

USE OF LDPE WASTE PLASTIC OIL FRACTIONS AS DI ENGINE FUEL

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ABSTRACT

Degradation of LDPE waste plastic by using fly ash as the catalyst with cat/pol ratio of 0.1 gives a 75.2 % of the plastic oil. The plastic oil obtained has been separated into four fractions with boiling range of less than 100 °C, 100 – 150 °C, 150 – 200 °C and above 200 °C. The yields of various fractions based on the weight of waste plastics are 8.2%, 32.5%, 29% and 3.5%. The properties of various fractions boiling above 100 °C are comparable to those of diesel and the fractions were tested on a diesel engine. The brake thermal efficiency is higher for two fractions. The smoke density and HC emissions are higher for all the fractions. Though NO_x is lower for all the fractions when compared to diesel they are within permissible limits. Hence, these can be used successfully as the substitute for diesel.

KEYWORDS: LDPE, Waste Plastic, Catalyst, Engine Pollution, Degradation Plant

INTRODUCTION

The applications of plastics are growing globally. Due to low-cost wood metals and ceramics are being replaced by plastics. Consequently, the accumulation of plastic waste arises and gives rise to environmental problems. It may take billions of years for plastic to degrade naturally. Recycling of plastics is one of the solutions to manage the plastic waste. The other methods of handling the waste plastics are land filling and incineration. Land filling requires a lot of space. Incineration is a process of burning waste plastic in the open atmosphere.

During burning carbon in the waste material is largely converted to CO₂ which can be converted to carbohydrates by plants through photosynthesis. However, combustion will not take place to the complete extent. Incomplete combustion will produce smoke and emission of toxic chemicals like CO. Also during combustion nitrogen in the air and the organic material will combine with oxygen to produce NO_x (NO and NO₂). Sulphur present in the waste materials will combine with oxygen to produce SO_x (SO₂ and SO₃)

The burning of waste plastic also produces carcinogenic materials like dioxin. The boiling point of water and dioxin are nearly the same. So it can easily mix with water and may be consumed by humans and animals. So burning of the plastic in open atmosphere is harmful to the humans. This causes a lot of health hazards. Harmful effects of dioxin have been well described by Nobuomatsuura *et al.*, [1].

Increase in energy demand and depletion of energy resources have driven the researchers to seek ways to utilize waste product as fuel that could replace the fossil fuels. Conversion of waste to energy is one of the recent trends in minimizing not only waste disposal but also could be used as an alternative fuel for internal combustion engines. With the help of the catalytic cracking process waste plastic can be converted into waste plastic oil.

In order to manage the twin problems of waste plastic and fuel requirement plastic has been converted into liquid hydrocarbons which can be used to run automobiles. [2-33] In this paper waste plastic oil is introduced as the alternative fuel.

MATERIALS AND METHODS

Plastics: Unused waste LDPE shown in Figure 1 is used for conversion it into liquid hydrocarbons. LDPE plastics are cut with the help of cutting machine.

Catalyst: Fly ash from the thermal plant at near places is used. Fly ash contains Si (Silicon), Al (Aluminium) and O (oxygen). Thus, it contains silica (SiO_2) and alumina (Al_2O_3). Since silica and alumina have been widely used as catalysts for the degradation of waste plastics fly ash can be used as a catalyst for this propose.



Figure 1: Waste LDPE Plastics

DEGRADATION OF WASTE PLASTIC

Description of the Degradation Plant

The sketch of the plant used for catalytic conversion is shown in Figure. 2. The reactor is a cylindrical vessel made up of stainless steel with a diameter of 1300 mm. The reactor is surrounded by three electrical coils. The power of each coil is 1.5 kW. These electrical coils are used for heating the reactor. The reactor is surrounded by a thin cylindrical sheet. Glass wool is placed in between the reactor vessel and the thin sheet. The glass wool acts as an insulator. The top of the reactor is provided with a stirrer, a safety valve, a pressure gauge, an inlet with an airtight stopcock for feeding the waste plastic and an outlet which is connected to water cooled condenser. The safety valve withstands a pressure up to 500 kg/m^2 . The stirrer runs by means of an electrical motor. A hand hole is provided with an airtight stopcock at the bottom of the reactor to remove the materials after cracking. A thermocouple is placed at the bottom of the reactor to measure the temperature inside the reactor. The control panel consists of a temperature indicator and a temperature controller with switches. The temperature indicator shows the temperature inside the reactor. The controller is used to control the temperature inside the reactor.

