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Influence of Heating Rate and Temperature on the Yield and Properties of Pyrolysis Oil Obtained from Waste Plastic Bag

M. Sigit Cahyono[1], Ucik Ika Fenti Styana[2]

[1]Universitas Proklamasi 45 Yogyakarta
[2]Institut Teknologi Yogyakarta
Email: sigitup45@gmail.com

Abstract

The objective of the research was to investigate the influence of heating rate and temperature in the reactor on the yield and properties of pyrolysis oil obtained from waste plastic bag, that is considered as low-density polyethylene (LDPE). The experiments were performed in fixed bed reactor equipped with a steam atomizing burner, a temperature controller, and a condenser. Approximately, the amount of ten kilograms of waste plastic bag loaded into the reactor chamber and then pyrolyzed using the temperature between 250 and 450°C and heating rates of 5 to 15°C/min. The results showed that as the oil yield decreased, the heating rate increased. Alternatively, the oil yield increased with temperature and the wax content decreases as the temperature increases. The highest quantity of pyrolysis oil was produced from waste plasctic bag is 45%, in the temperature 450^{o}C and the heating rate 15°C/min, with wax content of 25%, solid char of 12 % and non-condensable gas of 41%. The physical properties of oil were evaluated and compared to those of diesel oil. The analysis results showed that the oil product's properties from pyrolysis of the waste plastic bag in temperature 450^{0}C, were relatively closer to those of diesel oil with caloric value 11,043 kcal/kg, specific gravity of 0.812, kinematic viscosity 2.80 mm^2/s, and flash point of 27^{o}C.

Keywords *: Pyrolysis, heating rate, temperature, yield, waste plastic bag*

1. Introduction

The production of waste in Indonesia has become a major focus in recent years. The considerable growth of the population caused a great amount of wastes. Plastics as one of the wastes, has been used in many fields and it has already become a part of modern life nowadays, especially for the plastic bags made from polyethylene (PE).

The standard plastic bags with thin polyethylene sheets is produced commercially from polymerization of ethylene (PE). PE is divided into categories based on the density and the molecular branching frequency. The top two types of most important plastic bags production are high-density PE (HDPE) and low-density PE (LDPE). HDPE is a copolymer with the amount up to 1% of 1-butene and is made along with either Cr or Zieglercatalysts and the temperatures as low as 60 °C. More recently, single site catalysts such as metallocenes have also been used. LDPE is produced at high temperatures (200–300 °C) and supercritical ethylene pressures (130–260 MPa) using peroxide-free radical initiators. HDPE is a linear copolymer with a density range of 0.945–0.965 g/cm^3, LDPE is branched with densities ranging from0.915 to 0.925 g/cm^3 [1].

The use of plastic bags—not biodegradable—causes a significant increase of plastic waste. The recycling of plastic waste is not easy to be obtained, because it can be found with the significant quantities in landfills and also in the street causing the adverse impacts on health and strong environmental damage [2]. Thus, the recycling process and recovery efforts need to be done to avoid the pollution and reduce the damages caused by waste plastic bags.

One of the chemical recycling techniques for the plastic materials is pyrolysis, which recently increases public interest as an acceptable choice of waste material treatment from both environmental and economical aspects [3]. Pyrolysis is the process of thermally degrading long chain polymer molecules into smaller, less complex molecules through heat and pressure management. The process requires intense heat with shorter duration in absence of oxygen. The three major products that are produced during pyrolysis; oil, gas and char which are valuable for the industries especially for production and refineries sector [4] [5] [6]. The Process will be completed in four steps, including initiation, transfer, decomposition and termination [7].

Table 1
Fuel properties of pyrolyzed polyethylene hydrocarbons (PPEH) and ULSD along with a comparison to petrodiesel fuel standards.[a]

	Units	ASTM D975[b]	EN 590	PPEH-L	PPEH-H	1:1 L/H	ULSD
Low temperature	°C						
CP		–[c]	–[c]	−30.1 (0.1)	4.7 (0.2)	−5.9 (0.2)	−17.5 (0.3)
PP		–[c]	–[c]	−37.3 (0.6)	4.0 (0)	−8.3 (1.2)	−20.3 (0.6)
CFPP		–[c]	–[c]	−31.0 (0)	3.7 (0.6)	−6.0 (0)	−16.0 (0)
Oxidative stability:							
IP, 110 °C	h	–[c]	≥20	3.9 (0.3)/14.4 (0.8)[d]	12.9 (1.5)/>24[d]	7.7 (0.9)/>24[d]	>24
OT	°C	–[c]	–[c]	175.2 (0.3)/186.9 (0.4)[d]	190.1 (0.7)/202.1 (0.5)[d]	180.8 (0.5)/192.7 (0.6)[d]	196.2 (0.5)
KV, 40 °C	mm^2/s	1.9–4.1	2.0–4.5	1.20 (0.01)	2.96 (0)	2.08 (0)	2.28 (0.01)
DCN		≥40	≥51	54.6 (1.1)	73.4 (1.4)	66.3 (1.5)	47.4 (0.9)
Flash point	°C	≥52	≥55	<30	81.5 (0.7)	90.3 (1.8)	65.0 (0.7)
Wear scar, 60 °C	µm	≤520	≤460	293 (3)	198 (10)	282 (3)	581 (5)
Sulfur	ppm	≤15	≤10	3	2	2	8
SG, 15 °C		–[c]	–[c]	0.777 (0.001)	0.803 (0.001)	0.792 (0.001)	0.841 (0.001)
Density, 15 °C	kg/m^3	–[c]	820–845	776 (1)	802 (0)	791 (1)	840 (1)
ST, 40 °C	mN/m	–[c]	–[c]	22.5 (0.1)	24.7 (0.1)	23.6 (0.2)	25.1 (0.2)
Moisture	ppm	–[c]	≤200	106 (2)	64 (3)	84 (1)	49 (3)
HHV	MJ/kg	–[c]	–[c]	45.86 (0.22)	46.16 (0.09)	46.04 (0.08)	45.15 (0.19)

