



The Effect of Low Density Poly Ethylene (LDPE) Towards Plastic Oil Quality

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Received : September 11, 2020

Accepted : March 26, 2021

Online : April 29, 2021

Abstract – Nowadays, the use of plastics is inseparable from daily life activities for both industrial commercial and household needs. Every year, an average individual consumes 700 plastic bags. Furthermore, the major types of plastic pollutants are High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE). The nature of LDPE plastic makes it very difficult to undergo decomposition. Subsequently, efforts to overcome this problem have been carried out by several methods of processing or utilizing its waste through pyrolysis. This study aims to determine the effect of the quality of LDPE plastic waste on the plastic oil produced from the pyrolysis process. Based on their chemical compounds, all plastic oils produced were categorized as carbon compounds instead of hydrocarbons. Although, from the quality of the LDPE plastic used, the process produced gasoline, naphtha, and kerosene, the quality of each oil was different. Therefore, the higher the quality of the LDPE plastic used, the better the quality of the oil produced.

Keywords: Plastic, LDPE, plastic oil, pyrolysis process, quality, oil produced

Introduction

The increased rate of plastics production has led to a rise in the amount of waste produced. In the United States, plastics contribute 12.7% of the total waste generated (EPA, 2013). However, in several Asian countries, the waste composition depends on the economic level shown in their Gross Domestic Product (GDP). Therefore, its composition in Japan reaches 20% of total waste, while Indonesia only contributes 10% (Borongon and Okumura, 2010). Nowadays, the use of plastic is inseparable from daily life activities, both for industrial, commercial, and household needs. Every year, an average individual consumes 700 plastic bags. Furthermore, supermarkets around the world provide more than 17 billion every year.

Indonesia consumes 0.52kg of plastic/person/day and therefore, is the second largest plastic waste contributor after China in 2019 (Jambek *et al.*, 2019). In 2019, Indonesia's amount of plastic waste reached 9,520,000 tons or 14% of Indonesian waste. The major types of plastic pollutants are High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE) contributing 46% of total plastic waste.

Plastic waste is very difficult to decompose (relatively non biodegradable). According to Bell and Cave (2011), its natural decomposition by microorganisms takes 400-1000 years, which causes negative impacts on the environment. Currently, several methods for processing or utilizing plastic waste have been developed to overcome this problem, one of which is pyrolysis. Therefore, this study aims to determine LDPE plastic waste's effect on the quality of plastic oil produced from the pyrolysis process.

The production of plastic waste in Indonesia is vast with a total of 189 kilotons/day, which is much higher compared to other countries in Southeast Asia (Kholidah *et al.*, 2018). LDPE is the most dominant of all the existing plastic waste products reaching (56%) and 75% from household use. This figure is because plastic bags made of LDPE are widely used in everyday life.

Therefore, to minimize the environmental impact, the material from this waste should be recycled immediately to either obtain its products or other products of economic value. There are several recycling methods such as mechanical and feedstock, including energy recovery (Al Salem *et al.*, 2019): 1) mechanical

recycling refers to the processing of plastic waste to obtain its products by mechanical means. In this system, it is melted to make pellets used as raw material to manufacture plastic-based products. This recycled plastic is commonly used to make products of lower quality., 2) energy recovery is a method used to recover the energy contained in plastic waste through combustion to generate heat, steam, or electricity, 3) feedstock recycling involves a thermal degradation process called pyrolysis to break down polymers into monomers. Several thermal degradation methods have been developed. They include thermal degradation or pyrolysis, catalytic pyrolysis, and a combination of both.

As one of the petroleum derivatives products, the processing of plastic waste produces a fuel with high energy content. Table 1 shows the calorific value of plastic compared to fuel.

Table 1. Calorific values of several types of plastics and fuels.

