The conversion of expanded polystyrene waste to liquid fuel using Cu-Al$_2$O$_3$ by the thermal catalytic cracking process

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Abstract. The high use of plastic and the length of time the decomposition will worsen environmental conditions. The processing of plastic waste by incineration was not a safe method for the environment because it will produce gas emissions that potentially become pollutants. The catalytic cracking process is one of the ways to process polystyrene plastic waste into liquid fuel. The purpose of this study is to identify the effect of cracking temperature and mass of catalyst towards the volume and fuel quality of the production. The research conducted through the thermal catalytic cracking process. The mass of catalyst Cu-Al$_2$O$_3$ is 0.5 g, 1 g, 1.5 g. The cracking temperature is 150 °C, 200 °C, 250 °C. Cracking time is 90 minutes. The highest volume of the liquid fuel was 113 mL at a 250°C cracking temperature and the addition of 1g catalyst. The results of the best density analysis obtained at 0.74 g/mL, and the octane number of RON is 100, MON is 90, and AKI is 94.4.

1. Introduction

Plastic is one of polymer which has raw materials in general namely, polypropylene (PP), polyethylene (PE), polystyrene (PS), polymethyl methacrylate (PMMA), high-density polyethylene (HDPE), and polyvinyl chloride (PVC). Society life is now inseparable from the need for plastics as a packaging medium for various materials. Both food and clothing mostly use packaging made of polymer (plastic). The production of plastic waste in the world was around 230-250 million tons [1-4].

The use of excess plastic and the long time of the decomposition will worsen environmental conditions. The plastics were considered more practical than other materials. Therefore, the use of plastics continues to increase even though it takes a long time to degrade them. The processing of plastic waste by incineration was not a safe method for the environment since it will increase gas emissions that potentially become pollutants and the causes greenhouse effects, such as carbon dioxide gas, chlorine gas, SOx and some pollutant particulates [5-9].

The purpose of this study is recycling plastic waste of Expanded Polystyrene into liquid fuel using Cu-Al$_2$O$_3$ catalyst. Alumina (Al$_2$O$_3$) that impregnated with copper metal (Cu$^{2+}$). The expect hydrocarbon fraction from this type of plastic cracking was gasoline oil.

2. Experimental
Plastic waste as the raw material cleaned from impurities by washing and then drying it in the sun. The raw material was reduced in size with a diameter of 1-3 mm. The mass was 50 g for each sample. Preparation of Al₂O₃ catalyst was impregnation of Cu metal on Al₂O₃. The purity of Al₂O₃ was 99%. The total of 2 g of CuSO₄·5H₂O dissolved in distilled water, stirred using a spatula. Mix 25 g Al₂O₃ into CuSO₄·5H₂O solution. The mixture is heated using a heating stirrer at 90 °C for 3 hours. After obtaining Cu-Al₂O₃ sample, they were filtered and cleaned with distilled water. After that, they are dried in the oven for 3 hours at 90 °C and stored in a dry and closed place.

The mass of catalyst was 0 g, 0.5 g, 1 g, 1.5 g. The raw material and catalyst inserted into a fixed bed reactor. The Cracking process was 90 minutes with cracking temperatures of 150 °C, 200 °C, and 250 °C. The result of condensation is investigated using the measuring cup to calculate the volume and the physical properties compound resulted from the thermal catalytic process.

3. Results and discussions

3.1. The Effect of the Cracking Temperature and Mass of Catalyst to Volume

Figure 1 shows that the increasing temperature in the cracking process caused a tendency for an increase in the volume of fuel oil produced. In the sample without the catalyst, at a temperature 250 °C obtained the best volume of fuel liquid was 97 mL and at a temperature of 150 °C only a small amount of liquid fuel produced, 23 mL. Through the thermal cracking process, the degradation of polystyrene would begin to occur at a temperature of 200 °C, at a temperature of 150 °C, only a few fuels were produced because they had not reached the decomposition temperature yet. Based on the results of the analysis of the total volume produced, it was found that the higher the temperature, the more polystyrene waste that decomposed into liquid fuel.

![Figure 1. The Effect of Cracking Temperature and Mass of Catalyst to Volume](image)

Sample with 1 g catalyst produced the best volume of liquid fuel at a temperature of 250 °C is 113 mL. The sample with the addition of 1.5 g, the produced fuel decreased, namely, at temperatures of 250 °C, it was found that there was only fuel for 47 mL and at a temperature of 150 °C for 25 mL.

The addition of 1.5 g catalyst, there was a decrease in the volume produced. The reduced volume of liquid fuel caused by not all of the acid groups contained in the pores of the catalyst used for the decomposition of plastic molecules into simpler compounds [10-11].

3.2. The Effect of the Cracking Temperature and Mass of Catalyst on Density

Figure 2 shows that the density value of liquid fuels increased with the addition of catalyst. The highest density value was 0.871 g/mL with the addition of catalyst as much as 1.5 g. In the sample
with a cracking temperature of 150 °C, there was an increase in density value along with the addition of a catalyst up to 1 g and a decrease in the density value was 0.74 g/mL with the addition of 1.5 g of catalyst. Samples with cracking temperatures of 200 °C showed an increase in the density value was 0.831 g/mL with the addition of 0.5 g catalyst and then was back with the addition of 1 g and 1.5 g of catalyst, 0.797 g/mL and 0.74 g/mL. Furthermore, in samples with a cracking temperature of 250 °C it can be seen that the density value decreased for each addition of catalyst 0 g, 0.5 g, and 1 g, then density was obtained with values of 0.848 g/mL, 0.843 g/mL, and 0.823 g/mL.

