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EVALUATION, PERFORMANCE AND EMISSION CHARACTERISTICS OF HOUSE HOLD WASTE PLASTIC INTO WASTE PLASTIC OIL

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ABSTRACT

Domestic waste plastic consisting of polythene bags, milk cover and oil cover has been degraded into the plastic oil containing hydrocarbons using fly ash as the catalyst. This has been accomplished by using a waste pressure cooker as the reactor and waste plastic can as the condenser. The yield of the plastic oil obtained was 63.2%. Low boiling hydrocarbons were removed from the plastic oil by controlled heating at 100 °C for about 30 min. The properties of the resultant oil were compared to those of commercial diesel. This oil was tested as a fuel in the diesel engine. The fuel characteristics are quite comparable to those of diesel.

KEYWORDS: Domestic Waste Plastic, Plastic Oil, Engine Fuel, Fly Ash, Emission

INTRODUCTION

In modern days use of plastic is unavoidable. Almost all the food items are packed in polythene bags made of LDPE. LDPE is generally used for making flexible materials like bags and geomembranes. A family in India is polluting about 1 sq.feet land area by littering the waste plastic in a day. Managing of these plastic wastes is a serious problem. Land-filling and incineration are the methods used by the people in all places. When it is littered in the ground during the rainy season the plastics get floated in the water and chock the drain pipes. Due to this water gets stagnated in the living area. This is a very big problem in city and town areas.

In most of the places to avoid the above problem waste plastics are burnt in an open atmosphere. During burning the 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). Sulpher 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 human and animals. This causes a lot of health hazards. Harmful effects of dioxin have been well described by Nobuomatsuura *et al.,* [1].

So burning of plastic in the open atmosphere is harmful to the humans. To avoid this plastic can be converted into liquid hydrocarbons which can be used to run automobiles by mixing it with auto fuel at a proportional ratio. Waste HDPE and LDPE have been successfully converted into hydrocarbons [2-33].

Catalytic degradation has been found to be better than thermal degradation [5, 14, 21, 23, 25, 28, 31, 32, 33]. Largely acidic, Zeolite based and clay based catalysts have been used for degradation. Basic catalysts $MgCO_3$, $CaCO_3$, and $BaCO_3$ also have been used. Fly ash obtained after burning of coal has also been used.

So far no attempt has been made to convert domestic waste plastic like polythene bags into hydrocarbons. This paper reports the conversion of domestic waste plastic into hydrocarbons. Also, the obtained plastic oil has been tested on the diesel engine.

EXPERIMENTAL

Materials and Methods

Waste plastic: Unused waste plastics like the packed cover carry bags; milk cover and oil cover were collected from a house in a bag for a period of one month. Big plastic bags were cut into small pieces by using scissors.

Catalyst: Fly ash was collected from the nearby area where coal is burnt. This will act as a catalyst.

Degradation Plant

The photographic view of the waste plastic oil extraction plant is shown in Figure.1. It consists of a reactor, burner, LPG cylinder, condenser and a thermocouple attached to a digital meter which works in 230 V AC supply.

Figure 1: Photographic View of Degradation Plant

Fabrication of the Reactor

The reactor was fabricated by modifying a 5-liter waste cooker as follows

The steam outlet in the top cover of the cooker was removed and a steel pipe was fitted. This pipe is bent to connect it with a condenser. The safety valve is removed and a thermo well is made. The thermocouple is inserted in the thermo well and the thermocouple is attached to a digital thermometer. Six holes are made in the top cover and the bottom of the cooker to attach the top and bottom of the cooker tightly by bolts and nuts. The space between the top cover and bottom of the cooker was fitted with a mechanical seal to prevent leakage from or into the joined objects during the reaction process.

Modification of Waste Water Can Into Condenser

The tap was removed from the wastewater can. A flexible hose pipe was inserted through the hole formed by removing the tap. M-seal was used to prevent the leakage of water from the can. The hose was rolled into two rolls inside the condenser. One side of the flexible hose was open for oil outlet and the other side of the tube was connected to the reactor pipe.

