

The Effect of Polypropylene and Low-Density Polyethylene Mixtures in the Pyrolysis Process on the Quantity and Quality of the Oil Products

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ARTICLE HISTORY

Received 5 December 2023
 Received in revised form 7 December 2023
 Accepted 9 December 2023
 Available online 11 December 2023

ABSTRACT

Plastic waste is a type of waste that has economic value when processed properly, one of which is by converting it into fuel oil using the pyrolysis method. Pyrolysis of plastic waste involves the decomposition of materials at high temperatures without the presence of oxygen. This study aimed to examine the effect of the mixture of polypropylene (PP) plastic waste and low-density polyethylene (LDPE) plastic waste in the pyrolysis process on the quantity and quality of the oil products. The ratio of PP:LDPE was varied to 100 kg : 0 kg, 70 kg : 30 kg, 50 kg : 50 kg, and 30 kg : 70 kg. The pyrolysis was conducted at a temperature of 350°C for 10 hours. The research results show that the highest yield value of 82.24% wt. is obtained at PP:LDPE ratio of 100 kg : 0 kg. Furthermore, the best pyrolysis oil products are obtained at PP:LDPE ratio of 70 kg : 30 kg. The gasoline, kerosene, and diesel fuel products have densities of 760 kg/m³, 776.4 kg/m³, and 873 kg/m³, respectively. Then, the gasoline and diesel fuel have calorific values of 10,836 cal/g and 10,996.5 cal/g. The cetane number of diesel fuel is 42, while the octane number of gasoline is 78.9.

Keywords : Cetane Number, LDPE, Octane Number, Polypropilena, Pyrolysis

1. INTRODUCTION

Waste is the residual resulting from daily human activities or natural processes. Meanwhile, waste that continues to pile up will cause problems for the environment and the health of living creatures. Plastic waste takes a very long time to decompose naturally (about 400 to 1000 years) so it will cause quite large accumulations in landfills and will become a problem in the future (Chandra, 2006). In 2022, the amount of Indonesian plastic waste reached 3.6 million tons (18.55%). Furthermore, the regional plastic waste in Banten Province reached 93,140 tons in 2019 and 95,677 tons in 2020. Moreover, based on the Cilegon City Environmental Service, Cilegon City (one of the cities in Banten Province) resulted in plastic waste of about 84,135 tons in 2022.

Plastic waste is a type of waste that can still have economic value if processed properly. Plastic is a polymer resulting from the polymerization of hydrocarbon

monomers which have various boiling and melting points. In general, plastic polymers are composed of organic chemical compounds such as carbon (C), hydrogen (H), and non-metal elements (O, N, and Si). Apart from that, the polymers have a very large molecular structure and have a carbon chain as the main chain.

One of the interesting methods for dealing with plastic waste is to convert the plastic waste into fuel oil using the pyrolysis method because plastic is a polymer of hydrocarbon elements so plastic has the potential to be converted into alternative fuels (Selpiana et al, 2015). Pyrolysis is a process of decomposition of materials at high temperatures without the presence of oxygen to produce fuels in the form of liquids, solids, and gases. There are two types of pyrolysis which are catalytic pyrolysis and non-catalytic pyrolysis. The pyrolysis process is conducted under temperatures of 150 - 700°C, thereby resulting in products such as oil, gas, and solids/char (Paradela et al, 2009).

A previous study reported that the pyrolysis of polypropylene (PP) plastic at a temperature of 500°C resulted in an oil yield of 82.12% wt. Furthermore, pyrolysis of Low-Density Polyethylene (LDPE) plastic at a low temperature resulted in an oil yield of 32.5% wt and a gas yield of 50.2% wt (Buah et al, 2007). Polypropylene plastics most frequently used by the general public are *kresek* plastic bags, clear plastic bags, and plastic sachet wastes. Based on the description above, research on the effect of pyrolysis of a mixture of PP plastic waste and LDPE plastic waste on the characteristics of the resulting oil products needs to be conducted. It is hoped that the results of this research can be an alternative solution to reducing the accumulation of plastic waste originating from petroleum.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this research included clear plastic bag waste and *kresek* plastic bag waste from polypropylene (PP), and plastic sachet waste from Low-Density Polyethylene (LDPE) which were obtained from the community in the Serdag Village, Purwakarta sub-district, Cilegang City, Banten Province.

2.2 Raw Material Preparation

The collected plastics were sorted based on the criteria of PP and LDPE types namely the *kresek* plastic bag and clear plastic bag wastes as PP plastic wastes and plastic sachet wastes as the LDPE plastic wastes. After that, they were cleaned and crushed using a crusher into small pieces with a size of ± 4 cm.