Material Type	Calorific Value (MJ/kg)
Polyethylene	43,3 – 46,5
Polypropylene	46,5
Polystyrene	41,9
Kerosene	46,5
Solar	45,2
Heavy oil	42.5
Crude oil	42,3

Source: Al-Salem et al (2009)

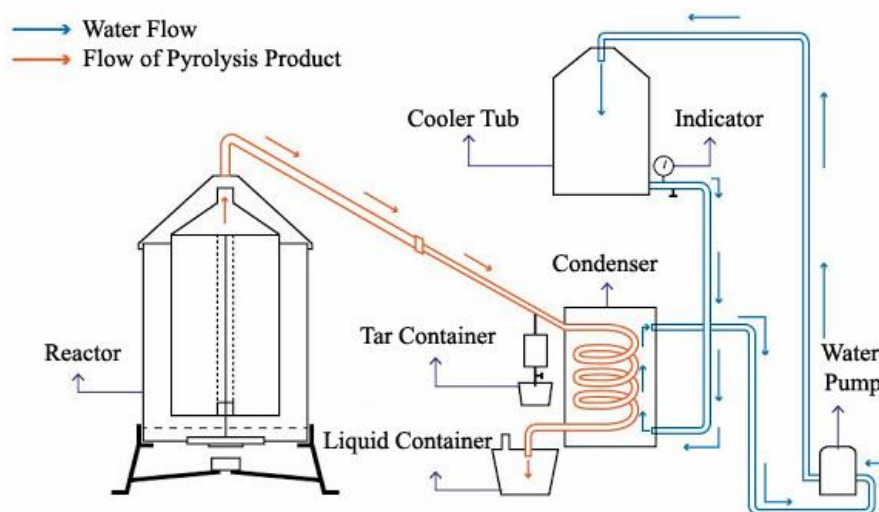


Figure 1. Schematic of the pyrolysis process.

Pyrolysis is the process of fractionating a material at a high temperature. It is also known as the thermal cracking process, which breaks down the polymer structure of a material by heating without or with little oxygen. Figure 1 shows a typical pyrolysis process, which begins at about 200 °C when the thermally unstable components and volatile matters in the waste break apart and evaporate together with other components. This is a process involving the thermal decomposition of organic material at high temperatures without oxygen. One of the factors influencing the process is temperature, which plays an important role in the thermal cracking reaction.

Plastics undergoing the pyrolysis process decompose into 3 phases of matter. They include the liquid phase in the form of fuel oil, the gas phase in the form of the condensable or non-condensable mixture, and the solid phase in residue or tar (Hamidi et al., 2013). Compared to biofuels such as biodiesel and bioethanol, oil from plastic pyrolysis has several advantages, such as the absence of water, which provides a greater calorific value. Furthermore, it does not contain oxygen, preventing corrosion (Hidayah and Syafrudin, 2018). In addition, the oil produced from this process is flammable, has a strong odor, and emits soot. Although it has unsaturated properties, this plastic oil is reprocessed until it becomes saturated and stable (Pareira, 2009).

The processing of LDPE plastic waste into oil through pyrolysis was also carried out by Iswadi (2017), which took 2 hours at a temperature of 250°C and pressure of 2 bars to produce 525 mL oil. However, this

study had limitations due to the inability of the tool to determine the flashpoint value.

LDPE is a type of plastic produced at high temperatures (200-300°C) and supercritical ethylene pressure (130-260MPa) using free peroxide radicals. It has long and branched chains with density varying from 0.915 to 0.925g/cm³. This type of plastic is widely used as food wrap due to its flexible yet strong properties (Cahyono & Styana, 2017). Although LDPE plastic is of great use in everyday life, the increase in its waste quantity has become a problem. This is because it is difficult to decompose directly by microorganisms in the soil. Therefore, it causes environmental pollution in the form of land degradation (Bashir, 2013).

