

Experimental Analysis of Fuel Produced from Automotive Waste Lube Oil

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Abstract - In this study, an experimental investigation was carried out to determine the effects of blends of pyrolysis fuel with diesel with ratios of 10%, 20%, 30% and 50% on the performance and emission characteristics of a diesel engine. As microwave heated pyrolysis has recently shown promise as a route for the treatment and recycling of the waste automotive oil. In this process, waste oil is mixed with a highly microwave-absorbent material such as carbon rod; as a result of microwave heating the oil is thermally cracked in the absence of oxygen into shorter hydrocarbon chains. The oil obtained by pyrolysis of automotive waste oil can be used as an alternate fuel for diesel engine without making any modification to the engine.

Properties of the pure pyrolysed fuel were checked. A series of engine performance and emission tests were conducted using the blends of fuel samples in the test engine. Effects of the fuels on the performance parameters, and emissions of NO_x, CO, CO₂, and HC were discussed. The results indicated that brake thermal efficiency decrease due to increase in brake specific fuel consumption with increasing amount of blends with diesel. The main effect of 10%, 20%, 30% and 50% blends of pyrolysed fuel additions to diesel on pollutant formation was that the NO_x ratio increased with increase in load, whereas that of CO also increased due to insufficient oxygen in the engine cylinder.

Keywords: Waste automotive oil(WAO), Pyrolysis, Microwave Pyrolysis, Diesel engine, Brake thermal efficiency.

1. INTRODUCTION

1.1 Automotive Waste Oil

Nowadays, we find increasing demand for lube oil use, which results in more waste lube oils. Waste lubricant oils are important alternative fuel sources proved to be the best substitutes for existing petro fuels, since waste generated oils represent more than 60% of used lubricant oils. Since the energy resources related to fossil fuels diminish and are limited, the research focuses on finding alternative energy resources and utilizing them. The recycling of the automotive waste oils and lubricants is an alternative for energy resources. The high-volume waste oils can be turned into valuable fuel products by refining and treating processes. Converting of the waste oils into diesel and gasoline-like fuels to be used in engines without disposing is very important. Consumption of the diesel like fuel and gasoline like fuels prepared from the waste automotive lube oils, and blending of the produced fuels with gasoline or turpentine decrease consumption of petroleum based fuels,

protecting environment from toxic and hazardous chemicals. It also saves of foreign exchange, reduces greenhouse gas emissions and enhances regional development especially in developing countries [1,2].

1.2 Pyrolysis

Waste oils can be reconstructed chemically by being heated in an oxygen-free environment. This process is called pyrolysis, which is defined as chemical decomposition by the action of heat and refers usually to chemical decomposition of organic materials heated in an environment of insufficient oxygen for combustion. Pyrolysis process has certain advantages over other treatment methods of waste disposal. The most important advantage of this method is that it does not pollute the environment when carried out in an appropriate way, because pyrolysis products such as gases, liquid oils and carbonaceous residue can be used as fuels.

2. EXTRACTION OF PYROLYSIS OIL BY USING MICROWAVE

Pyrolysis using microwave heating is a relatively new process in which the, waste hydrocarbons are mixed with a highly microwave-absorbent material such as carbon rod; as a result of microwave heating, they are then thermally cracked in the absence of oxygen into smaller hydrocarbon chains. The resulting gaseous products are subsequently condensed into liquid oils of different compositions depending on the features of the input substances and reaction conditions. The use of microwave radiation as a heat source is known to offer additional advantages over traditional thermal heat sources and the combination of carbon-based material and the novel use of microwave heating in pyrolysis processes are of increasing interest as reflected by considerable recent research. Microwave systems show a distinct advantage in providing a rapid, energy efficient, and targeted heating process compared to conventional technologies, thus facilitating increased production rates and decreased production costs. Moreover, thermal energy is targeted only to microwave receptive materials and not to gases within the heating chamber or to the chamber itself. It can promote certain chemical reactions by selectively heating the reactants, leading to a more uniform temperature profile and improved yield of desirable products.