Figure 2: Photographic View of Condenser

Procedure for Extracting the Waste Plastic Oil

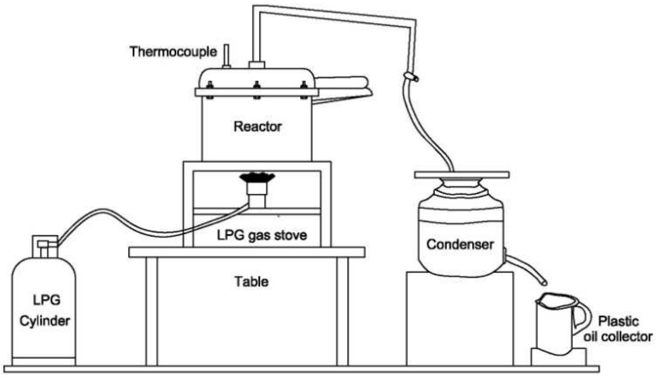

Figure 3: Schematic Diagram of Experimental Setup

Schematic diagram of the experimental setup is shown in Figure. 3. One kg of cut waste plastic was mixed with 100 g of catalyst and mixture was placed inside the reactor. The reactor was kept on the gas stove burner. After checking all the bolts and nuts for tight fixing the burner was ignited using a lighter. When the burner burnt the temperature inside the reactor was increased and the plastic got melt. As the temperature increased the plastic melted and cracking took place. The cracked vapor got passed through the condenser. In the condenser, the cracked vapor was cooled and became liquid. The temperature and the oil collected were noted at regular time intervals. The collection of plastic oil is shown in Figure. 4 Unburned hydrocarbon Collection of waste plastic oil.

Figure 4: Waste Plastic after Degradation

If the water in the condenser (can) become too hot it was replaced with fresh cool water. Some short chain hydrocarbons which cannot be cooled into liquid go out of the condenser as vapor.

REMOVING OF LOW BOILING HYDROCARBON

The reactor was thoroughly cleaned and dried. The collected waste plastic oil was poured into it. The reactor was tightly closed and was kept in an aluminum basin containing water. Waster was poured up to a level in the aluminum basin as shown in Figure. 5.

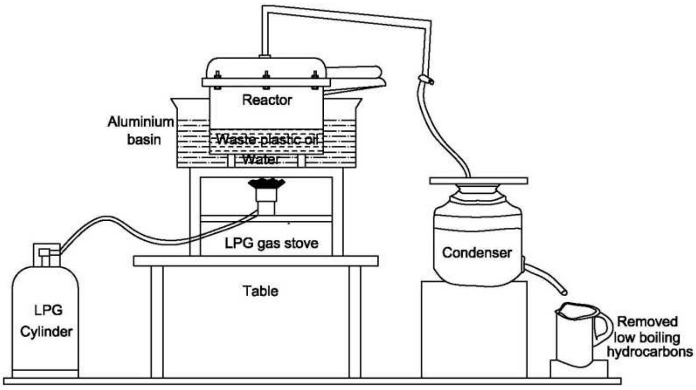

Figure 5: Schematic Diagram of Removing Low Boiling Hydrocarbon

The burner was lighted. The temperature of the water increased. Due to this the temperature of the oil also increased gradually. Now the low boiling hydrocarbons vaporized from the reactor and got cooled in the condenser. Heating was continued until the condensation of low boiling fraction oil stopped coming from the condenser. This oil may be used to run the petrol engine.

PHYSICAL PROPERTIES

Physical properties of the waste plastic oil obtained after removing the low boiling hydrocarbons were determined using the following standard methods for fuel: IS-1448-P16 for density, IS-1448 P-32 for specific gravity, IS-1445-P25 for kinematic viscosity, IP-36 for flash point and fire point, IP-16 for pour point, gross calorific value was determined as per IS-1448.