One way to reduce the accumulation of LDPE plastic wastes is by recovering and processing them into oil through the pyrolysis process. This is possible because plastics are formed from petroleum. In addition, they have a high calorific value, reaching 40 MJ/kg (Syamsiro & Arbiyantoro, 2014). Its conversion into fuel oil, solids, and gas is usually carried out at high temperatures; therefore, it is called a thermal decomposition process or pyrolysis. Cracking is the pyrolysis process that involves converting plastic waste into basic petrochemical materials used as raw materials for hydrocarbons or fuel.

Pyrolysis of LDPE plastic oil, pyrolysis is a thermal degradation process on polymeric materials such as plastics and organic materials such as biomass through a heating process with or without oxygen (Aguado *et al.*, 2007). It starts at around 200°C when the thermally unstable components and volatile waste matter are broken down and evaporated along with the other components. However, according to Aguado *et al.* (2007), the temperature at which the breakage and evaporation of the chemical components of plastic waste occur between 500-800°C. Meanwhile, according to Santo *et al.* (2016), the plastic pyrolysis process may be carried out at a temperature range between 100- 400°C with a reaction time of 0-60 minutes, with the first drop occurring at temperatures around 120°C.

In this process, plastic as the input material undergoes a breakdown of its chemical structure into a gas phase with or without producing solid residues. The liquid products which evaporate contain tar and polyaromatic hydrocarbons (Aguado *et al.*, 2007). Furthermore, the results are processed into 3 (three) products: gas, oil, and charcoal (Chaurasia *et al.*, 2005). Sumani and Any (2008) conveyed a similar result. Based on their study, oil, gas, and residues in solids are obtained from the pyrolysis of LDPE plastic. However, when carried out under perfect conditions, the pyrolysis of LDPE and HDPE plastics produces oil and gas without leaving any residue conducted by Aprian and Munawar (2012).

Furthermore, based on the study carried out by Lopez *et al.* (2010), it was concluded that when plastics classification and impurities separation are carried before pyrolysis, 90% of the plastic will be converted into oil and gas. Therefore, the raw material (input) composition dramatically affects the quality of the output produced. Al-Salem *et al.* (2009) also stated that sorting plastics based on grade or classification is the key to a successful recycling process, using the pyrolysis method.

Materials and Methods

In this study, the non-catalytic pyrolysis process was used to decompose LDPE plastic waste at the laboratory to obtain plastic oil. This process was carried out using the tool shown in Figure 2. The tool was a retort equipped with a thermocouple and a regulator to maintain the stability of the operational temperature. The retort of the device measured 60 x 60 x 30cm. Furthermore, the pyrolysis apparatus had three liquid outlets, i.e., 1, 2, and 3.

The LDPE plastic used had three quality variations which include the White LDPE plastic (plastic-P) derived from white plastic bags, LDPE-plastic mix (M-plastic) made from a mixture of various colored bags, and Blend-plastic LDPE (plastic-B). Each plastic used is shown in Figure 3.

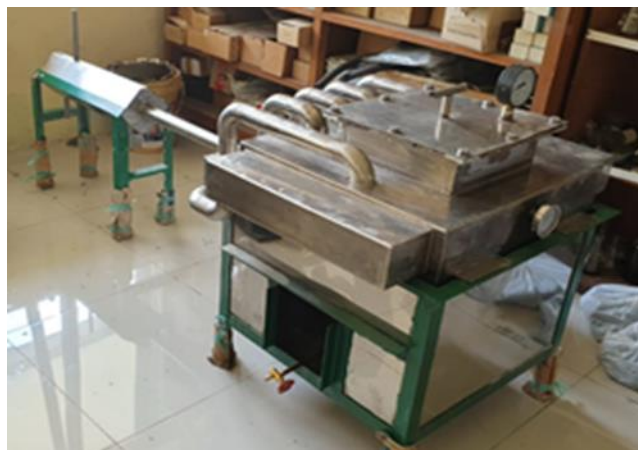


Figure 2. Pyrolysis reactor used.



Figure 3. Typical shreds and quality of LDPE plastic used: (a) white LDPE; (b) mix-plastic LDPE; (c) Blend-plastic LDPE.

