International Journal of Mechanical Engineering (IJME)
ISSN(P): 2319-2240; ISSN(E): 2319-2259
Vol. 5, Issue 1, Dec - Jan 2016, 143-156

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

DEGRADATION OF HDPE WASTE PLASTIC FRACTIONS AS DI DIESEL ENGINE FUEL

P. PREMKUMAR

Research Scholar, Department of Mechanical Engineering, Faculty of Engineering and Technology,
Annamalai University, Tamil Nadu, India

ABSTRACT

Degradation of HDPE waste plastic by using fly ash as the catalyst with cat/pol ratio of 0.1 gives 60.4 % of the plastic oil. The plastic oil obtained has been separated into four fractions with boiling range 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 6.9%, 25.6%, 23.6% and 2.5%. The properties of various fractions boiling above 100 are comparable to those of diesel and the fractions are tested in a diesel engine. The brake thermal efficiency is higher for all the fractions. The smoke density is low for all the fractions. Though NOx and HC emissions are higher 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: HDPE, Diesel Engine, Emission, Degradation, Plastic Oil Properties

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 CO_2 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 NOx (NO and NO_2). Sulphur present in the waste materials will combine with oxygen to produce SOx (SO_2 and SO_3)

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 plastic in the 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 HDPE is shown in Figure. 1 is used for conversion it into liquid hydrocarbons. HDPE 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 (Aluminum) and O (oxygen). Thus, it contains silica (SiO_2) and alumina (Al_2O_3). Since silica and alumina have been widely used as the catalyst for the degradation of waste plastics fly ash can be used as the catalyst for this propose.

Figure 1: Waste HDPE 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 at a lower speed 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.

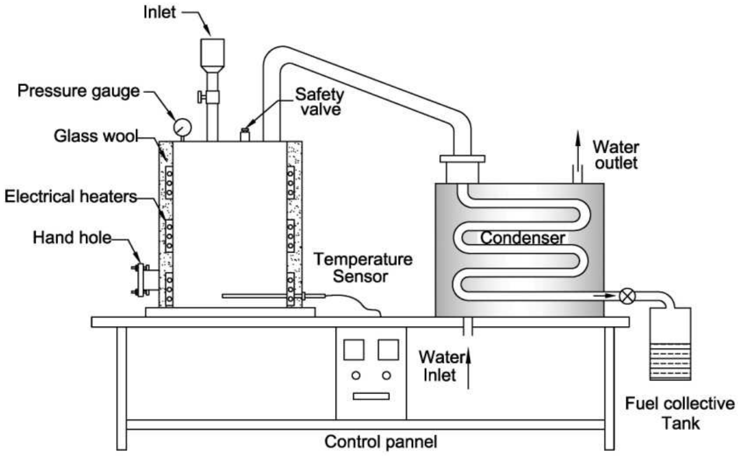

Figure 2: Schematic Diagram of Degradation Plant

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.

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.

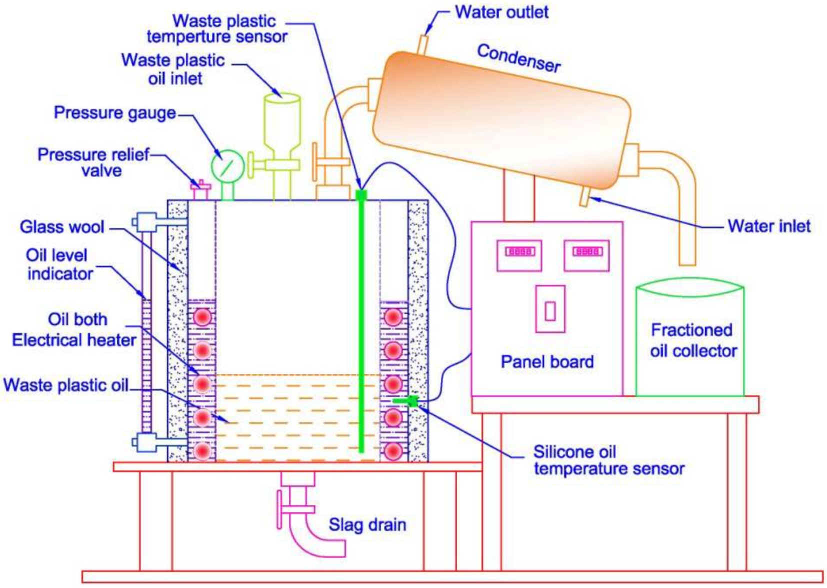

Figure 3: Schematic Diagram of Distillation Plant

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 thrice. For drawing graphs, the average values were taken.

