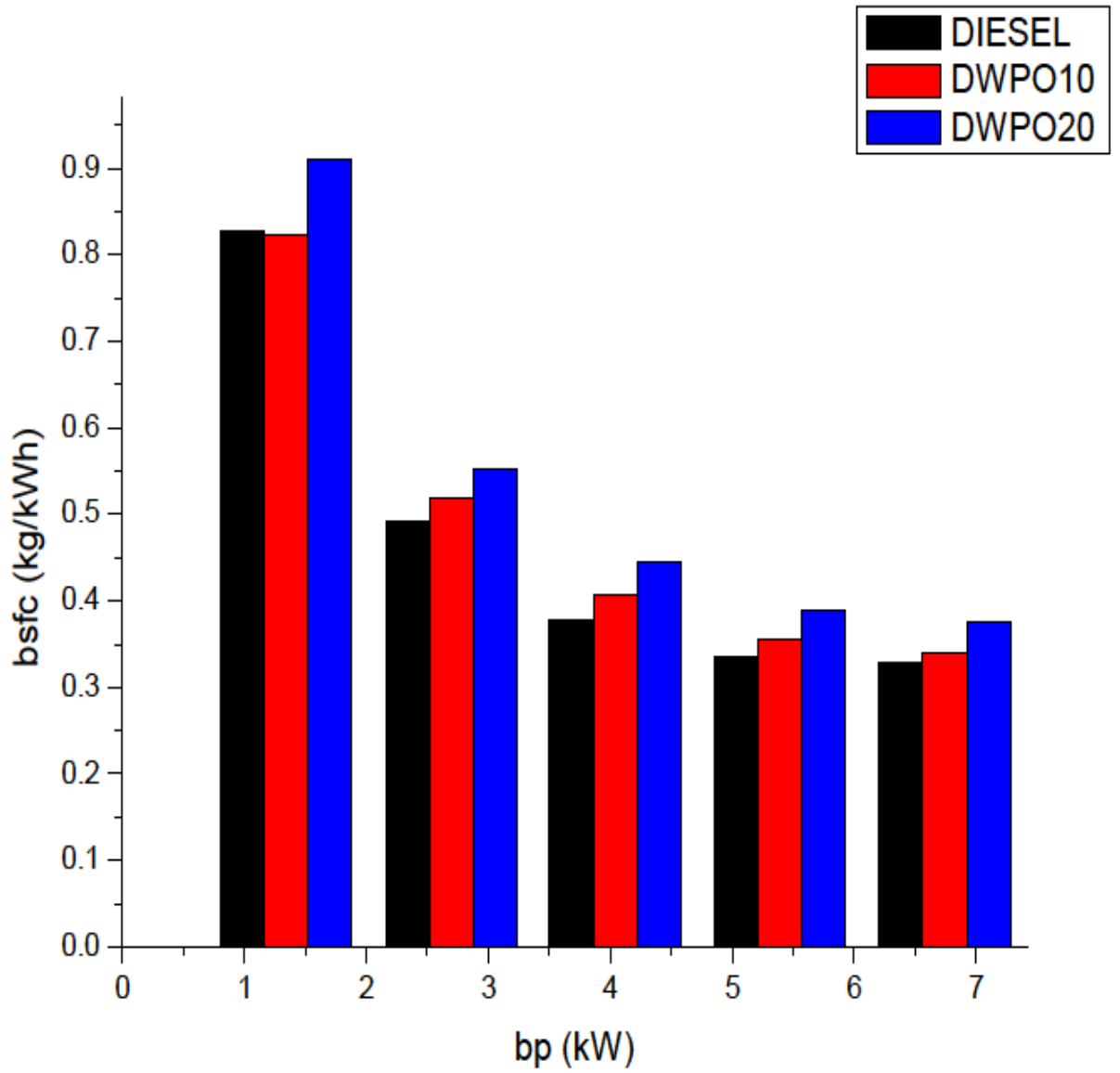
BSEC Vs BP



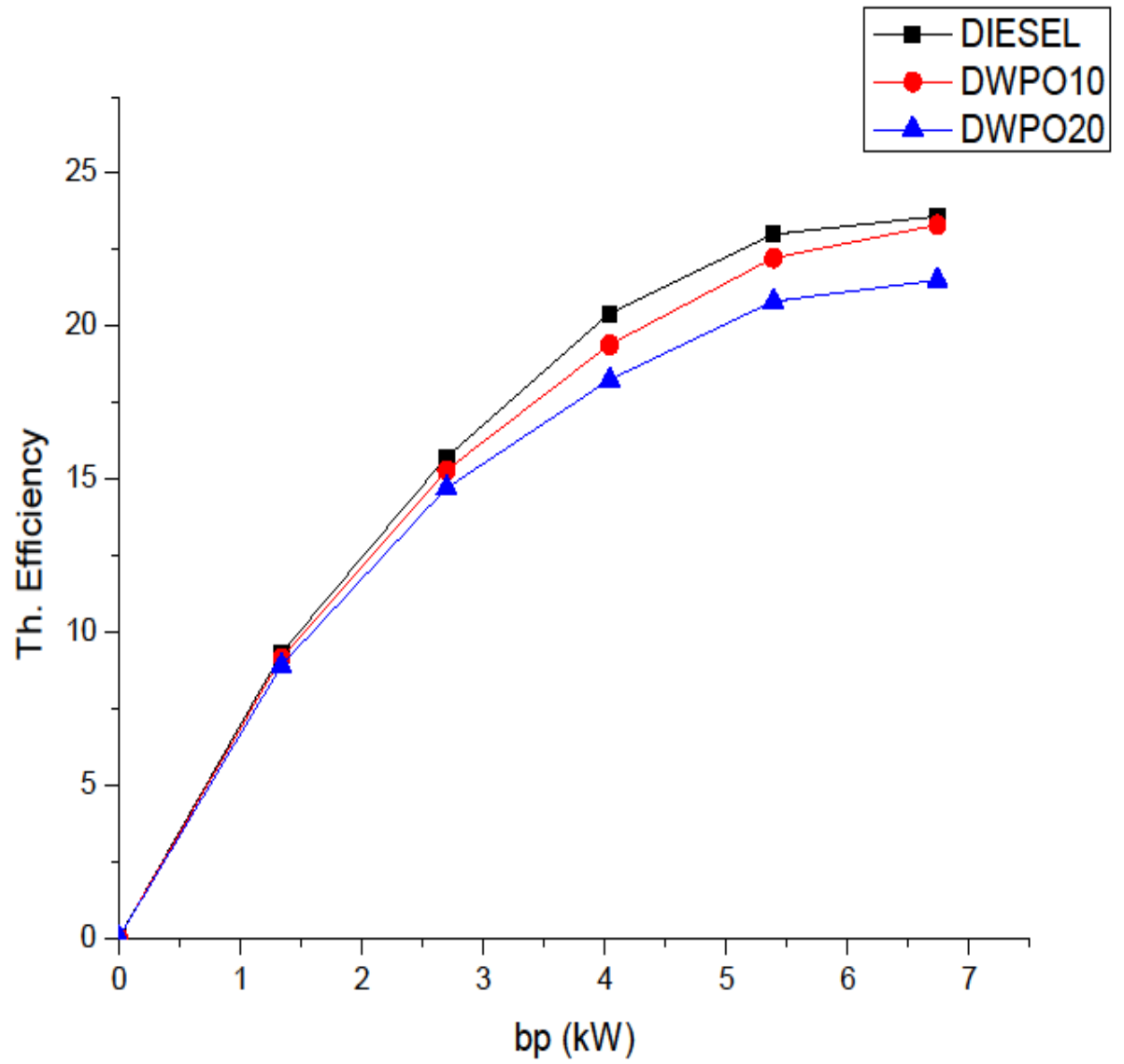
BSFC Vs BP



