Evaluation of oil derived from household waste plastic made up of plastic as a substitute for Diesel

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Abstract

Waste household plastic materials have been degraded into hydrocarbons utilizing fly ash as catalystand biogas as a source of heat for degradation. Biogas was produced using a mixture of cow dung andkitchen waste. Degradation has been carried using cat/pol ratios 0.10, 0.15 and 0.20. The amount of waste plastic taken for one batch is 1 kg. The temperatures at which oil formation commence and accomplishedwere recorded. The yields of liquid and gaseous hydrocarbons (Y_L & Y_G) were found. The maximum yield of liquid hydrocarbon (Y_L) was found to be 65.1% whenthe cat/pol ratio is 0.2.

The SEM and EDX spectra suggest that fly ash acts as catalyst. The obtained oil was separated into four fractions with boiling range of <100, 100-150, 150-200 and >200 ^{0}C, respectively. The physical properties of fractions boiling above 100 ^{0}C were found. All fractions have higher heating value and higher cetane number than diesel. Hence these oil fractions can be utilized as an alternative for diesel. These fractions were tested on a diesel engine. The oil produced from waste household plastics using cat/pol ratio 0.1 and boiling in the range 100-150 ^{0}C (A2) produces maximum Brake thermal efficiency of 33% and produces low smoke density and hydrocarbon emission of 48 HSU and 28 ppm. There was a significant amount of increase in NO_X emission. Among all the fractions diesel A2 is seen to be bestin performance & combustion and lower in emission.

Keywords: *HDPE, fly ash, Catalyst, Degradation, Engine Fuel.*

1. Introduction

Most home products are made up of plastic materials. Some plastics are used as containers for storing oil, detergent, dishwashers, food items etc. When these containers become empty's the thrown into trash and some are used as utilizing products like chairs, brushes, mug, packet etc. After long use it will break or become useless. All these products are thrown to trash. This creates pollution of the environment if not treated properly. These plastics can be converted into hydrocarbons by degradation process.

Plastics are polymers made up of large molecules having repeating units of shorter carbon compounds, calledmonomers. Chemists produce various types of polymers having different properties by combining various monomers. They have also modified naturally occurring polymers like cellulose and rubber using chemical reactions. Several books have been written on the synthesis, properties, and applications of polymers. For example, Flory wrote a book [1] on polymer chemistry in 1953. Recently, Ravee has written a book [2] on polymer chemistry.

However, all polymers cannot be made into plastics. This plastic does not react chemically with other substances like oil, soap solution, acid, liquid hydrocarbons, and alcohol. Most plastics are flexible, unbreakable, less in weight and can be molded into any shape in quick time. Hence, they are used in making.

toys, cups, bottles, utensils, wires etc. Since plastics can take colorants the plastic materials are available in various colours. Cost effectiveness is a major advantage of plastics.

Nowadays most of the food, health care, home appliances are packed and using plastics all over the world. So, plastic cannot be avoided, and it is widely used. The use of plastics creates post-use plastic wastes. Sinceplastic is not biodegradable it doesn’t decay. Land filling, touring, and reusing are the three available methodsof utilizing plastic waste. Land filling is storing the waste materials in waste lands. Land filling can be usedfor storing waste materials which can undergo biochemical transformation into useful and harmless products. However, most plastics are not easily biodegradable [3]. A plastic made of polyethylene, buried under earth, showed only 1% weight loss after a period of 10 years [4]. Moreover, land filling requires more land area since plastic wastes are voluminous.

Incineration is a method of burning waste materials. During incineration combustion takes place. Combustionis a chemical reaction of organic matter with oxygen in the air. Waste material contains carbon and producesgreen gas, Co_2. All are produced due to plastic having a high heating value, during open incineration of plastic produces higher temperature which produces NOx (NO and NO_2) Incomplete combustion will produce smokeand toxic CO emission.

The above-mentioned factors can be avoided by recycling the waste plastics. Reusing of plastic is one methodof recycling but the segregation of different types of plastic from waste is difficult. Hence, chemical recyclingis a preferable method of handling waste plastics.

Using chemical method plastics made up of polyesters and polyamides. Though polyesters are not affected bypure water or in the presence of acid they can be attacked by aqueous can be transformed into monomers alkali[5]. However, polyamides are attacked by acid hydrolysis [6]. Through polyesters and polyamides can be hydrolyzed into their monomers, depolymerized of polyalkenes into monomers difficult. However, polyalkenes have been converted into hydrocarbons successfully. The degradation generally gives a mixture of liquid hydrocarbons which have potential of being used as fuel in IC engines. Recycling of waste from polymer materials has been reviewed [7, 8].

Polyethylene (PE) is a thermoplastic polymer containing ethylene and $[CH_2\text{-}CH_2]_n$. is the chemical formula for polyethylene. Changing the ‘n’ value by chemist gives two types of plastics that are low density polyethylene (LDPE) and high-density polyethylene (HDPE). Since the density of the LDPE plastic is less itcan be used for making flexible plastic products. But the density of HDPE plastic is more so it can be used tomake hard plastic products.

Several successful attempts have been made to convert HDPE and LDPE into hydrocarbons. When comparedthermal degradation catalytic degradation is always ranked up in all aspects. Uddin et al. [9] have studied thethermal and catalytic degradation of HDPE. They have found the degradation of HDPE without catalyst and using two types of silica-alumina catalysts having SiO_2/Al_2O_3 ratios of 83.3/16.7 (SA-1) and 21.1/78.9 (SA-

2). They have carried out the degradation from a temperature of about 100 to a temperature of 430 °C. For the catalytic processes they have taken 1 g catalyst and 10 g HDPE (cat/pol = 0.1). They have obtained 58.4%of liquid products from HDPE without catalyst. Use of SA-1 as catalyst gave 68% of oil whereas use of SA-2 as catalyst gave 77.4% of oil products.

Ding et al. [10] have reported that the degradation of HDPE with and without catalyst. They have used $TiCl_3$ (Titanium Chloride) and HZSM-5 as catalysts. They have purchased $TiCl_3$ but have synthesized HZSM-5 following the procedure according to US patent 4,250,345. HZSM-5 catalyst contains Al_2O_3 and SiO_2 with a Si/Al mole ratio of 35. They have used 3-5% (wt.) of $TiCl_3$ or 2-4% (wt.) of HZSM-5 catalyst.

It has been found that thermal degradation needs 430 °C whereas catalytic reactions occur at a temperature span of 400-430 °C. When 3% $TiCl_3$ was used 88.6% of oil and 9.8% gas were obtained.

Aguado et al. [11] have reported that catalytic pyrolysis of HDPE and LDPE over various samples of zeolite beta. Zeolite beta contains Al to some extent. Zeolite beta can be synthesized from SiO_2-Al_2O_3 xerogel. This zeolite beta has been termed as Ti-Al-beta(X). Zeolite beta also can be synthesized by fluoride method. This zeolite beta has been termed Al-beta(F). Also, zeolite beta has been obtained by incorporating small amountsof titanium (Ti) in it. This zeolite beta has been termed as Ti-Al-beta(X).

Catalytic cracking was performed at a temperature of 400 °C for 30 min with plastic/catalyst ratio of 50. Theyhave obtained 52.3% conversion for HDPE and 55.2% conversion for LDPE using TiAl-beta(X) catalyst.