The experimental setup for production of pyrolysis oil by using microwave is shown in fig. 2.1 & fig. 2.2

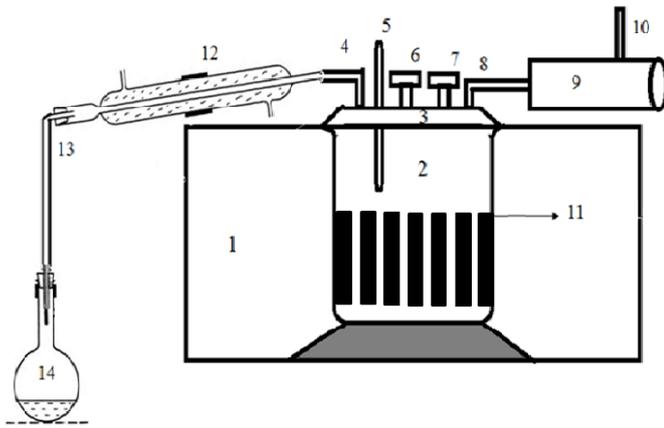


Fig.2.1 Schematic diagram of Experimental setup

1. Microwave oven
2. Kettle
3. Lid
4. Outlet
5. Thermocouple pocket
6. Stirrer Neck
7. Inlet for Nitrogen gas
8. Suction Port
9. Vacuum pump
10. Exhaust
11. Carbon Rods
12. Condenser
13. Receiver
14. Collecting Vessel

Note: Each joint in the setup is a Standard joint i.e. air tight joint and each joint is adhered with silicon grease in order to hold joints firmly

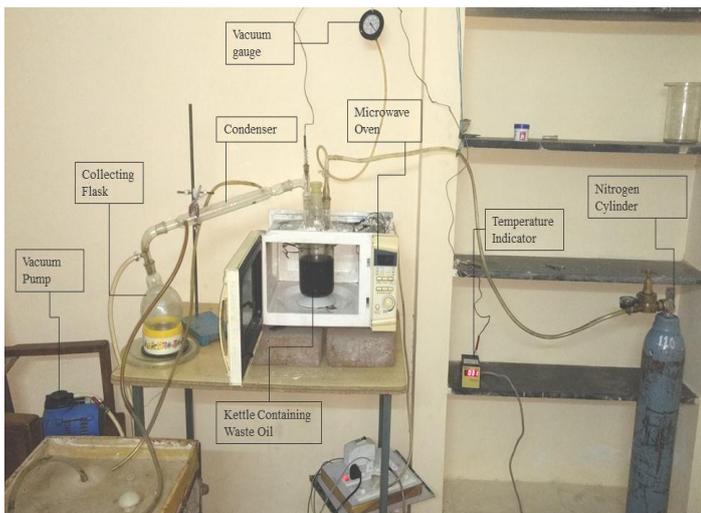


Fig.2.2 Actual Experimental Setup of producing pyrolysis oil

2.1 Experimental Procedure

The waste oil was collected from the engine of two wheelers from local service station. Before pyrolysis, the oil samples were filtered and 1.2 to 1.5 litre of waste oil was poured in the kettle. Carbon rods used as microwave energy absorbent to heat the waste oil. A total of half kg of carbon was fixed into the kettle reactor. The apparatus was assembled as in Fig.2.2, each joint was made leak proof with the help of silicon gel and preventive measures were taken. N₂ gas was vented through the apparatus air is sucked out of the kettle to remove oxygen from the kettle with the help of vacuum pump. Nitrogen is flushed in the kettle to ensure that the atmosphere inside the kettle is inert. A complete purge of all

air within the apparatus was ensured by flushing the system with N₂ gas for at least 10 min before heating commenced. After that power supply is switched ON and the heating of microwave gets started carbon rod were heated to temperatures ranging from 250 to 500°C, as carbon rod gets heated the waste oil present near by the carbon also gets heated. It took 3 hours to reach from room temperature to 250°C, and first drop of condensate oil was formed at 195°C, after that slowly formation of condensed oil gets started. After that it took 5-7 hours of process to get pyrolysis oil collected in the flask, by that time it was continuously under the observation, to prevent any accident and continuously operation of vacuum pump is done in the system to make oxygen free environment. When the accumulation of liquid product had stopped and further evolution of vapour phase products was no longer observed in the system, the reactor was visually inspected to ensure that the reaction was fully completed. Once the reaction had finished, the microwave oven was switched off and the reactor cooled with the aid of a fan. The N₂ flow was continued until the temperature of the reactor had fallen to 80°C. The reactor was then disconnected from the condensation system and sealed to prevent contact of the carbon bed with air. After some time pyrolysis oil was taken out and about 500 to 600ml of pyrolysis was collected in the flask which when measured with measuring flask and will be analysed to identify their chemical and physical properties. Then fuel so obtained will be compared with diesel for its chemical and physical properties. The fuel so produced will be tested for performance properties. The fuel can be tested in C.I. Engine purely or in a blended form with diesel.