The condenser consists of a cooling coil and a water jacket. The condenser is made up of stainless steel coil of length 1800 mm with a diameter of 20 mm. This coil is kept inside the water jacket with a diameter of 300 mm and a height of 500 mm. The water jacket is provided with an inlet at the bottom and an outlet at the top. Water is circulated in the jacket using the inlet and outlet. The condensed oil is collected in a tank made up of stainless steel.

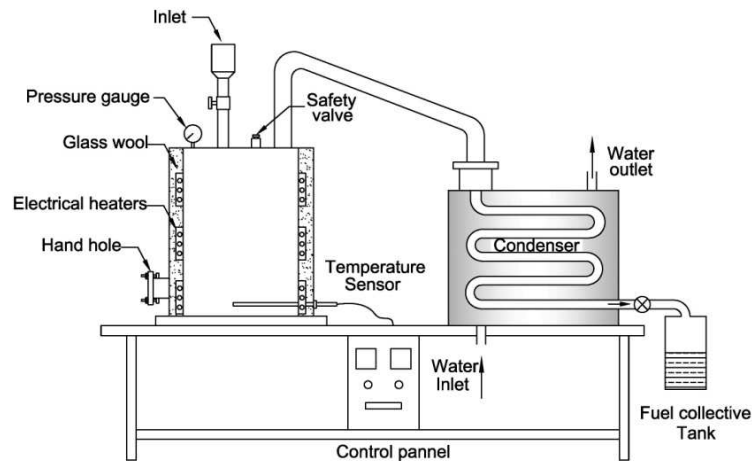


Figure 2: Schematic Diagram of Degradation Plant

Procedure for Degradation

The electrical heater was switched ON. The time was monitored using a stopwatch. The vapor formed due to the cracking of the plastic was passed through the water cooled condenser. The condensable vapor condensed into the liquid which was collected in the collecting tank. Due to heating the temperature of the reactor gradually increased. The temperature and time at which the oil formation commenced were recorded.

As the temperature of the reactor was gradually increased the cracking process in the reactor got accelerated. Due to this more oil was obtained from the reactor. The temperature at which the oil formation ceased was noted. The corresponding time also was noted.

DISTILLATION UNIT

Description of the Distillation Unit

The distillation unit consists of the cylindrical vessel made up of stainless steel with a diameter of 1100 mm. This cylindrical vessel is surrounded by another stainless steel cylindrical vessel of diameter 1300 mm. In between these two cylindrical vessels silicone oil is placed. An electrical heating coil is immersed in the silicone oil. This entire setup is insulated by glass wool and a metallic sheet which surrounds the glass wool.

The top of the distillation unit is fitted with a pressure relief valve, pressure gauge, waste plastic oil inlet with an airtight closing knob, thermocouple and an outlet which is connected to the water cooled condenser.