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. 6. 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)
- 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

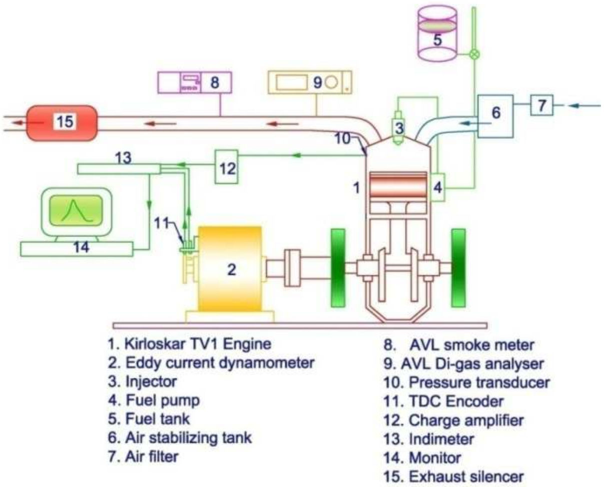

Figure 6: Experimental Set Up for Test Engine

RESULTS AND DISCUSSIONS

Degradation Process

Degradation was carried out with 1 kg of the polymer. The amount of oil collected and temperature measured at 10 min time interval are given in Table 2. The results are graphically represented in Figure. 7. In this experiment, the temperature at which oil formation started and temperature at which oil formation ceased were noted and are given in Table 3. The time at which oil formation ceased was also noted.

Table 2: Observation Table

Time (min)	Temperature of Sample Inside the Reactor Chamber	Quantity of the Oil Obtained (mL)
0	28	-
10	69	-
20	130	-
30	194	47
40	296	195
50	322	265
60	347	430
70	359	570
80	378	680
90	387	735
100	376	760
110	369	775
120	342	790
130	327	795

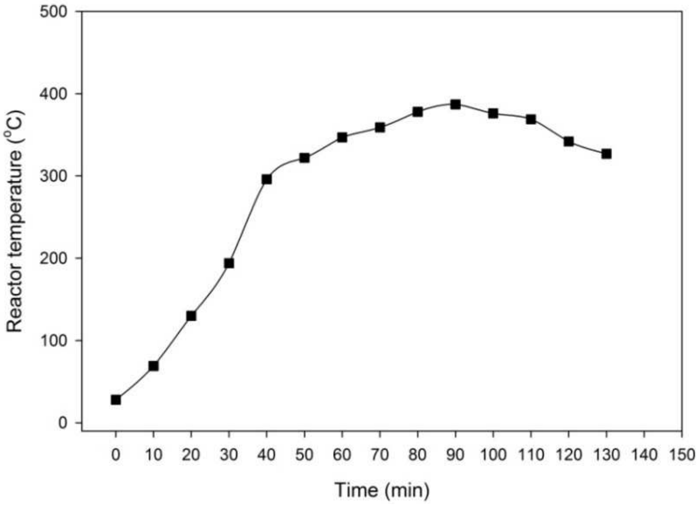

Figure 7: Graph Time Versus Reactor Temperature

The oil formation commenced at 198 °C and ceased at 327 °C. It has been observed that for LDPE from waste saline bottles the oil formation commenced at 210°C and ceased at 342°C for the same cat/pol ratio [32]. Thus, oil is formed at the lower temperature in the case of polyethylene bags compared to waste saline bottles. This is because polyethylene bags are generally made from LDPE which has low molecular weight compared to those used for making saline bottles.

Calculation of Yields

The yields of solid, liquid and gaseous products are denoted as Y_S, Y_L, andY_g, respectively. Let the weights of solid material remaining in the reactor after the reaction as W_P Let the 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 weight of the remaining product was found as 120 g. By subtracting the weight of catalyst from this it is seen that the amount of solid product is 20 g. This mass contains unrecompensed materials, waxy hydrocarbons, and carbonaceous matter. The percentage of total solid mass is 2. Thus, there is at least a 98% conversion. In the case of the waste saline bottle, 97% conversion has been achieved [32]. The results are given in Table 3.

