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Design, Fabrication and Performance Study of a Plastic Waste to Oil Converter

Asma-Ul-Husna[1], Farzana Nahid[1], Shahina Imam[1], Dr. Mohammed Rofiqul Islam[1], Md. Abdul Kader[1]
[1]Department of Mechanical Engineering,
Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh.
Phone: 880-1719445005
E-mail: evu_me04@yahoo.com, farzanarinthi@gmail.com

Abstract

Pyrolysis is one of the most important thermo chemical energy conversion methods for renewable energy sources. In this paper the conversion of waste Plastic/Polythene into pyrolytic oil by air tight reactor has been taken into consideration. The raw and crack plastic particle was pyrolized in an electrically heated 7.5 cm diameter and 18 cm high air tight reactor with nitrogen as a carrier gas. The reactor was heated by using electric heater. The parameters varied were running time and feed particle size. The different temperatures were found to influence the product significantly. The maximum liquid yield was 66 wt% at 350^{0}C for a feed size of 3 cm^2 at a Nitrogen gas flow rate of 2 liter/min with a running time of 40 minutes. The pyrolysis oil obtained at these optimum process conditions was analyzed for some of its properties as an alternative liquid fuel.

Keywords: Pyrolysis, Plastic, Pyrolytic oil, Thermal decomposition.

1. Introduction

Energy is defined as the ability to produce change or do work and that work can be divided into several main tasks. Energy is the main way for growth of economical development. From the present point of view we can see that a country economically successful if it utilize its own reserve of renewable and nonrenewable source of energy. Energy from Waste offers a Pyrolysis technology, which has the ability to produce a clean, high calorific value fuel gas from a wide variety of waste and biomass streams. Pyrolysis for energy conversion from carbonaceous wastes is defined as the thermal degradation of organic matter either in total absence of air or with a lack of a stochiomtrically needed amount of oxygen to the extent where gasification does not occur [1].

In this thesis waste plastic is taken into consideration. Because every year a great amount of plastic is manufacture as the same amount plastic waste is produced. Plastic has great negative impacts on environment. Plastic is mainly made from petroleum, it is estimated that 7% of the world's annual oil production is used to produce and manufacture plastic [2]. In Bangladesh the amount plastic waste is terrific. Table 1 shows the annual production of petroleum, plastic and rubber with their values in Bangladesh.

2. Materials

A Plastic material is any of a wide range of synthetic or semi-synthetic organic solids used in the manufacture of industrial products. Plastic are typically polymers of high molecular mass, and may contain other substances to improve performance and reduce production cost. Monomers of plastic are either natural of synthetic organic compounds [4]. The word plastic is derived from the Greek word "Plastikos" meanings capable of being shaped or molded.

There are mainly two types of plastics: Thermoplastic and Thermosetting polymers.

Thermoplastics are the plastics that do not undergo chemical change in their composition when heated and can be molded again and again. Examples include polypopylne, polystyrene, polyvinyl chloride and polytetrafluooethylene (PTFE) [5]. Thermosets can melt and take shape once; after they have solidified, they stay solid. In the thermosetting process, a chemical reaction occurs that is irreversible.

Polythylene is classified into several different categories based mostly on its density and branching. The mechanical properties of PE depend significantly on variables such as the extent and type of branching, the crystal structure and the molecular weight [6]. Such as- Ultra high molecular weight polyethylene (UHMWPE), High density polyethylene (HDPE), Linear low density polyethylene (LLDPE), Medium density polyethylene (MDPE), Low density polyethylene (LDPE) etc.

Table 1. Production of Selected Industrial Items (Value in 000 taka) [3]

Code and Items	Units	2007-08		2008-09		2009-2010	
		Quantity	Value	Quantity	Value	Quantity	Value
354 Petroleum products:							
Naphtha		134561	1488615	79666	1010953	15847	-
L.P.G.	M.Ton	9987	376690	6278	240622	-	-
M.S.		42868	3687962	28802	2483739	2186565	-
H.O.B.C.		34655	2965988	20715	1807964	3162502	-
356 Rubber products 3569 Rubber footwear	Doz. Pair	345618	49962	347165	50223	332752	-
357 Misc. plastic products 3579 PVC products	M.Ton	12761	692409	14848	816640	19015	-