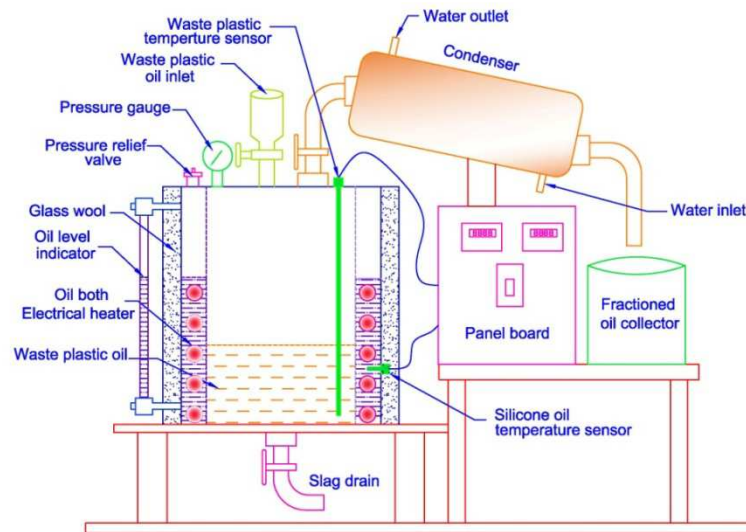


Figure 3: Schematic Diagram of Distillation Plant

The right side of the distillation unit is fitted with a thermocouple to measure the temperature of the silicone oil. The left side of the distillation unit is fitted with a glass tube to indicate the level of the silicone oil. The bottom of the distillation unit is fitted with a slag drain to remove the oil remaining after distillation. There is also a control panel to stop the heating when the distillation chamber reaches a particular temperature.

Test Engine Experimental Setup and Procedure

The following tests have been conducted on Kirlosker TV - I diesel engine, operated by diesel fuel and waste plastic oil.

- Performance Test
- Emission Test
- Combustion analysis

Procedure for Load Test

Specifications of the test engine are given in Table 1. The experimental setup is shown in Figure. 4. The engine was allowed to run with sole diesel fuel at a constant speed of 1500 rpm for nearly 30 minutes, to attain the steady state conditions at the lowest possible load. During the investigation, the temperature of the lubricating oil and temperature of the engine cooling water were held constant, to eliminate their influence on the results. The engine run was stabilized with injected fuel for the attainment of the lubricating oil temperature of 65 °C and the cooling water temperature of 70 °C. The cooling water flow rate was maintained at 7 L/min. Then the following parameters were determined twice for concordance:

- Time for 10 mL of fuel consumption (s)
- Smoke Density (HSU)
- NO_x emission (ppm)
- Hydrocarbon emission (ppm)

- Combustion parameters (analyzed by the use of AVL combustion analyzer)

After completing the experiments with sole diesel fuel, further experiments were conducted with the waste plastic oil. The engine was run at various percentages of loads (20%, 40%, 60%, 80% and maximum possible load). The performance, emission and combustion tests were carried out.

At each load, readings corresponding to performance and emission characteristics were recorded.

Table 1: Specifications of the Test Engine

Type	Vertical, Water Cooled, Four Stroke
Number of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5:1
Maximum power	5.2 kW
Speed	1500 rpm
Dynamometer	Eddy current
Injection timing	23° before TDC
Injection pressure	2.20 kg/mm ²

