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Thermal catalytic degradation of waste plastics to produce liquid fuel

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Abstract

Due to versatile properties like low weight and high strength with ease of processing, plastic becomes an important material for scientists and industries for research and development and product manufacturing respectively. Use of plastics in in day to day life is huge and due to use and through culture of society, it becomes big problem for plastic waste management. In this study, we have performed some experiments for conversion of plastic waste into liquid fuel. We have examined the different plastic waste like PET as well as LDPE for our experiments with and without catalyst and found that LDPE shows the good conversion into liquid fuel when fly ash is used as a catalyst. The fuel conversion found up to 55% for LDPE. We used modified readymade pressure cooker of 9 litre capacity as a reactor for this experimentation. The copper coiled condenser is fabricated for condensing the generated gases. We found 220 ml of fuel from 400 grams of waste LDPE at reaction temperature of 290^0C. 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 0.7616, density 0.71 gram/ml, net calorific value 9850 kcal/kg, flash point 15^0C, pour point 9^0C, cloud point 12^0C, aniline point 7^0C, octane number 76 and moisture content 0.08%.

Keywords: Thermal degradation, catalyst, plastic waste, LDPE, liquid fuel.

1. Introduction

Plastic/polymer becomes an important material of our daily life. Starting from the morning tooth brush to night dinner plates, everywhere we found the things made up of plastics. Plastics are produced on a large scale worldwide and its production crosses the 150 million tonnes per year globally [1]. As per the CPCB report India generates 5.6 million tonnes of plastic waste annually. 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. Due to large applications of plastics, the waste generation from plastic is enormous.

The recycling rate of the waste plastic generated in industries is high but the municipal plastic waste recycling is very low. Some municipal corporations are started the recycling of plastics in Maharashtra. They convert plastic waste into fuel. Rudra Environmental Solution (India) Ltd. Pune sarted 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.

Use and through culture of human beings results in plastic waste as plastics are relatively cheaper and being easily available. As the plastic has non-degradable in nature, plastic waste management becomes a universal problem. As littering of waste plastic is major problems in municipal areas, the recycling of plastic waste becomes necessary.

In this study we attempted to convert waste plastic to liquid fuel. For that we have examined the different plastic waste like PET bottles as well as LDPE from milk pouches for our experiments with and without catalyst and found that LDPE shows the good conversion into liquid fuel when fly ash is used as a catalyst.

2. Fuel demand

Despite significant domestic fossil fuel resources, India's fossil fuel import increased 38% in 2012. After China, US and Russia, India ranked fourth largest energy consumer in the world. Due to dynamic economic growth and modernisation, India's energy demand continues to climb day by day [2].

In consumption and import of crude oil, India ranked fourth in the world in 2013 after US, China and Japan. India's demand for petroleum products reached near 3.7 million barrels per day (bbl/d) as compared to production of petroleum products about 1 million bbl/d. Most of India's fuel demand is for transportation and industrial sectors. Due to less investment in developing more crude oil and liquids production resulted to grow at a slower rate than demand [2]. Fig. 1 shows the India's production and consumption of the petroleum fuel [2].