Walendziwski and Steininger [12] have studied the thermal and catalytic cracking of polyethylene. They haveused two kinds of catalysts. One was a hydrocracking catalyst containing NiW (an alloy of nickel and tungsten) and 10% HY-zeolite. Another was a commercial fluid cracking catalyst. They have used 0.3-0.5 wt% catalyst in relation to the weight of plastics. They have used a temperature of 370-450 °C. In the variousexperiments conducted they have obtained 1-10% solid residue and 10-70% liquid products.

Walendziewski [13] has studied the thermal and catalytic degradation of polyethylene, polystryene, blend of polyethylene and polypropene and blend of polyethylene and polystyrene. They have used basic catalyst ZnO and an acid cracking catalyst for the degradation. Experiments have been carried out under atmospheric pressure and in autoclaves at higher pressures. By carrying out the degradation of a mixture of polyethyleneand polypropene thermally and using the two catalysts (ZnO and cracking catalyst) it has been found that ZnO does not have much effect on the degradation. However, use of cracking catalyst reduced the reaction temperature.

Karagoz et al. [14] have studied the degradation of HDPE in vacuum gas oil over non-acidic and acidic catalysts. They have carried out the degradation in autoclaves at 425, 435 and 450 °C. They have carried out the degradation in hydrogen atmosphere using hydrocracking catalysts. They have used five kinds of metal supported on active carbon catalysts denoted as M/Ac (M stands for the metal). They have used Co/Ac, Mo/Ac, Ni/Ac, Co-Ni/Ac and Co-Mo/Ac as catalysts. They have also used acidic catalysts DHC-8 and HZSM-5. It has been found that use of M/Ac as catalyst decreases the total conversion. Though the use of DHC-8 and HZSM-5 results in complete conversion at 450°C the yield of liquid was higher for thermal process than for the catalytic processes.

Gobin and Manos [15] have studied the catalytic degradation of LDPE using zeolite based and clay-based catalysts. They have used LDPE in powder form with an average particle size of 100 μm. The amounts of polymer and dry catalyst were 2 and 1 g, respectively. Liquid products were collected in condensers placed in an ice bath. The reaction has been carried out for a period of 30 min. They have obtained 99% conversion.

Biswas et al. [16] have studied the degradation of polyethylene using catalysts. They have synthesized CAT-Z by calcination of commercial ZSM-5 at 520±5 °C for 4 h. By physical mixing of ZSM-5 with silica-aluminasupport, catalyst CAT-R was synthesized. They have synthesized CAT-A by impregnating silica alumina support with 4% Ni and 15% Mg loading. They have synthesized catalyst CAT-N by subjecting commercialFCC catalyst to calcination at 400±5 °C. The cracking of PE has been studied with 5 g material at 450±5°C for 30 min. They have reported almost complete conversion for the thermal and catalytic processes. Use of CAT-Z produces little more liquid compared to the thermal process. However, use of CAT-R gives 99.27% of gaseous products.

Jan et al. [17] have studied the degradation of HDPE using $MgCO_3$, having particle size 100 μm as the catalyst.For optimization study, 5 g sample was taken. For collection of large volume of liquid sample, the amount ofsample taken was 200 g. The optimum temperature was found to be 450 °C. The optimum cat/pol ratio wasfound to be 0.2 and the optimum reaction time was found to be 1.5 h. It has been found that thermal degradation for 2 h at 450 °C resulted in 95% conversion with 90% wax formation. When the degradation was carried out with $MgCO_3$ as the catalyst at 450 °C for 1.5 h the total conversion was 97.43% with 92% liquid formation. However, a large-scale experiment (with 200 g polymer) has produced lower liquid yield.

The degradation of HDPE has been studied using $BaCO_3$ as the catalyst [18]. A temperature of 450 °C has been used for the reaction. The degradation has been carried out for 2 h with 200 g of HDPE and 20 g of thecatalyst (cat/pol=0.1). These conditions were found to be the optimum conditions for degradation. Under these experimental conditions about 85% conversion has been achieved with 46.15% oil formation.

The degradation of HDPE has been carried out also using $CaCO_3$ as catalyst [19]. The optimum temperature for this reaction has been found to be 460 °C. The optimum cat/pol ratio has been found as 0.2 and the requiredreaction time was found to be 1.5 h. Using these conditions 97.20% conversion has been achieved with 55.33% oil yield. The literature survey reveals that high temperatures have been used for cracking waste plastics. A kinetic study [20] has suggested that the activation energy for the cracking should be very high as

194.9 kJ/mol. This value is for uncatalyzed reaction. However, even for catalytic reactions temperature above 400 °C has been used. In many studies catalysts have been synthesized. In some studies catalysts bought from chemical companies have been used. In the present study oil has been obtained by degradation of syringeand saline bottle waste plastics using fly ash as catalyst.

Nisthanth Jude Roy eta al [21] converted the waste plastic cover into liquid hydrocarbon and blended the obtained oil with diesel with ratios of 25:75, 50:50, 75:25. They found that the blend 25:75 produces better brake thermal efficiency with less emission.

Raja Kullayappa et al [22] converted medical waste plastic into hydrocarbon by using fly ash as catalysts. They found that 100% conversion was done in plastic cover and mask. They reported property of the degradedoil was near to the diesel.

Raja Kullayappa [23] converted the waste plastic cover used to cover the medical items into liquid hydrocarbon using biogas from food waste as a source of heat.

Prem et al [24] utilize the waste plastic oil blend in a Kirlosker TV-1 diesel engine by varying the injection pressure from customary pressure of 220 bar to 210,220 and 240 bar. They found that the blend B25 OF 240 bar produced better brake thermal efficiency with less emission. Abdul Munaf [25] utilized the waste plastic oil blend as a fuel in diesel engine and found that B25 produces less emission when compared to other blends and diesel.

2. Experimental

2.1. Materials

Household waste plastics were collected from nearby houses. This plastic contains used detergent, oil, shampoo, toilet cleaning liquid plastic bottle, used toothbrush, ice cream cups, broken plastic items etc., Flyash was obtained from fly ash bricks making company. Cow dung was collected from annai cattle near our university.

2.2. Processing of Materials

A measured quantity of cow dung and kitchen waste was utilized to prepare slurry. In this work 20 kg of cow dung and kitchen waste is mixed with 60 liter is used. The preparation of slurry was done in six periods for 25 days. On each day the ratio of cow dung to kitchen waste was changed. The prepared slurry was poured in a biogas plant to produce biogas. After 25 days the produce of biogas 11.2 L [21]. The obtained waste plastics from household were cut into small pieces using a cutting machine which runs in electrical motor. The readily available fly ash catalyst was collected, and the impurities are removed by filter it.

