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Influence of waste sorting on the effectiveness of polymeric waste pyrolysis

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Abstract

Pyrolysis of polymeric wastes, including waste plastic bottles, discarded rubber tyres and pure water sachets, is one of the environmental-friendly processes for waste valorization. However, continuous effort must be made to reduce the cost implication of the pyrolysis process in terms of time, money and energy requirement. Based on this premise, this study examined the justification regarding heat absorption rate and product yield, for sorting polymeric waste mixture before the pyrolysis process. The objective was achieved by carrying out pyrolysis of the separated and mixed plastic bottle, rubber tyre and water nylon sachet wastes using a semi batch pyrolysis system. The results indicated that at residence time of 100 minutes, maximum heat absorption rates of 128.63 and 89.38 kJ/min were obtained for pyrolysis of separated and mixed wastes, respectively, of plastic bottles and rubber tyres. For the pyrolysis of separated and mixed wastes of plastic bottles, rubber tyres and water nylon sachets; maximum heat absorption rates of 144.56 and 119.46 kJ/min, respectively, were obtained. It was also observed that the amounts of pyrolytic products produced after the pyrolysis of the separated polymeric wastes were greater than the amounts obtained after the pyrolysis of the mixed polymeric wastes. This indicates that sorting polymeric wastes into different categories before pyrolysis contributes to effective pyrolysis process.

Keywords: Waste valorization; Heat absorption; Polymeric wastes; Waste sorting; Pyrolysis

1. Introduction

Indiscriminate landfill disposal or open burning of polymeric wastes such as plastic bottles, rubber tyres and pure water nylon sachets is a common phenomenon in most developing countries with consequent adverse effects on the environment and human health. The slow degradation rate of most polymeric wastes have made their disposal through landfilling challenging as they can litter the land for years for them to be decomposed naturally [1]. The difficulty associated with the disposal of polymeric materials could be due to the durability property which is one of the desirable properties that makes the polymeric materials to have wide applications in areas such as medical, electronics, construction, and automobiles, among others [2]. Meanwhile, pyrolysis process has been studied and applied for the production of valuable products including gaseous fuel, liquid oil and char from non-biodegradable polymeric wastes [3-10]. Pyrolysis process, which has been considered to be more environmental friendly than either landfilling, open burning or ocean dumping for management of polymeric wastes; involves the thermal or catalytic degradation of long chain polymeric molecules into less complex smaller molecules in the absence of air and at increased pressure and temperature for certain duration [11].

Although a lot of work has been carried out on conversion of polymeric wastes into various valuable products, there is a dearth of published literatures on the comparative analysis of the effects, regarding heat absorption rate, as well as

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the product yields; of conducting pyrolysis process on separated and mixed polymeric wastes. Therefore, the main objective of the study was to evaluate the effect of waste sorting on the heat absorption rates of polymeric wastes and the product yields, which could be used as an indicator for the effectiveness of the pyrolysis process. Having an effective pyrolysis process for polymeric wastes will create a viable platform for polymeric waste valorization.

2. Materials and methods

2.1. Materials

The feedstock used for the study included plastic bottle wastes, rubber tyre wastes and pure water nylon sachet. The wastes were collected from dumpsites and food vendors within the premises of Lagos State University Epe campus and the neighboring communities. Samples of the polymeric wastes were washed, dried and shredded. The pyrolysis system comprised of gas-fired furnace, pyrolysis reactor, heavy oil condenser, two cyclones for light oil condensation, scrubber for gas cleaning, and gas storage bag (Figures 1, 2a and 2b). A flow meter was connected between the gas scrubber and the gas storage bag. The pyrolysis reactor was a cylindrical steel vessel with thickness, internal diameter and capacity of 12 mm, 250 mm, and 25 kg of shredded polymer, respectively. The reactor vessel was closed with two pairs of flanges (top and bottom). There was a hole in the center of the reactor vessel which served as the gas exit. Solar-power temperature sensor was inserted in the reactor vessel to measure the temperature in the pyrolysis reactor (Figure 3). Chemical balance, measuring cylinder, and stop clock were also used during the pyrolysis experiment for measuring feedstock weight, cooling water volume, and progressing reaction time, respectively. Empty containers were prepared for the collection of condensed liquid oil and char.