Table.2.1 Properties of Obtained waste oil fuel and Diesel fuel

Property	Waste oil fuel	Diesel fuel
Density at 20°C (kg/m ³)	810- 820	820 - 840
Lower heating value (MJ/kg) and Higher heating value (MJ/kg)	42.5 - 43.2	45 - 46.5
Flash point (°C)	57	55
Viscosity (mm ² /s)	2.54 - 4.21	2.5 - 4.1

3. EXPERIMENTAL SETUP:

A single cylinder 4-stroke air-cooled diesel engine is used. An eddy current dynamometer is used for loading the engine. The parameters related to the performance of the engine are: brake specific fuel consumption, brake thermal efficiency, brake power, exhaust gases and smoke density were evaluated for diesel and each fuel Blends and at different engine loading conditions. Dynamometer mounted with speed sensor, this sensor feeds output to the control panel. Fuel meter is connected to the engine fuel intake line. Airflow meter measures inlet air flow at suction line of engine air inlet. Cylinder pressure is measured by probe inserted in cylinder, which feeds its output to control panel.



Fig. 3.1 Experimental setup

Table 3.1: Specification of engine used

Equipment	Specifications
Engine	Engine model: Single cylinder four stroke diesel engine. Maximum output: 5 Bhp/3.7 Kw at 1500 rpm Bore: 80 mm Stroke:110 mm Compression ratio: 16:1 Cooling: Air cooled
Eddy current dynamometer	Water cooled eddy current dynamometer Maximum BHP: 10 at 1500 rpm

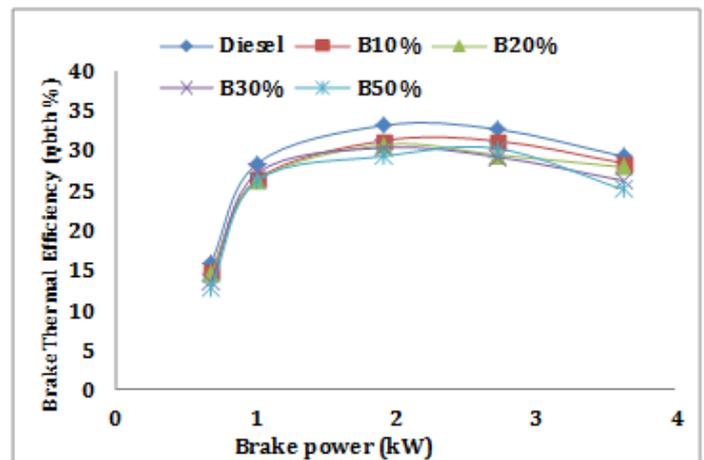
Experiments were performed with diesel fuel and blends of pyrolysis oil with diesel, namely B10%, B20%, B30%, B50%. Experiments are initially carried out on the engine using diesel fuel in order to provide base line data. The fuel consumption, exhaust gases and smoke were measured and recorded for different loads. Exhaust gas analyzer is used to measure the emission content of exhaust gas from the engine. It contain probe which is purged and then this probe inserted in exhaust pipe. It takes exhaust gas inside and then after processing it shows various readings of smoke opacity, NO_x, HC, CO and CO₂ on digital display. Similar procedures were repeated for the B10%, B20%, B30%, B50% different blends.

4. PERFORMANCE ANALYSIS

The results of this experiment on performance and emission measured from diesel engine in pure diesel, different percentage of blends of waste oil fuel with diesel mode are presented and discussed on the result in this section. The performance evaluated in terms of brake thermal efficiency (η_{bth} %), brake specific fuel consumption (BSFC), smoke opacity, and exhaust gases. The engine performance was tested at different loading condition.

