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Polyfuel - A Catalytic Thermal Cracking of Waste LDPE to Produce Liquid Fuel

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Abstract

This work is the diminutive attempt towards the plastic waste recycling conducted at Department of Plastic Engineering, Government Polytechnic, Miraj. The term 'Polyfuel' means the liquid fuel produced from waste plastics. We have performed the experiment for conversion of waste LDPE into liquid fuel. As LDPE is the long chain hydrocarbon polymer, it has to be broken into small chains hydrocarbons which have been done by catalytic cracking of the LDPE. Coal fly ash is used as a catalyst for thermal cracking of the LDPE. The 54 % yield of process was observed during experimentation. We modified readymade mild still pressure cooker of 9 litre capacity as a reactor for this experiment. The glass condenser is used for condensing the generated vapours during process. We found 270 ml of fuel from 500 grams of waste LDPE at reaction temperature of 300^0C. The source of waste LDPE is the milk pouches treated as the waste after utilisation of the milk. The fuel analysis shows that the specific gravity at 28^0C is 0.7466, density at 28^0C is 0.7228 g/cm^3, viscosity is 1.38 cP, volatile matter is 100 %, flash point is 4 ^{0}C, pour point is <-5 ^{0}C, acid value is 0.058, total ash is 0.00 %, moisture content is 0.10 %, carbon residue is 0.15 %, sulphur content is 206 ppm and gross calorific value is 9970 kcal/kg.

Keywords: Polyfue; LDP; Coal fly ash; Catalytic cracking; plastic waste.

1. Introduction

Plastic is a vital part our daily life. Starting from the morning tooth brush to night dinner plates, everywhere we found the things made up of plastics. Because of their elegant properties like light weight, flexibility, durability, easy availability, cost effective and faster production rate, plastics are used in almost every field. Plastics are produced and used on a large scale worldwide which results in its huge waste generation. As per the CPCB report, India generates 5.6 million tonnes of plastic waste annually [1]. The shopping and garbage bags, packaging films, fluid containers, clothing, toys, furniture, material wrapping, beverage bottles, household and industrial products etc. are some applications of the plastics.

The yearly consumption of plastic materials has been increased from 5 million tonnes to 100 million tonnes in last sixty years from 1950, i. e. 20 times more production of plastics today. This results in the utilization of more resources for production of plastics and hence more plastic waste has been generated [2].

Most of the plastic wastes are land filled or incinerated which release toxic gases resulting increase of pollution level in the environment [3]. So one has to think the alternative method for disposal of the plastic waste.

The industrial rate of recycling of the plastic waste generated is high but the municipal plastic waste recycling rate is very low. Some municipal corporations are started the recycling of waste plastics in Maharashtra. They convert plastic waste into fuel. Rudra Environmental Solution (India) Ltd. Pune started the manufacturing of the plants for plastic recycling to convert the plastic waste into fuel. Pune Municipal Corporation started one of such type of plant in Dhankewadi ward in Pune. This plant converts 9000 kg of plastic a month into 5400 litre fuel.

Plastics are relatively cheaper and being easily available so it has brought about use and throwaway culture in our society. As the plastic has non-degradable in nature, plastic waste recycling management becomes a worldwide problem. As the land filling sites allotted for plastic waste disposal approaching their full capacity, the recycling of plastic waste becomes necessary. Hence, being a department of plastic engineering at Government Polytechnic, Miraj, we thought to try the conversion of waste LDPE into liquid fuel.

2. Fuel Demand

World's consumption of petroleum products increase day by day from 86.1 – 92.1 million barrels per day from 2007 – 2020 and will increased up to 110.6 million barrels per day in 2035 [4]. Hence the available petroleum fuel reserve lasts for next 50 years and thus we have to think for the alternate fuel.