- Time for 10 mL of fuel consumption (s)
- Smoke Density (HSU)
- NOx 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

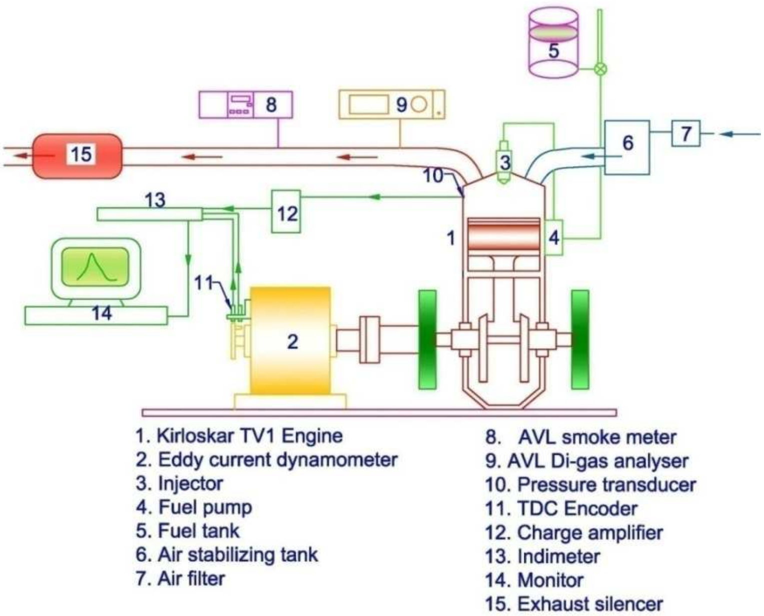

Figure 4: Experimental Set Up For Test Engine

RESULTS AND DISCUSSIONS

Degradation of HDPE Waste Plastics

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

In order to study the use of the liquid product as an IC engine fuel, the raw plastic oil was separated into various fractions by fractional distillation. The fuel properties of various fractions were evaluated. Fractions having fuel properties as those of commercial diesel were tested as fuel in DI diesel engine. Degradation of HDPE 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/pal.

Weight of catalyst is 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 plastic oil also was determined and denoted by D_L

Table 2: Physical Data for Degradation of HDPE Waste Plastic

T_i (°C)	T_f (°C)	Y_S (%)	Y_L (%)	Y_g (%)	D_L (kg/m^3)
252	403	14.4	60.4	25.2	807

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 HDPE 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 HDPE are given in Table 3. In this study, plastic oil has been obtained from HDPE. 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 HDPE are given in Table 3.

Table 3: Volume of Various Fractions from 1000 mL of Plastic Oil Obtained from HDPE and Density of Fractions

Fractions	Volume mL	Density (kg/m^3)
1	120	**772**
2	440	**791**
3	380	**812**
4	40	**826**

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

The densities of various fractions are given in Table 3. It is seen that from 100mL plastic oil 120 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

$$.= \frac{120}{1000} \times 772 = 92.64g$$

Since the density of plastic oil is 807 kg/m^3 the weight of fraction 1 from 807 g of plastic oil is 92.64 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 604 g.

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

$$.= \frac{604}{807} \times 92.64 \ = 69.33\ g$$

This value comes as 69.33 g.

Therefore, the amount of fraction 1 from 100 g of the waste plastic should be 6.933g.

In other words, the yield of fraction 1 is 6.9 % (wt %, after round off) based on the amount of waste plastic.