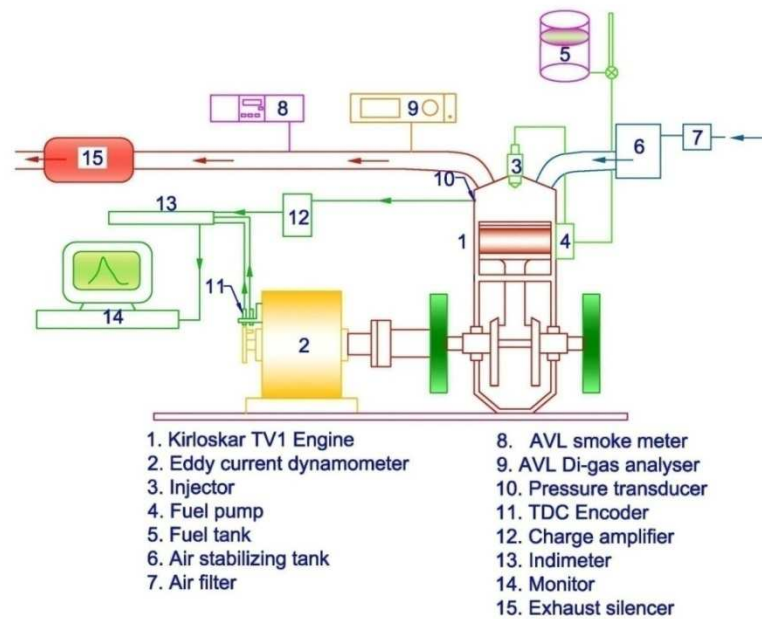


Figure 4: Experimental Set Up for Test Engine

RESULTS AND DISCUSSIONS

Degradation of LDPE Waste Plastics

This study investigates the use of the products of degradation of LDPE waste plastics as fuel.

In order to study the use of a liquid product as the IC engine fuel, the raw plastic oil was separated into various fractions by fractional distillation. The fuel properties of various fractions were determined. Fractions having fuel properties as those of commercial diesel were tested as fuel on DI diesel engine. Degradation of LDPE was carried out taking one kg of polymeric material in one batch. Experiments were done with 100 g catalyst.

The yields of solid, liquid and gaseous products are denoted as Y_s , Y_L and Y_g , respectively. Let the weights of solid material remaining in the reactor after the reaction as W_p . Let the catalyst polymer ratio denoted as cat/pol.

Weight of catalyst be W_c .

Weight of solid product (W_s) = $W_p - W_c$

Let the weight of liquid be W_L . The values of W_p , W_c , W_s and W_L are expressed in g

Weight of polymer taken = 1 kg = 1000 g

$$Y_s = \frac{W_s}{1000} \times 100 (\%)$$

$$Y_L = \frac{W_L}{1000} \times 100 (\%)$$

$$Y_g = (100 - Y_s - Y_L) (\%)$$

The density of the liquid D_L was also determined for one run for each case.

Table 2: Physical Data for Degradation of LDPE Waste Plastic

Cat/pol	T_i (°C)	T_f (°C)	Y_s (%)	Y_L (%)	Y_g (%)	D_L (kg/m ³)
0.10	210	342	2.8	75.2	22.0	801

The values of T_i (the temperature at which the oil commences), T_f (the temperature at which oil formation ceased) Y_s , Y_L , Y_g and D_L for the degradation of LDPE are given in Table 2.

Fractional Distillation of the Raw Plastic Oil

The volumes of various fractions obtained by the fractional distillation of plastic oil (1000 mL) from LDPE are given in Table 3. In this study, plastic oil has been obtained from LDPE. The plastic oil obtained was fractionated into the following four fractions by fractional distillation.

- Fraction boiling within 100 °C
- Fraction boiling in the range 100 – 150 °C
- Fraction boiling in the range 150 – 200 °C
- Fraction boiling above 200 °C

The volumes of various fractions obtained by the fractional distillation of plastic oil (1000 mL) from LDPE are given in Table 3.

Table 3: Volume of Various Fractions from 1000 mL of Plastic Oil Obtained from LDPE

Fractions	Volume (mL)	Density (kg/m ³)
1	115	765
2	445	780
3	385	805
4	45	820

Hydrocarbons with low carbon number will have lower boiling points. If the extent of degradation increases the amount of hydrocarbons with low carbon number should increase.

The densities of various fractions are given in Table 3. It is seen that from 100 mL plastic oil 115 mL of fraction 1 is obtained. From the density of fraction 1 in Table 3, the weight of fraction 1 from 1000 mL plastic oil is

$$= \frac{115}{1000} \times 765 = 87.975g$$

Since the density of plastic oil is 835 kg/m^3 the weight of fraction 1 from 835 g of plastic oil is 87.975 g.

From Table 2 it can be inferred that the amount of oil formed from 1 kg of HDPE when cat/pol = 0.10 will be 752 g.

Hence, the amount of fraction 1 from 1 kg of the waste plastic (HDPE)

$$= \frac{752}{801} \times 87.975 = 82.593 g$$

This value comes as 82.593 g.

