Thermal decomposition of mixed simulated plastics to convert in a fuel oil

Ritul Bhatt[1], Mr. Hemant Balsora[2], Mr. Kartik S.[3]
[1]*student, Department of chemical engineering, Shroff S. R. Rotary institute of chemical technology, Ankleshwar, India*
[2,3]*Assistant Professor, Department of chemical engineering, Shroff S. R. Rotary institute of chemical technology, Ankleshwar, India*

***Abstract*- Plastic Waste management can be practiced in an effective manner by converting waste plastics into useful fuel grade products by thermal pyrolysis process. Municipal plastic waste stream, which mainly comprises of high- density polyethylene, low-density polyethylene, polypropylene and polystyrene after separation can be treated to address the issue of plastic waste disposal. The study was focused on thermal decomposition of mixed simulated plastic. Batch experiments involving pyrolysis of a fixed amount of mixed plastics will be carried out for the quantitative estimation of oil.**

***Index Terms*- Mixed simulated plastic, municipal plastic waste stream, plastic waste management, pyrolysis, Thermal decomposition.**

INTRODUCTION

Rapid increases in the amount of waste plastic are results of its key innovation of many products in various sectors. Plastic waste is one among the major constitutes of municipal and industrial waste in cities. Due to non-biodegradability and emission of toxic chemicals during incineration/combustion, plastic disposal/management becomes difficult with conventional management techniques.

In India, approximately 12 Million tones plastic products are consumed every year, which is expected to rise further. It is also known that about 50-60% of its consumption is converted into waste [1]. In the year 2014-15, 11 kg/capita of virgin plastic is consumed and only 3.8 kg/capita was recycled [2]. Besides this Fossil fuels occupy are most dominant position in the market with more than 85% of the world demanded energy is supplied by fossil fuel sources. It is a finite source of energy and is projected to cater energy need in upcoming few decades. The estimated consumption of crude oil has a steady increase, from 146.55 MMT during 2006-07 to 232.87 MMT during 2015-16. It clearly indicates that there was a decrease of 2.28% in the estimated reserve of crude oil for the country as a whole during 2015-16 as compared to the position a year ago [3]. Petroleum and other liquid fuels consumption grow by 18% between 2015 and 2040 [4].

The available energy content in plastic is can be extracted by various thermo-chemical processes like pyrolysis, gasification and combustion.

Thermal cracking or Pyrolysis, involves the degradation of the polymeric materials by heating in the absence of oxygen. The process is usually conducted at temperatures between 350 °C to 900 °C and results in the formation of a carbonized char (solid residues) and a volatile fraction that may be separated into condensable hydrocarbon oil [5].

At waste plastic sites, mixed plastics are available and it contains a variety of its types of polyethylene, polypropylene, polystyrene, polyvinyl chloride, polyethylene terephthalate, etc. [6].

In Table 1, waste plastic composition is showing in kg/MT of Gujarat major populated cities. Four plastic material i.e. HDPE, LDPE, PP, and PS are present in a huge amount in the waste sites. So, it is very important to study the thermal pyrolysis of mixed plastic.

Table 1: City wise waste plastic composition in Gujarat in kg/MT [6]

	Ahme-dabad	Rajkot	Surat	Gandhi nagar
PET	0.67	7.64	1.25	0.77
HDPE/ LDPE	92.41	42.91	117.8	38.35
PVC	0.82	3.55	0.9	0.944
PP	6.75	1.17	0.68	1.52
PS	4.4	2.14	1.39	6.01
Other	0	11.85	2.64	0.46

Williams and Williams [7] investigated pyrolysis of mixed-plastic waste in which they study the interaction of the main plastic types in plastic mixtures is significant. Experiments are carried on fixed bed reactor and they produced a hydrocarbon gas consisting of hydrogen, alkane, and alkene gases and an oil/wax with negligible concentrations of aromatic species with alkenes, alkanes, and alkadienes in predicting the likely yield and composition of products from different plastic mixtures. They concluded that pyrolysis of PS produced a low yield of gas and no char formation. Pyrolysis of PVC also produced an aromatic oil; there was also a significant formation of char. Pyrolysis of PET produced a large yield of gas mainly. The influence of mixing HDPE, LDPE, PP, PVC, and PET in a 1:1 mixture with PS resulted in a much higher gas yield than would be predicted from the single plastic pyrolysis data. The molecular weight distribution and number and weight averaged molecular weights of the oil produced from the mixed plastics pyrolysis was markedly reduced due to the process of mixing compared to those of the individual plastic pyrolysis oil/wax.

Siddiqui and Redhwi [8] investigated the thermal pyrolysis of low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polyethylene terephthalate (PET) and polystyrene (PS). These plastics were studied individually and in mixed ratios with PS. The experiments were carried in a microtubular reactor. The result indicated that ratio 1:1 afforded best results in the form of conversion.

