

Pyrolysis Of Polystyrene Wastes For Pyrolytic-Oil Recovery

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Abstract

Polystyrene wastes was pyrolyzed in a directly heated fixed-bed reactor under nitrogen atmosphere. The weight loss of the biomass at different temperature was deduced from the thermogravimetric analyzer (TGA). From TGA results, it was inferred that maximum devolatilization takes place at pyrolysis temperature of 400°C. The effects of pyrolysis temperature on the pyrolysis of the PS were also studied in a fixed bed pyrolysis reactor. Pyrolysis runs were performed using reactor temperatures between 400°C, 450°C and 550°C with heating rate of about 10°C min⁻¹. As the pyrolysis temperature was increased, the percentage mass of char decreased while gas product increased. The product yields were significantly influenced by the process conditions. The pyrolytic-oil obtained at 450°C, at which the liquid product yield was maximum, was analyzed.

Keywords: wastes, polystyrene, pyrolysis, fixed-bed reactor, pyrolytic-oil, fuel.



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1.0 Introduction

The world population growth and technology advancement has led to severe increase in energy demand. Worldwide, fossil such as crude oil, natural gas or coal are the main sources of huge amounts of energy supply. This source of energy diminishes gradually since they are not renewable. In order to sustain the utilization of fossil fuel it must be utilized in a cost effective manner. Suitable waste management practice is an essential component for converting waste to wealth. Plastics are derivatives of petroleum and have played a key role in changing the quality of human life because of its low cost, ease of processing and light properties. Consequently, the amount of waste generated from plastic is increasing and this state poses severe environmental challenges.

In 2015, global plastic production reached 322 million tons, a dramatic increase compared to the 279 million tons produced in 2011 (Miandad et al., 2016). These non-biodegradable waste materials have resulted into obstruction of sewer, drainage channels and choking of water bodies. Methods of waste disposal like land filling and incineration tends to cause problems such as pollution of ground water and release of poisonous gases. It is also expensive and non-biodegradable in nature (Al-Salem et al., 2017). Another waste disposal technique is through recovering. This method converts waste materials into products that can be reused and leads to reduction in cost of waste disposal. Although, recycling may be a possible route but the end products are usually of low quality. There are two main types of recycling: chemical and mechanical. Mechanical recycling can be applied mostly in single individual polymer plastic waste, while chemical recycling can be done on more complex and contaminated plastic waste. Chemical recycling, or feedstock recycling, aims to chemically degrade plastic waste into its monomers or other chemicals (such as alternative fuels). Chemical recycling can be done by conventional refinery processes such as gasification, pyrolysis, hydrocracking and catalytic cracking. The pyrolysis procedure is one of the most favorable technologies in the conversion of waste plastics into high quality liquid oil. Through pyrolysis, plastic polymers are thermally decomposed by heating in the presence of inert atmosphere. The main products of the pyrolysis process are gaseous and liquid, producing only a small quantity of solid. The quantity and quality of the pyrolysis products depend on the waste plastics composition and the process parameters (temperature, residence time, catalyst, etc.).

During the process pyrolysis, organic matter and other materials such as plastic remnant are converted into energy (pyrolysed oil) and valuable product (char) (Demirbas 2004; Bartoli et al., 2015; Rathore et al., 2016). The process can be performed by using different types of reactor such as tube reactor (Miskolczi et al., 2009), rotary kiln reactor (Li et al., 1999), microwave reactor (Undri et al., 2015), fixed bed reactor (Ringer et al., 2006), semi batch reactor (Lopez et al., 2011), and batch reactor (Syamsiro et al., 2014). Batch and semi-batch reactors are commonly used at laboratory scale due to their easy operation, simple design, and safety point of view. However, at commercial scale, continuous pilot reactors such as fluidized bed and spouted bed reactors are used with continuous plastic feeding, temperature, reaction time, heating rate, particle size, feedstock composition and moisture content are some of the factors that affect the yield and quality of product.

Plastic materials are made up of synthetic or semi synthetic organic compounds that can be redesigned into desired shapes, because of its complex molecular structure and high molecular mass. Plastics are the two major classes; thermosets and thermoplastics. Thermosets are cooled and hardened after undergoing heating; they retain their shapes and cannot return to their original form, they are used in applications where strength and durability is highly required like in the automobile and aircraft industry. Example includes; polyesters, polyurethanes, epoxy resins and phenolic resins. Thermoplastics are less rigid, they soften when heated and return to their original form upon cooling, they can be moulded into various forms. Example includes; polyethylene terephthalate (PET or PETE), polypropylene (PP), low density polyethylene (LDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC) and polystyrene (PS). Plastics are available in large quantities in the environment as waste and occur in various forms. Hence the use of plastics as biomass will go extensively in fuel production due to plenty of adequate raw materials.