As shown in figure 1, India's Compound Annual Growth Rate (CAGR) for consumption of diesel increases 7% from the year 1970-71 to 2012-13 [5]. The country's diesel demand continues to climb as a result of its dynamic economic growth and modernization. As the population of India increases day by day, the fuel demand also increases in the future. Conventional sources of the fuel are limited and in future we have to depend on the alternate fuels like bio fuels, ethanol and fuels from the other resources for our survival. Polyfuel is one of the alternative sources for the conventional fuels. Hence we have tried to make the fuel from plastic waste.

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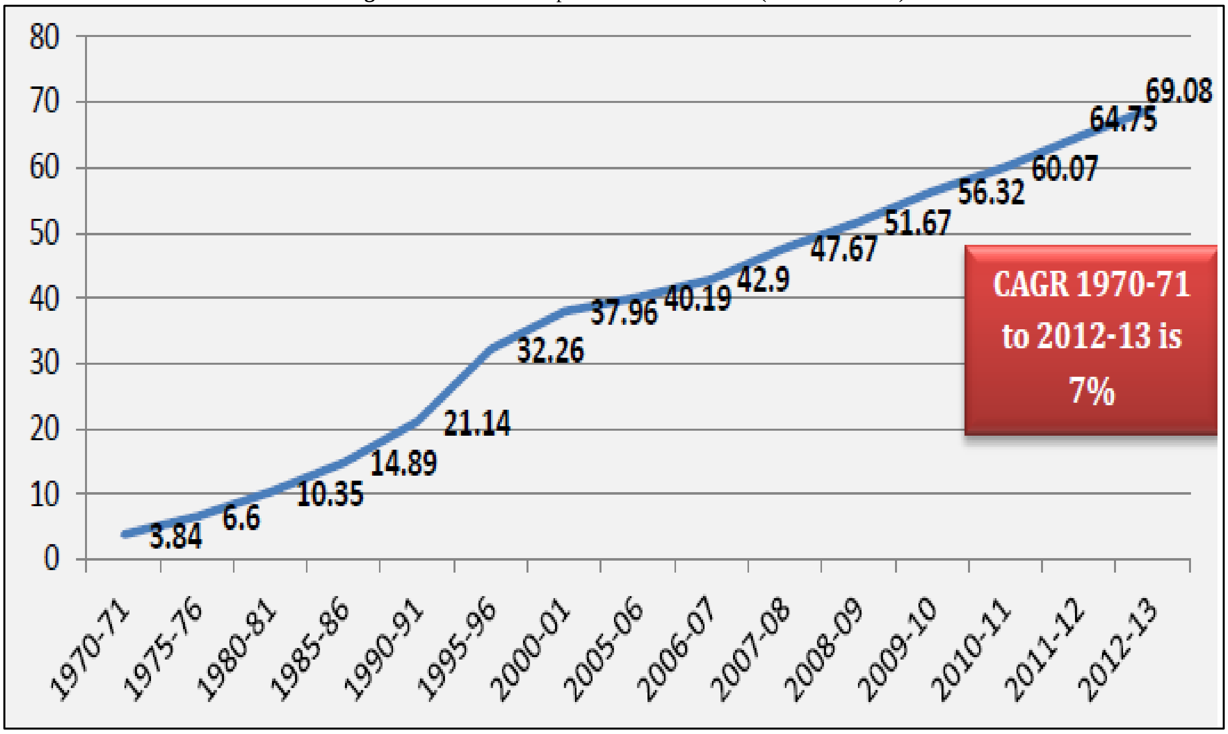
Fig-1. Trends in consumption of Diesel in India (Million Tonnes)



Source: [5]

3. Equipments for Experimentations

The equipments used to conduct the experimentations are described under. Some equipment is used as it is and some are get modified for ease of the experimentations.

3.1. Reactor

It is a mild steel 09 lit capacity pressure cooker purchased from the market having the dimensions as, Height: 270 mm, internal diameter: 200 mm, outer diameter: 220 mm. The provision is made for transporting the generated vapours from reactor to condenser by means of half inch of GI pipe welded on the top cover of the reactor. The provision for pressure gauge mounting is made on the top cover and pressure gauge is fitted in it for measurement of reactor pressure. Thermowell is provided for inserting the thermocouple/thermometer for measurement of the reactor temperature. The provision of safety valve for the reactor is also made. The reactor which was fabricated is shown in the fig.2.