4.1 Effect on Brake Thermal Efficiency

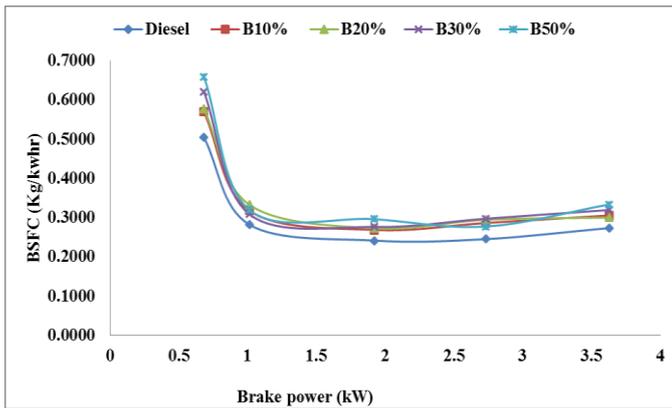
The brake thermal efficiency of the engine is one of the most important criteria for evaluating the performance of the engine. It indicates the combustion behaviour of the engine to a great extent. The brake thermal efficiency is defined as the actual brake work per cycle divided by the amount of fuel chemical energy as indicated by the fuel calorific value. Graph.4.1 shows the variations in brake thermal efficiency of the engine for diesel, and blends of waste automotive pyrolysis oil with B10%, B20%, and B30%. The BTE is nearly same at lower loads for all combinations of waste automotive oil fuel. From the Fig.4.1 there is reduction of brake thermal efficiency for blends as compared to neat diesel fuel. The maximum efficiency attained by the blends B10% is 31.24% at 1.924 kW, for B20% is 30.71% at 1.924 kW, for B30% is 30.33% at 1.924 kW, for B50% is 30.21% at 2.735 kW and for diesel is 33.15% at 1.924 kW which are less as compared to diesel. The less calorific value and more fuel consumption may be the reason for decreased brake thermal efficiency.



Graph.4.1 Brake power (kW) Vs. Brake Thermal Efficiency %

4.2 Effect on brake specific fuel consumption

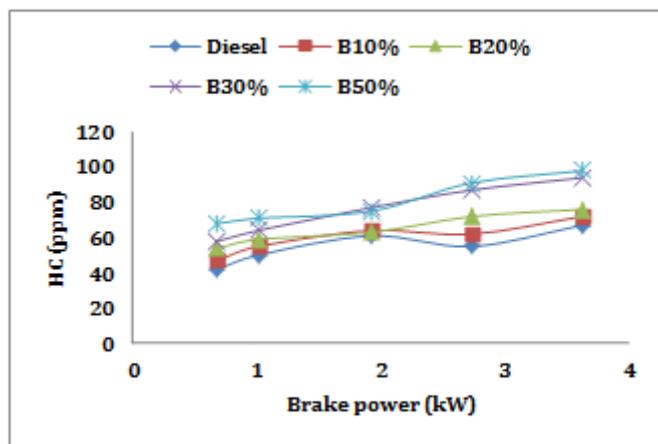
Graph.4.2 shows curve between brake specific fuel consumption with brake power. The figure reveals that pure diesel fuel has BSFC of 0.504 kg/kWh at 0.684 kW and 0.2735 kg/kWh at 3.632 kW (full load). For B10% 0.569 kg/kWh at 0.684 kW and 0.305 kg/kWh at 3.632 kW, for B20% 0.5766 kg/kWh at 0.684 kW and 0.3 kg/kWh at 3.632 kW, for B30% 0.6206 kg/kWh at 0.684 kW and 0.3194 kg/kWh at 3.632 kW, for B50% 0.6592 kg/kWh at 0.684 kW and 0.3337 kg/kWh at 3.632 kW. The BSFC in case of blends was higher compared to diesel in the entire load range, due to its lower heating value.



Graph.4.2 Brake power (kW) Vs. Brake specific fuel consumption kg/kWh

4.3 Effect on HC Emission

Unburned hydrocarbon consists of fuel that is incompletely burned. The hydrocarbon means organic compounds in the gaseous state and solid hydrocarbons are the particulate matter. Unburned hydrocarbon emissions are caused by incomplete combustion of fuel-air mixture. Graph.4.3. shows the emission of HC with increasing loads. For diesel, unburned hydrocarbon varies from 42 ppm at 0.684 kW and 67 ppm at 3.632 kW (full load). For blends B10%, B20%, B30%, B50% the values are 47, 54, 58, 68 ppm respectively at 0.684 kW and 72, 76, 94, 98 ppm at 3.632 kW respectively. The reason behind increased unburned hydrocarbon in blends of fuel may be due to higher fumigation rate. The increase in HC emission with the use of B10%, B20%, B30%, B50% can be attributed to the leakage of the fuel through the injector nozzle due to the considerably low viscosity of the fuel at that temperature.