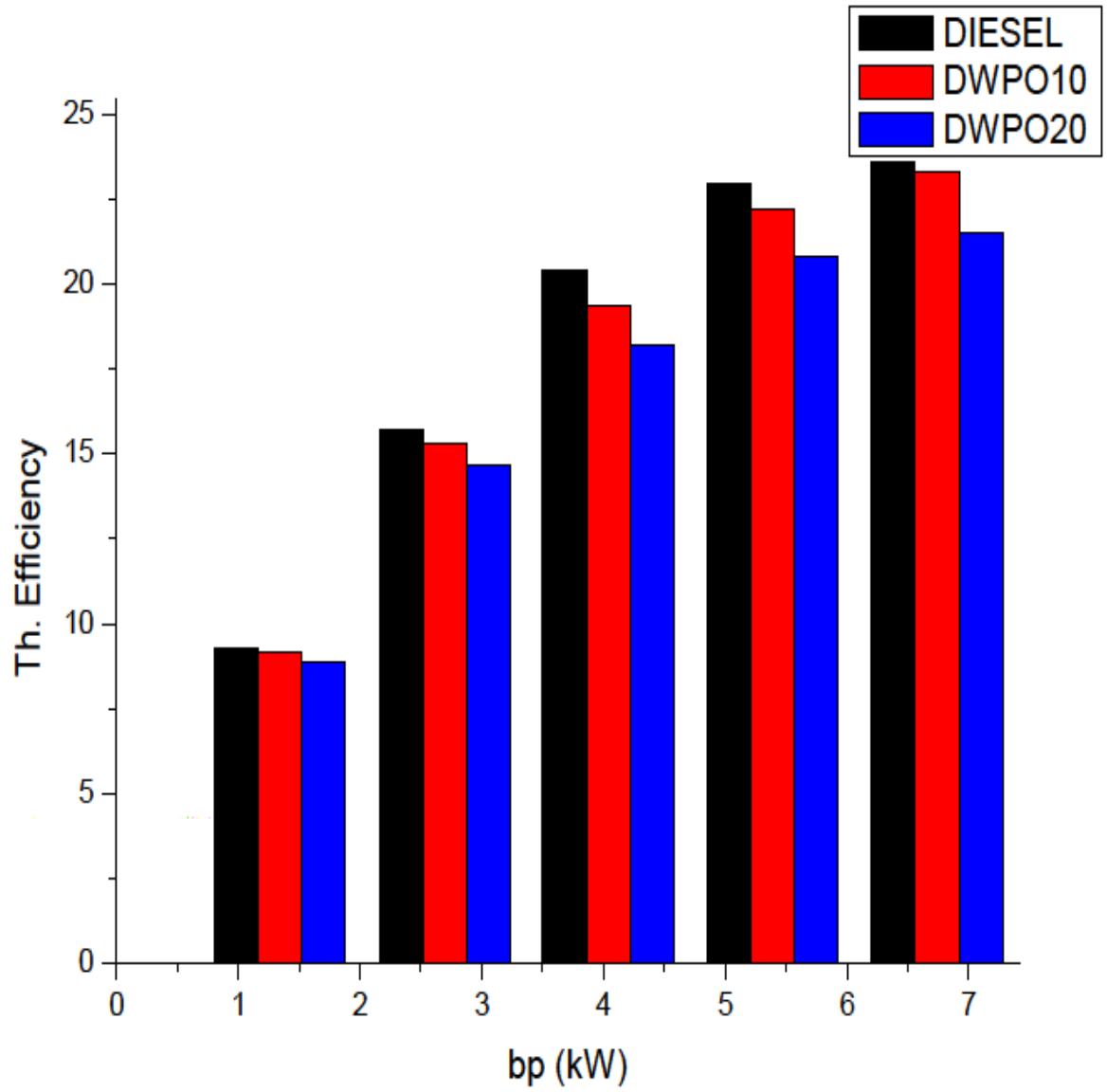
BSFC Vs BP



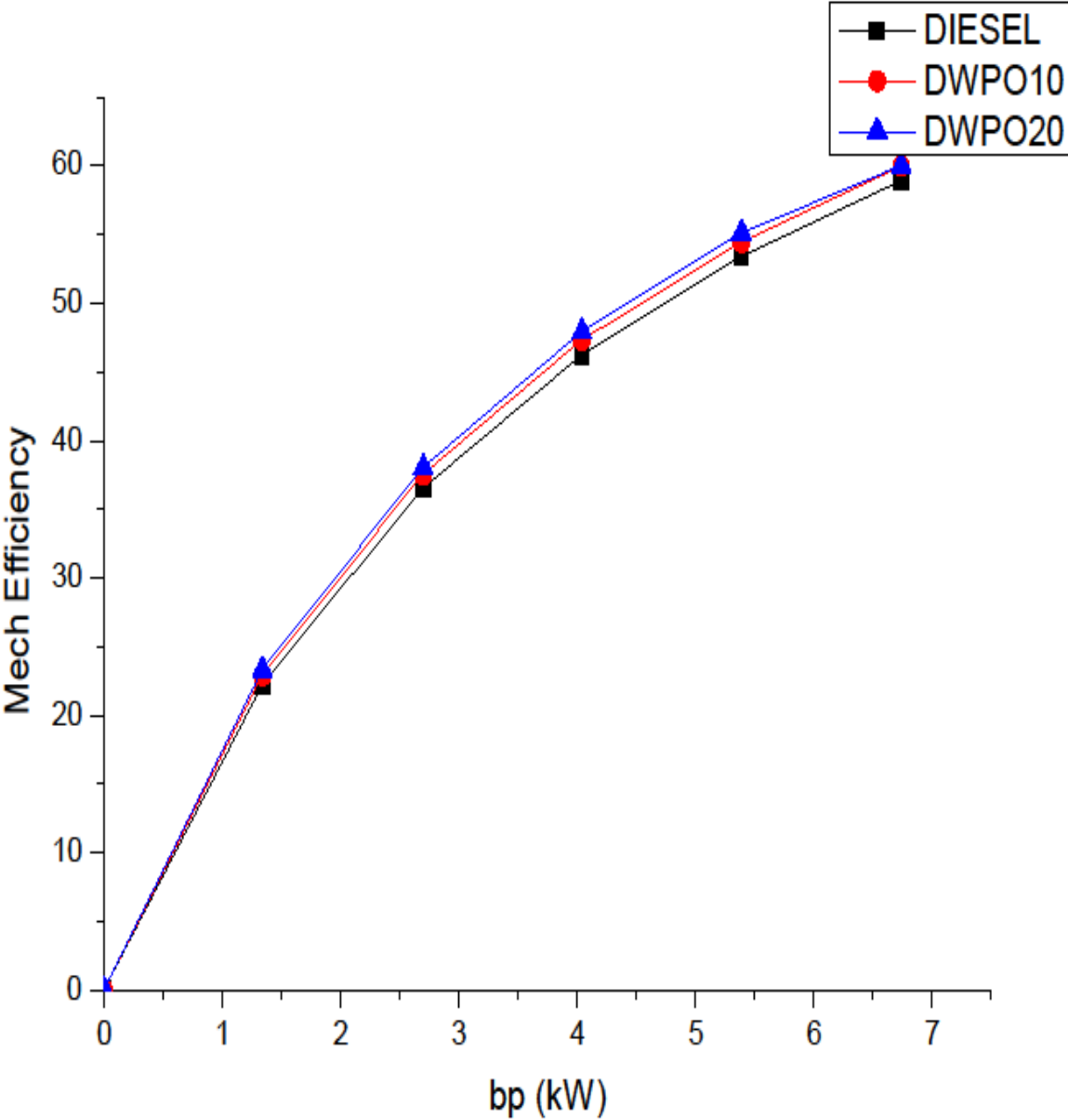
Th. Efficiency Vs BP



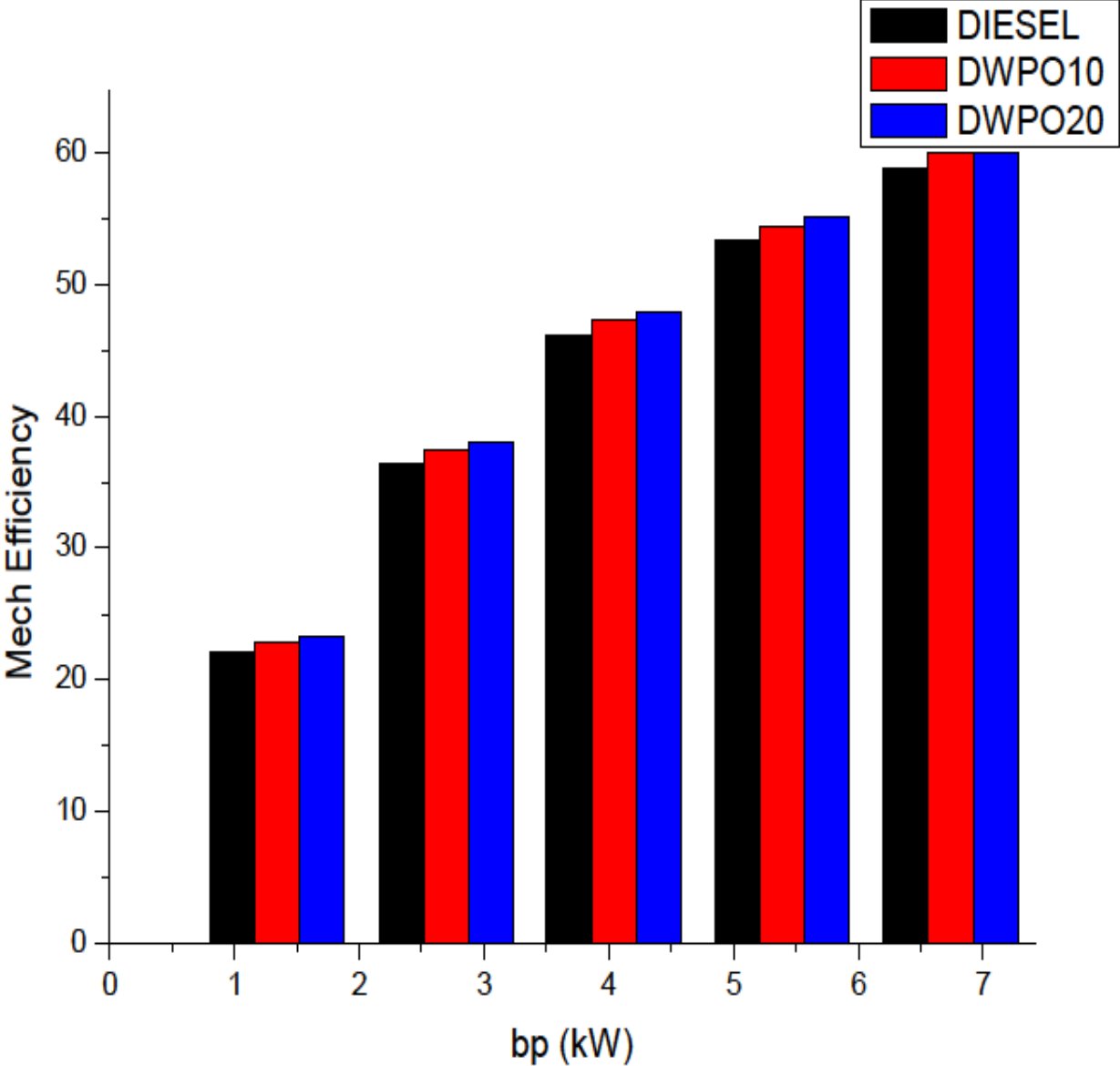