Therefore, the amount of fraction 1 from 100 g of the waste plastic should be 8.259 g.

In other words, the yield of fraction 1 is 8.2 % (wt %, after round off) based on the amount of waste plastic.

Table 5: Yields of Various Fractions (wt%)

Fractions	Yield of Fraction (%)
1	8.2
2	32.5
3	29.0
4	3.5

Properties of Various Fractions

The objective of this study is to examine the use of oil obtained by degradation of waste plastics, as fuel, in DI diesel engine. Fraction 1 boiling within $100 \text{ }^\circ\text{C}$ is unsuitable to be substituted for diesel. This has a low boiling point and is likely to cause more knocking in the diesel engine. Hence, only the other three fractions viz, fraction 2 boiling in the range $100\text{-}150^\circ\text{C}$, fraction 3 boiling in the range $150\text{-}200 \text{ }^\circ\text{C}$ and fraction 4 boiling above $200 \text{ }^\circ\text{C}$ are tested as fuels in DI diesel engine.

For this purpose the fuel properties like density, kinematic viscosity, flash point, fire point, pour point, calorific value and cetane number have been determined for all the fractions boiling above $100 \text{ }^\circ\text{C}$.

Table 6: Fuel Properties of LDPE and Diesel

Properties	Fraction 2	Fraction 3	Fraction 4	Diesel
Density $15 \text{ }^\circ\text{C}$ (kg/m^3)	780	805	820	820
Kinematic viscosity at $40 \text{ }^\circ\text{C}$ (cSt)	1.76	2.04	2.51	2.51
Flash Point ($^\circ\text{C}$)	22	34	38	53
Fire point ($^\circ\text{C}$)	25	38	43	64
Pour point ($^\circ\text{C}$)	-3	-4	-4	-
Grass calorific value (MJ/kg)	42.7	42.7	42.6	42.3
Cetane number	51.4	50.9	51.2	50.0

Performance Parameter

Brake Thermal Efficiency

Variation of the brake thermal efficiency with the brake power of the engine is shown in Figure. 5. From the figure it is seen that the brake thermal efficiency for fraction 2 and fraction 3 are higher than that of diesel. This is due to the high cetane number, high calorific value and low viscosity of these fractions. These properties of these fractions lead to improved vaporization, atomization, and combustion, which influence the improvement in the brake thermal efficiency. The maximum brake thermal efficiency at maximum brake power of the engine shows 31.7 % for fraction 2 which is higher than that of the other fractions and diesel.

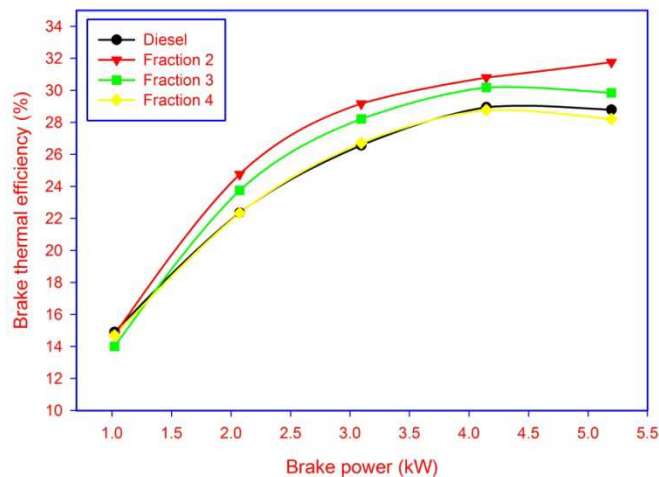


Figure 5: Brake Thermal Efficiency against Brake Power

Emission Parameters

Unburned hydrocarbon emission consists of fuel that is incompletely burned. The terms hydrocarbon means organic compounds in the gaseous state, solid hydrocarbons are part of the particulate matter.