Fig-2. Mild steel reactor

3.2. Condenser

Glass condenser is used for converting the waste LDPE vapours in to the Polyfuel. It condenses the total vapour generated in the reactor. The provision for cooling water to flow through it is made by inlet and outlet ports. This condenser is used for generated vapour condensation. The generated vapours at approximate 260- 280 ^{0}C are condensed to about room temperature or below as shown in fig.3.

Fig-3. Glass condenser

3.3. Heating Media

To provide the thermal energy for cracking the waste LDPE, a LPG cylinder with burner is used. The heating media shown in the figure 4 uses LPG as a heating source which is borrowed from the market.

Fig-4. LPG cylinder and burner

Fig-5. Connecting pipe and safety valve

3.4. Connecting Pipe and Safety Valve

The hose pipe is used for connecting the condenser and the vapour outlet port of the reactor. The safety valve is also provided to release the excess pressure if any to avoid the bursting of the reactor due to high pressure as shown in figure 5.

3.5. Condensate Collector

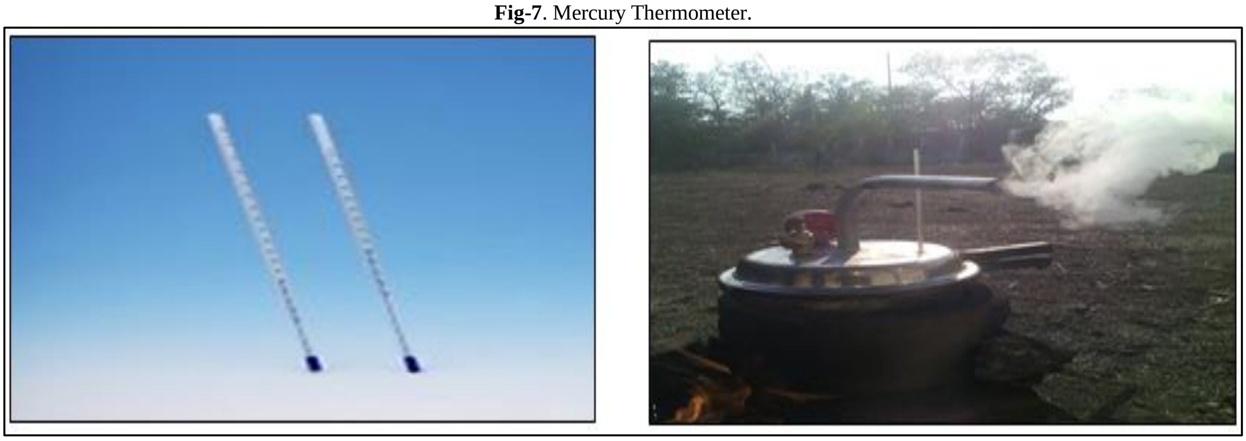
Condensed liquid fuel has been collected in conical flask used as a condensate collector as shown in figure 6. The size/volume of the collector depends upon volume of fuel production.

Fig-6. Collector (Conical flask and PET bottle).

3.6. Temperature Sensor

Mercury thermometer is used to determine the temperature of the reactor. The temperature range of the thermometer is from 0 ^{0}C to 360 ^{0}C.