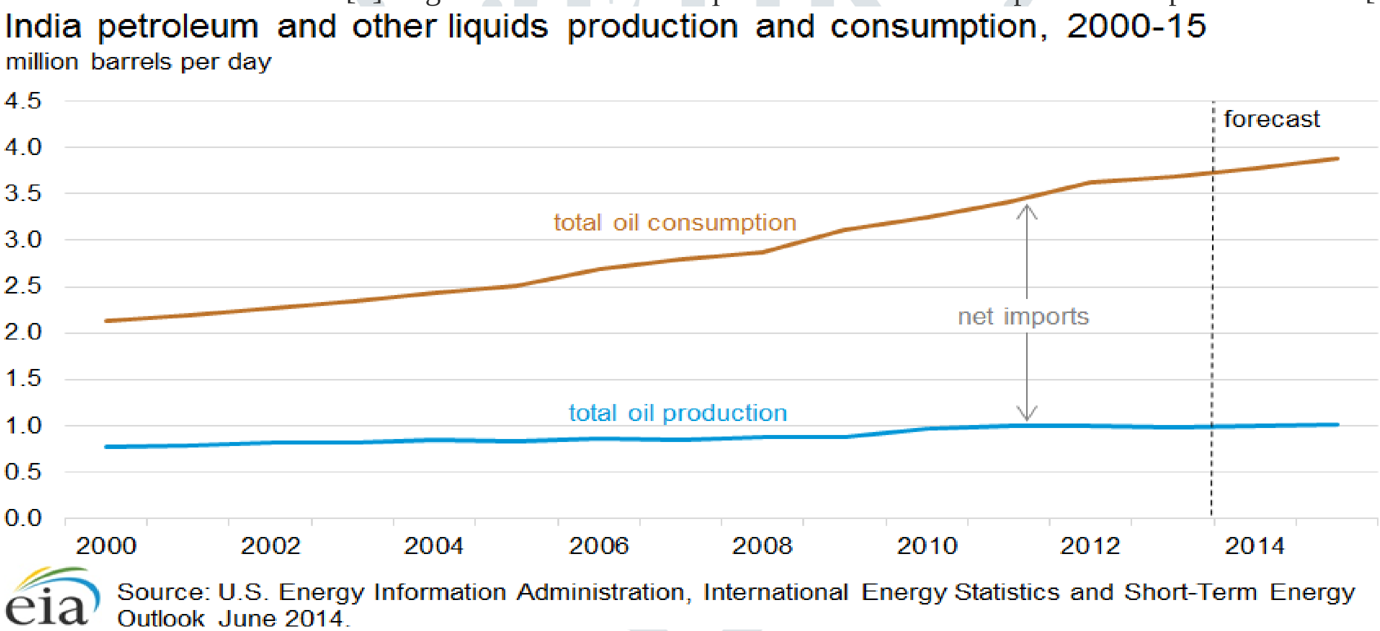

fig.1. India's production and consumption of the petroleum fuel.

In future we have to depend on the alternate fuels like bio fuels, ethanol and fuels from the other resources for our survival as conventional sources of the fuel are limited and it depletes in near future. Fuel from waste plastics is one of the alternative sources for the conventional fuels. Hence we have tried to make the fuel from plastic waste as the generation of waste plastic is very large.

3. Experimental Methods

The experiments are conducted by taking the known amount of plastic waste and coal fly ash (CFA) as a catalyst in a reactor. Heat is supplied to the reactor by heating source. After reaching the reactor temperature up to 160^0C, vapours starts to generate in the reactor and it continues to generate as the reactor temperature increases. The generated vapours are condensed in the condenser. The condensed product is collected in the conical flask. This condensed product is called as a liquid fuel from plastic waste.

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 for passing the generated vapours from the reactor to the condenser is made by welding the half inch diameter GI pipe with 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

Condenser is used for converting the plastic vapours in to the Polyfuel. Coiled condenser is used for this experiment in which copper coil is having 5 mm diameter and 1 mm thickness inserted in to the water bath of carbon steel. The fabricated coiled condenser is shown in fig.3.

fig.3. Copper tube coiled condenser

3.3 Heating media

For this purpose electrical coil heater of rating 1.5 KW is used to provide the thermal energy required for the cracking of the plastic molecules present inside the reactor. The heater shown in the fig. 4 used as a heating source which is purchased from the market.

fig.4. Electric coil heater and wood burning stove.

3.4. Connecting pipe and safety valve

The escape of vapours from the reactor to the condenser was made by the half inch diameter GI pipe. Also the safety valve is provided at the top cover of the reactor to release the excess pressure to avoid the bursting of the reactor due to high pressure. The arrangement is shown in fig. 5.

fig.5. Connecting pipe and safety valve.

3.5. Condensate collector

After condensation process the obtained liquid fuel is collected in conical flask used as a condensate collector as shown in fig. 6. This collector size or volume depended upon volume of production.

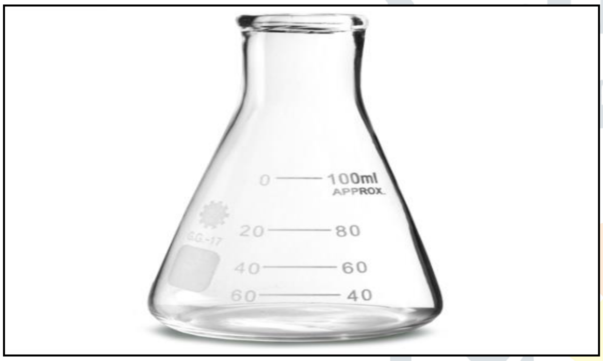

Fig.6. Collector. (Conical flask and PET bottle)

3.6. Temperature sensor

Mercury thermometer is used to determine the temperature of the reactor. The temperature range of the thermometer is from 0^0C to 360^0C as shown in fig. 7.

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 by providing a large surface area on which the waste plastic molecules can sit and so be exposed to high temperature inside the reactor, which breaks them apart resulting in the vapour generation.

fig.8. Coal fly ash as catalyst

4. Experimental Procedure

Experiments are conducted by taking known amount of plastic waste and the catalyst at moderate reactor temperature. The vapours generated from the reactor are condensed in the coiled condenser and the condensate i.e. liquid fuel is stored in the plastic bottle. Fig. 9 shows the experimental set up for production of fuel from plastic waste.

fig.9. Experimental setup for production of fuel from plastic waste.

To confirm the production of the liquid fuel initially we have performed the trial experiment by raw method on waste PET without catalyst. In this method first we feed about 500 grams shredded waste PET bottle material into the reactor (shown in following figure) and started the heating. After reaching the temperature about 270^0C, fumes are started to come out from the pipe. These fumes are collected in the plastic bottle which is immersed in the water bath. These fumes get condensed in liquid but the amount of the condensate is very less approximately 2-3 ml. From this trial experiment we confirmed that the plastic waste can be converted into liquid fuel. Fig. 10 shows the experimental setup for trial experiment.

fig.10. Experimental setup for trial experiment and shredded pet bottle.

