Physical properties analysis of the liquid produced by polystyrene pyrolysis

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Abstract. The higher consumption of plastic causes environmental problems. This study was aimed at recycling plastic wastes by using a pyrolysis process with the variables were the ratio of polystyrene mixture and heating rate. The types of polystyrene were used namely, oriented polystyrene (OPS), expanded polystyrene (EPS) and high impact polystyrene (HIPS). Ratios of raw material mixture (OPS: EPS: HIPS) of 1: 0, 0: 1, 0: 0, 1: 2, 1: 1, 1: 2, 1: 1: 1. Heating rate variations were 2 °C/min, 4 °C/min, 6 °C/min, 8 °C/min and 10 °C/min. The analysis was conducted to the physical properties of liquid produced by pyrolysis, namely heating value, kinematic viscosity, density, and flash point. The heating value tended to increase with the increase of heating rate, the highest heating value was obtained at a ratio of a mixture of 2: 1: 1. The lowest kinematic viscosity value was at the ratio of a mixture of 1: 2: 1 and 1: 1: 1. Density fluctuated but tended to increase with the increase of heating rate. Flashpoint of the entire sample was below 32.6 °C. The ratio of a raw material mixture and heating rate affected the content of the compound of the liquid fuel produced. These compounds had different physical properties. The difference of physical property of each compound of the liquid fuel would affect the physical properties of the liquid produced by pyrolysis.

1. Introduction
The growth of plastic waste has become a serious social and environmental problem faced throughout the world. Plastic is a non-biodegradable material. The method that can be done to degrade plastics is using thermal and catalytic degradation [1-3].

Polystyrene is the number 2 most commercially used plastic in the world [4]. The types of polystyrene such as High Impact Polystyrene (HIPS), Expanded Polystyrene (EPS) and Oriented Polystyrene (OPS). The difference in the type of polystyrene is based on the process of making and the additives addition that was mixed into the production process [5-7].

Pyrolysis is thermal degradation of wastes without oxygen/air. The Pyrolysis for most of the plastics starts at temperatures around 300°C and for thermosensitive resins even at lower temperatures. Decomposition of polystyrene plastic to become styrene monomer occurred at temperatures of 300-500 °C [8-10]. The focus of this study was to analyze the physical properties of liquid fuels of various polystyrene produced by pyrolysis results at a specific heating rate.
2. Experimental
This study used raw materials of polystyrene waste. The types of polystyrene were used namely Oriented Polystyrene (OPS), Expanded Polystyrene (EPS) and High Impact Polystyrene (HIPS). Each raw material is cleaned, dried and reduced. The size of OPS and HIPS was ± 1 cm² and the diameter of EPS was 3-5 mm. The raw materials ratios of (OPS: EPS: HIPS) of 1: 0: 0, 0: 1: 0, 0: 0: 1, 2: 1: 1, 1: 2: 1, 1: 1: 2, 1: 1: 1. The mass of every sample was 100 g. The temperature of pyrolysis was 350 °C. The heating rate variation was 2 °C/min, 4 °C/min, 6 °C/min, 8 °C/min and 10 °C/min. The pyrolysis process was conducted in a fixed bed reactor as the main tool. The pyrolysis process was conducted for ± 7 hours which was marked by there were no any liquid came out of the condenser. Liquid condensate analyzed for its physical properties are heating value, viscosity and density.

3. Results and Discussions
3.1. The Effect of the Ratios of Mixture and Heating Rate toward Heating Value
Based on Figure 1, the heating value of the fuel did not have any significant difference, the value was between 9700 cal/g to 9950 cal/g, the difference of heating value was caused by the difference of the compound found in the liquid which was produced by pyrolysis. The highest heating value was obtained from the ratio of a mixture of 2: 1: 1, this result indicated that oriented polystyrene had a big role to increase the heating value of fuel which was produced by cracking. Cracking of oriented polystyrene which is at high temperatures will produce the main product of ethylbenzene [14].

![Figure 1. The Effect of Heating Rate and Raw Materials toward Heating Value](image)

Table 1. The dominant chemical composition of pyrolysis products of mixed polystyrene raw materials [14]

| Compounds  | The Raw Material Ratio (OPS:EPS: HIPS) |
|------------|--------------------------------------|
|            | 0:0:1 (A5) | 0:1:0 (B5) | 1:0:0 (C5) | 1:1:2 (D5) | 1:2:1 (E5) | 2:1:1 (F5) | 1:1:1 (G5) |
| Ethylbenzene | 0.00% | 23.85% | 31.88% | 26.36% | 31.10% | 31.28% | 28.00% |
| p-xylene    | 29.02% | 0.00% | 0.00% | 0.00% | 0.00% | 34.22% | 37.08% |
Ethylbenzene and p-xylene compounds have the highest heating value compared to other cracking compounds. This is consistent with research on the heating value of hydrocarbon compounds was conducted by Prosen et al. The heating value of compound of fuel produced by pyrolysis could be seen in Table 2.

| Compounds                  | Heating Value (cal/gram) |
|----------------------------|--------------------------|
| Ethylbenzene               | 10276.26                 |
| p-Xylene                   | 10250.19                 |
| Styrene                    | 10085.45                 |
| 2-phenyl-1propene          | 9836.44                  |
| 1,3-Diphenylpropane        | 9603.34                  |

3.2. The Effect of Ratio of Mixture and Heating Rate toward Kinematic Viscosity

Figure 2 shows the increase in viscosity with increasing heating rate in each mixture. Significant differences were shown by the ratio of the mixture of raw materials, the cracking results with a ratio of 0: 1: 0 and 1: 2: 1 had a higher viscosity value than the results of cracking other ratios. This high viscosity value could happen because the cracking results of both ratios had the main component of styrene, compared to other cracking compounds of styrene which had higher viscosity values.