The results of the pyrolysis process in the form of plastic oil were obtained by weighing the liquid (Oil: M-1, M-2, and M-3) produced at any given time interval. At the end of the process, the solid residue in the retort was weighed to determine its weight. The amount of gas wasted was determined from the difference between the weight of the input and the total weight of oil yield and residue. Furthermore, Fourier Transform Infrared (FTIR) analysis was carried out to ascertain the effect of the LDPE plastic used on the quality of oil produced. This analysis was also used to determine the functional groups contained in the sample. The test was carried out at the Chemical Engineering laboratory, Bandung Institute of Technology (ITB).

Results

As previously stated, the pyrolysis device used in this study had three outlets (1, 2, and 3) from which oil was produced. Figure 4 shows the oil from the pyrolysis of white LDPE plastic (Plastic-P), namely MP-1, MP-2, and MP-3; Plastic Mix Oil, namely MM-1, MM-2, and MM-3; and Blend Oil namely MB-1, MB-2, and MB-3. A spectrophotometric test was carried out on each of these oils to determine the chemical properties of each LDPE. Furthermore, the boiling point of each oil was also tested to determine the type of oil produced.

Spectrophotometric of MP LDPE

In Figure 5, it is seen that the oils from the pyrolysis of LDPE Plastics-P, i.e., MP-1, MP-2, and MP-3, had an infrared absorption distribution that was relatively the same, with ten absorption peaks each. Furthermore, these oils contained compounds or chemical chain groups, such as single-bonded alkenes (CH), aromatic rings (CH), alkenes (CH), double-bonded alkenes (C = H), hydrogen bonding alcohols and phenols (OH), amines, and amides (NH). Therefore, it was concluded that the oil obtained from this plastic contains not only hydrocarbons but other compounds. Consequently, it was not classified as a hydrocarbon compound but as a carbon compound.



Figure 4. Visualization of oil produced from LDPE plastic pyrolysis: (a) LDPE Plastic Oil: MP-1, MP-2, and MP-3; (b) Mix Oil of LDPE Plastic: MM-1, MM-2, and MM-3; (c) Blend Oil of LDPE Plastic: MB-1, MB-2, and MB-3.

Spectrophotometric of MM LDPE

From the FTIR test results on MP LDPE spectrophotometry towards MM, as shown in Figure 6, it was seen that the infrared adsorption distribution for MM-2 and MM-3 was relatively the same but different from MM-1. MM-2 and MM-3 had 11 absorption peaks, while MM-1 only had 10. Although they have different infrared distribution peaks, these oils contain the same types of compounds or main chemical chain groups. They include single-bonded alkenes (CH), aromatic rings (CH), alkenes (CH), double-bonded alkenes (C = H), hydrogen, and phenol bonded alcohols (OH), amines, and amides (NH). However, M-2 and M-3 oils contain amines and amides from the CH group and nitro compounds (NO₂).

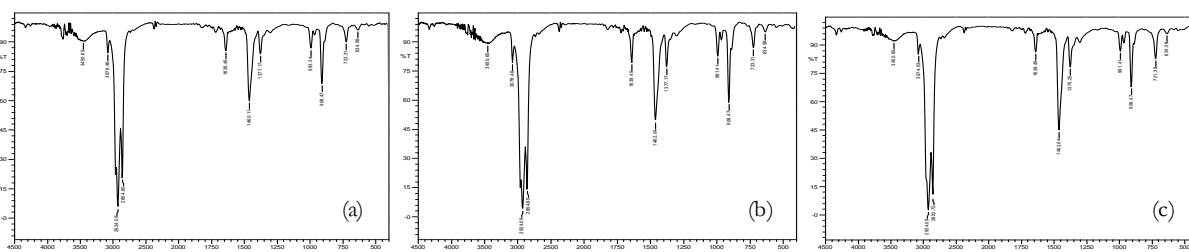


Figure 5. Spectrophotometry of MP LDPE: (a) Spectrophotometry of MP-1; (b) Spectrophotometry of MP-2; (c) Spectrophotometry of MP-3.