[a] Values in parentheses represent standard deviations from the reported means (n = 3). For flash point, n = 1.
[b] For No. 2 grade S15 (15 ppm S) ULSD.
[c] Not specified.
[d] With 1000 ppm BHT added.

Table 1. Fuel Properties of pyrolyzed polyethylene Hydrocarbons

Comparison of pyrolysed polyethylene hydrocarbons (PPEH) oil with conventional petroleum-derived ultra-low sulfur (b15 ppm S) diesel fuel (ULSD) is shown in Table 1 [8].

There are numerous published research papers based on the potential of various types of plastics for the pyrolysis process in liquid production. It should be noted that the results and quality of the product are highly dependent on the parameter setting. The main parameters are temperature, reactor type, residence time, pressure, different catalysts usage and type of fluidizing gas with its flow rate [4]. Furthermore, the TGA experiment showed that the heating rate has an important role on the decomposition reaction; when the heating rate increases, the decomposition temperature of the plastics samples also increases [9]. Thus, the aims of this paper is to study the influence of heating rate and temperature on the yield and properties of pyrolysis oil obtained from waste plastic bag, which are immensely available in Indonesia.

2. Materials and Methods

2.1. Materials

The plastics used in this research were waste plastic bags from *Low Density Polyethylene* material. First step, the plastic is washed until it dried up and then be prepared into small pieces. Ten (10) kg of the plastic pieces the be placed into the reactor for each pyrolisis process.

2.2. Methods

The experiment was performed in a cylindrical reactor with conical top cover, made from steel with the dimension of 0.7 m in diameter and 1.5 m in high with a K type thermocouples were placed in the top of reactor. The furnace was covered with firebrick as heat isolator. The condensers were made from carbon steel tube with diameter of 4 inch. The length of first condenser is 1 m and second condenser is 1.5 m length. There were ten vapor tubes with diameter ½ inch placed inside each condenser. The pump with 0.5 kW power, was used to flow the cooling water from receiver to condenser. The pyrolysis batch reactor used in this study was shown in Figure 1.

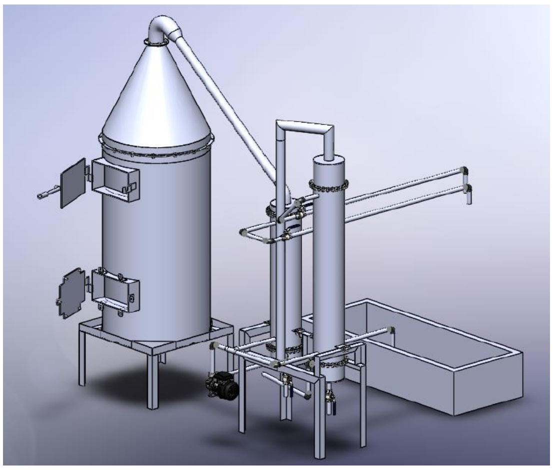

Figure 1. Pyrolysis Batch Reactor

The experiments were obtained in two parts; first, to investigate the effect of the heating rate on the pyrolysis product yields, for this purpose, plastic bags were pyrolysed at heating rates 5, 10, and 15°C/min. The reactor was heated from the room temperature to a final temperature of 450 °C (held 15 min). The second part was performed to establish the effect of pyrolysis temperature on the pyrolysis yields. The reactor was heated from room temperature to desired temperature (250, 350, and450°C, held for 15 min) at heating rate of 15°C/min.

The reactor was heated till reach the ideal temperature using a hot flue gas from combustion of pyrolysis oil by steam atomizing burner. The organic vapors produced within the heating chamber at high temperature and then was condensed into liquid oil in the condenser. Water circulating cooler was used to decrease the temperature of condenser for the maximum condensation of organic vapors into liquid oil in the condenser. The condensed organic vapors (liquid oil) were collected from the oil collector assembly at the bottom of the condenser, while the uncondensed products (gases) from the same liquid oil pipe were exhausted outside, and solid char were taken from the bottom of reactor.

