Performance Evaluation of Waste Plastic Oil Converter

Asia Pacific Journal of Multidisciplinary Research
Vol. 5 No.2, 58-63
May 2017
P-ISSN 2350-7756
E-ISSN 2350-8442
www.apjmr.com

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Date Received: February 21, 2017; Date Revised: April 11, 2017

Abstract - *This research aimed to evaluate the performance of the waste plastic oil converter. The equipment is a prototype model powered by electricity and utilizes a non-catalytic pyrolysis process of converting waste plastic to oil. The primary objective of the study is to identify the type of waste plastic that the equipment can process and determine its performance in terms of conversion efficiency (wt %), waste reduction efficiency (wt %) and oil recovery (ml oil/kg waste plastic). The equipment was initially tested for Type 1-Polyethylene Terephthalate, Type 2-High Density Polyethylene, Type 4-Low Density Polyethylene), Type 5-Polypropylene and Type 6 -Polystyrene. It was observed that the equipment is only capable of converting Type 5 and 6 waste plastic into oil. For the performance evaluation of the equipment, 1000g Type 5 and 1000g Type 6 waste plastic were used as feedstock. The experiments were performed separately for each of them. Five trials using 200g per trial for each type of plastic was conducted to test the equipment. The temperature at the bottom of the reactor was set to 400^{0}C and the operating time was 2 hour per trial with 15 minutes cracking time, 1 minute vapor residence time and 1 minute vapor evacuation time. Results show that the conversion efficiency of the equipment for Type 5 was 60.90% and for Type 6 was 83.6%. Waste reduction efficiency was 94.8% for Type 5 and 95.6% for Type 6. The oil recovery of the equipment was 766 ml/kg for Type 5 and 919 ml/kg for Type 6. Thus, the waste plastic oil converter is a potential solution in reducing the amount of plastic waste due to its capability of producing oil out ofwaste Type 5 and Type 6 plastics.*

Keywords - *Performance Evaluation, Waste Plastic Oil Converter, Type 5 - Polypropyleneplastic, Type 6-Polystyreneplastic*

INTRODUCTION

Waste plastic generation is expected to increase each year due to increasing population and continuous growth of living standards. Plastic becomes an essential commodity due to its varied household and industry application. Plastic products may be non-toxic but the monomers and additives used in the manufacturing process may be toxic. Improper disposal of unsegregated different types of waste plastics can create surface and groundwatercontamination that may pose a serious problem in the environment and human health.

The Department of Environment and Natural Resources (DENR) have adopted the principles of Ecological Waste Management (EWM)in addressing the pressing problem of waste management. The solid waste management principles includes the reduction of waste, recovery of waste for recycling and reuse of materials forenergyproduction [1]. However, the scenario of zero plastic waste is impossible to foresee in the future. Generation of waste plastic is expected to continue along with economic and national development.

To guide the consumers and recyclers in identifying the different types of plastic, the Society of the Plastic Industry created a classification system in 1988. SPI code or number is placedby the manufacturers generally molded in the bottom of every plastic product [2]. Number coding of plastic productsnot only allows the consumer to classify each type but it alsobeneficialin the segregation and recovery of waste plastic.

Although the government existing resources, technology and programs on waste reduction, recovery, recycling and re-use are effective at some point, it cannot eradicate the entire problem of waste disposal. A large volume of unsegregated and untreated waste will still go the landfills daily posing threat to the environment and all living creatures.

In other countries such as Japan, United Kingdom, India, United States of America, Netherlands, Germany and China, there are companies and manufacturers which developed a technology in converting waste plastics into a resource. They usually utilize the catalytic pyrolysis process of turning waste plastic into oil.Pyrolysis is the process of applying heat ranging from 300 to 650 degree centigrade to the plastic in the absence of oxygen to decompose the plastic. It is an alternative method for the treatment of unsegregated and contaminated waste plastics, wherein the wastes undergo the process of thermal decomposition without combustion inside special chambers called reactors [3].

Research conducted by Low, et.al, showed that simple method of batch pyrolysis can turn mixed waste plastics particularly polyolefin's and polystyrene into a useable liquid fuel with a yield of at least 70%. In their preliminary test, it was confirmed that using unsorted waste plastics to produce liquid products is promising and feasible. Compositions of the liquid product have common characteristics with that of the existing hydrocarbon fuels like diesel, gasoline and kerosene. Accordingly, it is possible to use the liquid product directly as fuel or can be process in the refinery to further improve its quality. The result of their study also suggests that using small-scale simple pyrolysis process to address plastic wastes can be good but needs further investigations on ways to remove PVC and PET from mixed waste plastics; and establish the extent to which patterns of thermal decomposition of plastic mixtures conform to those of the individual polymers present [4].

