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INFLUENCE OF RESIDENCE TIME TO THE PROPERTIES OF LIQUID PRODUCT FROM PLASTIC WASTE PYROLYSIS

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ABSTRAK

Pirolisis adalah sebuah metode daur ulang yang digunakan untuk mengurangi dampak lingkungan dari sampah plastik di Indonesia. Dalam penelitian ini, karakteristik dari produk minyak pirolisis sampah plastik jenis Low Density Poly Ethylena (LDPE) telah dipelajari dengan baik. Penelitian ini bertujuan untuk mengetahui pengaruh waktu tinggal pada rendemen dan properti produk cair (minyak pirolisis) yang dihasilkan. Penelitian dilakukan menggunakan reaktor batch skala kecil yang dilengkapi dengan sebuah siklon, kondensor, steam-atomizing burner, dan sistem flare. Pirolisis dilakukan dalam waktu 30, 60, dan 90 menit pada suhu 350^{0}C. Hasil penelitian menunjukkan bahwa semakin lama waktu tinggal akan menghasilkan jumlah minyak dan gas yang lebih besar, namun menghasilkan arang yang lebih kecil. Produk minyak tersebut memiliki sifat fisik yang mendekati kerosene dengan nilai kalor 20.019–20.047 BTU/lb, massa jenis 0.7754–0.7802 g/ml, viskositas kinematik 1.392–1.603 mm^2/s, dan titik nyala di abwah 11°C. Minyak tersebut juga mengandung asam asetat, metil oleat, 1-hidroksi-2-propanon, furan metanol, and metil siklopentan sebagai senyawa-senyawa yang utama.

Kata kunci: LDPE, pirolisis, reaktor batch, steam-atomizing burner

ABSTRACT

Pyrolysis is a waste processing method used to decrease the environmental impact of plastic in Indonesia. Herein, the characteristics of low-density polyethylene (LDPE) waste pyrolysis products have been investigated. The objective of this research is to study the influence of residence time on the yield and properties of the liquid (oil pyrolysis) product. Experiments were performed in a batch reactor equipped by a cyclone, condenser, steam-atomizing burner, and flare system. Pyrolysis was conducted at 30, 60, and 90 min over a temperature of 350°C. Results show that longer residence time yields a greater amount of oil and gas and a lower amount of char. The oil product has physical properties close to that of kerosene with a caloric value of 20.019–20.047 BTU/lb, a density of 0.7754–0.7802 g/ml, kinematic viscosity of 1.392–1.603 mm2/s, and flash point under 11°C. It contains acetic acid, methyl oleate, 1-hydroxy-2-propanone, furan methanol, and methyl cyclopentane as majority compounds.

Keyword: Batch Reactor, LDPE, Pyrolysis, steam-atomizing burner

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INTRODUCTION

The main problem in Indonesia is the energy crisis, especially fuel unavailability, since the rapid population growth and fast industrial development have increased fuel consumption. Fuel production in Indonesia has decreased due to a decline in oil production; therefore, it does not meet the national needs and has to be imported from other countries [1].

On the contrary, waste utilization has become a major concern in Indonesia. The rapid population growth has caused a large number of wastes. One of them is plastic, which has already become a part of modern life. They have good characteristics, such as durability, lightweight, corrosion resistance, low cost, and processability. Unfortunately, besides of their satisfying usage, they become highly problematical wastes due to their awfully poor ability to degrade [2].

Low-density polyethylene (LDPE), as a kind of plastic, is widely used for food packaging. LDPE is a flexible but strong type of plastic, high temperatures producing (200–300°C), and pressurized by supercritical ethylene (130–260 MPa). LDPE has long and branched chains with varying density between 0.915 and 0.925 g/cm^3 [3].

Plastic products have a very short life cycle and mostly end up in landfills [4]. They have disturbed environmental and operational problems at landfills due to the high durability which it takes billions of years to degrade [5]. Besides that, plastic wastes release air and waterborne pollutants or act as a habitat for disease-causing vectors, rodents, and flies [6]. They also create pollution due to presence of toxic chemicals and it will be spread diseases in social society [7].

Based on the facts, we need to manage the effect of plastic wastes to reduce environmental damage. There are some methodologies to utilize the plastic waste into a valuable product, for examples recycling, gasification, incineration, and hydrogenation.