Fig .1 Household waste plastics

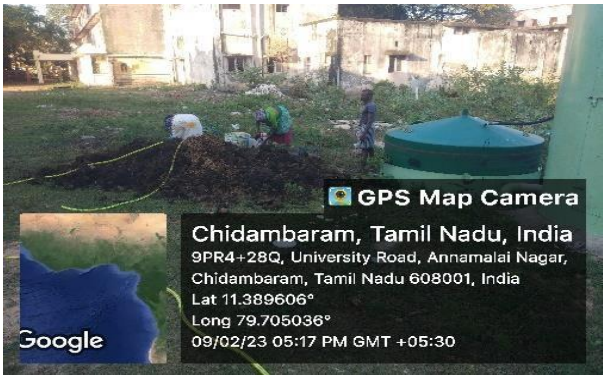


Fig .2 Preparation of slurry

The photographic view of the waste plastic degradation plant is shown in Fig 3. It consists of a 100 kg biogas plant placed under the ground. A biogas holder is placed above the biogas plant. The biogas holder slides up during the production of gas and slides down during the utilization of gas. The gas is connected to a moistureremover to remove the moisture present in the biogas. The moisture removed biogas is supplied to a biogas burner which fits at the bottom of the reactor. The reactor is made up of stainless steel and it is fabricatedin a cylindrical shape fitted in a stand in horizontal position. The top of the reactor circumference is fitted with two openings. One opening will be open while loading the waste plastic. After loading gets over it will be closed tight. Another opening is fitted with a pipe and connected to the water-cooled condenser. This is used to pass the cracked vapour into the condenser. A pressure gauge and safety valve are fitted in the top of the reactor. A thermocouple is fitted in the side of the reactor which is used to measure the temperature inside the reactor. A handhole is provided in the side of the reactor to remove the product after degradation. The bottomof the reactor fits with a biogas burner. The water-cooled condenser cools the vapour and converts it into liquid form.

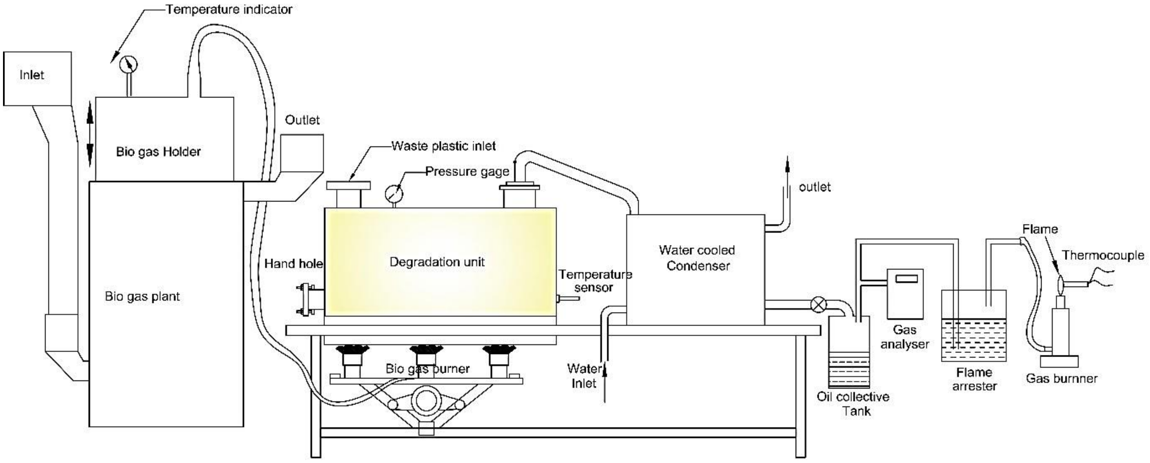


Fig. 3 Waste plastic degradation plant

One kg of household waste plastics made up of HDPE were utilized for the degradation process. Experimentswere made with catalyst, with cat/pol = 0.10 (100 g catalyst), cat/pol = 0.15(150 g catalyst) and cat/pol = 0.20(200 g catalyst).

The reactor temperature increased gradually. This makes the waste plastic mix with catalyst into cracked vapour cool in a water-cooled condenser to produce waste plastic oil. The oil was collected continuously. The initiation and accomplished temperature at which oil form and ceased were recorded.

The temperature at which the liquid hydrocarbon initiation and accomplished was denoted Ti) & (Tf). The density and weight of the oil was found.

After the production of oil gets stopped the biogas burner gets off. The degradation plant is made to be cooledin the atmospheric temperature. Then the hand hole is opened to remove the product inside the degradation plant. The weight of the unprocessed product is measured.

3. Fractional Distillation of the plastic oil

The fractional distillation was carried out in a stainless-steel cylindrical vessel. The vessel was kept in vertical position closed in the top and bottom. The top side was provided with two openings, one was fitted with avalve. This opening is used to feed the input plastic. After the feeding the valve is closed. The other opening was fitted with a pipeline connected to a water-cooled condenser. The bottom of the reactor was fitted with a valve to remove the oil remaining after distillation. The circumference of the distillation vessel was made with twolayers. Electrical heating coil was placed in between the layers and silicon oil was poured in between the layers.The circumference of the distillation unit was well insulated.

The required temperature was set on the control panel. The electrical heater heated the silicon oil. The siliconoil heated the oil inside the distillation unit. As the heat rose, the oil got vaporized and condensed. Now thetemperature was set for the next distillation range. Different fractioned oils were collected in different jars.

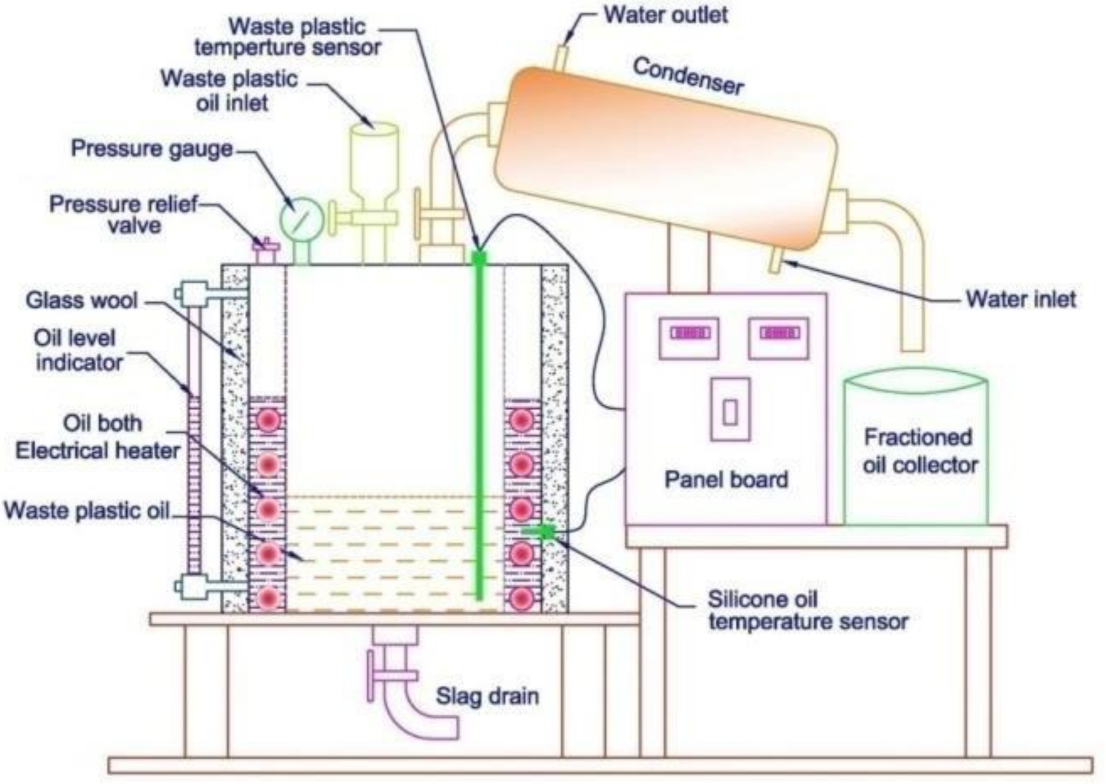


Fig. 4 Distillation unit

4. Results and Discussion

The yield of liquid and gaseous products was denoted as Y_L & Y_G produced during degradation. Theunconverted product was denoted as Y_S. Where W_P refers to the weight of the plastic used for degradation.