Study of Lopez et.al [5] on the recycling of packing and packaging plastic wastes through pyrolysis proved that pyrolysis is potential way of treating that kind of waste because the obtained conversion to liquid + gas can reach more than 95%. However, the pyrolysis product is greatly influenced by the amount of temperature which plays a vital role in the conversion process.High proportion of wax-like liquids can be generated at a low temperature process while a very aromatic liquids and more short chain hydrocarbons in the gases can rise at higher operating temperature. It is also believe that secondary repolymerization reactions contributed to the formation of some chars.

Investigation both theoretical and experimental was conducted in a laboratory scale pyrolysis reactor using polyethylene, polypropylene and polystyrene. It was reported that the pyrolysis cracking temperature for polypropylene and polyethylene is at 450 degree centigrade while for polystyrene is much lower at 320 degree centigrade. Production of light hydrocarbons can be significantly influenced by high reaction temperature and heating rate. Long residence time can also contribute to the production of light hydrocarbon products. Catalyst, type of reactor, reflux rate and pressure were some of the factors investigated in their review of literature. Pyrolysis product of polypropylene with high reflux rate has 84.2% liquid product, 15.7% non-condensable gases and less than .025% char. In the pyrolysis of polystyrene, the product consists of 93% liquid, 4% non-condensable gases and 3% char [6].

In the pyrolysis performed by Lee [7] of mixture of waste High Density Polyethylene (HDPE) and Polystyrene (PS) in a semi-batch reactor with 9.1 wt% catalysts at a temperature of 400^0C,the amount of liquid products clearly increases with an increase in the mixing proportions of Polystyrene against High Density Polyethylene. High yield of liquid product and high degradation rate is the result of increase Polystyrene content in the mixture PS and HDPE. This implies that pyrolysis of Polystyrene is predominant over the pyrolysis of High Density Polyethylene in the mixture.

Foreign companies and manufacturers of these conversion technologies may have limited ability to export their equipmentto overseas customers like that of the Philippines without the assistance of experienced trading companies and or stopped to sell waste plastic conversion technologies for industry and intellectual property reasons.

The cost of the technology, equipment and transport may seem impractical to import equipment for waste plastic conversion technologies from other countries. With this predicament, Rapsing, E.Jr. C.,designed and fabricated a waste plastic oil converter in 2016. It was a prototype model purposely developed as an attemptto find environment-friendly means of waste recycling. The equipment is powered by electricity and utilizes a non-catalytic pyrolysis process of converting waste plastic into oil. It has a fixed bed reactor and operates on batch basis [8]. It was proven operational and functional using Type 6 waste plastic as feedstock. However, the equipment was not tested using other types of waste plastic. Hence, this study was conducted to know the performance of the locally developed equipmentin converting other types of waste plastics into oil.

This study is deemed significant in addressing the increasingproblem on waste disposal. Volume of plastic that will be incinerated and deposited in the landfill or dumpsite will be minimized thereby reducing the carbon emission and carbon sink in the environment.Only the converted oil and char were collected as a product of the equipment. Uncondensed vapor or gas was not collected due to nonexistence of vapor recovery facility. Economicaspect of the equipment was not included in the study for the reason that the equipment is a prototype model intended for laboratory experiment only and still in its development stage.Physical and chemical properties of the collected oil were not also included in the study.

OBJECTIVES OF THE STUDY

The primary objective of this study is to evaluate the performance of the waste plastic oil converter. Specifically it intendsto answer the following questions: (1) What other types of waste plastic the equipment can process, (2) What is performance of the equipment in terms of conversion efficiency (wt %), waste reduction efficiency (wt %) and oil recovery (ml oil/kg waste plastic) and (3) Is there a significant difference on the performance of the equipment between different types of waste plastic.

MATERIALS AND METHOD

Research Design

This study utilized the experimental method of research. The previously developed waste plastic oil converter was evaluated using different types of waste plastic for its efficiency in terms of conversion, waste reduction and oil recovery. Significant difference test was also conducted on the performance of the equipment between different types of waste plastic.

Equipment

The equipment used in this study was the waste plastic oil converter designed and fabricated by Rapsing, E. Jr. C., [4]. The main components werethe base which holds the other parts of the equipment, reactor assembly where the waste plastics are melted to form into a vapor, condensing chamber where the vapor is condensed and collected, vapor line assembly where the uncondensed gas passes, smoke cleansing unit where the uncondensed gas is cleaned of dust particles before releasing to the atmosphere and the waste water collecting unit where the water from smoke cleansing unit is being stored before disposal.

Materials

The materials used in the study were digital weighing scale for measuring the weight of the feedstock, recovered char and the converted oil;graduated cylinder for measuring the volume of the converted oil; and digital clamp meter for measuring the input voltage and current.