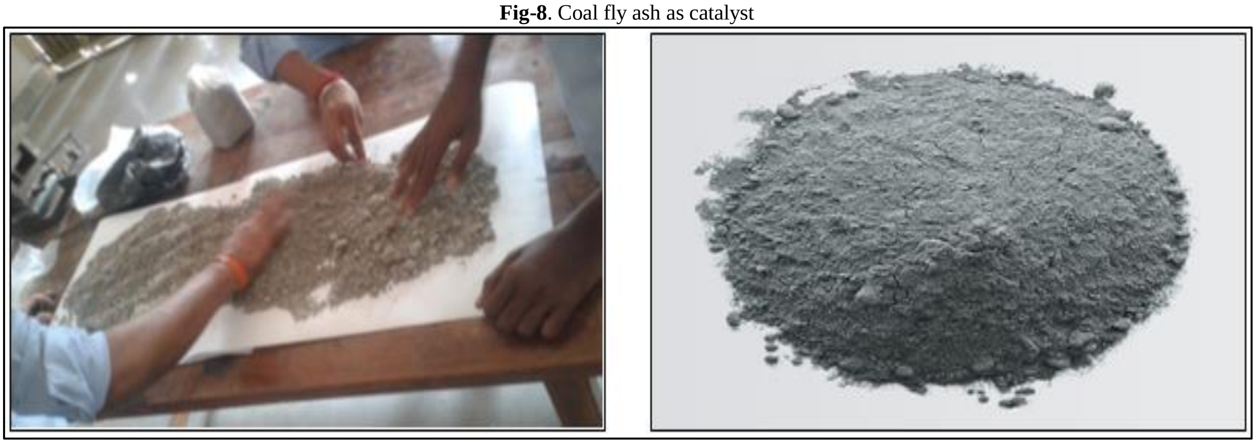
Fig-7. Mercury Thermometer.



3.7. Catalyst Used

To get the fast cracking of the plastic waste molecules the catalyst used in this study was the coal fly ash (Fig. 8). Coal fly ash contains about 70 % of aluminium and silica in the form of Al_2O_3 and SiO_2 which acts as a catalyst which fastens the cracking of the waste plastics, resulting in the high rate of vapour generation. As fly ash is available free of cost, it reduces the manufacturing cost of the product produced.

Fig-8. Coal fly ash as catalyst



4. Experimental Method

4.1. Collection of Waste LDPE Milk Pouches

Waste milk pouches are collected from the houses which are thrown after utilisation of milk from it as well as from milk chilling plants which are damaged during the processing (Fig. 9).

These collected milk pouches are initially washed with tap water and then again with detergent to ensure removal of contamination if any. Then these washed pouches are sun dried to remove the moisture before shredding.

Fig-9. Collected milk pouches

Fig-10. Shredded milk pouches

4.2. Shredding of Waste LDPE Milk Pouches

Shredding is the process in which the large size particles are converted in to smaller size particles. Here we cut the washed milk pouches into smaller particle size as shown in figure 10.

4.3. Experimental Procedure

Experiments are conducted by taking known amount of waste LDPE and the catalyst at moderate reactor temperature. The vapours generated from the reactor are condensed through glass condenser and the condensate i.e. liquid fuel is stored in the plastic bottle. Figure 11 shows the experimental set up for production of fuel from waste LDPE. The detailed experimental procedure is as under.

Experiment is started by taking the shredded waste LDPE weighing 500 grams and 20 grams of coal fly ash as catalyst in the reactor. Heating is started to melt and crack the plastic waste present in the reactor. When temperature reaches above 115^{0}C, the waste LDPE starts to melt. After reaching the temperature up to 170 ^{0}C, the vapour generation has been started. Increase in temperature started gradually by applying the extra heat from 170 ^{0}C to 300 ^{0}C in the time span of 10 minutes. The first drop of condensate is observed when the reactor temperature reaches to the 250 ^{0}C. From 250 ^{0}C to 270 ^{0}C temperature range nearly 30 % fuel has been collected. When temperature reaches up to 290 ^{0}C, the fuel collection rate increases and we get another 40 % of liquid fuel. Remaining fuel is collected when temperature reaches above 300 ^{0}C. We have collected total 270 ml of liquid fuel from 500 grams of waste LDPE milk pouches which shows the conversion efficiency of 54% of the total waste.