![Figure 2. The effect of Cracking Temperature Mass of Catalyst on Density](image)

The lower the density value, the liquid fuel produced will be better because it approaches the density value of the gasoline oil fraction [12]. The high-density value indicates that the quality of the fuel is low because it contains a lot of wax and has a low heating value. On the other hand, the lower the specific gravity, the higher the quality of the liquid fuel, because it contains a lot of gasoline [13-15].

The more catalyst addition, the liquid fuel density decreases. Increasing Amounts cause an increase in the number of reactants that react to produce short-chain hydrocarbons (lighter hydrocarbons). The density value will increase when the compound of the double bond and the length of the carbon chain produced increases. At the addition of 1.5 g of catalyst, the density is 0.871 g/mL. The formation of coke in cracking reactions causes increased molecular weight. Adding the amount of catalyst causes the intermediate cations to accumulate increase, the density also increases [16].

As could be seen from Figure 2, the results of the density value were between 0.7-0.9 g/mL which indicated that the fuel produced was close to the gasoline fraction (gasoline). The density decreased at the addition of a 5 g catalyst for 780 g/mL.

3.3. The Effect of Cracking Temperature and Weight of Catalyst on Octane number

An octane number is a number that indicates how much pressure can be applied before the gasoline burns spontaneously. Inside the engine, the fuel is pressed by the piston and burned by the spark generated by the spark plug. Due to the magnitude of this pressure, the mixture of air and gasoline can also burn spontaneously before the spark from the spark plug comes out. If this gas mixture burns due to high pressure, it causes a knock in the engine. This knock causes the engine to break quickly so this condition must be avoided [17-19].

The octane name was from octane (C8) because of all the molecules that makeup gasoline, octane has the best compression properties. Octane can be compressed to a small volume without experiencing spontaneous combustion while heptane can burn spontaneously with a little pressure [18].
Figure 3. The Effect of Cracking Temperature and Mass of Catalyst on RON

Figure 4. The Effect of Cracking Temperature and Mass of Catalyst on MON

Figure 5. The Effect of Cracking Temperature and Mass of Catalyst on AKI
Liquid fuel quality is mainly determined by octane number. The higher the octane number, the better the quality of the liquid fuel. Compounds that affect the increasing of octane number were aromatic, naphtha and isoalkane with carbon numbers in the C5-C8 range, while olefins and n-paraffins could reduce octane numbers [17-18].

The octane number of a fuel is the value of the Research Octane Number (RON). The RON is comparing the mixture between iso-octane and n-heptane [17]. Figure 3 shows that the RON value (Research Octane Number) tended to increase along with the increasing number of catalysts and temperature. The highest RON value was 100 at a temperature of 250 °C with the addition of a 0.5 g catalyst. The smallest RON value was 94.5 at a temperature of 150 °C with the addition of a 1 g catalyst.

Another type of octane number was the Motor Octane Number (MON) which was determined at 900 rpm [20]. MON testing uses a test engine similar to that used in RON testing, but with a heated fuel mixture, higher engine speed, and ignition time variables to emphasize tapping fuel resistance. Figure 4 shows that the MON (Research Octane Number) value tends to increase along with the increase in the number of catalysts and an increase in temperature. Without the addition of the catalyst, the best MON value of 90 obtained at 200 °C cracking temperature. The best MON value at the addition of 1 g with a cracking temperature of 250 °C is 89.4.

The average values of RON and MON is called the Anti-Knock Index (AKI), and the formula is (R+M)/2 [19]. Figure 5 shows that the AKI value tends to increase along with the increase in cracking temperature and the addition of catalyst. When there is no addition of the catalyst, the greatest AKI value obtained at 200 °C cracking temperature, which is 89.4. In the sample with the addition of catalyst 1 g and a cracking temperature of 250 °C, the best AKI value was 89.4.

The increase in octane value proves that the amount of isoctane contained in the liquid fuel is high. Octane numbers were also proportional directly to density. The RON value was 90 which based on the standards and quality (specifications) of petroleum fuel which is in the decision of the Secretary of General of Petroleum and Gas of the Republic of Indonesia (RI) Number 313.K/10/DJM.T/2013. The results of this study indicated that the range of RON values is in accordance with quality standards were 94-100.

4. Conclusion
Based on the results of the study it can be concluded that the higher the temperature, the volume of liquid fuel produced tends to increase. The highest volume obtained at cracking temperatures of 250°C with the addition of a 1 g catalyst which was 113 mL. The lowest density, obtained at cracking temperatures of 150 °C of is 0.74 g/mL. Octane values tend to increase with increasing temperature and increasing the amount of catalyst. The best results obtained were RON 100, MON 90, and AKI 89.4.

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