The weight of oil formed was 632 g. This is the percentage of oil formed is 63.2. In the case of waste saline bottle 75% oil has been obtained for this cat/pol ratio. Since polyethene bags are produced from low molecular weight LDPE the amount of gaseous product formed is higher in this case than in the case of the waste saline bottle.

Table 3: Physical Data for Degradation

Reaction Temperature ^{A}	Reaction Time	Conversion	Oil	Gas^b	Density of the Oil
(°C)	(min)	(%)	(%)	(%)	(kg/m^3)
206-360	140	98	63.2	34.8	789

- The lower temperature is the temperature at which oil formation commenced and the higher temperature is the temperature at which oil formation is ceased.
- Obtained by balance.

When low boiling hydrocarbons were removed from 100 mL of the plastic oil the remaining oil obtained was 880 mL. The properties of oil were determined and are compared with those of diesel in Table 4.

Table 4: Properties of Plastic Oil and Diesel

Properties	Plastic Oil	After Removing Low Boiling HC (WPO)	Diesel
Specific gravity at15/15 (°C)	0.795	0.82	0.825
Kinematic viscosity at 40°C (cSt)	2.55	2.49	2.522
Flash point (°C)	63	67	69(52-95)
Fire point (°C)	71	77	86
Grass calorific value (MJ/kg)	42.6	42.6	42.4
Density at 15°C (kg/m^3)	795	820	825

Engine Parameters for the Waste Plastic Oil

Various parameters such as brake thermal efficiency, smoke density, NOx emission, and hydrocarbon were determined for the above plastic oil

Brake Thermal Efficiency

Variation of the brake thermal efficiency with the brake power of the engine is shown in Figure. 8. In all cases, brake thermal efficiency has the tendency to increase with an increase in brake power. This is due to the reduction in heat loss and increases in power developed with an increase in brake power. From figure. 8 it is seen that the brake thermal efficiency for WPO is higher than that of diesel. The properties of the WPO 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 29 % which is higher than that of the diesel.

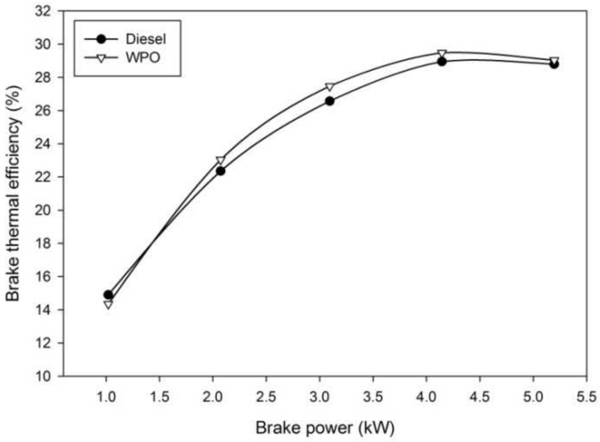

Figure 8: Brake Thermal Efficiency against Brake Power

Emission Parameter

Smoke Density

The variation of the smoke density with brake power is shown in Figure. 9. From figure. 9 it is seen that the smoke density is higher for WPO than diesel. This is due to the low viscosity, heavier molecular structure, present of carbon residue in the WPO. Due to this, the smoke produced by the WPO is higher at all the loads. The maximum smoke produced is 75.4 HSU for the maximum brake power.