W_c refers to the catalyst weight.

Weight of unprocessed product in solid state (W_S) = $W_P - W_c$

Let the weight of oil obtained be W_L.

Weight of all products are measured in grams.

Weight of household waste plastic taken =1 kg = 1000 g

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

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

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

Physical data for the degradation of waste plastic are given in Table .1.

Table 1 Physical data for degradation of waste household plastics

Cat/pol	T_i (°C)	T_f (°C)	Y_S (%)	Y_L (%)	Y_G (%)	D_L (kg/m^3)
0.00	270	430	48.6	42.5	8.9	860
0.10	260	410	14.8	60.1	25.1	800
0.15	230	396	5.7	62.2	32.1	790
0.20	190	378	0	65.1	34.9	770

From Table 1 it is seen that the yield of liquid and gaseous hydrocarbon was higher as 65% & 34.9. Whenthe cat/pol ratio is 0.2. At this cat/pol ratios complete degradation was occurred. All the plastic is convertedinto liquid and gaseous hydrocarbon. For this plastic as the cat/pol ratio increase the produce of liquid and gaseous hydrocarbon gets increased. During the non-catalytic process, the yield of liquid is low and the producedremain in the reactor is 48.6%. This shows the non-catalytic process conversion percentage is more. From the study the results implies that increased in cat/pol ratio from 0.1 to 0.2 increased the liquid and gas Y_L & Y_G yield and decreased the yield of non-converted plastics (Y_S).

The data in Table 1 shows that the catalyst flying ash places a virtual role during the degradation process. It's seen that as cat/pol ratio gets increased the density of the liquid gets deceased. The liquid shouldbe a mixture of alkanes and alkenes. The density of these hydrocarbons increases with an increase in the molecular mass. Thus, it is seen that the formation of low molecular mass hydrocarbons increases with increase in cat/pol ratio.

In a pervious study [9] 75.66% of liquid product has been obtained by cracking of HDPE SA-2 a synthesizedcatalyst. However, this reaction has been carried out on a small scale taking 10 g of HDPE. Ding et al. [10] have obtained 88.66% of oil by the cracking of HDPE (10 g) using $TiCl_3$ as catalyst at 400-430 ^{0}C. Jan et al. [17] have obtained 92% liquid by cracking 5 g HDPE using $MgCO_3$ as the catalyst. However, they have reported that in a study using 200 g HDPE the yield of liquid was lower.

In the present study 65.1% oil yield has been obtained by taking 1 kg of the polymer. Using cat/pol ratio as Also, the degradation temperature is in between 190 to 378°C used in the present study is less than thoseused previously [9,17].

4.1. Total Conversion and Selectivity for oil formation

Since only solid products can contain any unprocessed plastic, in any case the total conversion (%) should begreater than the sum of the yields of liquid and gaseous products.

Total conversion (%) > Y_L (%) +Y_G (%)

Selectivity for liquid formation L_S is defined as follows

$$L_s = \frac{Y_L}{Y_g + Y_S} \times 100\ (\%)$$

Indeed, LS is a measure of the tendency for liquid formation over formation of gaseous products. The valuesof total conversions (%) and LS (%) for household waste plastics are given in Table2.

Table 2. Total conversion (%) and LS (%) for Household Waste Plastic (HHWP)

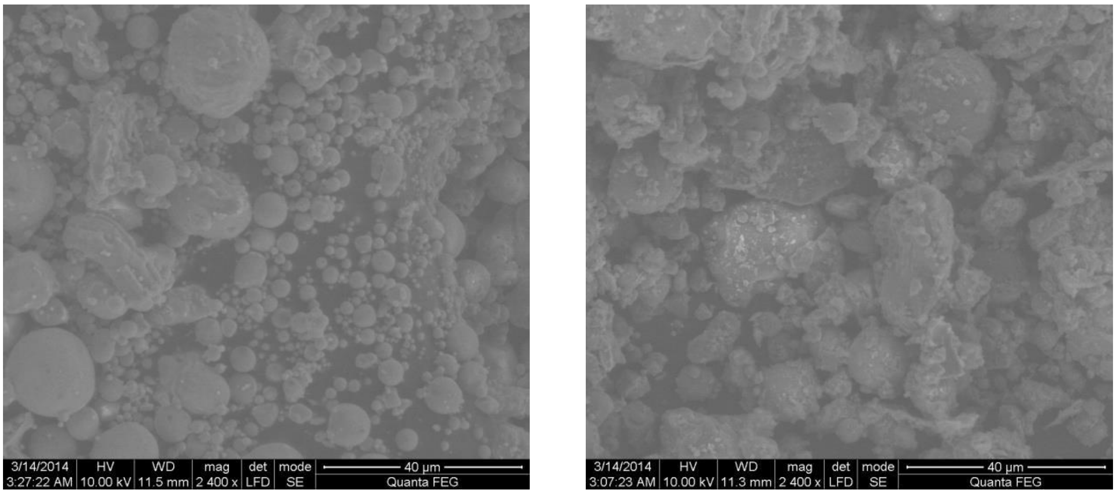
Cat /pol	Conversion (%)	LS (%)
	HHWP	HHWP
0.00	> 51.6	79.8
0.10	> 85.2	70.1
0.15	> 95.4	66.0
0.20	100	65.3

From Table 2 it is seen that the total conversion is greater when the cat/pol = 0.20. It is seen that the rate of converted gets increased as the cat/pol ratios gets increased. From the above data for complete conversion HDPE requires a high cat/pol. Also, as the cat/pol ratio gets increased the LS conversion gets decreased.

Uddin et al, [9] have observed that the total conversion is higher for the cracking of LDPE than for the crackingof HDPE with and without catalyst. Similar observation has been made by Aguado et al, [11] using zeolite Al- beta (X) as the catalyst. They have observed 40.1% conversion for HDPE. The observations made on thedegradation of HDPE show that fly ash functions as a catalyst in the degradation of HDPE.

4.2. Evidence for the role of fly ash as catalyst

A catalyst may undergo a physical change during the reaction in which it acts as a catalyst. However, it doesnot undergo any permanent chemical change. Its chemical nature is not altered after the reaction. The changein the physical nature can be detected by using SEM images. The 40 µm, SEM images of the raw fly ash remaining after the reaction for cat/pol = 0.10 are shown in Fig. 6. From the images shown in Fig ,5 it is evident physical nature of fly ash is changed during the degradation.