The recycling process has become very popular, wherein plastic wastes will be re-melted into lower-quality plastic raw materials. However, there is a limit to the ability of plastic recycling until its quality decreases and cannot be recycled. In reality, only a few plastic wastes can be recycled and the recycled material also has low quality; therefore, it is considered inefficient [8]. So, it is necessary to process plastic waste into other more useful materials, one of them being a synthetic fuel to substitute gasoline, diesel, or other fuel. This is possible because plastic comes from petroleum; therefore, it only returns to its original form. On the contrary, plastic also has a high heating value, reaching 40 MJ/kg, equivalent to fossil fuels, such as gasoline and diesel fuel.

The main product obtained during the plastic thermal decomposition process is oil, which is equivalent to conventional fuels. According to Syamsiro (2015), plastic oil can be used to replace diesel fuel in diesel engines both as a single fuel or mixed with diesel. The close heating value makes it more suitable as a substitute for diesel fuel. However, there are some properties that must be changed to improve its performance [9]. Beside in diesel engine, plastic pyrolysis oil can be used as fuel in steam-atomizing burner that give good performance of heating process in burner [10].

There are some research publications about producing liquid fuels through pyrolysis process. It must be noted that the results and products quality were dependent on several parameters, such as temperature, type of reactor, residence time, pressure, and use of catalysts [11]. However, thermo-gravimetric analysis (TGA) shows that the rate of temperature rise is important in the decomposition of plastic molecules [12]. Therefore, the aim of this study is to investigate the effects of residence time on the yield and properties of the liquid (pyrolysis oil), gaseous (non-condensable gas), and solid products (char).

MATERIALS AND METHODS

1. Materials

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Herein, raw materials used in the form of LDPE plastic bags were taken from waste collectors around Piyungan Integrated Waste Processing Site (TPST), Yogyakarta. The raw material was cleaned from impurities and weighed to 2 kg of raw material for a one-time process. The fuel for the pyrolysis process was liquefied petroleum gas (LPG), which was obtained from the Energy and Environment Laboratory of the Proklamasi 45 University, Yogyakarta.

2. Methods

This research was conducted by laboratory experimental testing using a batch reactor (1) which is equipped with a furnace (2) and two condensers (3), and fueled by gas from an LPG cylinder (4). The equipment used is shown in Figure 1.

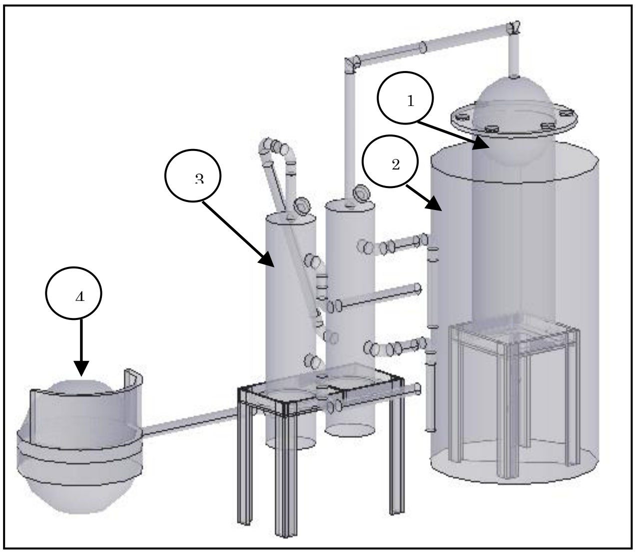

Fig. 1. Pyrolysis equipment

The first stage was loading raw material into the pyrolysis reactor equipped with furnace and temperature–pressure indicator. The cover was tightened so that no gas comes out through the reactor. On the contrary, cooling water was inserted into the condenser to condense the pyrolysis vapor and become liquid. After all the equipment was ready, the heating process was conducted using LPG to a temperature that had been adjusted.

During the heating process, observation of processing time and temperature in the retort was conducted every five min. There was an increase in the reactor temperature, from room temperature to final temperature (350°C) and held for 30, 60, and 90 min, and finally turned off.

