Natural zeolite study as a catalyst: A case study of pyrolysis of polyethene terephthalate (PET) waste into liquid fuel

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Natural zeolite study as a catalyst: A case study of pyrolysis of polyethene terephthalate (PET) waste into liquid fuel

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Abstract. Plastic waste is still one of the biggest problems of environmental pollution because it is nonbiodegradable. One effort to utilize plastic waste is the process of pyrolysis of plastic waste into alternative fuels. This study aims to optimize the pyrolysis process by using local natural zeolites. Local natural zeolite is mashed with a size of 250 mesh and mixed into PET as a catalyst for the pyrolysis process. The plastic material used in this study is Polyethylene Terephthalate (PET) which was cut to 1x1 cm² in size. The zeolite ratio used is 10% mass basis. The heating variation was set at temperatures of 250, 300 and 350 C with a heating time of 60 minutes. The results showed that the use of local natural zeolites for PET pyrolysis produced more fuel liquids, but some important physical properties related to the fuel for SI engines decreased.

1. Introduction
Plastic polymers are the largest share of waste from current community activities. Plastic is an essential material in everyday life because its ability to be applied at a low cost and has advantages over conventional materials. Plastics have lightweight, durability, energy efficiency, high production speed and top design flexibility. The superiority of plastic materials makes plastic materials one of the most widely used materials in the world community today [1]. Thermoset type of plastic material is plastic that cannot be reprinted and has a high population. The six types of plastic that are becoming the problem of waste are polyethene-terephthalate (PET), low-density polyethene (LDPE), high-density polyethene (HDPE), polypropylene (PP), polystyrene (PS), and polyvinylchloride (PVC). The source of various types of plastic waste are presented in the following Table 1 [2].

Pyrolysis is a popular method in supporting the preservation of petroleum resources (fossils) in addition to promoting environmental conservation by reducing waste that cannot be degraded naturally [3]. The principle of the pyrolysis process is the generation of energy through the combustion of waste plastic without oxygen by breaking up long-chain hydrocarbons into shorter chains. Pyrolysis was interesting because it does not produce CO₂ in its production process [4]. Pyrolysis of plastic waste is becoming increasingly important because of high conversion rates to fuel oil while the gas product from the pyrolysis process has a high enough energy value that can also be converted as fuel [5]. Recycling plastic waste by pyrolysis has a high economic potential of high potential when compared to the destruction of waste plastics with conventional combustion.
Table 1. The source of various types of plastic waste

<table>
<thead>
<tr>
<th>Plastic type</th>
<th>The source of plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene Terephthalate (PET)</td>
<td>Bottled mineral water bottles, cooking oil bottles, juice bottles, bottle chili sauce, medicinal, and cosmetic bottles</td>
</tr>
<tr>
<td>Low-density Polyethylene (LDPE)</td>
<td>Crackle bag, plastic cap, plastic wrappers, frozen meat and a variety of other flimsy plastic.</td>
</tr>
<tr>
<td>High-density Polyethylene (HDPE)</td>
<td>Drug bottles, liquid milk bottles, Jerry cans and bottles lubricants, cosmetics</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>Plastic cups, plastic bottle caps, children's toys, and margarine</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>CD box, plastic forks and doc cents, plastic cups, or food from styrofoam, plastic and transparent</td>
</tr>
<tr>
<td>Polyvinyl Chloride (PVC)</td>
<td>Pipe water hose, pipes, building toys, plastic tablecloths, bottles of shampoo, and a bottle of chili sauce.</td>
</tr>
</tbody>
</table>

The initial stages of the pyrolysis process occur at temperatures around 250°C and end at 550°C [2]. The main products of pyrolysis are carbon residue (char), pyrolysis oil and gas. Researchers have conducted many studies to convert plastic waste into renewable fuel oil [6]. This conversion is possible because at first, plastic was made from crude oil. While crude oil is a very limited source of energy to fuel the transportation sector, so crude oil is a non-renewable energy source and will soon run out shortly.