Smoke Density

The variation of the smoke density with brake power is shown in Figure. 6. From figure is seen that the smoke density is higher for fraction 2 and fraction 4 than diesel. However, the smoke density for fraction 3 is close to that of diesel. This is due to the low viscosity of this fraction. This low viscosity leads to better atomization, vaporization and complete combustion. Due to this, the smoke produced by the fuel has the smoke density at 63.3 HSU for the maximum brake power. At higher brake powers the smoke density is slightly higher than that of diesel.

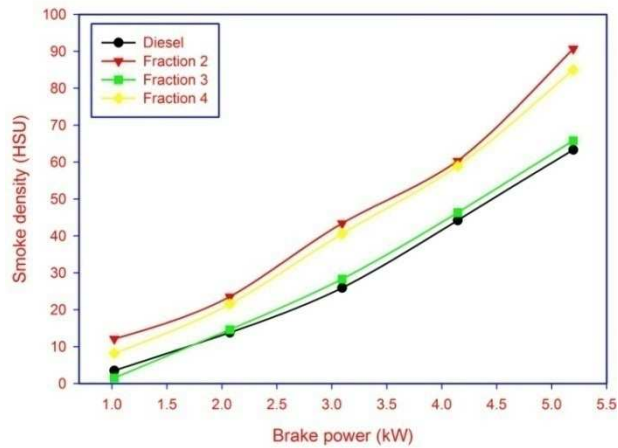


Figure 6: Smoke Density against Brake Power

Oxides of Nitrogen

Figure 7 shows the variation NOx emission with brake power for the various fractions. It is seen that NOx emission is lower for all the fractions than diesel. This is due to the clean combustion of all fractions compared to diesel. Due to this the temperature increases during the combustion. This rise in temperature leads to an increase in NOx emission.

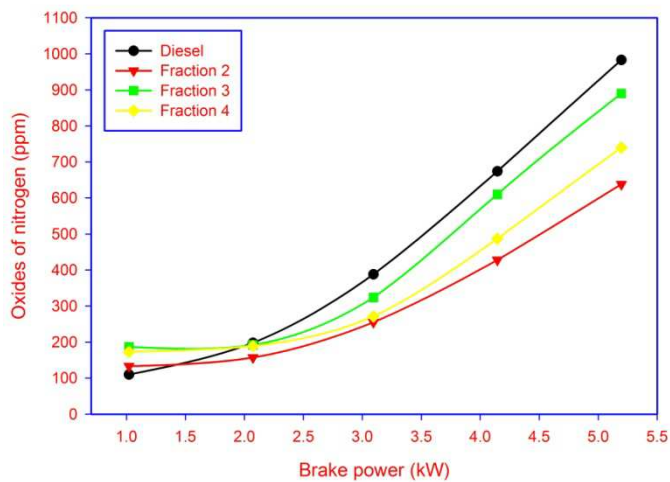


Figure 7: Oxides of Nitrogen against Brake Power

HC Emission

The variation of the amounts of hydrocarbons in the exhaust gas with brake power is shown in Figure. 8. It is seen that the hydrocarbon level increases with an increase in brake power. Unburned hydrocarbon emission consists of fuel that is incompletely burned. The term hydrocarbon means organic compounds in the gaseous state, solid hydrocarbons are part of the particulate matter. From the figure, it is seen that the hydrocarbon emission is lower for fraction 2 when compared with fractions fraction 3 and fraction 4. However, fraction 2 has a slightly higher emission when compared with diesel. This is due to power fuel distribution, and a lean fuel-air mixture.

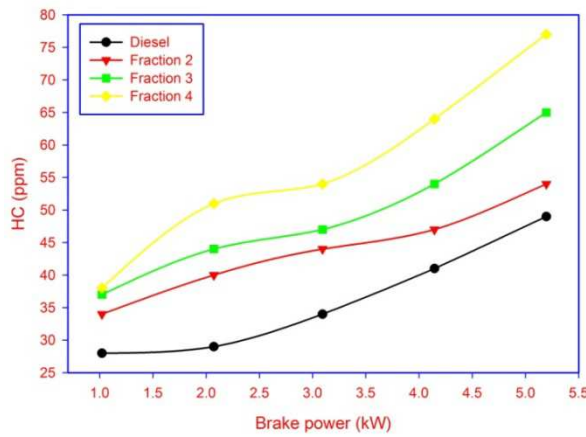


Figure 8: Hydrocarbon against Brake Power

Combustion Parameters

The combustion parameters reading are taken at full load by running the engine and readings are taken for 100 cycles and the average cycle readings are used to plot the graph.