During pyrolysis, the volatile matter evaporation has occurred and decomposition of plastic polymers had produced plastic monomers vapor. It flew to the condenser and cooled by cooling water so that it can converse into plastic oil. The non-condensable gas was stored in a gas storage tube and had taken to be tested in the laboratory. In addition, there were remaining solids in the reactor, which were removed after completion of the experiment.

The plastic oil was stored in a container to measure its volume, and its characteristics were tested in the laboratory. The remaining solids were weighed to determine the mass. The yield of non-condensed gas was calculated from the difference of raw material mass with a total mass of oil and solids produced.

The characteristics of oil products were tested at the Petroleum, Gas, and Coal Technology Laboratory, Department of Chemical Engineering, Gadjah Mada University. Tests conducted include calorific value (gross heating value) using calorimeter bomb equipment, density with ASTM 1298 method, kinematic viscosity with ASTM D 445 method, flash point with ASTM D 93 method, and water

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content with ASTM D 95 method, while the gas products were tested in an integrated chemical laboratory at the Indonesian Islamic University using Shimadzu GC-8A equipment.

RESULTS AND DISCUSSION

1. Yield of Pyrolysis Products

Herein, there is a cracking (pyrolysis) process from LDPE plastic characterized by the discharge of liquid collected in the storage tank. The resulting liquid comes from a broken and condensed LDPE chain, while the uncondensed product will remain as a non-condensable gas. The remaining solids in the reactor were characterized as char products.

The products from the LDPE waste pyrolysis process with residence time variables are listed in Table 1 and Figure 2.

Table 1. The yield of LDPE waste pyrolysis products

Residence Time (minute)	Yield of Products (%)		
	Oil	Solids	Gas
30	28.16%	63.89%	7.95%
60	35.83%	49.44%	14.72%
90	36.71%	44.44%	18.85%

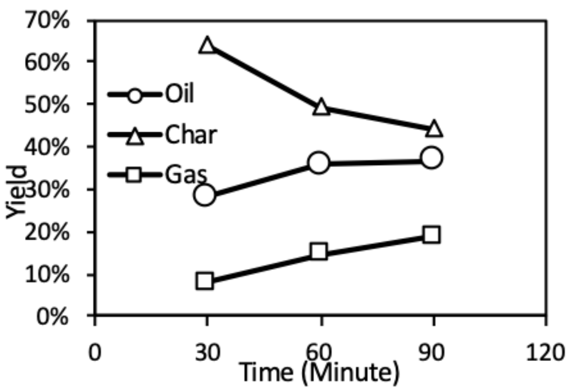

Fig. 2. Effect of Residence Time on the Yield of LDPE Pyrolysis Products

Figure 2 shows that an increase in the residence time increased the oil and gas yield and decreased the solid yield. The largest oil and gas yield is 36.71% and 18.85%, respectively, produced from the pyrolysis process with 90 min residence time at 350°C, wherein the solid yield was smallest, i.e., 44.44%.

The trend of oil and gas production has increased and the solid product has decreased from the pyrolysis process is in agreement with the research conducted by Pei et al. (2013) [13]. They reported that pyrolysis can be seen as a process for removing volatile materials from plastic waste. More specifically, if the process temperature is very high, a light organic matter will be released in the form of evaporating gases, and the organic matter with larger boiling point and molecular weight will be left as part of the solid residue. Finally, the evaporating gases will condense into the oil.

2. Characteristics of Pyrolysis Oil

During the pyrolysis process, a liquid produced by vapor condensation is the main product. This liquid is expected to replace conventional fuels. To find out the physical characteristics of oil products, a number of related parameters were examined, as shown in Figures 3 and 4 and Table 2.

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The relation between residence time and physical properties of oil from LDPE waste pyrolysis is shown in Figures 3 and 4.