Table 4: Yields of Various Fractions (wt %) by Degradation of HDPE using Cat/pol ratio 0.1

Fractions	Yield of Fraction (%)
1	6.9
2	25.6
3	23.6
4	2.5

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 °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 100-150 °C, fraction 3 boiling in the range 150-200 °C and fraction 4 boiling above 200 °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 °C.

Table 5 Fuel Properties of HDPE and Diesel

Properties	Fraction 2	Fraction 3	Fraction 4	Diesel
Density 15 °C (kg/m^3)	791	813	826	820
Kinematic viscosity at 40 °C (cSt)	1.52	1.84	2.26	2.51
Flash Point (°C)	45	47	50	53
Fire point (°C)	33	57	49	64
Pour point (°C)	-8	-7	-4	-
Grass calorific value (MJ/kg)	44.0	44.1	44.1	42.3
Cetane number	52.4	52.4	52.4	50.0

Performance Parameter

Brake Thermal Efficiency

The variation of brake thermal efficiency with brake power is shown in Figure 5. From the figure it is seen that fraction 2 shows maximum brake thermal efficiency than fractions 3 and 4 and diesel beyond a particular load (brake power above 3 kW). Fraction 2 shows the maximum brake thermal efficiency of 32 % at the maximum power of the engine. It is higher than other fractions and diesel fuel. This is due to the high calorific value and higher energy released by the fraction 2.

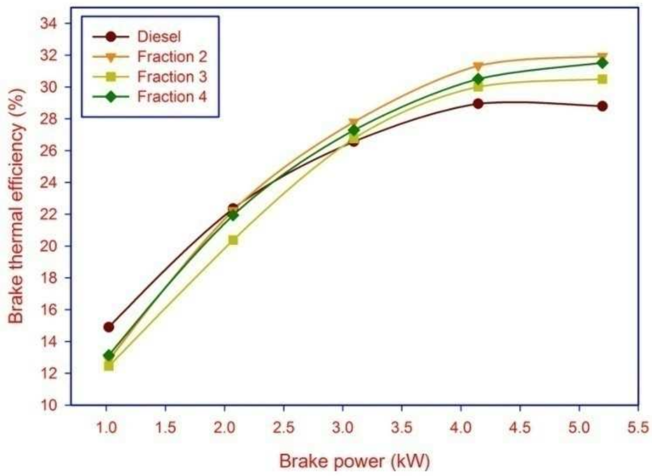

Figure 5: Brake Thermal Efficiency against Brake Power

Emission Parameters

Smoke Density

The variation of smoke density with the brake power for the various fractions is shown in Figure 6. From the figure, it is seen that the smoke emission for diesel is high 63.3 HSU for the waste plastic oil the smoke emissions are, 57.9 HSU for fraction 2, 55.8 HSU for fraction 3 and 49.7 HSU for fraction 4. It can be noticed that the smoke for all the fractions is lower than diesel. This is due to the availability of homogeneous charge inside the engine cylinder. Higher combustion temperature increases the duration of combustion and smooth flame propagation may also be the reason for low smoke intensity.

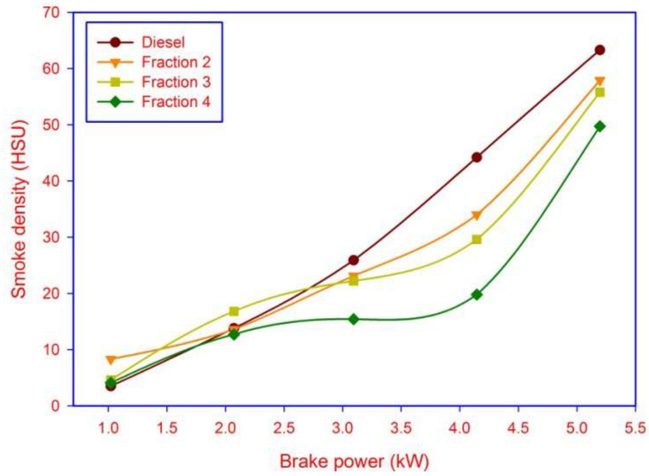

Figure 6: Smoke Density against Brake Power

Oxides of Nitrogen

Figure. 7 shows the variation NOx emission with brake power for the various fractions. It is seen that NOx emission is higher 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. The NOx concentration at the maximum load is 1180 ppm for the fraction 4