2.2. Experimental Procedure

Before the pyrolysis of the polymeric wastes, 20 liters of clean water were measured into each of the two cyclones used for light oil condensation. The pyrolysis process was in two phases; the first phase was the pyrolysis of separated polymeric wastes including plastic bottle wastes (3.5 kg), rubber tyre wastes (3.5 kg) and pure water nylon sachet (1 kg) while the second phase involved the pyrolysis of mixed polymeric wastes including mixture of plastic bottle wastes (3.5 kg) and rubber tyre wastes (3.5 kg), as well as, mixture of plastic bottle wastes (3.5 kg), rubber tyre wastes (3.5 kg) and water nylon sachet (1 kg). The main reactor containing the polymeric wastes was placed inside liquefied petroleum (LPG) gas-fired furnace for semi-batch pyrolysis process at a temperature range between 25 and 800 ^{0}C and residence times of 20, 40, 60, 80 and 100 minutes. The heating rates for the respective residence times within the temperature range were determined.

At the end of the pyrolysis experiment, the pyrolysis products (liquid oil, non-condensable gas and char) formed within the temperature range were also collected and measured. The furnace was left to cool down to room temperature (25 ^{0}C) before the char left in the reactor vessel was removed.
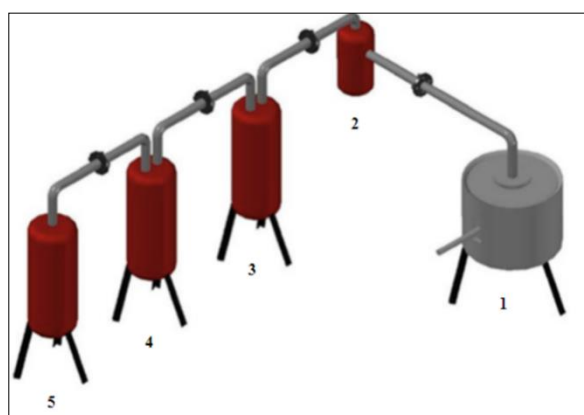
1: Pyrolysis reactor enclosed in gas-fired furnace; 2: Heavy oil condenser; 3: First cyclone for light oil condensation; 4: Second cyclone for light oil condensation; 5: Scrubber for gas cleaning

Figure 1 Pyrolysis system set-up

Figure 2a Gas storage bag connected to the gas scrubber (before experiment)

Figure 2b Gas storage bag filled with pyrolysis gas (after experiment)

Figure 3 Gas-fired furnace with attached solar-powered temperature sensor

3. Results and discussion

Results from the experimental work are given in Tables 1 to 3. The heat absorption rate was calculated using Equation

Table 1 Comparison between pyrolysis heat absorption rates for separated and mixed plastic bottle wastes and Rubber tyre wastes

S/N	Reside-nce Time (min)	Heat Energy absorbed by polymeric wastes (KJ)				Heat absorption rate (KJ/min)	
		Separated wastes pyrolysis			Mixed wastes pyrolysis	Separated wastes pyrolysis	Mixed wastes pyrolysis
		Plastic bottle wastes (3.5 kg)	Rubber tyre wastes (3.5 kg)	Total (7 kg)	Mixture of plastic bottle wastes and rubber tyre wastes (7 kg)	Total for the separated wastes Pyrolysis (7 kg)	Mixture of plastic bottle wastes and rubber tyre wastes (7 kg)
1	20	316.58	196.98	513.56	1364.16	25.68	68.21
2	40	571.73	1217.00	1788.73	1834.56	44.72	45.86
3	60	1422.23	3172.79	4595.02	2281.44	76.58	38.02
4	80	2749.95	4918.29	7668.24	7150.08	95.85	89.38
5	100	6615.00	6247.91	12862.91	3292.80	128.63	32.93

1 while the heat absorbed by the polymeric wastes is given by Equation 2;

$$eat\ absortion\ rate = \frac{Heat\ absorbed\ by\ polymeric\ wastes}{\mathrm{Re}\ sidence\ Time} \quad (1)$$

$$Q = m * c * (T_1 - T_0) \quad (2)$$

where Q, m, c, T_1 and T_0 are heat absorbed by polymeric wastes, mass of the polymeric wastes, specific heat capacity of polymeric wastes, pyrolysis temperature(final temperature) and ambient temperature (initial temperature), respectively.