Fly Ash HDPE

Fig. 5 40 µm SEM images of raw fly ash, materials reaming after degradation of HDPE and using cat/pol = 0.20

The EDX spectrum of raw fly ash is compared with those for fly ash obtained after degradation of HDPE for cat/pol = 0.10, 0.15 & 0.20 in Plates 1, 2,3 and 4. Examination of EDX spectra in Plates 1, 2, 3 and 4 clearly showsthat the peaks for Si, Al and O are not affected by the degradation. This shows that fly ash does not undergoa permanent chemical change during the degradation of waste household plastic. These EDX spectrum and SEM Images show that fly ash is involved as a catalyst in the degradation.

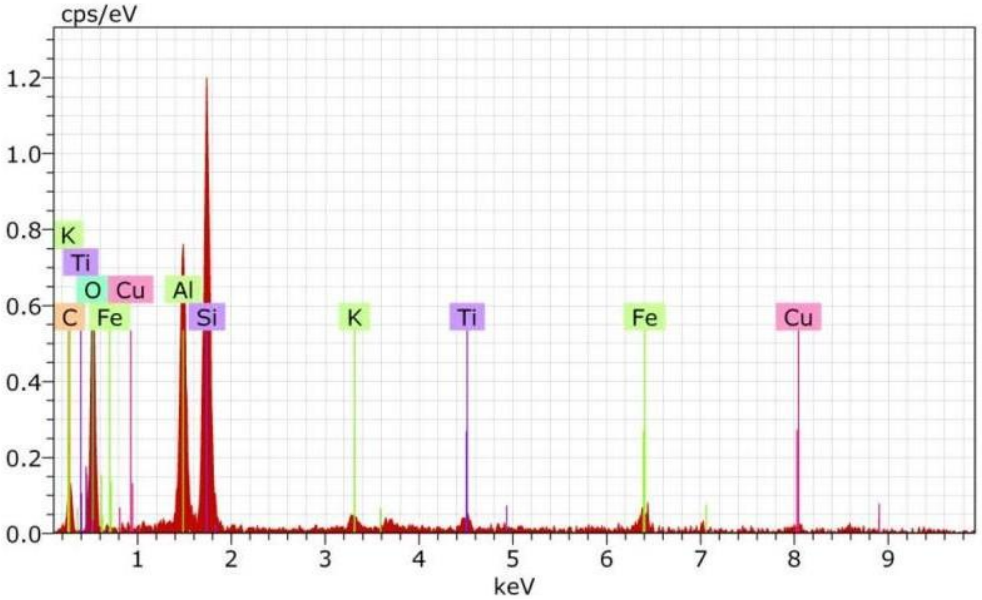


Plate 1 EDX Spectrum of Fly ash

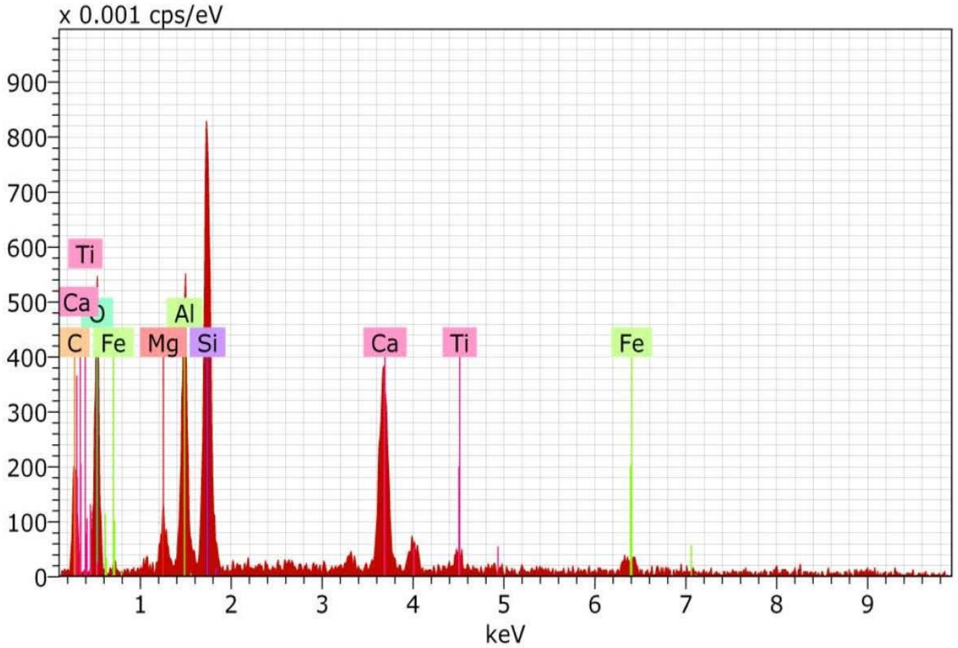


Plate 2 EDX spectrum of fly ash remaining after degradation of HDPE using cat/pol = 0.10

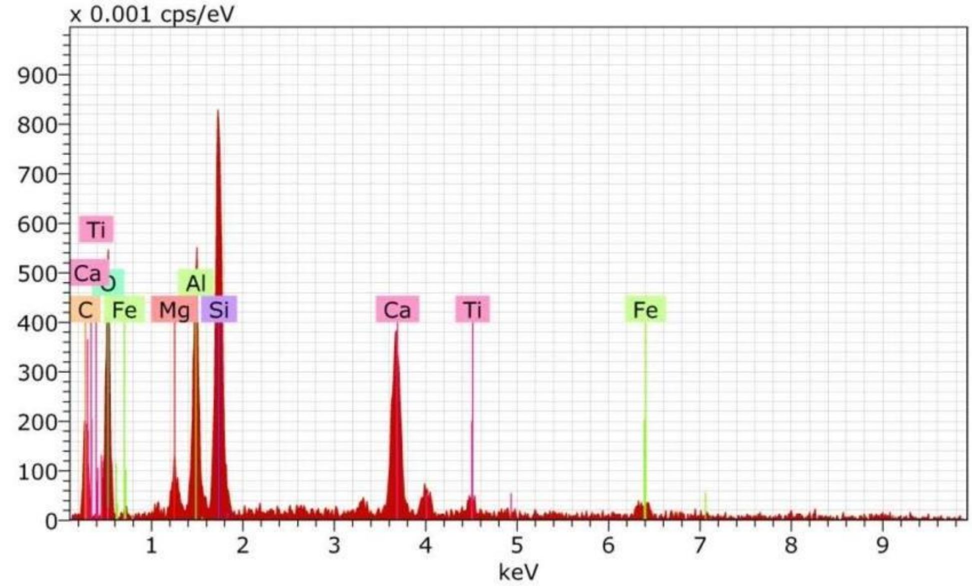


Plate 3 EDX spectrum of fly ash remaining after degradation of HDPE using cat/pol = 0.15