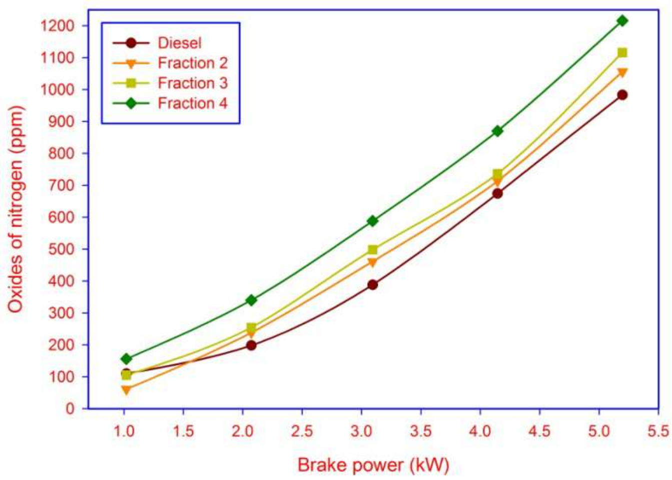

Figure 7: Oxides of Nitrogen against Brake Power

HC Emission

Figure. 8 show the variation of HC emission with brake power for the various fractions. It is seen that HC emission is higher when compared to diesel. The maximum hydrocarbon produced in fraction 2 is 144 ppm. This is due to an insufficient amount of oxygen present inside the cylinder. Unburnt hydrocarbon emissions consist of fuel that is incompletely burned. The term hydrocarbon means organic compounds in the gaseous state; solid hydrocarbons are part of the particulate matter. Typically, unburnt hydrocarbons are a serious problem at light loads in CI engines. At light loads the fuel is less to impinge on surfaces; but because of poor fuel distribution, large amounts of excess air and low exhaust temperature, lean fuel-air influence regions may survive to escape into the exhaust.

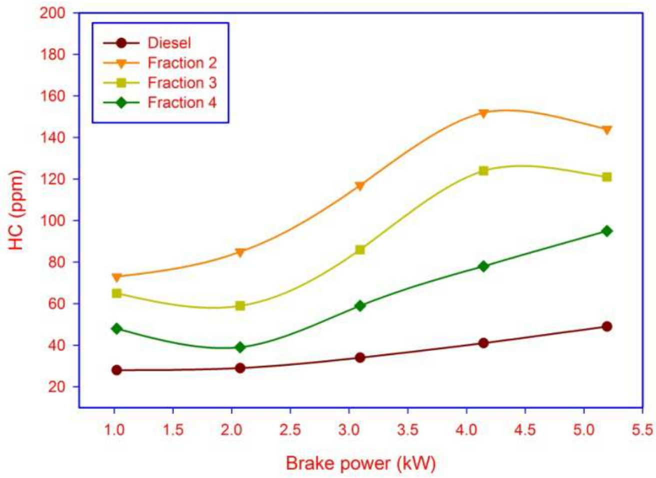

Figure 8: Hydrocarbon against Brake Power

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

Figure 9 show the variation of the cylinder pressure with the crank angle for all fractions. From the figure it is seen that fractions 2, 3 and 4 show higher cylinder pressure than diesel. The peak pressure depends on the combustion rate in the initial stages which is influenced by the amount of fuel taking for in the control combustion face, which is governed by the delay period. It is also affected by the fuel-air mixture preparation during the delay period. It can be seen from the figure that the peak cylinder pressure for fraction 4. This is due to long ignition delay resulting in a higher heat release rate as observed.