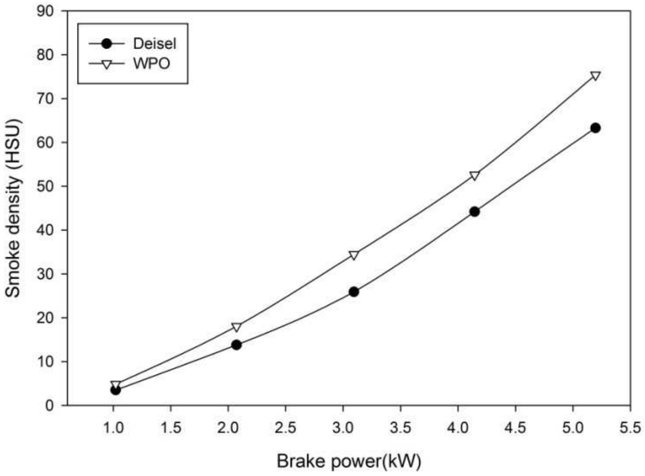

Figure 9: Smoke Density against Brake Power

Oxides of Nitrogen

Comparison of NOx emission for WPO with diesel is shown in Figure. 10. It is seen that the NOx emission is lower than that of diesel at fairly higher brake powers. The lower NOx emission of the WPO is due to a lower heat release rate when compared to diesel.

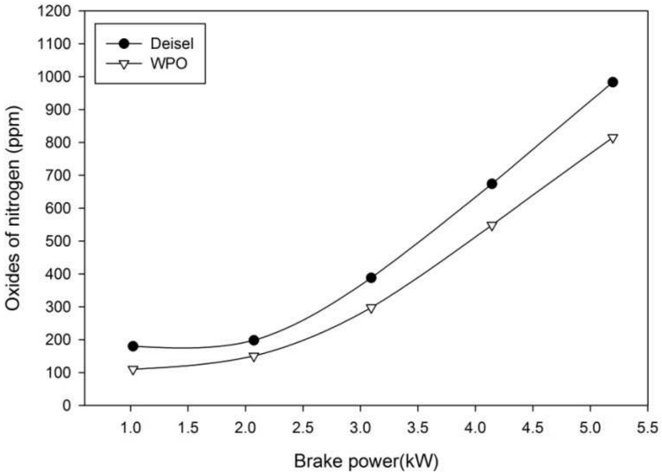

Figure 10: Oxides of Nitrogen against Brake Power

Hydrocarbons

The variation of the amounts of hydrocarbons in the exhaust gas with brake power is shown in figure. 11. It is seen that the hydrocarbon level increases with an increase in brake power. The hydrocarbon level of WPO was a slightly higher emission when compared with diesel. Since the viscosity of the WPO was low the fuel injected with the engine is high when compared with diesel.

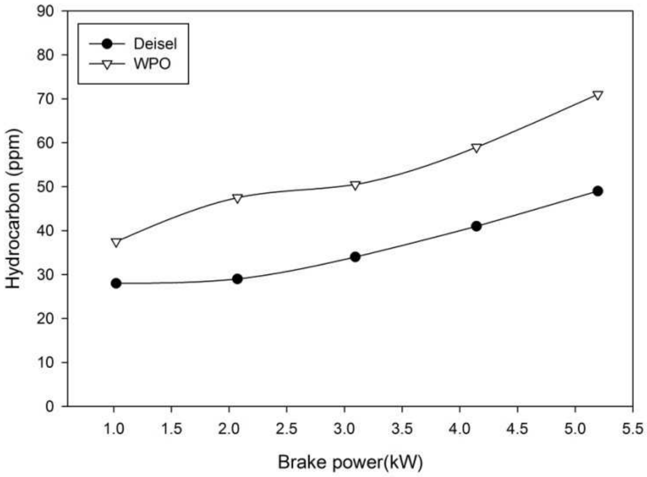

Figure 11: Hydrocarbon against Brake Power

Combustion Parameter

In the combustion parameter cylinder pressure and heat release rate were also determined for the above waste plastic oil

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. 12. The cylinder pressure for diesel fuel is 61 bar which is higher than that of WPO. From figure 12 it is seen that WPO shows 58 bar cylinder pressure at maximum load which is lower than that of diesel.