The lowest viscosity value was shown by the sample with a ratio of a mixture of 1: 1: 1 and 2: 1: 1, this could happen because both samples had the main content of ethylbenzene and p-xylene, both of these compounds had low viscosity values. The viscosity value could be higher than 0.9 cSt because of the effect of the presence of phenylpropane and diphenyl propane. The following was a table of viscosity values of the constituent compounds of fuel.
Table 3. Viscosity Compounds of Constituent Compounds of Fuel [12]

| Compounds       | Viscosity (20°C) cSt |
|-----------------|----------------------|
| Toluene         | 0.590                |
| Ethyl Benzene   | 0.669                |
| p-Xylene        | 0.647                |
| Styrene         | 0.762                |
| Phenylpropane   | 0.980                |

3.3. The Effect of Ratio of Mixture and Heating Rate toward Density

Figure 3 showed the significant effect caused by the difference in the ratio of the mixture of raw material. The highest density value was obtained from the sample with a mixture ratio of 1: 1: 2 at a heating rate of 10 °C/min, which was 0.9167 g/mL, this result was caused by the compound of constituent of fuel that was produced was a compound with a high density of styrene and 1,3 diphenyl propane. The formation of compounds such as diphenyl propene was due to the production process of high impact polystyrene which required polybutadiene additives. Polybutadiene was found in high impact polystyrene also experiences the cracking along with polystyrene and produced hydrocarbons with a higher density than other polystyrene cracking products. This was also the reason for the second highest density value obtained from cracking with a ratio of 0: 0: 1, which was 0.9023 g/mL.

Figure 3. The Effect of Heating Rate and Raw Materials toward Density

The lowest density of one type of cracking polystyrene without mixture was obtained in pure oriented polystyrene, the mixture ratio was 1: 0: 0 at 0.8923 g/mL, this happened because the process of oriented polystyrene did not require additives, so that the oriented polystyrene cracking process was a pure cracking polystyrene polymer, producing ethylbenzene and styrene which were more dominant than phenylpropene and diphenyl propane. The density obtained from the polystyrene cracking fuel was in accordance with the research conducted by Miandad et al., which ranged from 0.92 g/mL [13].

3.4. The Effect of Ratio of Mixture and Heating Rate toward Flash Point

Flash point was a point of fuel that could be ignited by fire instantly. All samples showed analysis of flash point was below 32.6 °C, this meant that the fuel of cracking polystyrene had low flash points of aromatic hydrocarbons. A research conducted by Miandad et al. stated that the fuel produced by cracking polystyrene had flash points, 28.7 °C-30.2 °C [13].
4. Conclusion
Based on the study, it can be concluded that the ratio of the type of polystyrene and the heating rate affected the physical properties of the liquid produced by pyrolysis. The results of the analysis of physical properties, namely heating value, viscosity, density, and flash point were affected by cracking compounds of each type of polystyrene. Viscosity and density tended to increase with increasing heating rate. The heating value of the liquid fuel which was produced was strongly influenced by the ratio of the mixture of raw materials. The highest heating value was produced by a mixture of 2: 1: 1. The liquid fuel produced was classified as combustible fuel. All liquids produced by pyrolysis had flash points below 32.6 °C.

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References
[1] Scheirs J and Kaminsky W 2006 Feedstock recycling and pyrolysis of waste plastics : converting waste plastics into diesel and other fuels (Bloomington: J Wiley & Sons)
[2] Serrano D P, Aguano J, Escola J M, Garagarri E, Rodriguez J M, Morselli M, Palazzi G and Orsi R 2004 Appl. Catal. B Environ. 49 257–265
[3] Ergut A, Levendis Y A and Carlson J 2007 Fuel 86 1789–1799
[4] Durlak S K, Biswas P And Shi J and Bernhard M J 1998 Environ. Sci. Technol 32 2301–2307
[5] Durst R R, Griffith R M, Urbanic A J and Van Essen W J 1976 Advanc in Chem. 154 239–246.
[6] Feigenbaum A and Scholler D 1987 J. Chem. Educ 64 810
[7] Nielsen L E and Buchdahl R 1950 J. Appl. Phy 21 488–493
[8] Demirbas A 2004 J. Anal. Appl. Pyrolysis 72 97–102
[9] Liu Y, Qian J and Wang J 2000 Fuel Process. Technol 63 45–55
[10] Rizka A, Sri P P and Juliastuti R 2013 J. Teknik Pomits 2 1–10
[11] Prosen E J, Gilmont R and Rossini F D 1945 J. Res. Natl. Bur. Stand. 34 65
[12] Lange N A and Dean J A 1979 Lange’s Handbook of chemistry 10 th (New York: McGraw-Hill)
[13] Miandad R, Nizami A S, Rehan M, Barakat M A, Khan M I, Mustafa A, Ismail I M I, Murphy J D 2016 Waste Manag. 58 250–259
[14] Selpiana, Aprianti T, Rayosa I and Fuspitasarie D 2018 Expanded Polystyrene and Multilayer Plastic Waste Conversion Into Liquid Fuel by The Pyrolysis Process Preprint AIP Conference Proceedings 2014 020127