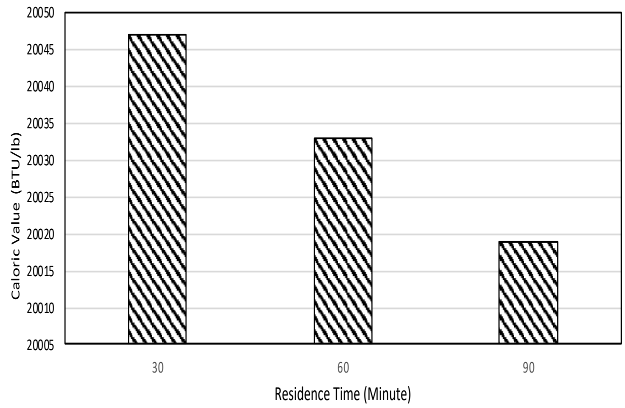

Fig. 3. Influence of residence time on the calorific value of pyrolysis oil

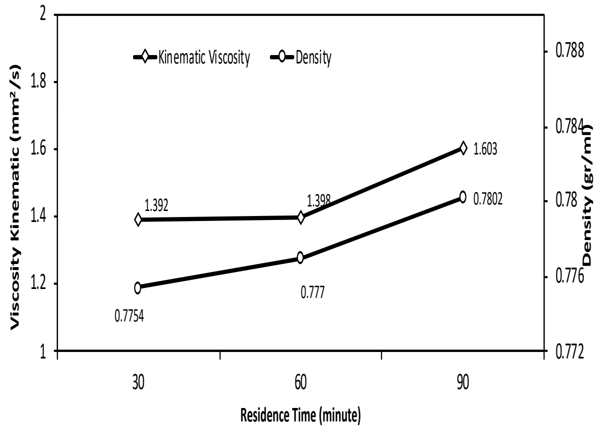

Fig. 4. Influence of residence time on the viscosity and density of pyrolysis oil

Figure 3 shows that an increase in residence time had increased the heating value of oil products. The highest heating value was produced by the pyrolysis process with 90 min residence time, which was 20.047 BTU/lb. This condition is in accordance with Pei (2013), where the heating value of oil formed from PE plastic will decrease with a decrease in the residence time, which was due to a decrease in the smaller number of hydrocarbon fractions that had high heating value in pyrolysis oil; therefore, the total calorific value of oil was smaller.

On the contrary, an increase in the residence time has an impact on the decrease of density and viscosity of oil produced from the LDPE waste pyrolysis process, as shown in Figure 4. It was due to a faster heating rate and lower residence time that would reduce the occurrence of secondary reactions from hydrocarbon vapor into gas; therefore, the heavy fractions were entered into the condenser and condensed into the oil. The amount of weight fraction also caused the liquid to become more concentrated because it had a greater viscosity.

Table 2 lists the physical characteristics of pyrolysis oil, which are close to the properties of conventional fuels, especially kerosene. The heating value, viscosity, and flash point of LDPE waste pyrolysis oil are close to the characteristics of kerosene, whereas the density is close to that of gas oil. In addition, plastic pyrolysis oil also had a small flashpoint (<11°C) and did not contain water like other fuel, except gas oil.

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The physical properties of oil from pyrolysis were almost the same as those of the research conducted by Yuliansyah et al. (2015) [14]. According to them, there are similarities in the oil characteristic of pyrolysis and kerosene. In comparison with kerosene, the pyrolysis oil was lighter and more volatile but slightly more viscous. In addition, both oils had similar energy content.

Table 2. Characteristic of pyrolysis oil from LDPE waste compared to commercial fuels

No	Parameter	Unit	Residence Time (minute) [1]			Kerosene[2]	Gas Oil [2]	Diesel[2]
			30	60	90			
1	GHV	BTU/lb	20.019	20.033	20.047	20.111	19.852	20.305
2	Density	gr/ml	0.7802	0.777	0.7754	0.84	0.78	0.82
3	Kinematic viscosity	mm^2/s	1.603	1.398	1.392	1.20	3.3	2.1
4	Flash point	^0C	<11	<11	<11	40	75	55
5	Water content	%	-	-	-	-	0.05	-

Sources: [1] Primary data, 2017
[2] Yuliansyah et al., 2015.

CONCLUSION

Based on this study, it can be concluded that with longer residence time, the oil and gas produced from LDPE Pyrolysis were higher but the solids products were lower. The highest oil yield was obtained from the pyrolysis with a residence time of 90 min, which was 36.71%, where the yield of gas and solids were 18.85% and 44.44%, respectively.

The characteristics of oil products from LDPE waste pyrolysis also vary depending on residence time in the reactor. The increase in the residence time had an increased heating value of the oil, while density and viscosity decreased. In comparison with commercial fuel, the quality of oil from pyrolysis is quite good and close to some types of fuel, especially kerosene. It is feasible to be used as an alternative fuel to replace fossil fuel.