2.3 Pyrolysis Process

The crushed plastics were mixed with PP:LDPE ratios of 30:70, 50:50, 70:30, and 100 w/w with a total mass of 100 kg. Then, they were put into the pyrolysis reactor and heated to a temperature of 350°C then maintained constant. At a temperature of 100°C, all valves began to open so the condensed liquid could drip out. Samples were taken every 10 minutes from the first drop of oil to the last drop of oil. Then, the oil's content was analyzed. The pyrolysis process was carried out at atmospheric pressure. When the reactor temperature reached 200°C, cooling water was flowed using a condenser with a cooling water temperature of 28°C and the heater started to turn on with the help of a compressor engine until it reached a temperature of 350°C. The pyrolysis process was carried out with a holding time of 10 hours. The pyrolysis process was carried out until the desired product was obtained. The analysis of the resulting oil was carried out using several tests, including the density test through the ASTM D1298 standard, the octane number test through the ASTM D163 standard, the cetane

number test through the ASTM D613 standard, and the heating value test through the Bomb 6400 or C2000 calorimeter standard. A detailed pyrolysis reactor is shown in Figure 1. The pyrolysis process was conducted at the Integrated Waste Processing Industry of "Atasi Sampah-Kelola Mandiri" (IPST ASARI).



Fig. 1. Pyrolysis Equipment Scheme for Treating Plastic Waste

3. RESULTS AND DISCUSSION

3.1 Effect of Heating Time on Temperature Profile

Based on the results shown in Figure 2, the relationship between pyrolysis time and temperature is directly proportional. It means that the longer the pyrolysis process time, the higher the temperature of the pyrolysis process will be. The increase in temperature is caused by the absorption of heat by the plastic raw material. The plastic will absorb heat and distribute it to all surfaces of the raw materials in the reactor. The longer the contact time between the raw material and heat, the temperature will increase, so the hydrocarbon chain in the raw material degrades to become shorter (Novi, 2021).

Plastic is a macromolecule formed through a polymerization process. Polymerization is the process of combining simple molecules (monomers) by chemical reactions to become larger molecules (polymers). Plastic has thermal properties such as melting point. The melting point is the point at which the plastic begins to soften and turns into a liquid, where the melting point of PP is 160°C and LDPE is 115°C. In Figure 2, it can be seen that the mixture of PP and LDPE produces a zone where the temperature will increase more quickly compared to the PP alone (without LDPE addition). The ratio of PP:LDPE of 30:70 w/w has a temperature increase rate percentage of 55.2%.

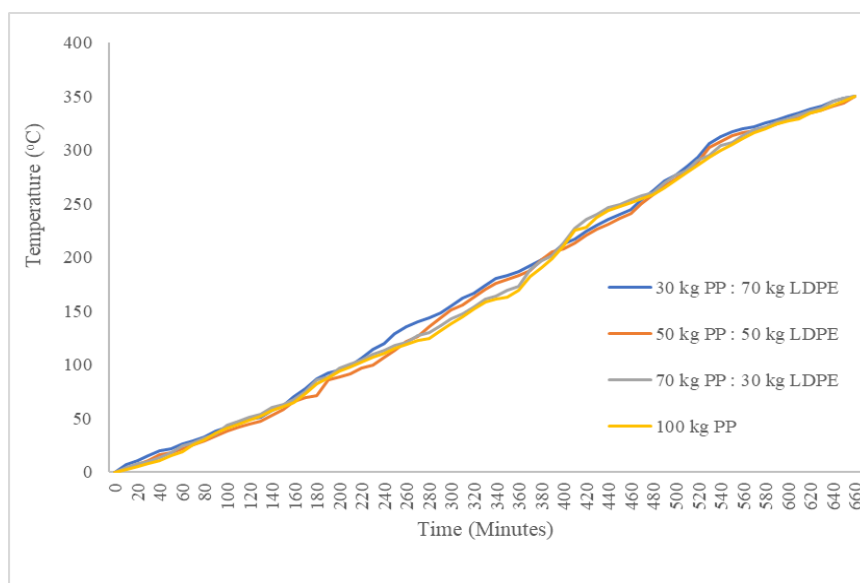


Fig. 2. Effect of Heating Time on Temperature Profile

LDPE plastic is a thermoplastic type that can absorb heat quite well. Heat transfer from the reactor to the raw material is also influenced by the thermal conductivity of the raw material used. Thermal conductivity is a measure of the ability of raw materials to conduct heat from one place to another. Thermal conductivity is used to classify whether a material is a conductor or an insulator (Prihartono & Irhamsyah, 2022). The thermal conductivity of LDPE plastic is 0.38 W/m.K, while the thermal conductivity of PP is 0.239 W/m.K (Sabet et al., 2019). Based on those thermal conductivity values, it can be stated that LDPE has a higher thermal conductivity value than PP, so LDPE can receive and transmit heat better than PP.

3.2. Effect of Heating Time on pyrolysis products

Based on the results shown in Figure 3, the pyrolysis product mass increases with increasing the pyrolysis reaction time. The pyrolysis product mass increases because the longer the pyrolysis process, increases the time of contact between heat and raw material, so more compounds are decomposed and converted.

Increasing the processing time will increase the conversion. However, it can reduce the liquid product because the raw material is converted into more gas products. It is because the process time used is too long so the contact between raw material and heat exceeds the limit or maximum thermal degradation point of the raw material (Imtiaz et al, 2014). The temperature used will control the degradation behavior of the main material and the plastic cracking reaction in which the van der Waals forces between the constituent particles will break due to vibrations caused by heat so the solid raw material will evaporate and result in the breaking of the carbon

chain. Organic compounds or hydrocarbons in gas form that have been disconnected from the main chain will condense and produce liquid products (Billmeyer, 1963).