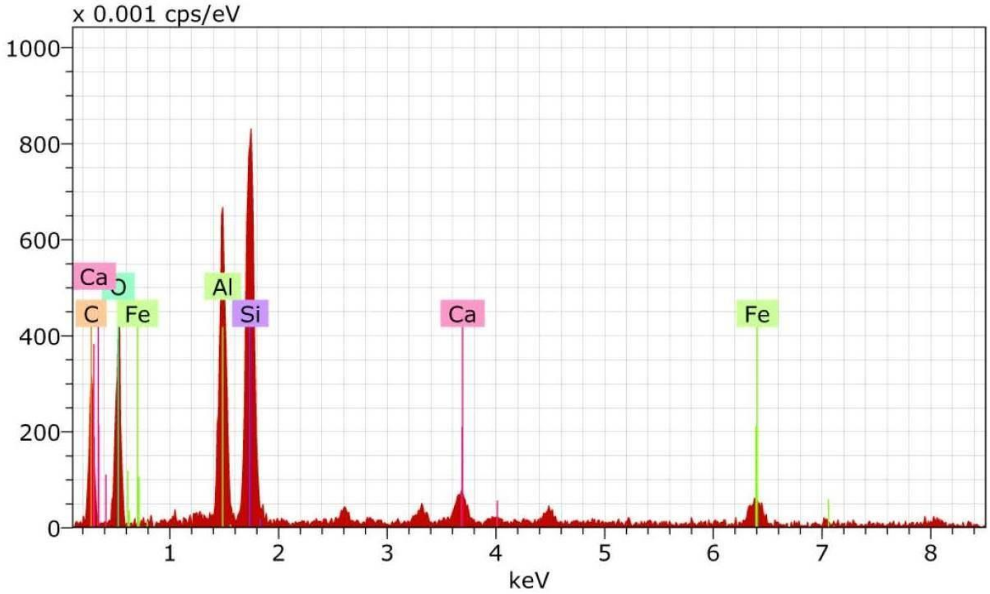


Plate 4 EDX spectrum of fly ash remaining after degradation of HDPE using cat/pol = 0.20

4.3. Designation of various fraction

Letters A, B and C refer to cat/pol of 0.1, 0.15, and 0.20. Numbers 2,3 and 4 refer to the fractions boiling range of 100 to 150, 150 to 200 and above 200 ^{0}C ratio. The fractions are designated as A2, A3, A4, B2, B3, B4, C2, C3 & C4. The various parameters have been determined for these nine fractions.

4.4. Physical Properties of various fractions

The physical properties of the various fractions from syringe and saline bottles are given in Tables 3, respectively. These properties are compared with those of diesel. It is seen that the physical properties are comparable to those ofdiesel. Hence all these fractions can be used as substitute for diesel.

Table 3 Properties of various fractions of HHWP

Property	Diesel	A			B			C		
		2	3	4	2	3	4	2	3	4
Density 15°C (kg/m^3)	820	791	781	760	813	801	797	826	824	816
Kinematic viscosity at 40°C (cSt)	2.5	1.98	2.10	2.27	1.63	1.67	1.83	1.46	1.52	1.53
Flash Point (°C)	50	46	45	47	54	50	54	64	68	76
Fire point (°C)	54	57	46	54	59	54	63	69	73	83
Pour point (°C)	-	-8	-9	-10	-7	-8	-9	-4	-5	-8
Grass calorific value (MJ/kg)	42.3	44.5	44.3	44.1	43.2	43.7	43.9	42.4	42.2	44.1
Cetane number	50.0	52.4	52.1	51.8	52.4	52.1	51.8	52.4	52.1	52.8

The combined oil of fraction 2,3 & 4 is designated as diesel substitute oil. The yield of diesel substitute oil forcat/pol 0.1, 0.15 & 0.2 are 51.7, 46.9 & 46.0 %.

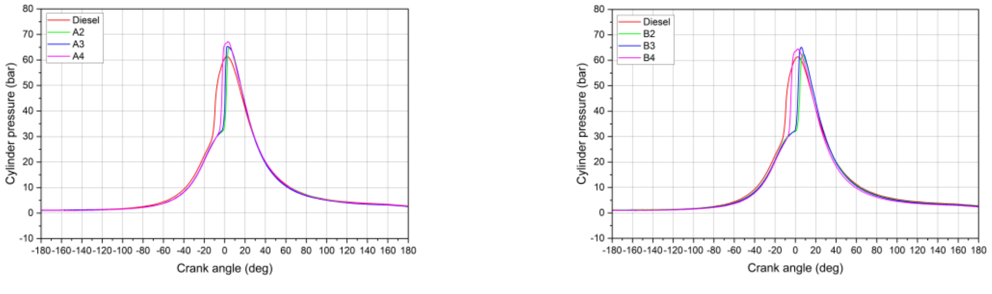
4.4. Performance, Combustion and emission parameters

The various parameters for performance, combustion and emission were evaluated for all these fractions.

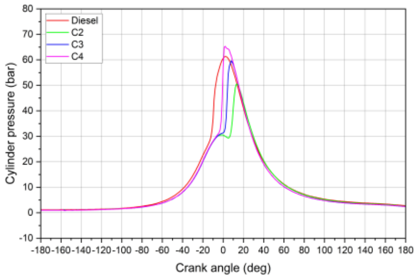
These are compared with corresponding parameters for commercial diesel.

Combustion parameters *Cylinder pressure*

Fig 5 (a-c) shows the variation of the cylinder pressure with crank angle for all fractions. From Fig. 5.a it is seen that fractions A2, A3 and A4 show higher cylinder pressure than diesel. Also, from Fig. 5.b it is seen that fractions B2, B3 and B4 show higher cylinder pressure than diesel. From Fig. 5. it is seen that fractions C2 and C3 (fractions 2 and 3 obtained using cat/pol = 0.20) show lower cylinder pressure than diesel. However, fraction C4 shows a maximum cylinder pressure of 67 bar.



a. Cat/pol ratio = 0.1 b. Cat/pol ratio = 0.15



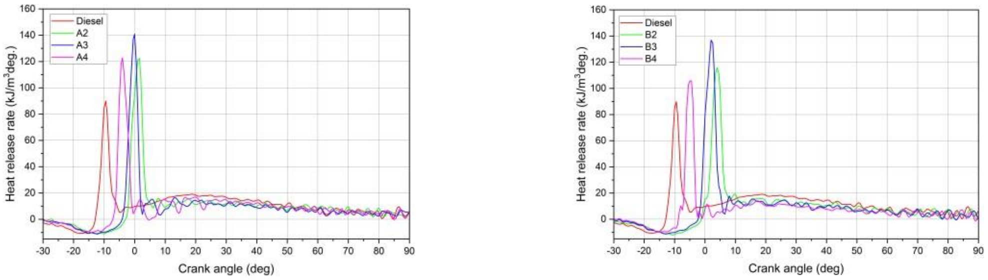
c. Cat/pol ratio = 0.2

Fig 5. Cylinder pressure vs Crank angle

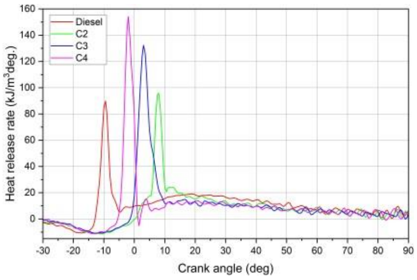
This is due to the low density and viscosity of the fuel. Due to low density the compression pressure inside the cylinder gets increased and produces high cylinder pressure.