Spectrophotometric of MB LDPE

From the spectrophotometric results of LDPE Blend-Plastic pyrolysis, as shown in figure 7, it is seen that the infrared absorption distribution for MB-1 and MB-2 was relatively the same and different from MB-3. MB-1 and MB-2 had 11 absorption peaks, while MB-3 had 13 peaks. MB-1 and MB-2 contained the same types of compounds or chemical chain groups, which include single-bonded alkenes (CH), aromatic rings (CH), alkenes (CH), double-bonded alkenes (C = H), aldehydes, ketones, carboxylic acids, and esters (C = O), hydrogen and phenol bonded alcohols (OH), amines and amides (NH). Conversely, MB-3 oil contained single-bonded alkenes (CH), aromatic rings (CH), nitro compounds (NO₂), alkenes (CH), double-bonded alkenes (C = H), aldehydes, ketones, carboxylic acids, and esters (C = O), hydrogen and phenol bonded alcohols (OH), amines and amides (NH). Therefore, the oil obtained from the pyrolysis of the LDPE Blend-plastic compound was also not included in the group of hydrocarbons but classified as a carbon compound. The spectrophotometric test results on MP, MM and MB oils mentioned above were all classified as carbon compounds instead of hydrocarbons. However, only MB contained the carbonyl compound group (C=O). This shows that only the LDPE Blend-plastic had polymers reactive to hydrogen atoms in polymeric structures such as -OH and =O.

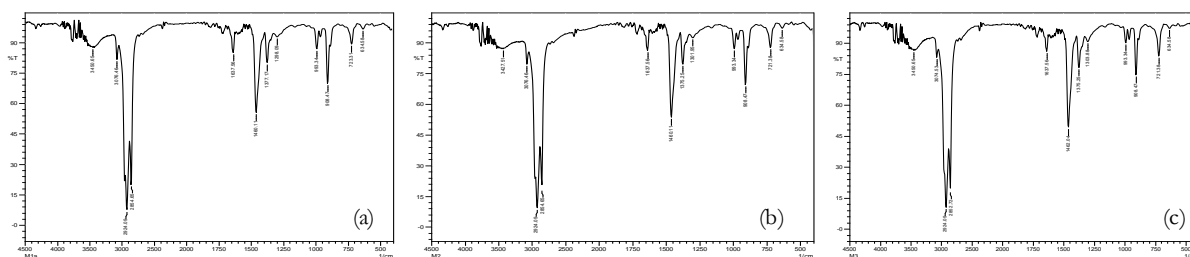


Figure 6. Spectrophotometry of MM LDPE: (a) Spectrophotometry of MM-1; (b) Spectrophotometry of MM-2; (c) Spectrophotometry of MM-3.

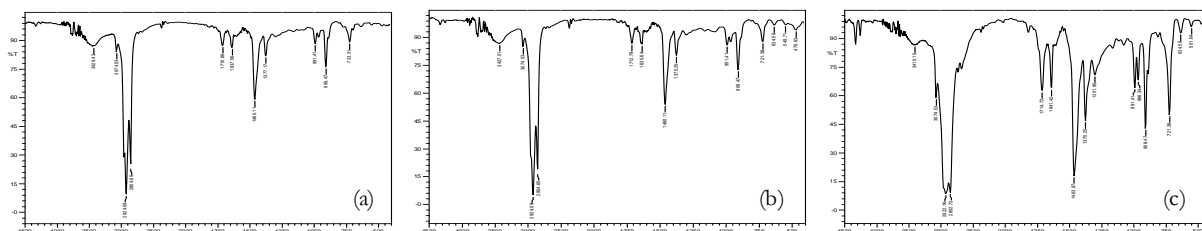






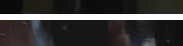




Figure 7. Spectrophotometry of MB LDPE: (a) Spectrophotometry of MB-1; (b) Spectrophotometry of MB-2; (c) Spectrophotometry of MB-3.