In addition, the recommendation for the next research is upgrading the pyrolysis oil product if the oils were to be used as a kerosene substitute. Other oil properties, such as smoke point, sulfur content, copper strip corrosion, and odor, should be evaluated and meet the standard criteria for commercial kerosene.

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REFERENCES

[1] M. Sigit Cahyono, M; Liestiono, M.R.P.; Widyawidura, W.; Prasetya, A.; Syamsiro, “Pyrolysis of Plastic Waste in the Rotary Drum Reactor in the Variation of Heating Rate,” in *Seminar nasional Teknologi Terapan 2017*, 2017, pp. 10–18, [Online]. Available: https://sntt.sv.ugm.ac.id/unduhan/.

[2] H. Saptoadi and N. N. Pratama, “Utilization of Plastics Waste Oil as Partial Substitute for Kerosene in Pressurized Cookstoves,” no. January 2015, 2017, doi: 10.7763/IJESD.2015.V6.619.

[3] M. Sigit Cahyono and U. I. F. Styana, “Influence of Heating Rate and Temperature on the Yield and Properties of Pyrolysis Oil Obtained from Waste Plastic Bag,” vol. 1, no. 1, pp. 1–8, 2017.

[4] Z. Al Afif, "Solid waste management in Saudi Arabia : A review," no. May 2016, 2017.

[5] P. Kasar, "Thermal and catalytic decomposition of waste plastics and its co-processing with petroleum residue through pyrolysis process," 2020.

[6] M. E. Abdullah, N. Asyiqin, M. Martynis, S. Sambhi, and P. Dahiya, "Plastic solid waste utilization technologies : A Review Plastic solid waste utilization technologies : A Review," 2017, doi: 10.1088/1757-899X/263/2/022024.

[7] M. Rehan *et al.*, "International Biodeterioration & Biodegradation Effect of zeolite catalysts on pyrolysis liquid oil," 2016, doi: 10.1016/j.ibiod.2016.11.015.

[8] M. Sigit Cahyono, M. R. P. Liestiono, and C. Widodo, "Proses Pirolisis Sampah Plastik dalam Rotary Drum Reactor dengan Variasi Laju Kenaikan Suhu," vol. 3, no. 2502, pp. 63–68, 2018.

[9] M. Syamsiro, "Kajian pengaruh penggunaan katalis terhadap kualitas produk minyak hasil pirolisis sampah plastik 1), 2)," pp. 47–56, 2015.

[10] M. Sigit Cahyono, A. Prasetya, and M. Syamsiro, "Combustion of plastic pyrolysis oil in steam-atomizing burner and its application for pyrolysis process," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 11, 2019, doi: 10.35940/ijitee.J9855.0981119.

[11] S. Dayana, A. Sharuddin, F. Abnisa, W. Mohd, and A. Wan, "A review on pyrolysis of plastic wastes," vol. 115, pp. 308–310, 2016.

[12] P. Taylor, İ. Kayacan, and Ö. M. Do, "Energy Sources , Part A : Recovery , Utilization , and Environmental Effects Pyrolysis of Low and High Density Polyethylene . Part I : Non-isothermal Pyrolysis Kinetics Pyrolysis of Low and High Density Polyethylene . Part I : Non-isothermal Pyrolysis Kinetics," no. December 2014, pp. 37–41, 2008, doi: 10.1080/15567030701457079.

[13] T. Pei, M. Xiao-bo, C. De-zhen, and W. Hai, "Pyrolysis of Waste Plastics : Effect of Heating Rate on Product Yields and Oil Properties," vol. 666, pp. 1–10, 2013, doi: 10.4028/www.scientific.net/AMR.666.1.

[14] R. L. Ahmad Tawfiequrrahman Yuliansyah, Agus Prasetya, Muhammad A. A. Ramadhan, "Pyrolisis of Plastic Waste to Produce Pyrolytic Oil as an Alternative Fuel," *Int. J. Technol.*, vol. 6, no. 7, pp. 1076–1083, 2015, [Online]. Available: https://ijtech.eng.ui.ac.id/old/index.php/journal/article/view/1241.