Th. Efficiency Vs BP



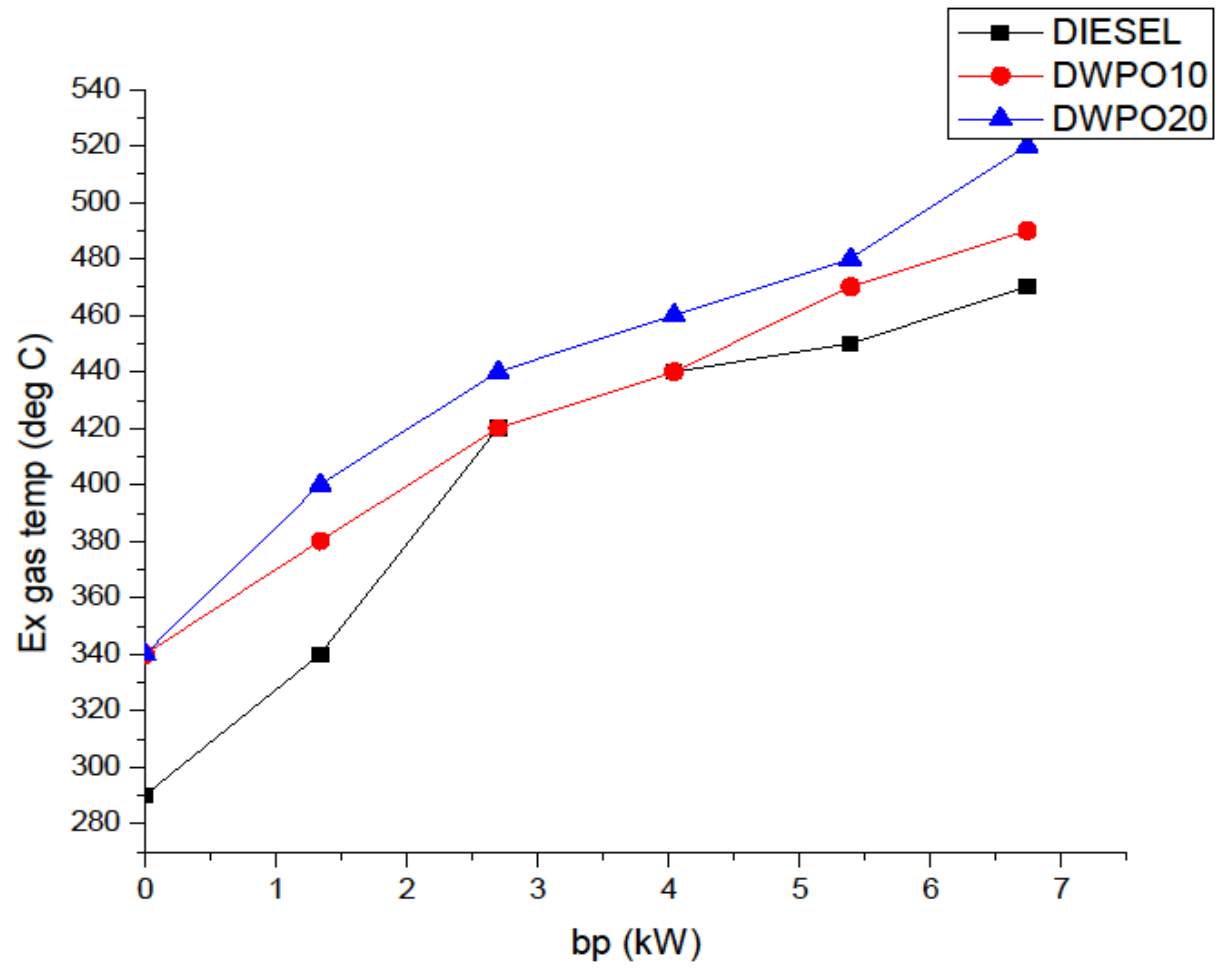
Mech Efficiency Vs BP



