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Effect of catalysts on the conversion of polystyrene plastic waste into fuel with Catalytic Pyrolysis Method

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Abstract. Polystyrene is a useful product that widely used today. However, when it becomes waste, polystyrene can cause environmental problems such as air pollution, soil contamination, as well as an economic burden due to the need for disposal space and costs. On the other hand, polystyrene converted into fuel. It expected there could be a solution to these environmental problems. This research aims to convert polystyrene plastic waste into liquid fuel used the pyrolysis method with catalytic thermal cracking. Zeolite and Al_2O_3 were used as a catalyst in this research as much as 8 % of the feed—temperature set at 250 ℃. At the optimum reaction condition (catalyst Al_2O_3 and cracking time of 30 minutes), the liquid yield of the catalytic pyrolysis process was 29.40 %. Physical properties like density, specific gravity, ^{o}API gravity, and calorific value of fuel samples are determined and compared to the gasoline standard. The result showed that density, specific gravity, ^{o}API gravity, and calorific value were close to the density, specific gravity, ^{o}API gravity, and calorific value of the gasoline standard.

Keywords : catalytic cracking, liquid fuel, polystyrene, pyrolysis

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Introduction

Plastic waste is still a severe problem, especially in Indonesia. Based on data from the Ministry of Environment, in 2008, Indonesia produced 38.5 million tons of waste per year. Plastic waste is ranked second at 5.4 million tons per year or 14% of total waste production [1]. Indonesian people extensively use plastics due to several advantageous properties of the plastic, including lightweight, stable, cheap, and easy to obtain. Nevertheless, on the other hand, plastic waste is a problem for the environment. Plastic has unbiodegradable properties, or it is difficult to decompose. It takes decades to decompose plastic waste [2][3].

The most popular handling of plastic waste is 3R (Reuse, Reduce, Recycle). Reuse is repeatedly using items made of plastic. Reduce is to reduce the purchase or use of goods made of plastic, especially disposable items. Recycle is recycling plastic items. Recycling is done by reprocessing goods that considered to have no value. Economical again through physical and chemical processes or both to obtain products that can be used or traded again [4]. Each waste management mentioned above has weaknesses. The disadvantage of reuse is that certain items made of plastic, such as plastic bags if used many times over time, will not be suitable for use. Also, some types of plastic are not suitable for health if they are used repeatedly. The disadvantage of reducing is the availability of cheaper and more practical plastic replacement goods while the disadvantage of recycling is that the plastic that has been recycled for plastic goods again will decrease in quality [5][6].

In addition to the three ways above, those that handle plastic waste utilizing incineration (combustion), this method can produce harmful gases such as COx, NOx, and SOx [7][8]. For this reason, it is necessary to have an alternative treatment for plastic waste that is environmentally friendly. Plastic waste can be converted into fuel by the pyrolysis method with the thermal cracking process. The cracking process is a process to convert plastic waste from long alkyl chains of polyolefins into hydrocarbons [9][10].

Polystyrene is a type of plastic waste that has quite a lot of production. Polystyrene widely used for various applications, as food and beverage wrappers [11], electronic goods wrappers [12], fillers [13], additives [14], and also as a membrane base material [15][16]. Besides, because polystyrene is thermoplastic, its thermal stability is relatively high and is difficult to process, but the price is relatively low.

Pyrolysis process converts polystyrene waste into liquid fuel, solid residue (char), and gases at high temperatures (300-900 °C) via thermal cracking/ thermal decomposition process. However, there are certain limitations in the conventional thermal pyrolysis, where the whole process is temperature-dependent. The liquid oil produced from thermal pyrolysis may contain impurities like residues, chlorine, and Sulphur [17]. Moreover, the thermal pyrolysis of Polystyrene type plastics such is difficult to conduct due to their crossed chain hydrocarbon structures. Therefore, the catalytic pyrolysis method developed to overcome the problems of thermal pyrolysis. A range of catalysts has been utilized, including Zn bulk [18], Al-MSU-F [19], natural zeolite [20], and silica-alumina [21] in catalytic pyrolysis to improve the quality of liquid oil. This research will examine the effect of various catalysts such as zeolite and alumina for catalytic cracking processes on the conversion of polystyrene plastic waste.

Experimental

Raw material preparation. There are two types of polystyrene plastic waste used in this study, namely food and beverage containers and plastic wrapping electronic equipment. Food waste still attached to polystyrene plastic waste was cleaned with soap, then dried in the sun. After that, the size reduced by using scissors. Likewise, with the plastic wrapper of electronic equipment, without washing it first, the size was reduced using a wire brush so that the size is 4 mm - 6 mm. After that, the weighed raw material transferred into the reactor.