Heat release rate

Fig 6. (a-c) shows the variation of the heat release rate with crank angle for all the fractions. It is seen that heat release rate for all the fractions is slightly shifted when compared to diesel by about 10°Crank angle. This is due to the longer ignition delay period for all the fractions. The burning rate is low at the first stage of combustion for diesel. However, the oil fractions have a very high rate of combustion. In thesecond stage of combustion the rate of combustion gradually decreases for diesel but increases for the oil fractions. The observed high heat release rate for the oil fractions is due to the energy release during the second stage of combustion. This is due to the presence of long chain alkanes and alkenes in the oil fractions.



a. Cat/pol ratio = 0.1 b. Cat/pol ratio = 0.15



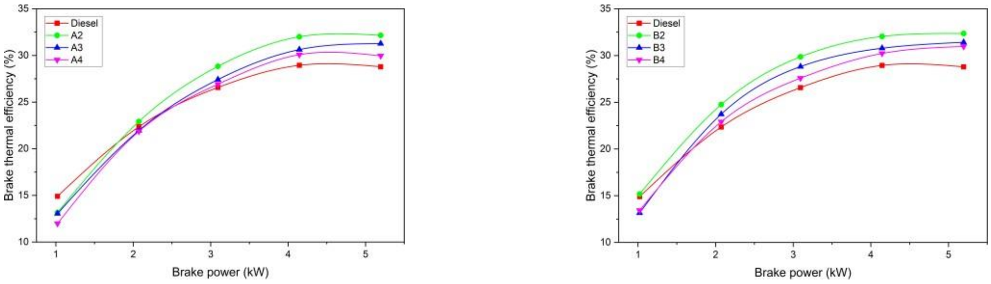
c. Cat/pol ratio = 0.2

Fig 6. Heat release rate vs Crank angle

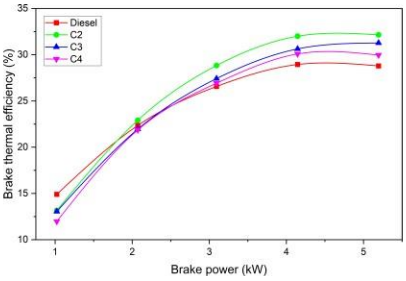
Performance

Brake thermal efficiency

The fig 7. (a, b & c) shows the variation in the brake thermal efficiency with respect to brake power. From Fig. it is seen that fraction A2 shows the higher brake thermal efficiency of 33% than other fractions A3and A4 and diesel. Similarly, from Fig.7. b & c it is seen that fraction B2 & C2 shows the maximum brake thermal efficiency of 32% than the other fractions and diesel. From the above three figures it is seen that thefractions A2 shows the maximum brake thermal efficiency when compared with all fractions and diesel. Thisis because of the fuel having high heating value and low viscosity when compared to other fractions.



a. Cat/pol ratio = 0.1 b. Cat/pol ratio = 0.15



c. Cat/pol ratio = 0.2

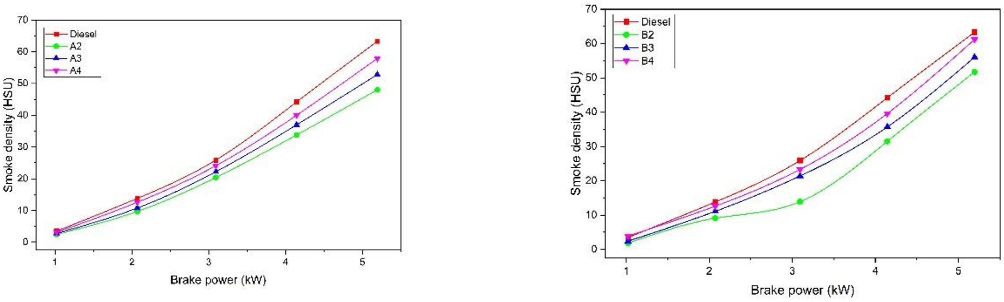
Fig 7. Brake thermal efficiency Vs Brake power

Emission parameters

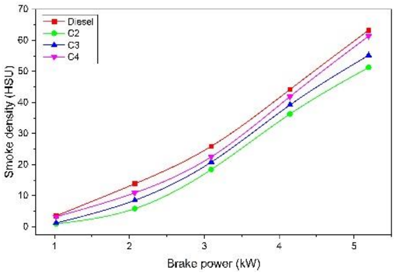
Smoke density

In complete combustion of the fuel produce white colour smoke.

The variation in the density of smoke with shown in Fig 8. (a-c). From the figures it can be noticed that smoke density is lower than that of diesel for almost all the fractions. It is seen that for the fraction A2 B2 & C2 the smoke density is significantly reduced than other fractions and diesel. This smoke density of fractionA2 is 48 HSU of higher engine power. Among the fractions B2 & C2 shows lowest smoke density. However,among fractions C2, C3 and C4 fraction C3 shows the lowest smoke density. This is caused because of low viscosity and high volatility of the oil. This leads to better atomization and complete combustion.



a. Cat/pol ratio = 0.1 b. Cat/pol ratio = 0.15

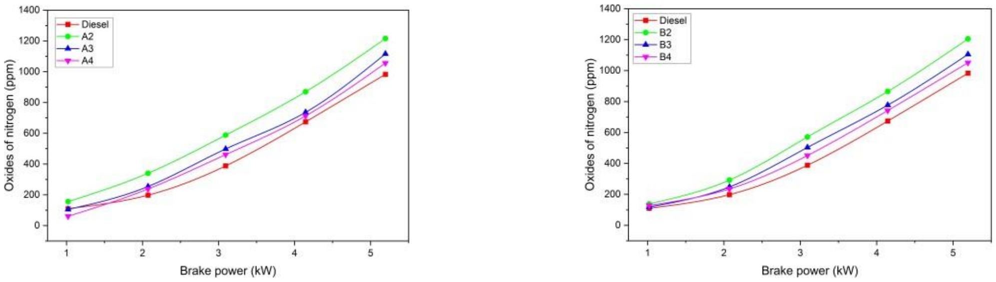


c. Cat/pol ratio = 0.2

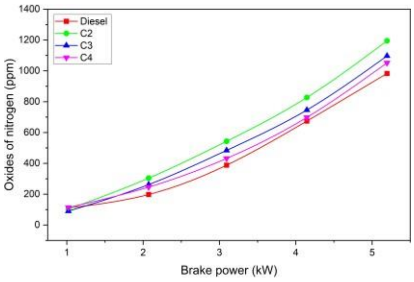
Fig 8. Brake thermal efficiency Vs Brake power

Oxides of Nitrogen

Fig 9. (a-c) shows the production of NOx emission from various fractions of oil with brake power. It is viewed that NOx emission is lower for diesel and higher in all the fractions. The production of NOx is 1190 ppm at maximum load for the fraction. A2 1192 ppm for fraction B2, 1190 ppm for fraction C2. For all the other fractions the NOx emission is slightly higher than that of diesel. However, in all cases the emission for NOx is within permissible limits. It is seen that generally the number of oxides of nitrogen increased with decrease smoke density. This is because of the higher heating value of the fuel which makes the combustion clean. This implies that all the hydrocarbons are burnt. This leads to high temperatures. Hightemperature during combustion reacts with nitrogen in the air and produces NOx.



