Thermal Cracking of Polyethylene Terephthalate (PET) Plastic Waste

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Abstract. In 2015, the United Nations Environment Program (UNEP) revealed that there are 280 million tons of plastic produced globally each year. This research was conducted to convert plastic waste to be useful products. Polyethylene Terephthalate (PET) is converted into gas and coke using thermal cracking method and a stainless steel batch type reactor. Looking for the effect of temperature variations on the thermal cracking of PET plastic waste and studying the kinetic phenomena are the purpose of this research. A total of 40.17 grams of Polyethylene Terephthalate (PET) plastic waste was cracked in a batch reactor at 450, 500 and 550 °C for 15, 30 and 45 minutes. The highest percent yield of gas (89.92%) was resulted at 30 minutes of reaction time and 550 °C of the reaction temperature. The highest percent yield of coke (26.01%) was resulted at 45 minutes of reaction time and 500 °C of the reaction temperature. The activation energy for the highest percent yield of coke, 26.01% is -9,257701 kJ/mol, otherwise the process needs to be revised to get the positive activation energy.

1. Introduction

Energy conversion from waste materials such as plastic waste is increasingly being developed at this time. The types of plastic that are often used are PP (Polypropylene), PE (Polyethylene) and PET (Polyethylene Terephthalate). The United Nations Environment Program (UNEP) revealed that losses from the disposal of plastic waste have reached USD13 billion, or as much as Rp. 153 trillion per year. In 2015, a study by UNEP and its partners estimated that 280 million tons of plastic were produced globally each year. Based on Indonesia is ranked second in the world as a producer of plastic waste to the sea which has reached 187.2 million tons after China which reached 262.9 million tons. Converting plastic waste into alternative fuel oil is one way to deal with plastic waste itself [1].

In general, researches that have been done to convert plastic waste into energy are the research that wants to produce oil and gas fuel products, where fuel products can be form as hydrocarbons, such as gasoline or diesel and gas with an amount of C less than 5 [2-6].

Various attempts have been made to reduce the growth of plastic waste such as incineration and gasification processes. But, in these technologies, the process temperature is too high and the...
combustible gas is very dangerous. Finding other method to deal with the amount of plastic waste is a better way, one of that method is processing plastic waste to be alternative fuel by pyrolysis [7-10].

Polystyrene and PET are types thermo-chemically treated plastic (as a recycling route) through pyrolysis in dynamic thermography. The behavior of the material is analyzed, especially the kinetics of the depolymerization reaction which is determined through general kinetics theory [8-10].

2. Methodology

2.1. Instruments and materials
This research used cracking reactor from stainless steel. In addition, the equipment used in this research are included mortals, 100 mesh filters, digital scales, glassware, porcelain crushers, ovens, magnetic stirrers, Welch Duo Seal 1400 vacuum pumps, cylindrical furnaces. All of these tools are available at the Energy and Nano Materials Center, University of Jambi.

Polyethylene Terephthalate (PET) waste is obtained from the Bank Sampah Bangkitku, and then nitrogen gas and water.

2.2. Procedure
PET waste is washed and dried before sizing section by chopper machine. The sample needs to be cut into small pieces / chopped up to ± 2cm in size. Samples were put into the reactor with an initial mass of 40.17 grams. Batch reactor has function as a container where the cracking reaction takes place with the variations of temperatures as 450 °C, 500 °C and 550 °C, and the cracking times as 15 minutes, 30 minutes and 45 minutes.

3. Results and discussions

3.1. Conversion of Gas and Coke at 450°C

3.1.1. Gas. By comparing weight of gas with the initial sample weight, the percentage of gas can be obtained. Based on that comparison, at temperature 450°C, the highest conversion of gas was obtained 81.88% where the time of thermal cracking was 15 minutes. Followed by 45 minutes with 79.71%. Lastly, the lowest conversion of gas was obtained 74.91% where the time of thermal cracking was 30 minutes.

From this comparison, it can be made a graph of the relationship between the percentage of gas and cracking times.

![Figure 1. Graph of Gas Percentage at 450°C](image)

3.1.2. Coke. By comparing weight of coke with the initial sample weight, the percentage of coke can be obtained. Based on that comparison, at temperature 450°C, the highest conversion of coke was obtained 25.09% where the time of thermal cracking was 30 minutes. Followed by 45 minutes with...
20.29%. Lastly, the lowest conversion of coke was obtained 18.12% where the time of thermal cracking was 15 minutes.

![Graph of Coke Percentage at 450°C](image1.png)

**Figure 2.** Graph of Coke Percentage at 450°C

3.2. Conversion of Gas and Coke at 500°C

3.2.1. Gas. Using the same method as temperature 450°C. Based on that comparison, at temperature 500°C, the highest conversion of gas was obtained 80.31% where the time of thermal cracking was 15 minutes. Followed by 30 minutes with 77.32%. Lastly, the lowest conversion of gas was obtained 73.99% where the time of thermal cracking was 45 minutes.

From this comparison, it can be made a graph of the relationship between the percentage of gas and cracking times.