Due to high rate of vapour generation after 270 ^{0}C, approximate 10 % of vapours get lost during experimentations as the capacity of glass condenser is not enough to condense all the vapours. Also, the uncondensed gases escape from the condenser which amount approximately 16 % of the total feed and the residue generated was found to be 30 % of the total feed.

In next experiment we have got another 270 ml of liquid fuel from 500 grams of waste LDPE. The experimental setup and the liquid fuel (crude) collected are shown in figure 11 and 12.

Fig-11. Experimental setup

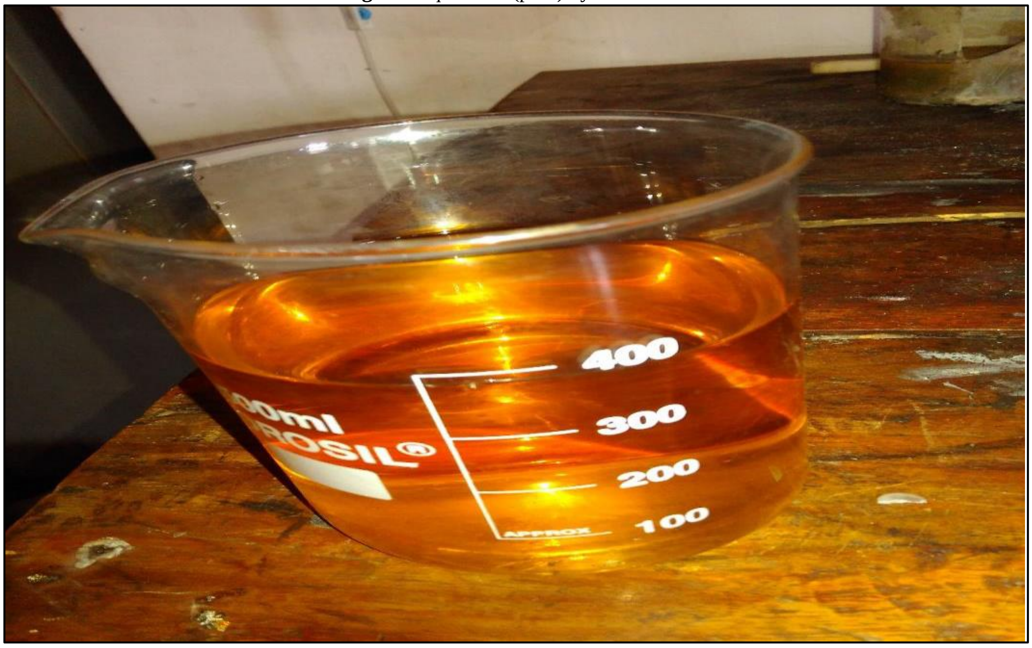
Fig-12. Liquid fuel (crude) collected

4.4. Distillation of the Crude Liquid Fuel

A simple distillation glass apparatus as shown in figure 13 is used for this purpose. In this process, crude liquid fuel obtained from waste LDPE is filled in 1 Litre Borosil round bottom flask. This flask is heated by electric heating mental. Heat is applied in the range of 30 - 60 ^{0}C. As temperature reaches to 40 ^{0}C, the crude fuel in the flask start to boil and generates the vapours when temperature is increased gradually. The generated vapours then condensed through condenser and collected in 500 ml Borosil beaker which is the purest form of the liquid fuel as shown in figure 14. The contaminant in the crude fuel remains in the flask. We collected 400 ml of pure fuel from 540 ml of crude fuel with 74.07 % collection efficiency.

Fig-13. Simple distillation apparatus

Fig-14. Liquid fuel (pure) by distillation



4.5. Residue Generated

After end of the experiment, the residue generated is like a tar which is shown in the figure 15. It is greenish black in nature having 30 % of the total feed charged in the reactor. This residue can be used in road making process as alternate to the tar because it has a good strength.

Fig-15. Residue

5. Results and Discussion

5.1. Physical Testing

Appearance of the liquid fuel is viscous liquid with brownish colour with odour like mint. Flammability test of fuel has been taken on wooden stick by dipping the stick into the fuel and applying the fire to it. It was observed that fire catches immediately without any leftover residue.