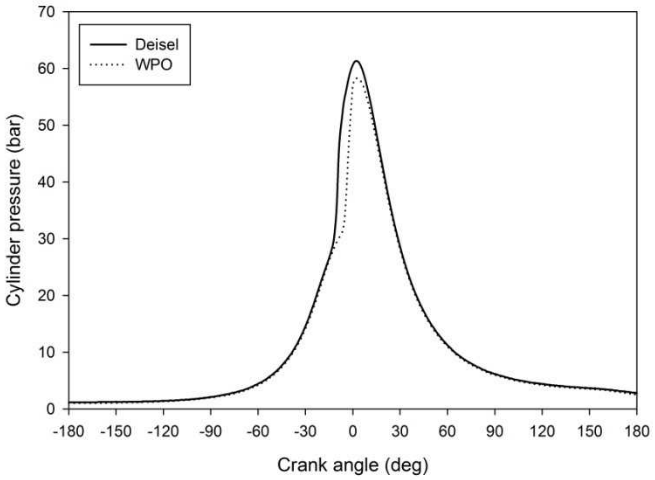

Figure 12: Cylinder Pressure against Crank Angle

Heat Release Rate

From Figure. 13 it is seen that the heat release rate for WPO is shifted about 5° crank angle. This is due to prolonged ignition delay because of different hydrocarbon fractions available in the fuel.

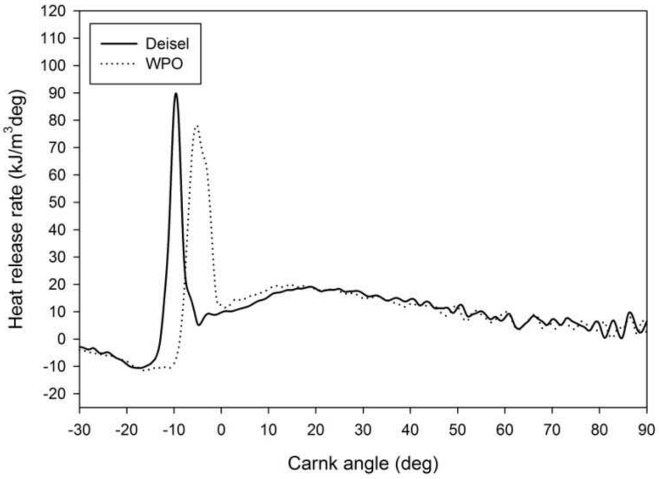

Figure 13: Heat Release Rate against Crank Angle

CONCLUSIONS

Domestic plastic waste can be converted into plastic oil. The plastic oil can be easily separate the low boiling hydrocarbons using a simple procedure. The higher boiling fraction can be used as a fuel on the diesel engine. The brake thermal efficiency is 29% higher than that of diesel. This smoke produced at maximum brake power is slightly higher than that of diesel but are within the permissible limits. The emission of NOx is less than that of diesel at all loads. Though the emission of hydrocarbons is slightly higher than that of diesel it is within permissible limits. The combustion parameters were also comparable to those of diesel.

From this work, it is concluded that all the household waste plastic can be converted into liquid fuel by following the easy procedure shown in this study. This will reduce the pollution due to waste plastic in the environment.

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, chemosphere, 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 micro porous 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, “Thermo gravimetric study of polymer catalytic degradation over micro porous 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 higher-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 ultras table-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. Sankaranarayanan, G. (2017). Experimental study on waste plastic oil with diesel biodiesel and water emulsion blends in di diesel engine.
12. 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.
13. 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.
14. 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.

15. 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.
16. 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.
17. 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.
18. 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.
19. 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.
20. 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.
21. 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.
22. 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.
23. 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.
24. 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.
25. 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.
26. Jerzy Walendziewski, “Engine fuel derived from waste plastics by thermal treatment” Journal of Fuels, 81 (2002) pp. 473-481.
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 behavior 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 micro porous 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.