Figure 1. *The prototype waste plastic oil converter*

The feed stocks used were Type 1-Polyethylene Terephthalate, Type 2-High Density Polyethylene, Type 4-Low Density Polyethylene, Type 5-Polypropylene and Type 6-Polystyrene waste plastics.

Experimental procedures

Two hundred grams of each type of waste plastic were used in the initial testing to identify what type of plastic the equipment can process. Each sample feedstock were cut into small pieces and loaded to equipment separately. After identifying the type of plastic that the equipment can process, one kilogram of each identified type were prepared, cut into small pieces and weighedat 200g per sample that was used in the performance evaluation of the equipment.The experiment started by loading the sample to the reactor tank, setting the temperature controller to 400^0C and turning on the electric heater. Each experiment lasted for 2 hours per trial to totally dry the char inside the reactor, with vapor residence time of 1 minute and vapor evacuation time of 1 minute. The reactor tank was let to cool before collecting the char. Recovered char and oil were measured accordingly at the end of each trial. Five trials were performed in each identified type of waste plastic.

Descriptive analysis of data was used. The average results of the parameters were used to describe the performance of waste plastic oil converter. H-test or the One- Way Analysis of Variance by Ranks was used to compare the difference in performance of the equipment.

P-ISSN 2350-7756 | E-ISSN 2350-8442 | www.apjmr.com
Asia Pacific Journal of Multidisciplinary Research, Vol. 5, No. 2, May 2017

Figure 2. The feedstocks

Performance Evaluation Parameters

The performance of the prototype waste plastic oil converter was evaluated for conversion efficiency (wt %), waste reduction efficiency (wt %), oil recovery (ml oil/kg plastic) and was expressed by the following formula.

1. Conversion Efficiency (wt %)

$$CE = \frac{Wo}{Wsm} \text{x} \quad 100\%$$

Where:
CE = Conversion Efficiency
Wo = Weight of oil converted (g)
Wsm = weight of the sample material (g)

2. Waste Reduction Efficiency (wt %)

$$WRE = \frac{Wsm - Wc}{Wsm} \text{x} \quad 100\%$$

Where:
WRE = Waste Reduction Efficiency
Wc = Weight of char inside the reactor (g)
Wsm = weight of sample material (g)

3. Oil Recovery (ml/kg)

$$OR = \frac{V}{Wsm}$$

Where:
OR = Oil Recovery (ml/kg)
V = Volume of oil recovered (ml)
Wsm = Weight of sample material (kg)

RESULTS AND DISCUSSION

The equipment was initially tested for Type 1-Polyethylene Terephthalate, Type 2-High Density Polyethylene, Type 4 -Low Density Polyethylene, Type 5-Polypropylene and Type 6-Polystyrene waste plastics. Result of the initialtesting revealed that the prototype waste plastic oil converter is only capable of converting Type 5 and 6 waste plastic into oil. For the performance evaluation of the equipment, only the Type 5 and Type 6 were used as feedstock. One thousand grams of each Type 5 and Type 6 waste plastic were prepared, cut into small pieces and divided into five sample weighing 200g each. Five trials were conducted for each type of plastic.

The performance of the equipment was measured in terms of conversion efficiency, waste reduction efficiency and oil recovery.

Conversion efficiency is the ability of the equipment to convert waste plastic into oil in terms of weight. This is computed by dividing the weight of oil recovered by the original weight of plastic and is multiplied by 100. Based on the result of the study, the waste plastic oil converter has conversion efficiency of 60.90% for Type 5 and 83.6% for Type 6. However, significant difference test showed that there is a significant difference on the conversion efficiency of the equipment between Type 5 and Type 6 waste plastic because the Computed value of 6.90 is higher than the Tabulated value of 3.84 at0.05 level of significance.

Table 1. Data gathered during the experiment

	WASTE PLASTICS									
	TYPE 5 (PP-Polypropelene)					TYPE 6 (PS-Polystyrene)				
TRIAL	**Weight of Sample(g)**	**Duration (hr)**	**Volume of Oil (ml)**	**Weight of Oil (g)**	**Weight of Char (g)**	**Weight of Sample(g)**	**Duration (hr)**	**Volume of Oil (ml)**	**Weight of Oil (g)**	**Weight of Char (g)**
1	200	2	152	120	12	200	2	181	165	10
2	200	2	154	122	10	200	2	184	167	9
3	200	2	151	121	12	200	2	183	167	9
4	200	2	155	124	7	200	2	186	169	8
5	200	2	154	122	11	200	2	185	168	8
Total	**1000**	**10**	**766**	**609**	**52**	**1000**	**10**	**919**	**836**	**44**
Average	200	2	153.2	121.8	10.4	200	2	183.8	167.2	8.8