Table 2. Quality, properties, and types of LDPE plastic pyrolysis oil.

Code	Plastic Oil			Oil Category Based on Boiling Point *		
	Boiling point (°C)	Ambient Temperature Properties	Oil Color	Boiling point (°C)	Type	Number of Atoms C
P-1	75	Liquid		60 - 100	Fuel	6 - 8
P-2	128	Liquid		100 - 200	Gasoline (Naphtha)	8 - 11
P-3	200	Liquid		200 - 300	Kerosene	12 - 15
M-1	75	Liquid		60 - 100	Fuel	6 - 8
M-2	135	Liquid		100 - 200	Gasoline (Naphtha)	8 - 11
M-3	215	Liquid		200 - 300	Kerosene	12 - 15
B-1	80	Liquid		60 - 100	Fuel	6 - 8
B-2	150	Liquid		100 - 200	Gasoline (Naphtha)	8 - 11
B-3	230	Semisolid		200 - 300	Kerosene	12 - 15

* Source: Heavy Equipment (2014), Basic Process of Petroleum Processing, <http://www.alatberat.com/blog/proses-dasar-pengolahan-minyak-bumi/>

Discussion

As previously mentioned, Plastics-P, M, and B LDPE in pyrolysis using a device with three outlets produced three different types of oil (see Figure 4). From the visual observation of the boiling point after the pyrolysis process, it was seen that the plastic oil from white LDPE plastic was liquid and had a light yellow to brown color. In addition, that from LDPE plastic-mix was also liquid and brown to black. Meanwhile, the oil from LDPE blend-plastic was black, and only B-1 and B-2 oils were liquid. The B-3 oil hardened (freezes) at ambient temperatures but becomes liquid at relatively high temperatures. From the test results, each oil produced had a different boiling point, as shown in Table 2. Plastic-P, M, and B may be classified as gasoline, heavy gasoline (naphtha), and kerosene based on the boiling point value. However, although each LDPE plastic produced's pyrolysis process was in the same category, the quality and color of the oils were different.

The above explanations said that B-3 oil is semisolid at ambient temperatures but is liquid at relatively high temperatures. These properties can be said to resemble those of asphalt slightly. However, if it is in a liquid condition, the B-3 oil is more viscous than asphalt, but when it hardens, it is not as hard as asphalt; it is much softer than asphalt. Also, B-3 oil does not have elastic properties like asphalt. It is believed that the nature of the hardening or freezing of B-3 oil at this ambient temperature is because the oil contains paraffin (wax). This is confirmed by the results of research conducted by Qonita et al. (2015) on pyrolysis plastics that have different melting points, namely HDPE (200-280°C), PET (250-260°C), and PS (180-260°C). One of the products produced from pyrolysis of the three types of plastics is wax but with a distinction.

Conclusions

The following results may be concluded from this study: (1) In the LDPE plastic pyrolysis process, the plastic quality greatly affects the quality of the oil produced. Higher plastic quality used in the process produces better oil quality; (2) Based on chemical compounds, all LDPE plastic oils produced in this study (MP, MM, and MB) were categorized as carbon compounds instead of hydrocarbons; (3) Only Blend-plastic pyrolysis oil (MB-1, MB-2 and MB-3) contained the carbonyl compound group; and (4) Based on boiling point, MP-1, MM-1, and MB-1 were categorized as gasoline, MP-2, MM-2, and MB-2 as naphtha (oils P-2, M-2, and B-2), while MP-3, MM-3, and MB-3 as kerosene. In this research, the pyrolysis of a plastic-blend was used as an asphalt solvent, but further studies are still needed to looking the effect of oil plastic in the rheological properties of asphalt, especially asphalt with high hardness levels such as 30/40 penetration grade asphalt or natural rock asphalt (asbuton) which is available in huge amount in Buton Island of Indonesia.

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