2.0 Methodology

Polystyrene (PS) was collected from student's residential houses Gidan kwano (G.k.) Futminna Niger state and washed, cleansed and dried to remove impurities such as dust and certain chemical which can affect the experiment. The resulting sample was shredded to smaller pieces this is to increase the plastic surface area for ease of melting. It was again washed to increase the purity of the feed and achieve proper product distribution.

The effects of temperature on product yield at 400, 450°C, 500°C and 550°C were used. The boat-like metallic container was filled with 40g of PS plastic pellet and was transferred into the reactor (see Figure 1). The system in the reactor was then purged using nitrogen gas for 5min heat was applied to the reactor and the temperature was adjusted 450°C. The setup was then allowed for 30min during which oil is expected to be formed. After 30min has elapsed the furnace is switched off and the reactor is allowed to cool so that the char and remaining liquid can be gotten and the volume or weight of the oil was then measured so that the yield was calculated using the expression I, II and III.

$$\% \text{ yield of oil} = \frac{\text{mass oil}}{\text{mass of plastic feed (40g)}} \times 100 \dots\dots\dots \text{I}$$

$$\% \text{ Yield of char} = \frac{\text{mass of char}}{\text{mass of plastic feed (40)}} \times 100 \dots\dots\dots \text{II}$$

$$\% \text{ Yield of gas} = \% \text{ yield of oil} + \% \text{ Yield of char} \dots\dots\dots \text{III}$$

3.0 Results and Discussion

3.1 Thermo gravimetric Analysis

Figure 2 shows the boiling point range distribution of pyrolysis oil produced from thermal decomposition of PS (TGA curve). At a temperature of 30°C to about 100°C showed the evaporation of moisture (water content). Further increase in temperature to 400°C showed the release of volatile gases. The decomposition PS material started at 400°C and reached its maximum decomposition point of 90% at a pyrolysis temperature of 450°C. As the pyrolysis temperature continues to raise from 450°C to 750°C it can be observed that there was 0% weight loss. At this point, complete decomposition of plastic with very small amount of solid char as residue was attained. Similar occurrences can be observed in the DTG curve, where an endothermic peak is obvious, in relation to the decomposition of the PS plastic. The melting temperature started around 300°C, melting peak at around 350°C and stopped at 400°C. The variation in pyrolysis temperature at a constant reaction time of 60 min using the fixed bed pyrolysis reactor also gave different yields of pyrolysis oil. In Table 1; at lower pyrolysis temperature 400°C, the char yield was highest (17.7%), while the gas yield was 10% and the liquid oil yield was 72.3%. While, at higher pyrolysis temperature of 500°C, the gas yield was highest (23.6%) and the char yield was lowest (3.7%). The highest liquid oil yield 76.4% was obtained at 450°C. TGA analysis also confirmed that 450°C was the optimum temperature, but with higher maximum liquid oil yield of 90% compared to the oil obtained from the pyrolysis reactor 76.4%. This observation may be clarified by the controlled conditions and very small scale of TGA experiment when compared to the pyrolysis reactor system. The yield pyrolysis oil obtained, especially the styrene yield increased with an initial increase in temperature and time, and after a certain temperature and time the oil yield started to decrease. Jung et al., (2013) and Mo et al., (2014), explained this phenomenon that after achieving optimum temperature, some secondary reactions such as polyaromatic formation reactions are started during PS pyrolysis, which decrease the liquid oil and styrene yield. While, the phenomenon of increased gases production at higher temperature was explained by (Lopez et al., 2011), that the strong cracking of C-C bonds at higher, temperature increases the production of lighter hydrocarbons with short carbon chain compounds. Moreover, according to Li et al., (1999) and Lopez et al., (2011), temperature lower than 450°C increases the char and decreases the liquid oil yield and temperature in excess of 500°C increases the gases and lowers the liquid oil.