For the separated polymeric wastes of plastic bottle wastes and rubber tyre wastes (Table 1); the heat absorption rate for separated polymeric wastes were observed to increase from 25.68 to 128.63 kJ/min as the residence time was increased from 20 to 100 minutes. Regarding the mixed polymeric wastes of plastic bottle wastes, rubber tyre wastes and water sachets; the heat absorption rate for mixed polymeric wastes decreasd from 68.21 kJ/min at residence time of 20 min to 38.02 kJ/min at residence time of 60 minutes. There was an abrupt increase of the heat absorption rate to 89.38 kJ/min at residence time of 80 minutes before it decreased to 32.93 kJ/min. In Table 2, the results for the pyrolysis of separated and mixed wastes of plastic bottle wastes, rubber tyre wastes and water nylon sachet wastes were presented. Similar to the observation during the pyrolysis of only rubber tyre and plastic bottle wastes; the results in Table 2 showed that the heat absorption rate for separated polymeric wastes increased with increase in residence time while having maximum heat absorption rate of 144.56 kJ/min occur at residence time of 100 minutes. For the mixed wastes of plastic bottle wastes, rubber tyre wastes and water nylon sachet wastes; the heat absorption rate was observed to decrease with increase in the residence time. For the mixed wastes, the maximum heat absorption rate of 119.46 kJ/min occurred at residence time of 20 minutes.

Table 2 Comparison between pyrolysis heat absorption rates for separated and mixed plastic bottle wastes, rubber tryre wastes and water nylon sachet wastes

S/N	Resid-ence Time (min)	Heat Energy absorbed by polymeric wastes (KJ)					Heat absorption rate (KJ/min)	
		Separated wastes pyrolysis				Mixed wastes pyrolysis	Separated wastes pyrolysis	Mixed wastes pyrolysis
		Plastic bottle wastes (3.5kg)	Rubber tyre wastes (3.5 kg)	Water nylon sachet wastes (1kg)	Total for the separated wastes (8 kg)	Mixture of plastic bottle, rubber tyreandwater nylon sachet wastes (8 kg)	Total for the separated wastes (8 kg)	Mixture of plastic bottle, rubber tyreandwater nylon sachet wastes (8 kg)
1	20	316.58	196.98	216.20	729.76	2389.25	36.49	119.46
2	40	571.73	1217.00	1000.50	2789.23	3064.13	60.73	76.60
3	60	1422.23	3172.79	1481.20	6076.22	3879.61	101.27	64.66
4	80	2749.95	4918.29	1575.50	9243.74	5074.71	115.55	63.33
5	100	6615.00	6247.91	1592.76	14455.67	5552.75	144.56	55.53

The amounts of products produced after the pyrolysis processes for the different polymeric wastes were presented in Table 3. The results showed that the amounts of products (gaseous fuels, liquid oils and char) obtained using polymeric wastes mixtures as feedstock for pyrolysis were less than separated polymeric wastes as feedstock

Table 3 Amount of products produced from pyrolysis of separated and mixed polymeric wastes

S/N	Separated waste pyrolysis	Pyrolysis liquid oil (kg)	Pyrolysis gas volume (m3)	Amount of char (kg)
1	Plastic bottle wastes (3.5 kg)	0.1751	0.3435	1.05
	Rubber tyre wastes (3.5 kg)	0.7715	0.936	2.00
	Water nylon sachet wastes (1 kg)	0.1430	0.012	No char
2	Separated plastic bottles and rubber tyre wastes (7kg)	0.9466	1.2795	3.05
3	Mixed plastic bottles and rubber tyre wastes (7kg)	0.405	0.6470	1.60
4	Separated plastic bottles, rubber tyre and water nylon sachet wastes (8 kg)	1.090	1.2915	3.05
5	Mixed plastic bottles, rubber tyre and water nylon sachet wastes (8kg)	0.50	1.2040	1.6

.For the separated plastic bottle and rubber tyre wastes, the amounts of gaseous fuels, liquid oils and char produced from 7kg of the total wastes were 1.2795m³, 0.9466kg and 3.05 kg, respectively, while for the mixed wastes of plastic bottle and rubber tyre wastes, the amounts of gaseous fuels, liquid oils and char produced from 7kg of the total wastes were 0.6470m³, 0.405 kg and 1.60 kg, respectively. For the pyrolysis of plastic bottle wastes, rubber tyre wastes and water nylon sachet wastes; the amounts of products obtained when the wastes were pyrolysed separately were 1.2915 m³, 1.09 kg and 3.05kg for gaseous fuel, liquid oil and char, respectively. For the mixed wastes of of plastic bottle wastes, rubber tyre wastes and water nylon sachet wastes; the amounts of gaseous fuel, liquid oil and char obtained were 1.204 m³, 1.50kg and 1.6kg, respectively.

4. Conclusion

The research sought to determine whether sorting of waste materials at the point of collection was justified in terms of the heat absorption rate of the polymeric wastes and the pyrolytic products obtained from the process. From the results obtained, it was observed that having a mixture of polymeric wastes as feedstock for pyrolysis would not be effective as having the mixtures separated into individual constituents for pyrolysis. It was concluded from the findings that waste materials for pyrolysis should be sorted at collection point before they are pyrolysed.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest with publication of the manuscript.

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