Environmental impact of plastic waste

Due to their insolubility in water and relative chemical inertness, pure plastics generally have low toxicity. Some plastic products contain a variety of additives, some of which can be toxic. For example, plasticizers like adipates and phthalates are often added to brittle plastics like polyvinyl chloride to make them pliable enough for use in food packaging, toys, and many other items. Traces of these compounds can leach out of the product. Owing to concerns over the effects of such lactates, the European Union has restricted the use of DEHP (di-2-ethylhexyl phthalate) and other phthalates in some applications. Some compounds leaching from polystyrene food containers have been proposed to interfere with hormone functions and are suspected human carcinogens. Whereas the finished plastic may be non-toxic, the monomers used in the manufacture of the parent polymers may be toxic. In some cases, small amounts of those chemicals can remain trapped in the product unless suitable processing is employed. For example, the World Health Organization's International Agency for Research on Cancer (IARC) has recognized that vinyl chloride, the precursor to PVC, as a human carcinogen [7]. Beside this

- Plastic are durable and degrade very slowly.
- Burning plastic can release toxic fumes and large amount of CO_2.
- The harmful chemical pollutants are responsible for the depletion of the Ozone layer.
- Plastic trash is polluting the oceans and washing up on beaches.
- Reducing fertility of soil.

3. Method

The low density plastic was first collected from dustbin and then washed properly in water. Then the washed plastic/polythene was crashed in small particle. The plastic was crashed in size of 0.5cm^2 – 3cm^2. So the average particle size is 3 cm^2. Then the plastic was died on sun ray. The gross calorific value of the solid crushed plastic is 38718.96 kj/kg (9218.8 kcal/kg).

Heating value or calorific value of a fuel is the magnitude of the heat of reaction at constant volume at a standard temperature (usually 25^{0}C) for the complete combustion of unit mass of fuel. Complete combustion means that all carbon is converted into CO_2, all hydrogen is converted into H_2O and any sulfur present is converted into SO_2 [8].The heating value of plastic is calculated by

Calorific Value = ΔTW / m

Here, ΔT= Temperature difference, W= Water equivalent, m = Mass of water.

Heating Value calculation

Initial Temperature = 34˚C

Final Temperature = 37.9˚C

C_v = {(37.9- 34) × 2426 cal/˚C} / 0.001 kg

= 39737.88 kj/kg.

Design and fabrication

The schematic diagram of the experimental set-up is presented in Figure.1.The experimental unit consists of five major components are

1. Air tight reactor chamber,
2. Condenser,
3. Thermometer,
4. Nitrogen gas flow meter and
5. An electric heater.

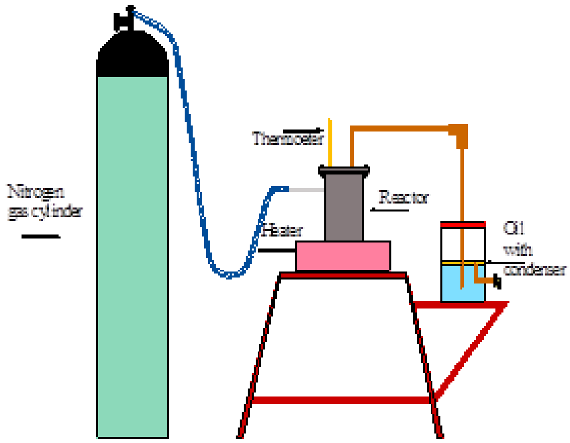

Figure 1. Schematic arrangements of plastic to oil convert

Electric heater heated the reactor, which is full with well cracked waste plastic particle. Stainless steel nut-bolt, gasket paper and liquid gasket shield is used make it air tight. The produce gas is passes from reactor to water container through a copper pipe. The gas is escape in the water and condensed. The liquid is stored as a layer on the surface of the water. The oil is collected by a tap using gravitational force. The nitrogen gas is used as a carrier gas and it also produce an inert environment within the reactor.

Limitations of this system

1. The range of the thermometer is 360˚C.
2. To avoid the leakage stainless steels nut bolt is used.
3. The thermometer must be fixed with the flange.
4. Gasket sheet with liquid gasket cement must be used.
5. Prevention of the leakage is the main challenge in this setup.
6. For tire waste feed material the condensing system is not enough.

4. Experimental results

Three common products oil, char and gases were recovered after each run of plastic waste oil pyrolysis. Higher percentage of liquid collection makes this plastic waste potential for liquid fuel extraction. The liquid appear brownish with a strong acrid smell. The liquid was not harmful for human skins, leaving temporary yellowish brown marks, which can be removed by detergent.

No phase separation was found to take place and the color of the liquid products does not depend on the color of the feed materials. There were some permanents gases produced during the pyolytic conversion. The gases had small acid smell and it was free to the atmosphere. The char was black in color and not sticky. It was not like powder but not wetted. There was no bad or acrid smell in the char.