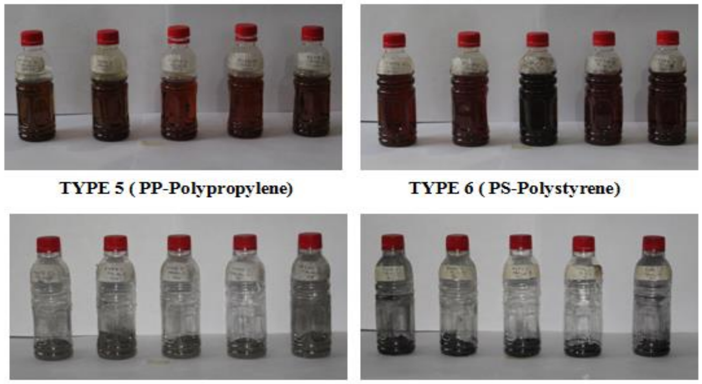

Figure 3. Oil and char as an output of the equipment

Table 2. Computed data for performance evaluation

TRIAL	WASTE PLASTICS					
	TYPE 5 (PP-Polypropelene)			TYPE 6 (PS-Polystyrene)		
	Conversion Efficiency (wt %)	Waste Reduction Efficiency (wt%)	Oil Recovery (ml/kg)	Conversion Efficiency (wt %)	Waste Reduction Efficiency (wt%)	Oil Recovery (ml/kg)
1	60.00	94.00	760	82.50	95.00	905
2	61.00	95.00	770	83.50	95.50	920
3	60.50	94.00	755	83.50	95.50	915
4	62.00	96.50	775	84.50	96.00	930
5	61.00	94.50	770	84.00	96.00	925
Total	304.50	474.00	3830	418.00	478.00	4595
Average	**60.90**	**94.80**	**766**	**83.6**	**95.60**	**919**

Waste reduction efficiency is the measure of how efficient the equipment in reducing waste in terms of weight. This is calculated by subtracting the weight of char from the original weight of the plastic divided by the original weight of the plastic and is multiplied by 100. As a result of the study, the equipment showed a waste reduction efficiency of 94.8% for Type 5 and 95.6% for Type 6. Significant difference test on the waste reduction efficiency of the equipment resulted to a not significant difference between Type 5 and Type 6 waste plastic because the Computed value of 2.19 is lower compared to the Tabulated value of 3.84 at 0.05 level of significance.

Oil recovery is the measure of how much oil the equipment can recover per kg of waste plastic. In this study, the waste plastic oil converter was able to recover 766 ml/kg for Type 5 and 919 ml/kg for Type 6.Result of the significant difference test showed that there is a significant difference on the oil recovery of the equipment between Type 5 and Type 6 because the Computed value of 6.86 is higher compared to the Tabulated value of 3.84 at 0.05 level of significance.

CONCLUSION AND RECOMMENDATION

Result of the study showed that the prototype waste plastic oil converter is only capable of converting Type 5-Polypropylene and Type 6-Polystyrene waste plastic into oil. Type 6 waste plastic ranked first in all performance evaluation parameter. The maximum attained performance in terms of conversion efficiency, waste reduction efficiency and oil recovery was 83.6 wt%, 95.6 wt%, and 919 ml of oil/kg of waste plastic, respectively. Data showed that there is a significant difference on the conversion efficiency and oil recovery of the equipment between Type 5 and Type 6 waste plastic; however a not significant difference on the waste reduction efficiency of the equipment between Type 5 and Type 6 was recorded.

This implies that the equipment can only convert two types of waste plastic under non-catalytic pyrolysis process at 400^{o}C temperature. Converted oil is a possible substitute for diesel fuel but needs thorough investigation. The equipment can reduce the amount of waste by as much as 95.6% in terms of weight and can recover a reasonable amount of oil per kilogram of Type 5 and Type 6 waste plastic.Hence, the waste plastic oil converter though a prototype model is a potential solution in addressing the continuing problem of waste plastic disposal.

The experiment was conducted under a constant temperature, vapor residence time and vapor evacuation time. Chemical and physical analyses of recovered oil were not included in the study and non-condensed vapor was not collected due to absence of recoveryequipment.

Further study must be conducted on the factors that affects the performance of the waste plastic oil converter such as but not limited to temperature, suction pressure, residence time and evacuation time. Oil recovered must be analyzed to determine its physical and chemical properties. Recovery equipment for non-condensable vapor must be fabricated to collect un-condensed vapor for storage or future use. Studies should be conducted on the uses, applications and benefits that can be drawn from the recovered oil out of waste plastic.

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