Miandad, Barakat, Aburiazaiza, Rehan, Ismail, and Nizami [9] investigated the influence of plastic waste type on pyrolysis yield. They concluded that pyrolysis of PE converted the feedstock into wax instead of liquid oil due to its long carbon chain structure. Addition of PS with PP reduced the liquid oil yield. Mixing of PS with PE reduced the liquid yield in comparison to individual PS pyrolysis. Mixing of PP with PE increased the gases and char yield with a decrease in liquid oil yield. Furthermore, an addition of PS and PP with PE at a ratio of 50/25/25% has slightly increased the liquid oil yield.

Buekens and Huang [10] suggested that thermal pyrolysis process for mixed plastic is carried out in a batch reactor. At various temperature, product yield is different, reactor type and its design also affect the product yield.

Temperature is one of the most significant operating parameters in pyrolysis since it controls the cracking reaction of the polymer chain. Temperature has the greatest impact on reaction rate that may influence product composition of liquid, gaseous and char for all plastics. Sharuddin, Abnisa, Daud, and Aroua [11] suggested that, for gaseous products, higher temperature more than 500 ºC is enough but if the liquid is preferred a temperature range of 300– 500 ºC is recommended. Murata, Sato and Sakata [12] concluded that the reaction pressure takes part directly in the scission of C–C links during thermal degradation of polymers. Chain-end scission that the reaction pressure has an effect on. On the other hand, the random scission does not exhibit any appreciable effect of pressure, since it takes place in a liquid phase.

Panda [13] concluded that longer residence time favors a secondary conversion of primary products, yielding more coke, tar, as well as thermally stable products, thus gradually obscuring the effect of original polymer structure. Effect of residence time on product yield is more pronounced at lower than higher temperatures.

In this study, experiments are carried out on a single as well as mixed virgin plastics and percentage yield analysis of the liquid product obtained from it.

EXPERIMENTAL

2.1 Plastic Investigated

Four virgin plastic i.e. high-density polyethylene, low-density polyethylene, polypropylene, and polystyrene are used in this study. Also, this four are mixed with each other and its composition is synthetically prepared, similar to Ahmedabad city waste plastic site shown in Table 2.

Table 2: Composition of plastic (in % mass) in the mixture

HDPE	LDPE	PP	PS
44.61	44.61	6.51	4.24

2.2 Proximate and ultimate analysis

The proximate and ultimate analyses were performed at BEIL Ankleshwar-India, the results of the same are shown in Table 3 and 4.

Table 3: Proximate analysis of mixed plastic

Material	Proximate analysis			
	M (LOD) %	Ash (%)	Volatile matter (%)	Fixed carbon (%)
Mixed Virgin Plastic	0.5	0.059	98.73	0.69

Table 4: Ultimate analysis of mixed plastic

Material	Ultimate analysis				CV $(\frac{Cal.}{gm})$
	S (%)	C (%)	H (%)	N (%)	
Mixed Virgin Plastic	0.01	85.3	8.4	5.6	9371

2.3 Lab scale experimental

The feedstock used for these experiments was high-density polyethylene, low-density polyethylene, polypropylene, and polystyrene. First set of experiments are carried out on individual plastic and then mixed plastic and its composition were similar to waste plastic composition of Ahmedabad city. The experimental set-up are shown in the Fig. 1.

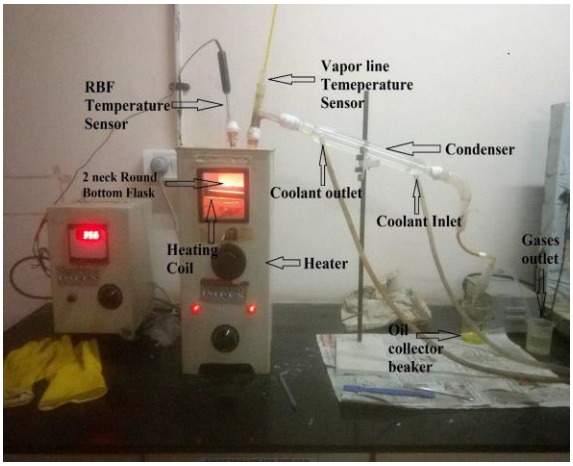

Fig. 1: Lab scale experimental set-up

In each experiment, a 250 ml, 2 necks round bottom flask was used. In which, in every experiment the same amount of feedstock was taken that is 25 gm. For these experiments, apparatus like the heater for the heating purpose of feedstock; the condenser for cooling of hydrocarbon vapors; temperature sensors for sensing the temperature is dipped in the round bottom flask for sensing the inner temperature which we can read on the display installed left side of the heater. A thermometer equipped with thermowell was used for checking the vapor temperature produced from the reactor. For cooling the hydrocarbon vapors, a simple tap water was introduced in the shell of the condenser and in the tube side, hydrocarbon vapors were condensed. This is one type of single pipe shell and tube heat exchanger. Here the coolant flow and hydrocarbon vapors flow in countercurrent fashion.