![Graphic of gas percentage at 500°C](image2.png)

**Figure 3.** Graphic of gas percentage at 500°C

3.2.2. Coke. Using the same method as temperature 450°C. Based on that comparison, at temperature 450°C, the highest conversion of coke was obtained 26.01% where the time of thermal cracking was 45 minutes. Followed by 30 minutes with 22.68%. Lastly, the lowest conversion of coke was obtained 19.69% where the time of thermal cracking was 15 minutes.
3.3. Conversion of Gas and Coke at 550°C

3.3.1. Gas. Using the same method as temperature 450°C. Based on that comparison, at temperature 550°C, the highest conversion of gas was obtained 89.82% where the time of thermal cracking was 30 minutes. Followed by 15 minutes with 80.53%. Lastly, the lowest conversion of gas was obtained 73.81% where the time of thermal cracking was 45 minutes.

From this comparison, it can be made a graph of the relationship between the percentage of gas and cracking times.

3.3.2. Coke. Using the same method as temperature 450°C. Based on that comparison, at temperature 550°C, the highest conversion of coke was obtained 26.19% where the time of thermal cracking was 45 minutes. Followed by 15 minutes with 19.47%. Lastly, the lowest conversion of coke was obtained 10.16% where the time of thermal cracking was 30 minutes.

From this comparison, it can be made a graph of the relationship between the percentage of gas and cracking times.
3.4. Comparison of gas and coke percentage at varied temperatures and times

3.4.1. Gas Product. By comparing weight of gas with the initial sample weight, the percent of gas can be obtained. Based on that comparison, at temperature 450 °C, 500 °C and 550 °C, the highest yield of gas was obtained 89.82% where the time of thermal cracking was 30 minutes at temperature 550 °C and the lowest yield of gas was obtained 73.99% where the time of thermal cracking was 45 minutes at temperature 500 °C. From this comparison, it can be made a graph of the relationship between the percentage of gas and cracking times. Figure 7 shows the comparison of gas percentage at varied temperatures and times.

3.4.2. Coke Product. By comparing weight of coke with the initial sample weight, the percent of coke can be obtained. Based on that comparison, at temperature at temperature 450 °C, 500 °C and 550 °C, the highest yield of coke was obtained 26.19% where the time of thermal cracking was 45 minutes at temperature 550 °C and the lowest yield of coke was obtained 10.16% where the time of thermal cracking was 30 minutes at temperature 550 °C. Figure 3 shows the comparison of coke percentage at varied temperatures and times.
4. Conclusion
The highest yield of gas was obtained 89.82% where the time of thermal cracking was 30 minutes at 550°C. The lowest yield of gas was obtained 73.81% where the time of thermal cracking was 45 minutes at 550°C. And for coke, the highest yield of coke was obtained 26.01% where the time of thermal cracking was 45 minutes at 500°C. The lowest yield of coke was obtained 10.16% where the time of thermal cracking was 30 minutes at 550°C. Activation Energy from coke product in thermal cracking using stainless steel batch reactor is -9,257701 kJ/mol.K, it shows the process should be revised to get the positive activation energy and for gas product activation energy cannot be determined.

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References
[1] Jambeck J R, Geyer R, Wilcox C, Siegler T R, Perryman M, Andrady A, et al. 2015 Science 347 768
[2] Nazarudin 2012 Doctor of Philosophy (University College London, London)
[3] Yan G, Jing X, Wen H, and Xiang S 2015 Energy & Fuels 29 2289
[4] Goad M A and Ali R 2017 Int. J. Eng. Inf. Syst. (IJEIS) 1 56
[5] Al-Sabagh A M, Yehia F Z, Eshaq G, Rabie A M, and ElMetwally A E 2016 Egypt. J. Pet. 25 53
[6] Sarker M, Kabir A, Rashid M M, Molla M, and Mohammad A S M D 2011 J. Fundam. Renew. Energy Appl. 1
[7] Achilias D S, Roupakias C, Megalokonomos P, Lappas A A, and Antonakou EV 2007 J. Hazard. Mater. 149 536
[8] Almeida D and Marques M d F 2016 Polimeros 26 (1) 44
[9] Al-Salema SM, Antelava A, Constantinou A, Manos G, and Dutta A 2017 J. Environ. Manag. 197 177
[10] Santella C, Cafiero L, Angelis D D, Marca F L, Tuffi R, and Ciprioti S V 2016 Waste Manag. 54 143
[11] Al-Salem S M, Lettieri P, and Baeyens J 2009 Waste Manag. 29 2625
[12] Peterson J D, Vyazovkin S, and Wight C A 2001 Macromol. Chem. Phys. 202 775
[13] Alsobaai A M. 2013 J. King Saud Univ. – Eng. Sci. 25
[14] Brems A, Baeyens J, Vandecasteele C, and Dewil R 2011 J. Air Waste Manag. Assoc. 61 721
[15] Gang L, Shunan X, Fang J, Yuguang Z, and Zhigang H 2017 Int J Agric & Biol Eng 10 198
[16] Meng X, Liu W, and Meng T 2018 Adv. Mater. Sci. Eng. 2018
[17] Benarbia A, Elidrissi A, Ganetri I, and Touzani R 2014 J. Mater. Environ. Sci. 5 1262