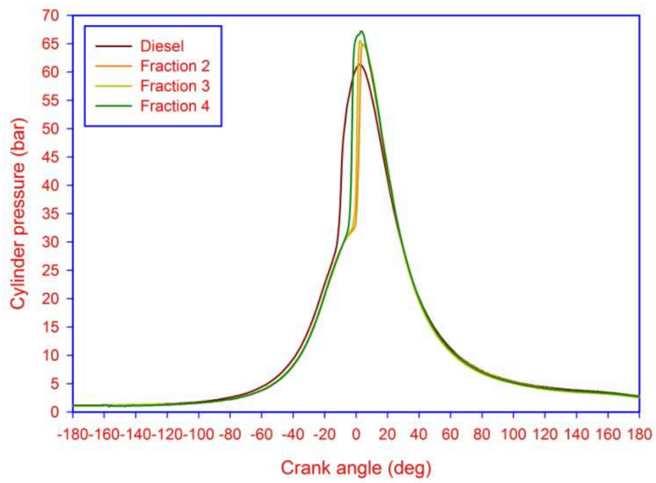

Figure 9: Cylinder Pressure against Crank Angle

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 low heat release rate during the initial stage and longer combustion duration at full load. It can be observed that the maximum heat release rate of diesel is 84.8 kJ/m^3 deg. For all the fractions it is higher than diesel. Fraction 3 shows the maximum heat release rate of140.8 kJ/m^3deg. This due to its longer ignition delay and burning rate in the diffusion combustion face is controlled by the availability of combustible fuel-air mixture. The diffusion combustion face is greater for waste plastic oil than diesel due to poor atomization. The increase in the heat release rate is probability due to better mixing of fuel and air in the second stage of combustion than diesel.

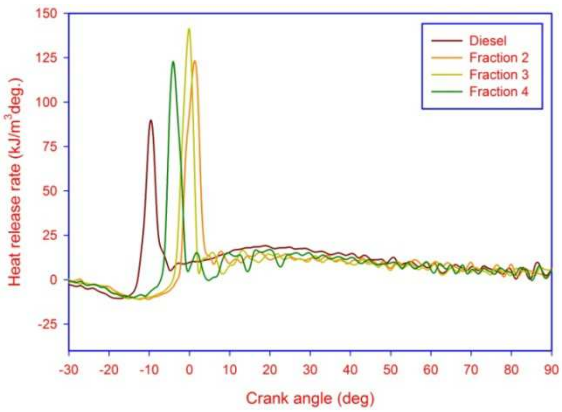

Figure 10: Heat Release Rate against Crank Angle

CONCLUSIONS

The plastic oil obtained from HDPE waste plastic to boiling range of 100-150□C, 150-200□C, 200 above can be used as a substitute for diesel.

REFERENCES

1. Nobuomatsuura, Tomoaki uchiyama, Hirosh, Tada, Yosikazu Nakamura, Naomi kondo, Mastoshi morila, Masdrc fukushi, 'Effect of dioxine and polychlorinated biphenyls (PCBs) on thyroid function in infants born in Japan', the second report from research on Environmental health, chemosphoree, 2001, 45, pp. 1167-1171.
2. Y.H. Lin, M.H. Yang, T.F. Yeh, M.D. Ger, "Catalytic degradation of high density polyethylene over mesoporous and microporous catalysts in a fluidized-bed reactor" Polymer Degradation and Stability, 86 (2004), pp. 121-128.
3. I.C. Neves, G. Botelho, A.V. Machado, P.Rebelo, S. Ramoa, M.F.R. Pereira, "Feedstock recycling of polyethylene over AlTuD-1 mesoporous Catalyst" Polymer Degradation and Stability, 92 (2007), pp. 1513-1519.
4. K. Gobin, G. Manos, "Thermogravimetric study of polymer catalystic degradation over microporous materials" Polymer Degradation and Stability, 86 (2004), pp. 225-231
5. N. Miskolczi, L. Bartha, G. Deak, B. Jover, D. Kallo, "Thermal and thermo-catalytic degradation of highe-density polyethylene waste" Journal of Analytical and Applied Pyrolysis, 72 (2004), pp. 235-242.
6. J.F. Mastral, C. Berrueco, M. Gea, J. Ceamanos, "Catalytic degradation of high density polyethylene over nano crystalline HZSM-5 Zeolite" Polymer Degradation and Stability, 91 (2006), pp. 3330-3338.
7. G. Manos, I.Y. Yusof, N. Papayannakos, N.H. Gangas, "Catalytic cracking of polyethylene over clay catalysts. Comparison with an ultrastable Y zeolite" Industrial & Engineering Chemistry Research, 40 (2001), pp. 2220-2225.