3. Result and Discussion

3.1. Influence of Heating rate

Table 2 showed the yield of conversion degree oil, char and gases (Gas yield estimated=100–char–liquid) from the pyrolysis of the waste plastic bag in relation to the heating rate from 5 to 15 °C/min to a final pyrolysis temperature of 450 °C in the fixed bed reactor.

No	Product	Heating rate (^{0}C/min)		
		5	10	15
1	Liquid	53.1	51.3	47
2	Char	14.5	11.4	12
3	Gases	32.4	37.3	41

Table 2. Yield of Pyrolysis Product (weight %) at various heating rate

The process of plastic pyrolysis can be obtained as the heating rate increases, the conversion degree and the yield of gases increased, while the yields of oil and char decreased, respectively. These results shows same tendency as obtained in the pyrolysis of plastics [10]. Williams and Ahmad [11] suggest that the pyrolysis process may be processed by a diffusion-limited process controlled by heat and product diffusion. They suggest that the extent of diffusion control increases at high heating rates because products are generated faster than it can diffuse out of the pores, consequently secondary coking reactions will occur.

3.2. Influence of Temperature

Second part of the experiments, it was performed in the reactor with pyrolysis temperature between 250 and 450 °C at the heating rate of 15°C/min, resulted the product yields of pyrolysis of the waste plastic bag in relation to the temperature as shown in the table 3.

No	Temperature	Pyrolysis Oil	Wax	Noncondensable gas	Solid Residue
1	250^{0}C	8	52	5	35
2	350^{0}C	15	27	35	23
3	450 ^{0}C	45	2	41	12

Table 3. Effect of temperature on th eyield of pyrolysis products (weight %)

At the lowest pyrolysis temperature of 250 °C, the pyrolysis oil yield was low, which reflects the incomplete pyrolysis process form as a large amount of wax. As the temperature was increased, the pyrolysis oil yield was also increased until it reached the maximum temperature at 450°C. Therefore, there was a progressive increasing in gas yield and conversion degree from 250°C to 450 °C, while the amount of char and wax has decreased.

These results showed the same tendency from pyrolysis of plastics [12] [13] [14]. So it can be concluded that temperature has an important role in the of products distribution. As material reached the elevated temperatures, the different chemical components experienced the thermal degradation affecting the conversion of yield and the product quality. The increasing of the pyrolysis temperature caused a significant increase in the pyrolysis oil and gas yields. This result was attributed to the gas phase cracking reactions to yield increased hydrocarbons. At low temperatures (below 250°C) the pyrolysis of oil yields are reduced because of the coking reactions of the pyrolysis oil through the conversion of the pyrolysis oil to solid product and/or incomplete pyrolysis form of waxes. Consequently, an optimum temperature which is maximum temperature of oil yields are obtained.

Furthermore, the characteristics of all liquid products (mixed of pyrolysis oil and waxes) have been evaluated, the analysis results of this examination are presented in Table 4.

No	Parameters	Temperature (^0C)			Diesel Oil [12]
		250	350	450	
1	Caloric Value (kcal/kg)	6,258	10,957	11,043	11,281
2	Flash Point (^0C)	96	55	27	55
3	Viscosity Kinematic at 40^0C (mm^2/s)	12.10	5.42	2.80	2.1
4	Spesific Gravity	1.0492	0.8601	0.8102	0.82

Table 4. Properties of the liquid products in comparison with diesel oil

Table 4 showed that the liquid produced from pyrolysis process in temperature 450^0C has higher gross heating value, and lower flash point. The result has more specific Gravity and Viscosity Kinematic than liquid that produced from pyrolysis process in other temperature. Since the increasing of temperature facilitated secondary of cracking reactions, it can be assumed that the liquid recovered had lighter hydrocarbon fraction (lower molecular weight hydrocarbon). In general, lighter hydrocarbon fraction in a homologous series had a lower boiling point, a higher heating value, and lower viscosity [15].

According to Table 4, it was indicated that among other processes, the liquid product taken from 450^0C of pyrolysis had the physical properties closer to diesel oil. If compared to it, the liquid was lighter and easier to burn and slightly more viscous. In addition, the liquid had similar quality of energy content with diesel oil. Although many similarities have been found in the liquid product (especially from pyrolysis process in 450^0C) and diesel oil. With the record, more comprehensive analyses should be done if the oil were to be used as a diesel oil substitute. Other oil properties, such as the smoke point, sulfur content, copper strip corrosion, and odor, should be evaluated and meet the standard criteria for commercial diesel oil [14].

3. Conclussion

Pyrolysis of waste plastic bag to produce oil increases along with the increasing of temperature. Highest pyrolysis oil yield is 47 % (weight) was obtained from 450^0C and heating rate 15^0C/min. The pyrolysis oil formation is also affected by the heating rate. As the heating rate increases, the conversion degree and the yield of gases increased and the yields of liquid and char decreased. The physical properties of the liquid production compared favorably with diesel oil, which shows that it can be used as diesel oil substitution. However, a more detailed analysis should be conducted to assure further utilization of the liquid. Hence pyrolysis of these waste plastic bags does not only manage the environment but is also a means of cheaper energy source for the alternative fuel.

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