Physical Properties and Chemical Composition Analysis

The physical characteristics of the plastic waste derived pyrolysis oil are shown in Table 2. The energy content of the oil is 39737 kJ/kg. The oil is found to be heavier than water with a density of 751.75 g/m^3 at 30^{0}C.

Table 2. Physical characteristics for plastic waste oil

Properties	Values
Flash point (˚C)	36
Density (kg/m^3)	751.92
GCV (kJ/kg)	39737.88
Fire point (˚C)	40
Viscosity (centipoises)	8.6

Fourier Transform Infra-Red (FT-IR)

The plastic pyrolysis oil and pyrolysis aqueous fraction were analyzed by Fourier Transform Infra-Red (FT-IR) spectroscopic technique. Pyrolysis oil consists of mainly alkanes, alkenes, aromatic rings and phenols [9]. The FT-IR spectrum represents the functional group compositional analysis of plastic derived pyrolysis oil. The presence of hydrocarbon groups C–H; C=C indicate that the liquid has a potential to be used as fuel. Due to absence of functional groups of O-H; C=O; C-O and aromatic compounds the plastic waste oil is not acidic. The presence of hydrocarbon groups in plastic waste oil C-H; C=C; and alcohols indicate that the liquid has a potential to be used. The FT-IR fractional groups and the indicated compound of the liquid product are presented in Table 3.

Table 3. FT-IR fractional groups and the indicated compounds of the pyrolysis oil

Frequency range (cm^{-1})	Functional groups	Class of compound
3050-2800	C-H stretching	Alkanes
1490-1325	C-H bending	Alkan
1020–845	C=C stretching	Alkenes

5. Discussion

Effect of reactor temperature on product yields

Figure 2 shows the variation of percentage mass of liquid, char and gases at different reactor bed temperature for plastic waste pyrolysis with particle size 3.00 cm^2, running time 40 minutes. From this figure it is found that the maximum liquid product yield was obtained at a reactor bed temperature of 350°C and this was 66 wt% of plastic waste feed. With the decrease of reactor temperature at 300°C, the liquid product was decreasing (50 wt% of plastic waste feed) while with the increase of bed temperature at 400°C the liquid product yield was constant (66 wt% of plastic waste feed). With the increase of reactor bed temperature, the solid char yield was decreasing over the temperature range of 150 to 350°C. For the feed particle size of 3.00 cm^2, at a bed temperature of 150°C yielded the maximum percentage of char, 90 wt% of plastic waste feed. At a higher temperature of 400°C, the solid char production was lower, it was found to be 8 wt% of plastic waste feed. Figure 2 also shows that as the reactor bed temperature was increased the gaseous product yield increased. A fixed bed temperature of 400°C yielded the maximum percentage of gas yield of 25 wt% of plastic waste feed.

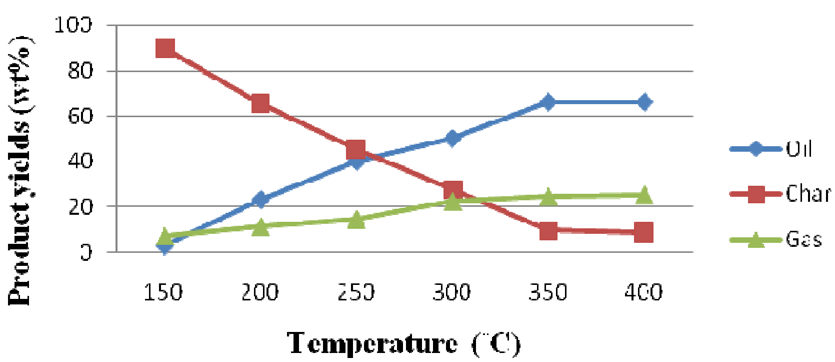

Figure 2. Effect of temperature on product yields for feed size 3 cm^2 and running time 40 minutes.

The reason behind the product distribution was that the lower temperature was not sufficiently high enough for the pyrolysis devolatization reaction to take place completely rendering reduced amount of liquid and gaseous products. Again the higher temperature was causing secondary cracking reaction of the vapors yielding more gas at the cost of the liquid product yield. However, the intermediate temperature was sufficient enough for complete pyrolysis reaction to take place and at the same time this temperature was not high enough for secondary reaction rendering maximum quantity of liquid product with less amount of char residue and gaseous products.