5.2. Analytical Testing

Results of the analytical testing of liquid fuel produced from the waste LDPE milk pouches are summarised in the table1. The analytical testing is done at NIKHIL Analytical & Research Pvt. Ltd., Near New Railway Godown, Sahyadri Nagar, Sangli – 416416, Maharashtra (India).

Table-1. Results of analytical testing of liquid fuel.

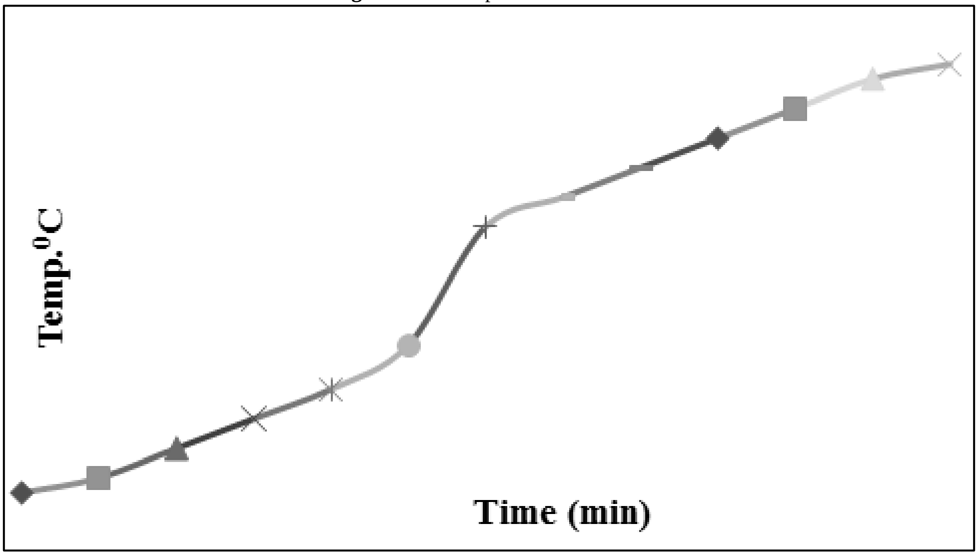
Sr. No.	Specifications	Fuel from waste LDPE
1	Specific gravity	0.7466
2	Density	0.7228 g/cm^3
3	Viscosity	1.38 cP
4	Volatile matter	100 %
5	Flash point	4 ^{0}C
6	Pour point	<- 5 ^{0}C
7	Acid value	0.058
8	Total ash	00.00 %
9	Moisture content	0.10 %
10	Carbon residue	0.15 %
11	Sulphur content	206 ppm
12	Gross calorific value	9970 kcal/kg

From analytical testing it was observed that all the properties are in the range and comparable with the regular diesel and the petrol from plastic waste [6].

5.3. Time-Temperature Behaviour

Temperature behaviour of the reactor with respect to time is shown in figure 16. It was observed that at initial stage of 45 minutes, reactor temperature shows 115 ^{0}C and the waste plastic present in the reactor starts to melt. At 200 ^{0}C and above temperature the waste plastic melts completely and when temperature reaches to 250 ^{0}C, it starts to crack the molecules resulting in the vapour generation. Maximum vapours are generated in the range of 250 ^{0}C to 300 ^{0}C.

Fig-16. Time-temperature behaviour



6. Conclusion

Converting the waste LDPE into liquid fuel resolves the two problems simultaneously i. e. Plastic waste recycling and the fuel demand in developing countries. The waste LDPE cracking can be done easily by using the low cost catalyst like fly ash. Fuel yield can be raised by varying the process parameters. This fuel was found to be similar to the commercial diesel used in automobiles. So this fuel which is termed as “Polyfuel” can be an alternative fuel of the future. The residue generated may be used in the road making process by blending it with tar. This process can be called green/zero discharge as there is no waste generation during the entire process.

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