Cylinder Pressure

Cylinder pressure mainly depends on the combustion rate in the initial stage which is influenced by fuel in taking the path, premixing combustion, viscosity and calorific value of the fuel. Cylinder pressure Vs crank angle diagram is shown in Figure. 9 for all the cases. The cylinder pressure for diesel fuel is 65 bar which is higher than that of all the other fractions. From the figure it is seen that fraction 2 shows 58 bar cylinder pressure at maximum load which is lower than those of the other two fractions.

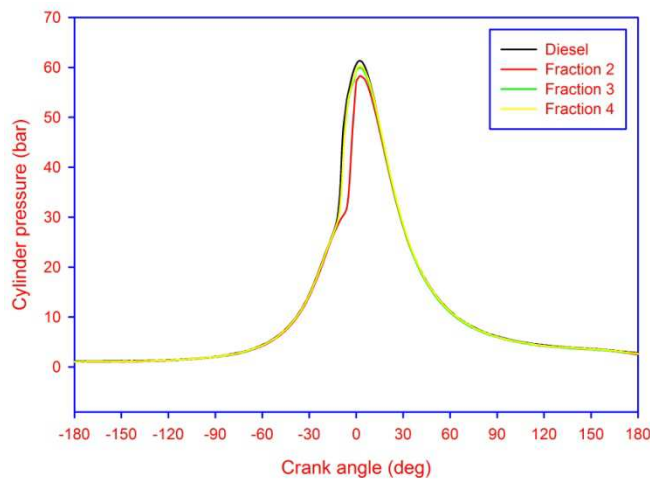


Figure 9: Cylinder Pressure against Crank Angle

Heat Release Rate

The comparison of heat release rate for waste plastic oil fraction and diesel fuel operation at full load is shown in Figure. 10. From the figure it is seen that irrespective of cat/pol ratio the heat release rate for fraction 2 is shifted about 10° crank angle. This is due to prolonged ignition delay because of different hydrocarbon fractions available in the fuel.

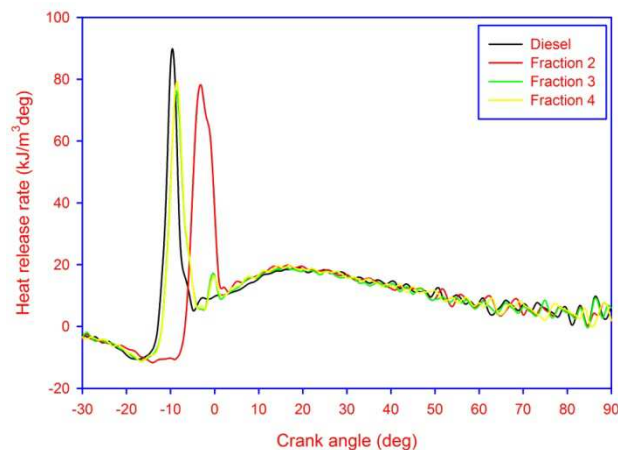


Figure 10: Heat Release Rate against Crank Angle

CONCLUSIONS

Based on the work the performance, emissions, and combustion of waste plastic oil, it is concluded that the waste plastic oil represents a good alternative fuel for diesel and therefore must be taken into consideration in the future for transport purpose. The plastic oil obtained from LDPE waste plastic to boiling range of 100-150°C, 150-200°C, 200 above can be used as a substitute for diesel. It is concluded that the engine was able to run with 100 % waste plastic oil.

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