Effect of feed size on product yields

Figure 3 represents the percentage yields of liquid, solid char and gaseous products for different feed size of plastic waste at optimum temperature of 350°C and running time 40 minutes. It was observed that the percentage yield of liquid product was maximum 66 wt% of plastic waste feed for particle size of 3.00 cm^2 with a solid char product of 9 wt% waste. The particle size of 13 cm^2 produced a percentage yield of liquid product of 64 wt% of dry plastic waste feed with a solid char product of 11 wt%. The large particle size of 32 cm^2 produced percentage yield of liquid and char products 65 wt% and 10 wt% respectively. Figure 3 represents that the particle size has not significant effect on the product distribution for plastic waste pyrolysis. This may be due to the fact that the thickness of plastic waste feed is same at all the portions.

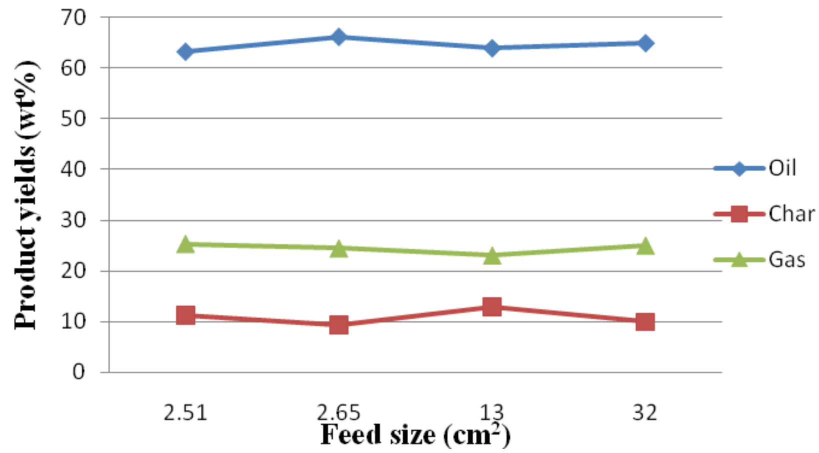

Figure 3. Effect of feed size on product yields for temperature 350°C and running time 40 minutes.

Effect of running time on product yields

Figure 4 shows the variation of product yields with respect to running time at optimum reactor temperature 350°C for feed particle of size 3.00 cm^2. The maximum liquid product was 66 wt% of plastic waste feed while the solid char product was 10 wt% for running time 40 minutes.

It is observed that for running time less than of 40 minutes the liquid yield is reduced due to incomplete pyrolysis reaction of feed. For the running time above 40 minute the liquid yield is almost constant with slight increase in gases and decrease in char yields. Thus it may be concluded that the pyrolysis of solid feed plastic particle is completed within 40 minute of running time.

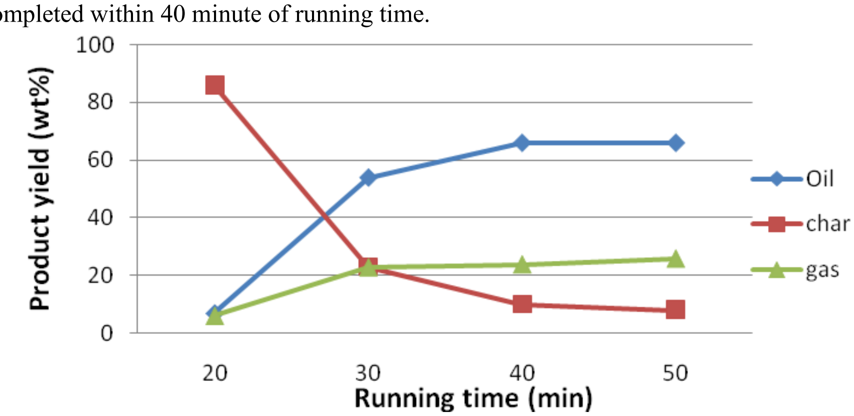

Figure 4. Effect of running time on product yields for feed size 3 cm^2 and temperature 350°C.

Figure 4 also represent that the char drop rapidly at 30 minutes and then slowly. This is because the pyrolysis devolatization reaction rapidly takes place at this time. So maximum liquid oil was convert from plastic at this time.

6. Conclusions

This report investigated the design of plastic to oil converter and produce oil and performance study of the oil and comparison with others. The results of this report may be summarized as follows:

- Plastic oil is produced from plastic waste by pyrolysis process.

- Maximum 66 wt% productions were found from 150g plastic waste at 350˚C.
- The higher temperature and longer running time contributes to secondary reactions results in more gaseous products with the expense of liquid while char yields remain almost constant.
- The fuel properties of pyrolysis liquids such as density, flash point, fire point and GCV are found almost comparable to petroleum fuels.
- The FT-IR spectrum shows that the liquids are dominant with pronounced functional groups which indicate the presence of alkenes. The liquid has a good potential to be used as fuel.

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