8. J. Mosio-Mosiewski, M. Warzala, I. Morawski, T. Dobrzanski, “High pressure catalytic and thermal cracking of polyethylene fuel process” Journal of Technology, 88 (2007), pp. 359-364.

9. I.C. Neves, G. Botelho, A.V. Machodo, P. Rebelo, “Catalytic degradation of polyethylene; An evaluation of the effect of dealuminated Y Zeolites using thermal analysis” Materials Chemistry and Physics, 104 (20070, pp. 5-9.

10. G. Manos, A. Garforth, J. Dwyer, “Catalytic degradation of high-density polyethylene on an ultrastable-Y zeolite. Nature of initial polymer reactions, pattern of formation of gas and liquid products, and temperature effects” Industrial & Engineering Chemistry Research, 39 (2000), pp. 1203 -1208.

11. K.H. Lee, D.H. Shin, “Catalystic degradation of waste polyolefinic polymers using spent FCC catalyst with various experimental variables” Korean Journal of Chemical Engineering, 20 (2003), pp. 89-92.

12. G. Elordi, M. Olazar, G. Lopez, M. Amutio, M. Artetxe, R. Aguado, “Catalytic pyrolysis of HDPE in continuous mode over zeloite catalysts in a conical spouted bed reactor” Journal of Analytical and Applied Pyrolysis, 85 (2009), pp. 345-351.

13. G. Elordi, M. Olazar, R. Aguado, G. Lopez, M. Arabiourrutia, J. Bilbao, “Catalytic pyrolysis of high density polyethylene in a conical spouted bed reactor” Journal of Analytical and Applied Pyrolysis, 79 (2007), pp. 450-455.

14. F.J. Mastral, E. Esperanza, C. Berrueco, M. Juste, J. Ceamanos, “Fluyidized bed thermal degradation products of HDPE in an inert atmosphere and in air/nitrogen mixtures” Journal of Analytical and Applied Pyrolysis, 70 (2003), pp. 1-17.

15. M.R. Jan, J. Shah, H. Gulab, “Degradation of waste high-density polyethylene into fuel oil using basic catalyst” Journal of Fuel, 89 (2010), pp. 474-480.

16. M.R. Jan, J. Shah, H. Gulab, “Catalytic degradation of waste high-density polyethylene into fuel products using $BaCO_3$ as a catalyst” Fuel processing Technology, 91 (2010), pp. 1428-1437.

17. R.A. Garcia, D.P. Serrano, D. Otero, “Catalytic cracking of HDPE over hybride zeolitic-mesoporous materials” Journal of Analytical and Applied Pyrolysis, 74 (2005), pp. 1-17.

18. G. Manos, A. Garforth, J. Dwyer, “Catalytic degradation of high-density polyethylene over different zeolitic structures” Industrial & Engineering Chemistry Research, 39 (2000), pp. 1198-1202.

19. G. Luo, T. Suto, S. Yasu, K. Kato, “Catalytic degradation of high density polyethylene and polypropylene into liquid fuel in a powder-particle fluidized bed” Polymer Degradation and Stability, 70 (2000), pp. 97-102.

20. Y. Sakata, M. Azhar-Uddin, A.Muto, Y. Kanada, K. Koizumi, K. Murata, “Catalytic degradation of polyethylene into fuel oil over mesoporous silica (KFS-16) catalyst” Journal of Analytical and Applied Pyrolysis, 43 (1997), pp. 15-25.

21. G.J.T. Fernandes, V.J. Fernandes J.R, A.S. Araujo, “Catalytic degradation of polyethylene over SAPO-37 molecular sieve” Catalysis Today, 75 (2002), pp. 233-238.

22. W. Ding, J. Liang, L. Anderson, “Thermal and catalytic degradation of high density polyethylene and commingled post-consumer plastic waste” Fuel Processing Technology, 51 (1997), pp. 47-62.

23. M. R. Jan, J. Shah, H. Gulab, "Catalytic conversion of waste high density polyethylene into useful hydrocarbons" Journal of Fuel, 105, (2013), pp 595-602.