Oil collector installed to collect the condensed oil and besides this non-condensable gases are direct goes into a beaker which is filled with water. Bubbles were formed during collected the non-condensable gases in the beaker.

RESULT AND DISCUSSION

3.1 Proximate and ultimate analysis

In Table 3 and 4 shows the result of a proximate and ultimate analysis. The data shows, the highest percentage of volatile matter (98.73 %) present. Volatile matter is that portion of the plastic material which is converted into the gas phases during the heating process. It represents the how much amount of liquid oil is produced where high volatile matter contents correspond to higher liquid oil produced from the pyrolysis process.

Moisture content is measured with the amount of water lost from the plastic material upon drying to a constant weight. In the mixed virgin plastic, moisture content (0.52 %) present. It is directly affected by physical and chemical properties of the material which it absorbs with the help of existing water in the environment.

Ash content of the plastic material is the non-combustible residue left after burning of plastics, which represents the natural substances after carbon, oxygen, sulfur, and water. In mixed virgin plastic, ash content (0.059 %) present.

Carbon found in the plastic material which is left after a volatile test is called fixed carbon. It is the carbon remaining on the surface as charcoal. In mixed virgin plastic, fixed carbon is (0.691 %) present. A high percentage of fixed carbon means that material requires a longer detention time on the surface to achieve complete combustion.

An ultimate analysis is also being carried out for the plastic sample, showing the component- wise fraction

content in the mixed virgin plastic. In this, high carbon (85.3%) and hydrogen (8.47%) content. This means mostly the hydrocarbon components present in the mixed virgin plastic. The presence of carbon and hydrogen content lead plastic to have higher energy content. Sulfur and nitrogen are content is very less amount 0.016% and 5.63% respectively. Sulfur present in very negligible amount but very less amount of this sulfur is due to physical processes of manufacturing of plastics. This negligible amount of sulfur and nitrogen fractions told that there were negligible chances to generate the SO_x, NO_x, etc. Also, no chlorine contents plastic were taken in this study which was generated the harmful gases like polychlorinated dibenzo para dioxins (PCDD), polychlorinated dibenzofurans (PCDF) etc.

In ultimate analysis (Table 4), the calorific value of the sample i.e. mixed plastic is 9371 calorie/gm. This value indicated that the huge amount of energy was contained in this sample and this amount of energy was converted into valuable liquid products.

3.2 Experimental

Experiments were carried in small lab scale which is available in the laboratory. Whatever yield was coming is shown in Fig. 2.

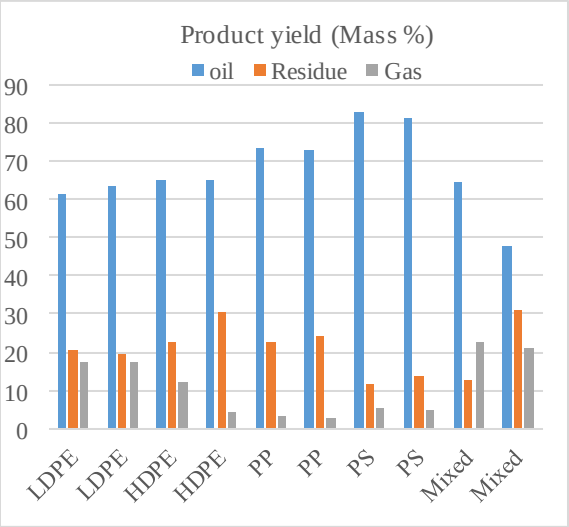

Fig. 2: Product yield (% mass)

Analysis of Fig. 2, Pyrolysis of an individual as well as mixed virgin plastic was carried out. The result shows that PS gives the highest amount of oil (Above 80%) producing from plastic. LDPE, HDPE producing average 62% and 65% of oil-producing respectively. Compare to all individual plastic material, mixed virgin plastics are less producing the oil, it is about 56.02% only.

Pyrolysis of HDPE and LDPE converted the feedstock into wax instead of liquid oil due to its long carbon chain structure. So, in mixed virgin plastic composition, highest amount of feedstock is HDPE and LDPE. PP and PS present in very less amount. Because of this composition ratio, there are decreasing in oil (mass %) in mixed virgin plastic.