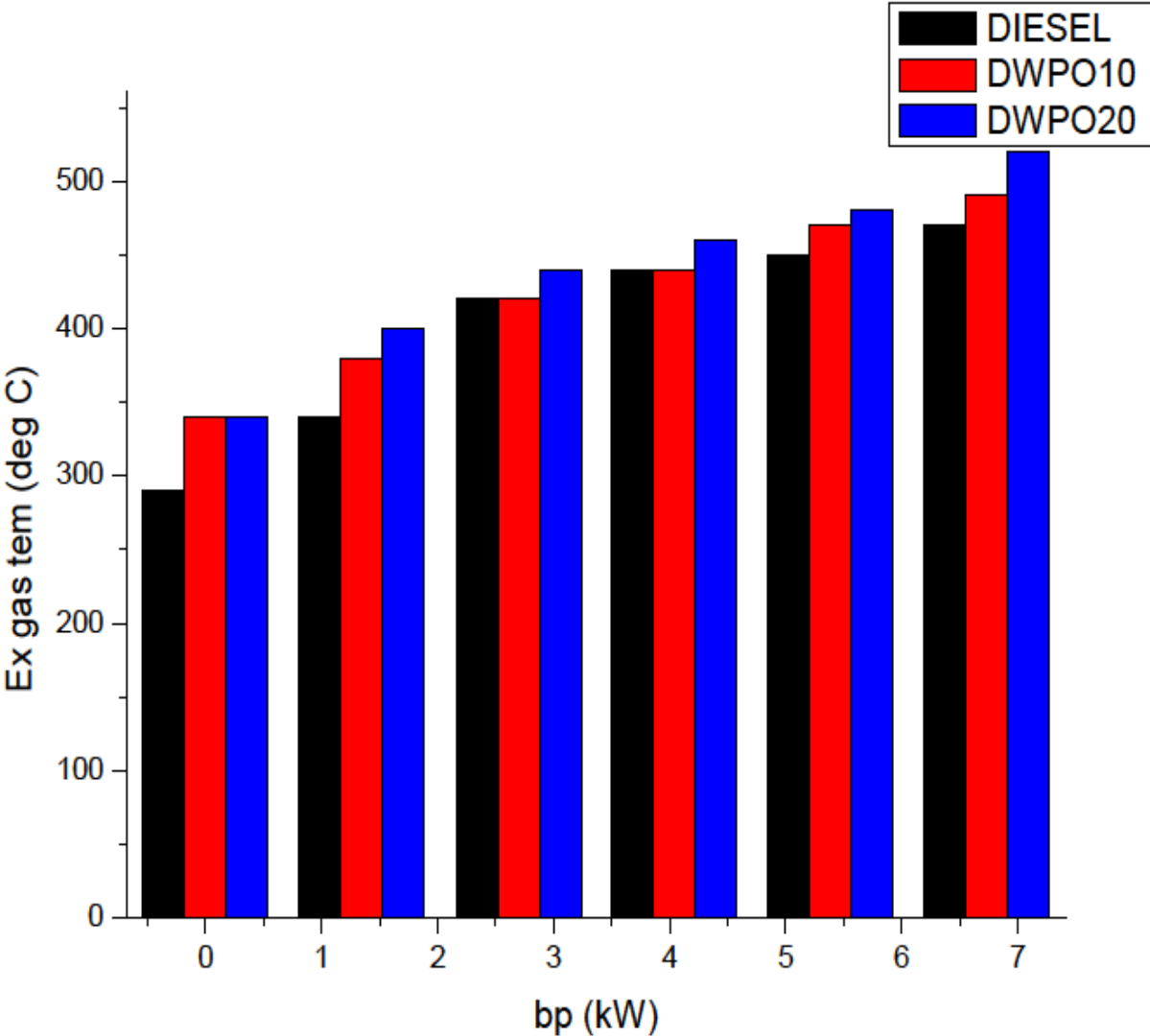
Mech Efficiency Vs BP



Ex Gas Temp Vs BP



Ex Gas Temp Vs BP



6. CONCLUSION

- a) 20 % blended oil consumes highest specific energy for same bp
- b) As blending increases, fuel consumption increases for same bp
- c) As blending increases, thermal efficiency decreases for same bp
- d) As blending increases, mechanical efficiency increases for same bp
- e) As the blending increases, exhaust gas temp increases for same bp

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