After confirming the fuel from plastic waste, we conducted the final experiment on well designed experimental setup. The experimental setup used for this purpose is as explained earlier shown in fig. 9. In this case, we are collected the waste LDPE as the milk pouches treated as the waste after utilisation of the milk. After collection, washing of milk pouches is done by detergent and plenty of water to remove the contamination. After washing it is dried in the sun for removal of water. Then these LDPE milk pouches are cut into small pieces to increase the surface area for the reaction. We used 400 grams of this LDPE milk pouches for this experiment.

Experiment is started by taking the waste LDPE milk pouches weighing 400 grams in the reactor. 25 grams of coal fly ash as a catalyst is added 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 160^{0}C, the vapour generation has been started. Increase in temperature started gradually by applying the extra heat from 160^{0}C to 290^{0}C in the time span of 30 minutes. The first drop of condensate is observed when the reactor temperature reaches to the 170^{0}C. From 170^{0}C to 250^{0}C temperature range nearly 30 % fuel has been collected. When temperature reaches up to 280^{0}C, the fuel collection rate increases and we get another 40% of liquid fuel. Remaining fuel is collected when temperature reaches up to 290^{0}C. We have collected total 220 ml of liquid fuel from 400 grams of LDPE milk pouches which shows the conversion efficiency of 55% of that plastic waste.

5. Results and Discussion

5.1. Physical Testing

Appearance of the liquid fuel is viscous liquid with brownish colour with odour like mint. Flammability of fuel has been checked by taking this fuel on wooden stick and applying the fire to it. It is observed that fire catches immediately without any leftover residue. Fig. 11 shows the fuel product.

fig.11. Liquid fuel product.

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). The density and viscosity of the fuel has been measured at our Plastic Engineering Department laboratory by specific gravity bottle and Ostwald's viscometer respectively.

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

Sr. No.	Specifications	Fuel from Plastic Waste
1	Specific gravity	0.7616
2	Density	0.71 gram/ml
3	Viscosity	1.042 cp
4	Calorific value	9850 kcal/kg
5	Flash point	15^{0}C
6	Pour point	9^{0}C
7	Cloud point	12^{0}C
8	Aniline point	7^{0}C
9	Octane number	76
10	Moisture content	0.08 %

From analytical testing it was observed that all the properties are in the range and comparable with the regular diesel fuel.

5.3. Time - Temperature Behaviour

Temperature behaviour of the reactor with respect to time is shown in fig. 12. It is observed that at initial stage of 35 minutes, reactor temperature shows 115^{0}C and the waste plastic present in the reactor starts to melt. At 120^{0}C and above temperature the waste plastic melts completely and when temperature reaches to 160^{0}C, it starts to crack the molecules resulting in the vapour generation. Maximum vapours are generated in the range of 200^{0}C to 290^{0}C.

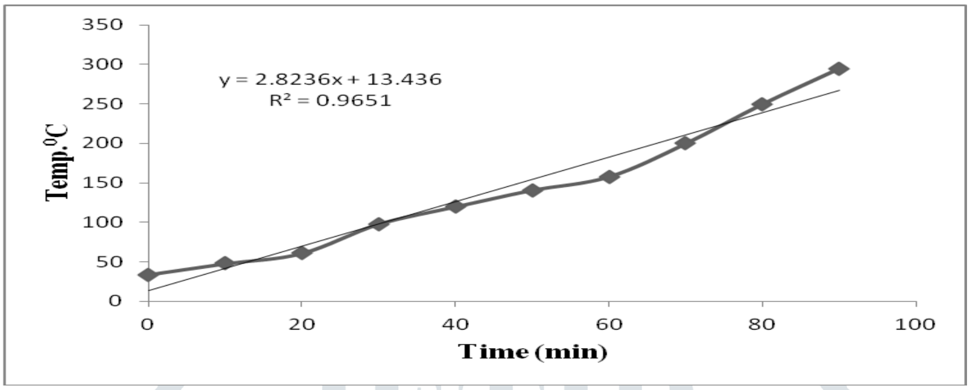

fig. 12. Time temperature graph for Thermolysis.

5.4. Residue generated

After end of the experiment, the residue generated is like a tar which is shown in the fig. 13. It is solid black in nature having 30 % of the total feed charged in the reactor. This residue (tar) can be used in road making process because it has a good elasticity.

fig.13. Residue.

6. Conclusion.

Conversion of waste plastic into liquid fuel can solve the problem of plastic waste management and the shortage of liquid fuel in developing countries like India. Thermal catalytic degradation of plastic can be done easily with economic means. The yield of the product can be increased by varying the process parameters like temperature, pressure, catalyst amount etc. The fuel produced in this study was found the properties comparable to the regular diesel fuel used in automobiles. So it can be concluded that the liquid fuel from waste plastics may be an alternative fuel of the future. The residue produced can be used in road making process, as no waste generated during the process, it can be called as zero discharge process or green process which avoids the pollution.

7. Future study.

To produce the liquid fuel from plastic waste in large quantity say up to 5 to 10 litres and to run the diesel engine for studying the exhaust gas analysis.

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