Also observing the residence time during these experiments. In all the experiments, 25 gm of mixed plastic is treated and all takes around one and half hour to complete the decomposition process. Also, temperature is the most affecting parameter. A temperature in these experiments is to maintain around 400-430 ºC. In this temperature range, maximum oil drops have come in oil collector. On the basis of this particular information we can say that in this temperature range, maximum decomposition of plastic material is taking place. During the experiments, observing also the temperature at which the first drop of oil comes. This indicates the decomposition process of plastic material is starts. A temperature at which the first drop of oil in both the run is comes in HDPE at 263 ºC & 268 ºC, LDPE at 256 ºC & 252 ºC, PP at 223 ºC & 231 ºC, PS at 168 ºC & 175 ºC and mixed plastic at 252 ºC & 243 ºC. In the beginning, white color fumes are generated in the reactor but that is not crack vapor. So need a specific residence time to crack the material. Once the cracking starts, oil drops are also coming in the collector. So, residence time and the temperature are highly affected in the decomposition process.

CONCLUSION

Numbers of experiments are carried out on the individual as well as mixed plastics and checked the percentage yield of products analysis. The result shows that PS gives the highest amount of oil (Above 80%) producing from plastic. LDPE, HDPE producing average 62% and 65% of oil-producing respectively. Compare to all individual plastic material, mixed virgin plastics are less producing the oil, it is about 56.02% only. Due to the long carbon chain in HDPE and LDPE, converted feedstock into wax and decreases in liquid yield.

Effect of residence time and temperature on the decomposition process also observed. Giving the

maximum residence time is helpful to crack the feedstock in a reactor before the first drop of oil was not come in a collector. The temperature in these experiments is to maintain around 400-430 ºC. In this temperature range, maximum oil drops have come in oil collector.

On the bases of proximate and ultimate analysis, it is concluded that no toxic as well as harmful gases like SO_x, NO_x, furans, etc. are generated from the decomposition process.

ACKNOWLEDGMENTS

I express my sincere thanks to my research guides Mr. Hemant Balsora and Mr. Kartik S. (Assistant Prof. of Chemical engineering Department), for them motivational support and continuous flow of encouragement while working in the direction of preparing of the project. I would like to appreciate the guidance given the judging panel especially in our project presentation that has improved our presentation skills by their comment and tips.

REFERENCES

[1] Status of implementation of plastic waste management (PWM), Central Pollution Control Board (CPCB), Ministry of Environment & Forests, Government of India November 2015.

[2] International journal of research in commerce, IT and Management, Volume No. 7, Issue No. 02, 2017. Available: http://ijrcm.org.in/

[3] Energy statistics 2017, Central Statistics Office, Ministry of Statistics and Programme Implementation, Government of India, New Delhi, 2017.

[4] Dr. Ian Mead, International Energy Outlook 2017, U.S. Energy Information Administration, 2017.

[5] Achyut K. Panda, R.K. Singh, D.K. Mishra, Thermolysis of waste plastics to liquid fuel A suitable method for plastic waste management and manufacture of value added products—A world perspective, Renewable and Sustainable Energy Reviews 14 (2010) 233–248.

[6] Assessment & Quantification of Plastic Waste Generation in Major Cities, Central Pollution Control Board (CPCB), Ministry of Environment & Forests, Govt. of India January 2015.

[7] Paul T. Williams and Elizabeth A. Williams, "Interaction of Plastics in Mixed-Plastics Pyrolysis", Energy & Fuels, 13, 1999, 188-196.

[8] Mohammad Nahid Siddiqui and Halim Hamid Redhwi, Pyrolysis of mixed plastics for the recovery of useful products, Fuel Processing Technology, 90, 2009, 545–552.

[9] R. Miandad, M.A. Barakat, Asad S. Aburiazaiza, M. Rehan, I.M.I. Ismail, A.S. Nizami, Effect of plastic waste types on pyrolysis liquid oil, International Biodeterioration & Biodegradation, 119, 2017, 239-252.

[10] A.G. Buekens, H. Huang, Catalytic plastics cracking for recovery of gasoline-range hydrocarbons from municipal plastic wastes, Resources, Conservation and Recycling, 23, 1998, 163–181.

[11] Shafferina Dayana Anuar Sharuddin, Faisal Abnisa, Wan Mohd Ashri Wan Daud, Mohamed Kheireddine Aroua, A review on pyrolysis of plastic wastes, Energy Conversion and Management, 115, 2016, 308–326.

[12] Katsuhide Murata, Kenji Sato, Yusaku Sakata, Effect of pressure on thermal degradation of polyethylene, J. Anal. Appl. Pyrolysis, 71, 2004, 569–589.

[13] Achyut Kumar Panda, Studies on process optimization for production of liquid fuels from waste plastics, Ph.D. Thesis, National Institute of Technology Rourkela, July 2011.