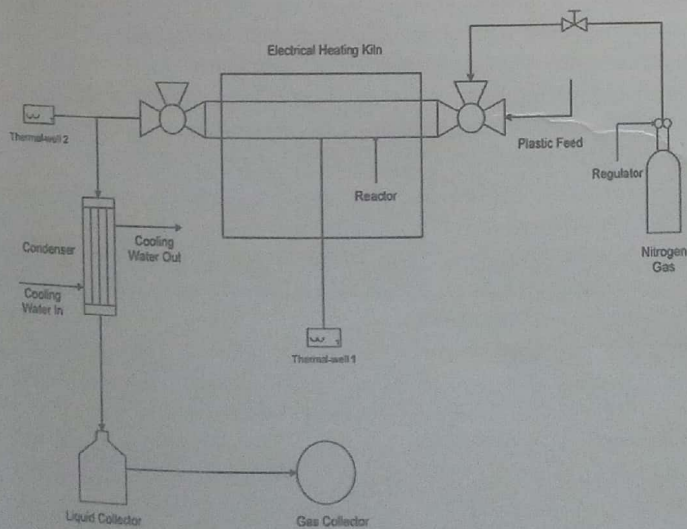


Figure 1. Schematic representation of the experiment setup

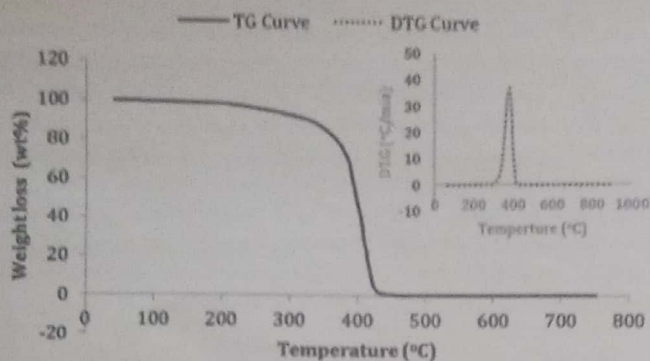


Figure 2 : Thermo and differential thermo gram of polystyrene PS at 10°C/min heating rate.

3.2: Effect of temperature

The pyrolysis of PS yielded pyrolysis oil, char and gases at 400°C at 60 mins were approximately 72.3 wt%, 17.7 wt% and 10 wt%, for liquid, solid and gas respectively and were similar to what has been reported previously by Miandad et al. (2016). During this study, the liquid yield was observed to be higher than solid and gas by 54.6wt% and 62.3wt% respectively. A comparative product yields at different temperature has been presented in Table 1. The yield of liquid oil obtained at 450°C, was observed to be higher than that of 400°C and 500°C. Therefore, it can be inferred that the optimum temperature was obtained at 450°C. The solid yield decreased as the pyrolysis temperature was raised, 17.7wt% at 40°C to 3.7wt% at 500°C. The decline in solid yield with raising temperature could either be attributed to main degradation of PS residue or via secondary degradation. The secondary degradation of the solid at higher pyrolysis temperature may also attributed to non-condensable gases. These lead to increase gas yield at higher temperature.

Table 1: Effect of temperature on the pyrolysis of polystyrene (PS).

	PYROLYSIS BIOMASS (g)	TEMPERATURE (°C)	TIME (min)	PERCENTAGE WEIGHT OF PYROLYSED PRODUCT (%)		
				LIQUID	SOLID	GAS
1	60	400	60	72.3	17.7	10.0
2	60	450	60	76.4	8.0	15.6
3	60	500	60	72.7	3.7	23.6

3.3: Effect of reaction time and heating rate on PS

The experiments were carried out at five different heating rate of 10, 20, 30, 40 and 50 °C/min at a constant reaction time of 60 mins at optimum pyrolysis temperature of 450°C to investigate the effect on PS decomposition. The purpose of using different heating rates was to find the optimum heating rate for the yield pyrolysis of oil from pyrolysis PS waste. The result (Table 2) showed significant difference in oil yield from 10 to 50°C/min heating rate. There was a gradual increase in oil yield, the lowest yield was observed at 10°C/min to be 33.3wt% while the highest yield at 50°C/min was 75wt%. The highest yield of char was obtained at heating rate of 10°C/min while the lowest yield was at 50°C/min. It can be stated that the heating rate shows similar yield for gas. Thus 50°C/min is suggested as the heating rate as it gave the highest yield of oil. The lowest heating rate 10°C/min produced more char and less liquid

oil, suggesting that a 10°C/min reaction time is not sufficient to convert PS feedstock to liquid oil at complete conversion efficiency. Related results were observed and reported by Lopez et al. (2011) on the yield of liquid oil with different heating rate. However, the effect of heating rate on pyrolysis is also one of the functions of the reactor dimensions and the heat transfer rate from the heating elements to the PS feedstock within the reactor. Therefore, the heating rate may change with other reactor configurations, especially of a continuous flow reactor, which would be the type of reactor that are mostly used in industrial application of the pyrolysis process (Miandad et al., 2016).

Table 2: effect of reaction time and heating rate on polystyrene (PS)

PYROLYSIS BIOMASS (g)	TEMPERATURE (°C/min)	HEATING RATE (%)	PERCENTAGE WEIGHT OF PYROLYSED PRODUCT (%)		
			LIQUID	SOLID	GAS
60	450	10	33.30	13	53.58
60	450	20	45.83	11.50	42.67
60	450	30	55.83	10.80	33.33
60	450	40	65.00	10	24.92
60	450	50	75.00	8.33	16.67

Conclusions

The yield of PS products is influence by the experimental conditions, such as pyrolysis temperature and heating rate of the plastic. In general, high temperature pyrolysis favors the production of gaseous products, moderate temperature pyrolysis favours oil yield, whereas low temperatures favor increased char yields. The highest liquid was obtained at the optimum temperature of 450°C.

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