a. Cat/pol ratio = 0.1 b. Cat/pol ratio = 0.15

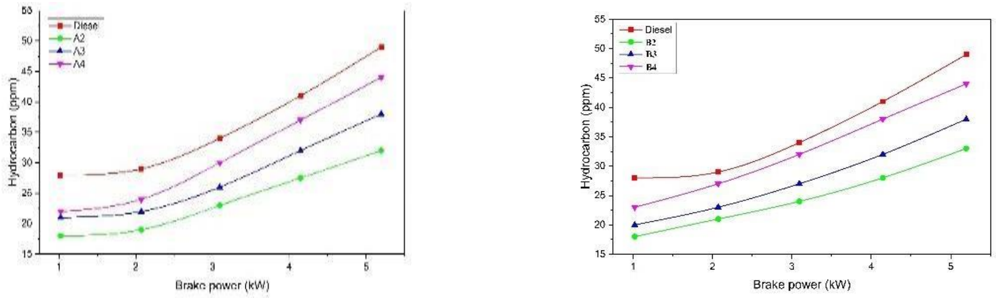


c. Cat/pol ratio = 0.2

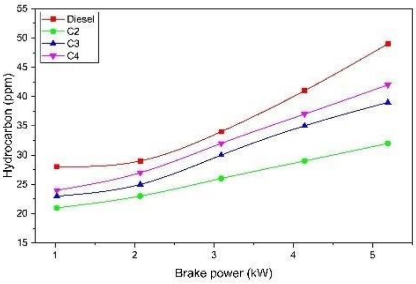
Fig 9. Oxides of Nitrogen Vs Brake power

Hydrocarbon emission

Figs 10 (a-c) show the variation of the HC emission with brake power for all the fractions. It is seenthat HC emission is lower than that of diesel for all the fractions, this is due to the presence of alcohol in thefuel. The alcohol burns little bit quick the diesel.



a. Cat/pol ratio = 0.1 b. Cat/pol ratio = 0.15



c. Cat/pol ratio = 0.2

Fig 10. Hydrocarbon Vs Brake power

This increases in prolong combustion and produces complete combustion. This reduces hydrocarbon emission. It is seen that among all the A2 produce less hydrocarbon emission of 28 ppm.

4. Conclusion

1. The household waste plastic can be converted into liquid hydrocarbon.
2. Complete conversion occurred when the cat/pol ratio is 0.2.
3. 65.1 % of oil yield was produced when the cat/pol ratio is 0.2.
4. The physical property value suggests that the oil having a fraction above 100 ^{0}C can be used as asubstitute for diesel.
5. The SEM images and EDX spectra are evident that the catalyst plays a vital role in degradation.
6. Cylinder pressure for diesel is less than all other fractions
7. Fraction A2 gives better brake thermal efficiency of 33%
8. NOx emission is lower for diesel and higher in all other fractions.
9. Smoke density is significantly reduced than diesel for HHWPO using cat/pol ratio 0.1 and boiling in the range of 100 -150ºC (A2)
10. A2 produce less hydrocarbon emission of 28ppm compare to diesel and other factions

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References

[1] *PJ. Flory, 'Principles of Polymer Chemistry", Cornell University press, 1953.*

[2] *A Ravee, "Principles of Polymer Chemistry", 3rd ed. Springer 2012.*

[3] *JD Hamilton, KH Reinert, V. Hagen, WV Lord, "Poluymers as solid wastes in municipal landfills"Journal of the AIV and Waste Management Association, 1995, 247-251.*

[4] *MJ Robey, G Field, M Stuzinski, "Degradable plastics", Mat Forum 1989, 13, 1.*

[5] *M. Haghinhatkish, M Yousefi, "Alkaline hydrolysis of polyester fibers – Statural affects" Iranian Journal of Polymer Science and Technology, 1992, 1, pp 56-61.*

[6] *S Hocker, AK, Rhydy, G Ginsburg, De Kranbuehi, "Polymide hydrolysis accelerated by small weak organic acids" Polymer 2014, 55 pp 5057-5064.*

[7] *AK Panda, RK singh, DK Mishra, "Thermolysis of waste plastics to liquid fuel" A suitable method for plastic waste management and manufacture of value-added products."*

[8] *K. Hamad, M Kaseem, F Devi, "Recycling of waste from polymer materials: An overview of the recentworks" Polymer Degradation and stability, 2013, 98 pp 2801-2812.*

[9] *M.A. Uddin, K Koizumi, Y Sakata "Thermal and catalyst degradation of structurally different types of polyethylene into fuel oil" Polymer Degradation and stability 1997, 56. pp 37-44*

[10] *W. Ding, J. Liang, L. Anderson, "Thermal and catalytic degradation of high-density polyethylene and commingled post-consumer plastic waste" Fuel Processing Technology, 1997, 51, pp. 47-62.*

[11] *J. Aguado, D.P. Serrano, J.M. Escola, E. Garagorri, J.A. Fernandez, "Catalytic conversion of polyolefins into fuels over zeolite beta" Journal of Polymer Degradation and stability 2000, 69, pp. 11-16.*

[12] *Jerzy Walendziewski, Mieczyslaw Steininger, "Thermal and catalytic conversion of waste polyolefines" Journal of Catalysis Today, 2001, 65, pp. 323-330.*

[13] *Jerzy Walendziewski, "Engine fuel derived from waste plastics by thermal treatment" Journal of Fuels,2002, 81, pp. 473-481.*

[14] *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, 2003, 245 pp. 51-62.*

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

[16] *S. Biswas, S. Maihi, P Mohanty, K.K Pant, DK Sharma, "Effect of different catalyst on the co-crackingof Jatropha oil, Vacuum residue and high-density polyethylene" Fuel, 2014,133, pp. 96-105.*

[17] *M.R. Jan, J. Shah, H. Gulab, "Degradation of waste high-density polyethylene into fuel oil using basiccatalyst" Journal of Fuel, 2010, 89, pp. 474-480.*

[18] *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, 2010, 91, pp. 1428-1437.*

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

[20] *S. Sharma; AK Ghoshal; "Study of kinetic of co-pyrolysis of coal and waste LDPE blends under argonatmosphere" Fuel, 2010, 89, pp. 3943-3951.*

[21] *J. Nishanth Jude Roy, P. Premkumar., S. Mohammed Iqbal, A Balaji. Experimental investigation strategies to augment the diesel engine performance and reduction of emission characteristics by the effect of waste plastic oil. ASEAN engineering journal. 13.3(2023) 47-53.*

[22] *D. Rajakullayappa, G Karthikeyan, P. Premkumar, C.G. Saravanan (2023) Conversion of medical plastic covers made up of LDPE into liquid hydrocarbons using biogas as a source of heat. Europeanchemical bulletin. 12(10), 1401-1422.*

[23] *D. Raja Kullayappa, G. Karthikeyan, P. Premkumar, V. Elangkathir, Conversion of medical waste plastics into liquid and gaseous hydrocarbon using fly ash as a catalyst. China Petroleum processing and petrochemical technology.*

[24] *Premkumar, P., Nalluri, P., & Munaf, A. A. (2021, February). Effect of waste plastic oil diesel blend on variant injection pressure of a diesel engine. In AIP conference proceedings (Vol. 2316, No. 1). AIP Publishing.*

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