Catalyst preparation. The catalyst used in this study consisted of zeolites and Al_2O_3. Before use, these catalysts need to be activated first. The method used for the activation of these catalysts was the heating method. The catalyst put into a porcelain cup, then put in the oven for 3 hours at a temperature of 300 ℃.

Catalytic Pyrolysis Process. This research conducted using a thermal catalytic cracking stainless steel reactor without a stirrer, which operated at an absolute pressure and temperature. A mixture of raw

Table 1. The volume and mass of the product produced with different operating time and catalyst

Catalyst	Operating Variable		Measured Parameters		Yield (%)
	Time (minutes)	Temperature (°C)	Volume (mL)	Mass (gram)	
Zeolit	30	250	54	40.88	20.44
Zeolit	60	250	67	50.76	25.38
Al_2O_3	30	250	78	58.81	29.40
Al_2O_3	60	250	60	45.36	22.68

material and catalyst put into the reactor, and then the reactor was tightly closed using a bolt so that no oxygen enters the reactor. The raw material that put into the was 200 grams of polystyrene plastic waste with a size of 3 - 5 mm. The catalysts used in this study were zeolite and Al_2O_3. The operation time carried out with variations of 30 minutes and 60 minutes. The reaction temperature can be adjusted using a controller—the temperature for the catalytic cracking process of polystyrene plastic waste set at 250 ℃. When the temperature inside the reactor increases, the raw material begins to melt, steam will appear as a result of the catalytic cracking process. Then the steam will pass through the condenser and convert into liquid fuel, and then the product collected in a container. In this research, a catalytic cracking process of polystyrene plastic waste carried out by using several catalysts, zeolites, and Al_2O_3 to obtain optimum fuel oil in quantity and quality.

Result and Discussion

Volume and mass of catalytic pyrolysis products. Volume and mass of products resulting from catalytic cracking at temperatures of 250 ℃, time variations of 30 minutes and 60 minutes, and variations of the catalyst used are zeolite catalyst and Al_2O_3 catalyst shown in Table 1.

Based on table 1, it can be seen that the zeolite catalyst used at longer operation times more volume produced at the operating time of 30 minutes. The volume is 54 ml, and at the operating time of 60 minutes, the resulting volume is 67 ml. It is equivalent to the mass and % liquid yield obtained. At 30 minutes of operation, time produced 40.88 grams of liquid fuel, and an operating time of 60 minutes produced 50.76 grams of liquid fuel. Liquid yield at 30 minutes of operation is 20.44%, while liquid yield at 60 minutes of operation is 25.38%.

In contrast to the use of zeolite catalysts, in the use of Al_2O_3 catalysts, there is a decrease in volume at variations in operating time. At the operating time of 30 minutes, the resulting volume was 78 ml, and at the operating time of 60 minutes, the resulting volume was 60 ml. It is also proportional to the mass and liquid yield produced. At 30 minutes of operation, 58.81 grams of liquid fuel produced, and an operating time of 60 minutes 45.36 grams of liquid fuel produced. Liquid yield at 30 minutes of operation is 29.40%, while liquid yield at 60 minutes of operation is 22.68%. Based on the research conducted, it found that the most abundant % liquid yield was 30 minutes in time variation, and the use of the Al_2O_3 catalyst was 29.40%. In the use of zeolite catalysts, the longer the operating time, the more volume of liquid fuel produced, while the use of Al_2O_3 catalyst the longer the operating time, the less the volume of liquid fuel produced. The effect of operating time on volume seen in Figure 1.

Figure 1 shows that for the zeolite catalyst, the longer the operating time, the more volume is produced [22], the optimum liquid fuel produced at a higher temperature and longer time of the pyrolysis process. As for the Al_2O_3 catalyst, the longer the operating time, the less volume is produced. According to Miandad et al. [17], the addition of catalysts can accelerate the process of oil formation so that amount produced and quality increases. The