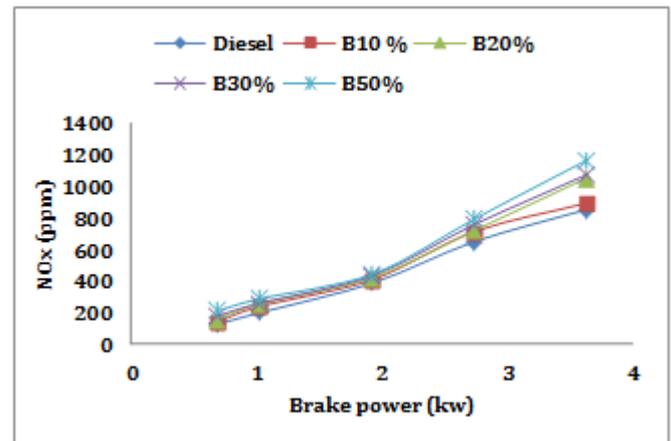


Graph.4.3 Brake power (kW) Vs. HC (ppm)

4.4 Effect on NO_x Emission

Oxides of nitrogen result from reaction of nitrogen and oxygen at relatively high temperatures. NO is a major component in the NO_x emission. The formations of NO_x for diesel, B10%, B20%, B30%, B50% are shown in Graph.4.4. The NO_x values for diesel vary from 129 ppm at 0.684 kW load and 855 ppm at 3.632 kW (full load). For B10% it varies from 142 ppm at 0.684 kW and 896 ppm at 3.632 kW, for

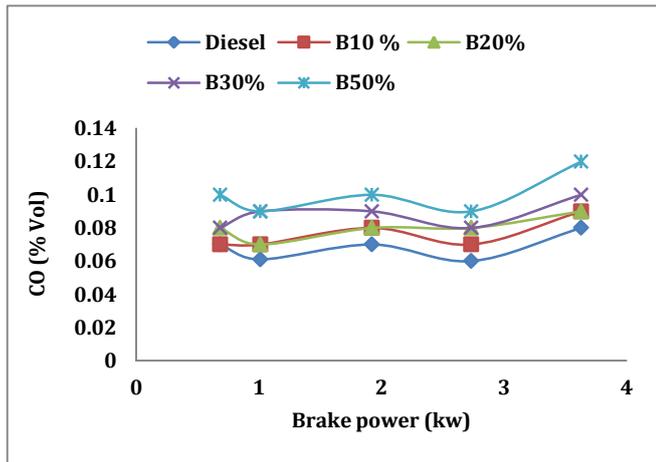
B20% it varies from 157 ppm at 0.684 kW and 1054 ppm at 3.632 kW, for B30% it varies from 181 ppm at 0.684 kW and 1075 ppm at 3.632 kW, for B50% it varies from 213 ppm at 0.684 kW and 1167 ppm at 3.632 kW. At lower loads the NO_x is less as compared to diesel, but as load increases NO_x also increases. The B10% and B50% curve gradually increases and follows the diesel curve upto load 2.735 kW and then increases. To reduce NO_x diethyl ether (DEE) can be added to the mixture, heat release decreases in the stage of diffusion controlled combustion, thereby leading to lower NO_x emissions [9]. Since DEE is a cetane improver and any increase in cetane number decreases NO_x emission.