Natural zeolite has proven to be the best candidate for the pyrolysis process of some plastic materials [7]. In the pyrolysis process, some of the hydrocarbons produced still have a long chain. In contrast, hydrocarbon liquids from the pyrolysis process with catalysts are known to produce hydrocarbon liquids with shorter chains and the advantage of lower temperature reductions [8]. The most commonly used catalysts in pyrolysis are solid acids (zeolites, silica-alumina) and activated carbon. But until now, very little work has been done on the investigation of Indonesia's local natural zeolite as a catalyst for this process. This study aims to examine the performance of local natural zeolites as catalysts for the PET pyrolysis process.

2. Method

2.1. Material

The material used in this study uses PET type plastic waste, which was mostly used as bottled mineral water. The visualization of PET material used in the study was presented in Figure 1 below.

Figure 1. Polyethylene terephthalate plastic waste used in research

PET-type plastic waste is cleaned and dried and then cut to an area of 1 cm², before being put into the pyrolysis reactor. The catalyst used for this work was natural zeolite obtained from Klaten, Indonesia. The zeolite was crushed and then sieved using a 250-mesh sieve. The Zeolite sieve was washed using a distilled product and then dried at 120 °C. The percentage of catalyst in this pyrolysis process were set at 10% of PET material. The main content of natural zeolites used in this study were silicon, aluminum, and oxygen. As for the other chemical substance contained in the zeolites used in this study, it can be seen from the following Table 2.
Table 2. The main content of natural zeolites used in this study

<table>
<thead>
<tr>
<th>Element</th>
<th>Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>64.55</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12.83</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.33</td>
</tr>
<tr>
<td>CaO</td>
<td>1.64</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.38</td>
</tr>
<tr>
<td>MgO</td>
<td>0.71</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.22</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.81</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>15.18</td>
</tr>
</tbody>
</table>

2.2. Set Up Temperature and Reaction Time

Pyrolysis temperature was set between 250, 300, and 350 °C. This temperature will determine the level of waste material decomposition, the residence time in the reactor, and pyrolysis results. The rate of decay and damage to the constituent structures of the material increases with increasing pyrolysis reaction temperatures [9]. The reaction temperature which was too high exceeds the pyrolysis temperature had an impact on the level of decomposition which was very reactive and causes the constituent components of the material to be converted into many forms of gas and liquid. Consequently, the solid product of pyrolysis was reduced with shorter residence time in the reactor.

Reaction time was related to the length of time the material in the reactor. This variable will affect the process of depolymerization, decomposition, and carbonization during the pyrolysis process. If the residence time was long enough, the pyrolysis process would be perfect for converting raw materials to gas and liquid. The length of stay of the pyrolysis process was adjusted to the raw material used, and each raw material has a proportional residence time [10]. In this study the pyrolysis time was set for 60 minutes (1 hour).

2.3. Set Up Experiment

This study uses a simple type of pyrolysis with the composition of the main equipment consisting of furnace and reactor, temperature controller, condenser, and collector as presented in Figure 2 below.

![Figure 2. Set up experiment](image)

1, 2, 3, and 4 were bottle; 5 was gas cylinder; 6 was water pump; 7, 8, and 9 were pressure regulator; 10 was nitrogen gas cylinder; 11 was furnace; 12 was thermocouple; 13 was condenser; 14 was gas stove; 15 was water reservoir; and 16, 17 were valve. This work compares the results of pyrolysis PET without catalyst (pure PET), PET with catalyst and conventional fuel (petralite) purchased from gas stations owned by PT. Pertamina Indonesia. Some essential parameters such as density, viscosity, flashpoint and octane number, are measured to compare with conventional fuel (petralite).
3. Result and Discussion

The following Figure 3 is an observation of the 60-minute pure PET pyrolysis process, for variations in temperature of 250ºC, 350ºC and 350ºC.