24. Selahan Karagoz, JaleYanik, Suat Ucar, Mehmet Saglam, Chunshan Song, "Catalytic and thermal degradation of high-density polyethylene in vacuum gas oil over non-acidic and acidic catalysts" Journal of Applied catalysis 245 (2003) pp. 51-62.

25. Jerzy Walendziewski, "Engine fuel derived from waste plastics by thermal treatment" Journal of Fuels, 81 (2002) pp. 473-481.

26. P. Senthilkumar, Environmental Effect of using Diesel on Waste Plastic Oil Fueled in Di Diesel Engine, International Journal of Mechanical Engineering (IJME), Volume 7, Issue 3, April-May 2018, pp. 1-8

27. J. Aguado, D.P. Serrano, J.M. Escola, E. Garagorri, J.A. Fernandez, "Catalytic conversion of polyolefin's into fuels over zeolite beta" Journal of Polymer Degradation and stability 69(2000) pp. 11-16.

28. Ikusei Nakamura, Kaoru Fujimoto, "Development of new disposale catalyst for waste plastics treatment for high quality transportation fuel" Journal of Catalysis Today, 27 (1996) pp. 174-179.

29. Jerzy Walendziewski, Mieczyslaw Steininger, "Thermal and catalytic conversion of waste polyolefines" Journal of Catalysis Today, 65 (2001) pp. 323-330.

30. N. Miskolczi, L. Bartha, G. Deak, B. Jover, "Thermal degradation of municipal plastic waste for production of fuel-like hydrocarbons" Journal of Polymer degradation and stability 86 (2004) pp. 357-366.

31. Mohammad Farhat Ali, Mohammad Nahid Siddiqui, "Thermal and catalytic decomposition dehavior of PVC mixed plastic waste with petroleum residue" journal of Annalytical and Applied Pyrolyysis, 74 (2005) pp. 282-289.

32. Karishma Gobin, George Manos, "Polymer degradation to fuels over microporous catalysts as novel tertiary plastic recycling method", Journal of Polymer Degradation and stability 83(2004), pp 267-279.

33. Premkumar., P, Saravanan, C.G., "Conversion of hospital low density polyethylene waste into hydrocarbons using fly ash as catalyst" Internal Journal of Engineering Trends and technology (IJETT), Vol. 16, 2014, pp. 241-251.

34. Premkumar., P, Saravanan, C.G., Gopalakrishnan, M., "Complete catalytic conversion of high density polyethylene into hydrocarbons without was formation using fly ash as catalyst" Internal Journal of Engineering science and Technology (IJEST), Vol. 6(11), 2014, pp. 786-792.

35. Shah J. Jan MR. Mabood F. Jabeen F. Catalytic pyrolysis of LDPE leads tovaluable resource recovery and reduction of waste problems. Energy ConversManag 2010:51:2791-801.

36. Passamonti FJ, Sedran U. Recycling of waste plastics into fuels. LDPE conversion in FCC. AppI Catal B Environ 2012:125:499-506.

37. Eriksson O, Finnveden G. Plastic waste as a fuel-CC>2-neutral or not? Energy Environ Sci 2009:2:907-14.

38. Mani M, Subash C, Nagarajan G. Performance, emission and combustioncharacteristics of a Dl diesel engine using waste plastic oiL AppI Therm Eng2009:29:2738-44.

39. Mani M, Nagarajan G, Sampath S. Characterisation and effect of using wasteplastic oil and diesel fuel blends in compression ignition engine. Energy2011;36:212-9.

40. Rakopoulos DC, Rakopoulos CD, Giakoumis EG, Dimaratos AM. Characteristicsof performance and emissions in high-speed direct injection diesel enginefueled with diethyl ether/diesel fuel blends. Energy 2012;43:214-24.

41. Kumar, S., Prakash, R., Murugan, S., Singh RK. Performance and emission analysisof blends of waste plastic oil obtained by catalytic pyrolysis of waste HDPEwith diesel in a CI engine. Energy Convers Manag 2013;74:323-31.