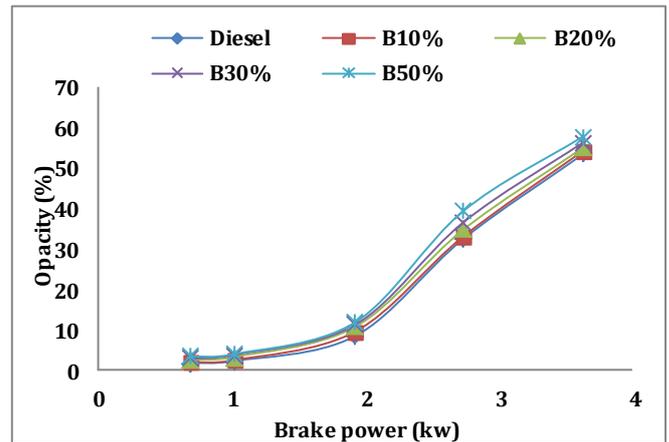
Graph.4.4 Brake power (kW) Vs. NO_x (ppm)

4.5 Effect on CO Emission

The carbon monoxide, a toxic gas produced during the combustion process, is mainly due to the lack of oxygen, poor air entrainment, mixture preparation and incomplete combustion during the combustion process. The variation of carbon monoxide with load for diesel, and blends of B10, B20, B30 and B50 are shown in Graph.4.5. The amount of CO emitted from diesel varies from 0.07% at 0.684 kW and 0.08% at 3.632 kW (full load). The B10% varies from 0.07% at 0.684 kW and 0.09% at 3.632 kW, for B20% varies from 0.08% at 0.684 kW and 0.09% at 3.632 kW, for B30% varies from 0.08% at 0.684 kW and 0.1% at 3.632 kW, for B50% varies from 0.1% at 0.684 kW and 0.12% at 3.632 kW. The reason for the increase in CO in case of different blends is less cylinder temperature or not enough oxygen to convert all carbon to CO₂. This can be reduced by adding diethyl ether in the mixture due to the availability of oxygen is more in diethyl ether DEE[9].



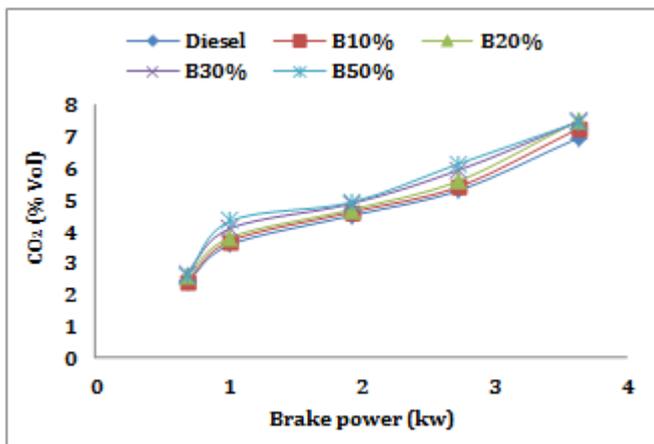
Graph.4.5 Brake power (kW) Vs. CO (% Vol)



Graph.4.7 Brake power (kW) Vs. Opacity (%)

4.6 Effect on CO₂ Emission

The variation of carbon dioxide with load for diesel, and blends of B10%, B20%, B30% and B50% are shown in Graph.4.6. The amount of CO₂ emitted from diesel varies from 2.39% at 0.684 kW and 6.95% at 3.632 kW (full load). The B10% varies from 2.41% at 0.684 kW and 7.24% at 3.632 kW, for B20% varies from 2.58% at 0.684 kW and 7.5% at 3.632 kW, for B30% varies from 2.69% at 0.684 kW and 7.47% at 3.632 kW, for B50% varies from 2.6% at 0.684 kW and 7.45% at 3.632 kW. At lower loads the value of carbon dioxide for blends is less as compared to diesel, and gradually increases with load.



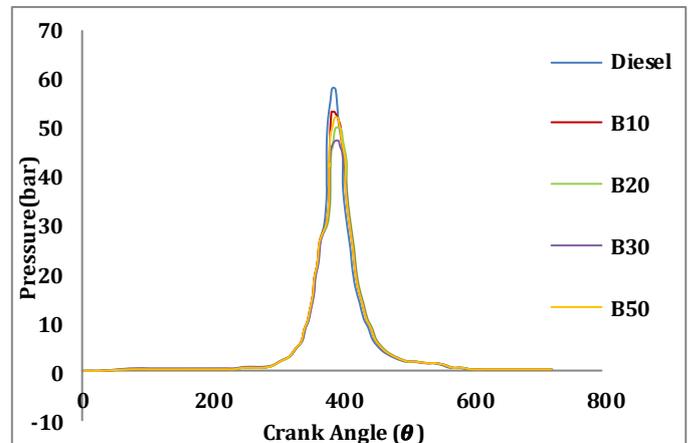
Graph.4.6 Brake power (kW) Vs. CO₂ (% Vol)