![Figure 3. Pyrolysis profile for pure PET](image)

Meanwhile, pyrolysis of PET with catalyst is presented in the following Figure 4.

![Figure 4. Pyrolysis profile for with catalyst](image)

Figures 3 and 4 show that the higher the pyrolysis temperature, both pure PET and PET with catalysts tend to produce more liquid yields. It’s because the breaking of the hydrocarbon chain requires a certain amount of energy, so the more power that is given the rate of breaking the hydrocarbon chain is faster.

3.1. The Viscosity Values

Viscosity is a characteristic of liquid fuel that correlates with the geometry of hydrocarbon molecules. The greater the molecular geometry of a liquid, the higher its viscosity. The results of testing the viscosity using tools viscometer obtained the following Figure 5.
Figure 5 shows that the addition of catalysts tends to produce a slightly higher liquid viscosity. The function of the catalyst as an accelerator of the reaction rate tends to reduce the energy requirements to generate a fuel liquid from the pyrolysis process. Figure 5 also shows that pyrolysis of PET material produces a liquid fuel with a viscosity value that is much higher than pertalite fuel.

3.2. Density.

The value of the pyrolysis liquid density is calculated using the following formula.

\[
\rho = \frac{m}{V}
\]  

(1)

Volume measurements were made with an empty Erlenmeyer glass with a capacity of 100 ml which is known to have a mass of 0.073 kg. The volume of the pyrolysis liquid was set at 100 mL and weighed with an Erlenmeyer glass with a digital scale that had an accuracy of 0.00001 kg. The results of the calculation of the liquid density of the pyrolysis and pertalite results are presented in Figure 7 below.

Figure 6. Density of pyrolysis results of pure PET material and PET with a catalyst to the density of pertalite.

The density of a liquid is a physical property related to the interaction forces between its constituent molecules. While the interaction forces between hydrocarbon molecules from PET material which is a non-polar substance so that it has a small interaction force. The interaction forces between hydrocarbon molecules with large geometry tends to be caused by inter-molecular surface tension[11].
3.3. Flashpoint
Flashpoint is the lowest temperature of liquid fuel where the vapours mixed with air will ignite when exposed to sparks then die again. In this study, the flashpoint of each sample was measured using a Flash Point Tester. The sample was put into a container that can be set the ambient temperature. The sample container is attached with a thermocouple to measure the temperature of the liquid sample. The results of the measurement of flashpoints liquid result of pyrolysis process and pertalite were presented in the following Figure 7.

![Figure 7. Flashpoints liquid result of pyrolysis process and pertalite](image)

The liquid fuels resulting from the PET pyrolysis process all show a higher flashpoint value than pertalite. Flashpoint is a descriptive characteristic of liquid fuel to characterize flammability.

3.4. The Octane Number
Octane numbers are numbers that indicate how much pressure can be applied before the fuel burns spontaneously. Octane numbers are an important parameter for the spark ignition (SI) Engine. From the results of research, alternative fuel pyrolysis products yield comparable values of octane or RON can be seen in Figure 8 below.

![Figure 8. Comparison of the octane value of PET pyrolysis results with Pertalite](image)

Figure 8 above shows that PET pyrolysis produces liquid fuels with higher octane values than Pertalite. This high-octane value correlates with some of the physical properties described above, such as higher viscosity and flashpoint values than pertalite.
4. Conclusion
The use of local natural zeolites as catalysts for PET pyrolysis processes has been carried out. Local natural zeolite as a catalyst is proven to be able to produce more PET pyrolysis results than without a catalyst. However, some physical properties of the liquid produced from PET pyrolysis using catalysts show less favorable performance, such as flashpoints and octane numbers for SI engine applications, while the density and viscosity of pyrolysis results did not show a significant difference. An important conclusion from this research activity is that local natural zeolites can reduce energy requirements for the PET pyrolysis process.

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References