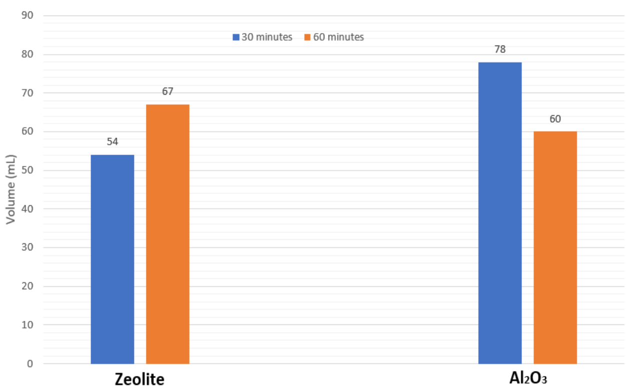

Figure 1. The effect of catalyst

Table 2. Physical properties of liquid fuels product

Catalyst	Operating variables		Physical characteristics			
	Time (minute)	Temperature (^oC)	Density (g/mL)	Spgr	^{o}API Gravity	Calorific (MJ/kg)
Zeolit	30	250	0.76	0.77	51.79	45.19
Zeolit	60	250	0.76	0.77	51.55	45.12
Al_2O_3	30	250	0.76	0.77	52.26	41.74
Al_2O_3	60	250	0.76	0.77	52.02	40.13

use of zeolite catalysts in this study was able to increase the volume of liquid fuel produced along with the long operating time. According to Pattiya [23], catalysts using the pyrolysis process can accelerate conversions that produce better quality oil. Miandad et al. [24] explained that the catalyst could increase the cracking that occurs in the pyrolysis process. Long hydrocarbon chains can be converted to hydrocarbon gas faster so that more oil formed from gas condensation. At Al2O3 catalysts, longer operating time resulting volume decreases, caused by the longer operating time more that is converted to gas, so that the liquid produced is reduced. The measurement of the resulting gas flowrate shows that the higher the catalyst concentration, the processing time needed to get the gas faster [17].

Physical properties of liquid fuel product. The obtained liquid fuel product is analysed of physical characteristics to determine the specific type of product. Physical properties of liquid fuel product result shown on Table 2.

Based on Table 2, it can be seen that for the use of two types of catalysts, zeolite, and Al_2O_3 catalysts, the longer the operating time, the higher the density produced. Measured density all product has same value is 0.76, where the results of this density test fall into the range of gasoline fuel density, which is 0.71-0.77 g/mL [25]. The highest density produced with the use of zeolite catalysts at 60 minutes operating time is 0.76, while the lowest density is produced in the variation of the use of Al_2O_3 catalysts at 30 minutes operating time, which is equal to 0.76.

Zeolite and Al_2O_3 catalysts, the longer the operating time, the higher the specific gravity produced. The measured specific gravity has the same value is 0.77, where the results of this specific gravity test approach the specific standard of gasoline fuel gravity, which is 0.75. The highest specific gravity was produced in variations in the use of zeolite catalysts at 60 minutes operating time, which is 0.77. While the lowest density was produced on variations in the use of Al_2O_3 catalysts at 30 minutes operating time, amounting to 0.77.

Zeolite and Al_2O_3 catalysts, the longer the operating time, the higher the ^{o}API gravity produced. ^{o}API measured gravity ranged from 51.55 to 51.26, where the specific gravity test results of the use of zeolite catalyst approached the specific gravity standard of gasoline fuel, which was 50.46. The highest gravity ^{o}API was produced on variations in the use of Al_2O_3 catalysts at 30 minutes operating time, which was 52.26, Whereas the lowest ^{o}API gravity was generated on variations in the use of zeolite catalysts at 60 minutes operating time, which amounted to 51.55.

On the calorific parameter, zeolite catalyst, and Al_2O_3 catalyst, at longer operating time, the lower the heating value of the liquid fuel produced. The measured heating value ranges from 40.13 MJ/kg to 45.19 MJ/kg, where the results of the heating value of the use of the Al_2O_3 catalyst approach the standard solar heating value of 42.32 MJ/kg [26]. The highest heating value generated from variations in the use of zeolite catalysts at 30 minutes of operating time in the amount of 45.19 MJ/kg while the lowest calorie value produced on variations in the use of Al_2O_3 catalysts at 60 minutes operating time, which is equal to 40.13 MJ/kg.

Conclusion

From the results of the research conducted, it can be concluded that: Operating time and catalyst affect the quantity and quality of the liquid fuel produced. The highest liquid fuel volume in the catalytic cracking process of polystyrene plastic waste found in the variation of the operating time of 30 minutes and the use of an Al_2O_3 catalyst that is equal to 78 mL. The highest mass of liquid fuel in the catalytic cracking process of polystyrene plastic waste found in the variation of the operating time of 30 minutes and the use of an Al_2O_3 catalyst that is equal to 58.81 grams. The characteristics of the liquid fuel produced are close to the characteristics of gasoline where density values obtained ranged from 0.75 to 0.76 g/mL; specific gravity ranges from 0.770 to 0.773; ^{o}API gravity ranges from 51.55 to 52.26, and the heating value ranges from 40.13 to 45.19 MJ/kg.

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