4.7 Effect on Smoke opacity

The smoke opacity of any fuel increases with the increase in load. The smoke opacity of blends is higher than that of diesel due to heavier molecules. The variation of opacity with load for diesel, and blends of B10%, B20%, B30% and B50% are shown in Graph.4.7. The amount of smoke opacity of diesel varies from 1.7% at 0.684 kW and 53.5% at 3.632 kW (full load). The B10% varies from 1.9% at 0.684 kW and 54.3% at 3.632 kW, for B20% varies from 2.8% at 0.684 kW and 55.1% at 3.632 kW, for B30% varies from 2.8% at 0.684 kW and 56.4% at 3.632 kW, for B50% varies from 3.3% at 0.684 kW and 57.9% at 3.632 kW.

4.8 Cylinder Pressure

Graph.4.8 shows the comparative P-Theta diagram of Diesel, B10%, B20%, B30%, B50% operation. As the blend possesses more viscosity, the p- theta diagram is not similar to diesel. More specifically, it offers shorter ignition delay, low peak pressure, long burn duration and early occurrence of peak pressure. The curves of blended fuels offer same ignition delay but different peak pressure this may be due to decreased volatility, decreased heat of vaporization and increased viscosity. The peak pressures values of diesel, B10%, B20%, B30%, B50% are 58.1, 53.33, 50.06, 47.37, 52.06 bars respectively.



Graph.4.8 P-Theta Diagram

5. CONCLUSION

The engine was tested under the same operating conditions with diesel fuel, and blends of diesel with the pyrolysis oil as B10%, B20%, B30% and B50%. From the experimental tests following conclusions are reached:

1. Microwave Pyrolysis of waste automotive oil can produce pyrolytic oil that could be used as a fuel. The chemical properties of the oil were nearly close to that of diesel. However, a more detailed analysis should be conducted to assure further utilization of the oil. Pyrolysis method, using a microwave oven as a heat source and carbon rod as

microwave energy absorbent produced more oil than that of conventional heating.

2. The blends of waste automotive pyrolysis oil are suitable fuel for a diesel engine and can be used without any modification made on the engine.

3. The brake thermal efficiency of blends B10%, is near to the efficiency of diesel at lower brake power, but as brake power increases the efficiency decreases, higher efficiency for blend B10% is obtained at 1.924 kW brake power than other three blends.

4. Thermal efficiency of blended fuel is decreased due to more brake specific fuel consumption as increase in brake power.

5. HC emissions were found to increase with the blending of pyrolysis fuel with diesel fuel; B10% curve followed the diesel curve with small increase in HC emission.

6. The formation of NO_x depends upon gas temperature and ignition delay. As load increases NO_x emission increases which is due to increase in temperature in combustion chamber.

7. The reason for the increase in CO in case of different blends is not enough oxygen to convert all carbon to CO₂. Rich mixture is required during starting or when accelerating under increasing load.

8. Heavy imports in the field of petroleum can be reduced by converting the waste automotive oil to fuel. This increase the economic stability.

NOMENCLATURE:

DLF	Diesel like fuel
GLF	Gasoline like fuel
CV	Calorific value (MJ/kg)
P	Pressure(bar)
Bmep	Brake mean effective pressure (bar)
BP	Brake power(kW)
BSFC	Brake specific fuel consumption (kg/kWh)
N	Engine speed (rpm)
W	Load (kg)
TFC	Total fuel Consumption(kg/min)
B10%	Blend 10% of Pyrolysis fuel with Diesel
B20%	Blend 20% of Pyrolysis fuel with Diesel
B30%	Blend 30% of Pyrolysis fuel with Diesel

B50%	50% of Pyrolysis fuel with Diesel
WAO	Waste automotive oil
HC	Hydrocarbon (ppm)
NO _x	Oxides of nitrogen (ppm)
CO	Carbon monoxide (%vol)
CO ₂	Carbon dioxide (%vol)
AFR	Air fuel ratio
L	Length of stroke(m)
D	Diameter of piston (m)

Greek Symbols:

P	density of fluid (kg/m ³)
θ	Crank angle

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