Based on Figure 3, in the pyrolysis process with the same reaction time, an increase in PP fraction in the mixed raw materials can increase the total volume of liquid products. However, there are differences in the heating zones for each liquid product. The addition of PP will extend the heating zone because the melting point of PP is quite high, namely 160°C. Meanwhile, the addition of LDPE will shorten the heating zone because the melting point of LDPE is relatively lower than polypropylene, namely 115°C.

In Figure 3, it can be seen that different PP:LDPE ratios in the pyrolysis process will affect the product mass. An increase in the PP fraction in the mixed materials can increase the liquid product mass. This is because the PP has a high carbon content. The carbon content in raw materials is directly proportional to the resulting product, where the higher the carbon content, the higher the hydrocarbon derivative liquid products. The results of this study are consistent with those of a previous study reporting that an increase in products is because PP plastic has a high carbon content, which is around 85.- - 86.1% (Li et al., 2005). Furthermore, in line with this study, a previous study reported that increasing the PP fraction in the mixed materials of PP and polystyrene can increase the liquid products while increasing the polystyrene can increase the gas products (Wong & Broadbelt, 2001). In this study, the liquid products resulting from the pyrolysis process using mixed materials with various PP:LDPE ratios are shown in Figure 4.

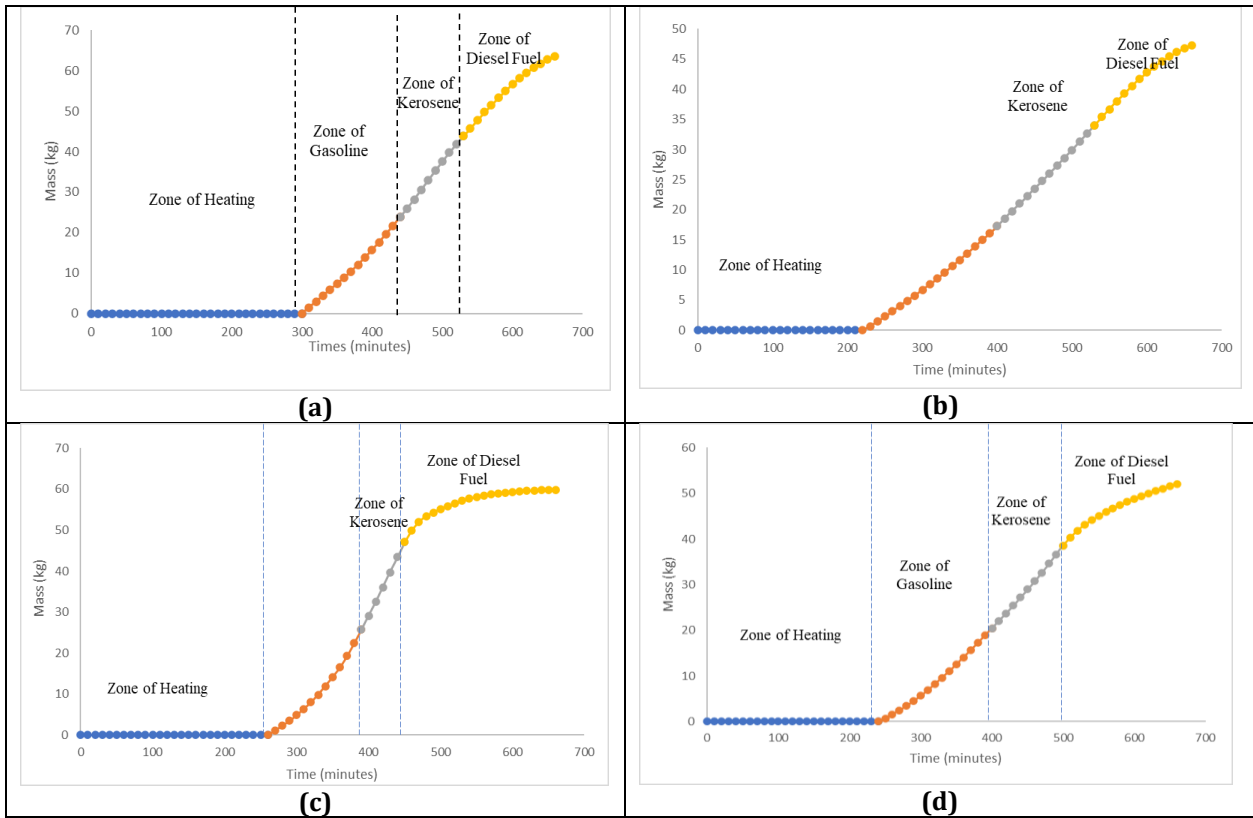


Fig. 3. Effect of heating time on the mass of pyrolysis products at PP:LDPE ratios of (a) 100 kg : 0 kg, (b) 30 kg : 70 kg, (c) 70 kg : 30 kg, (d) 50 kg : 50 kg

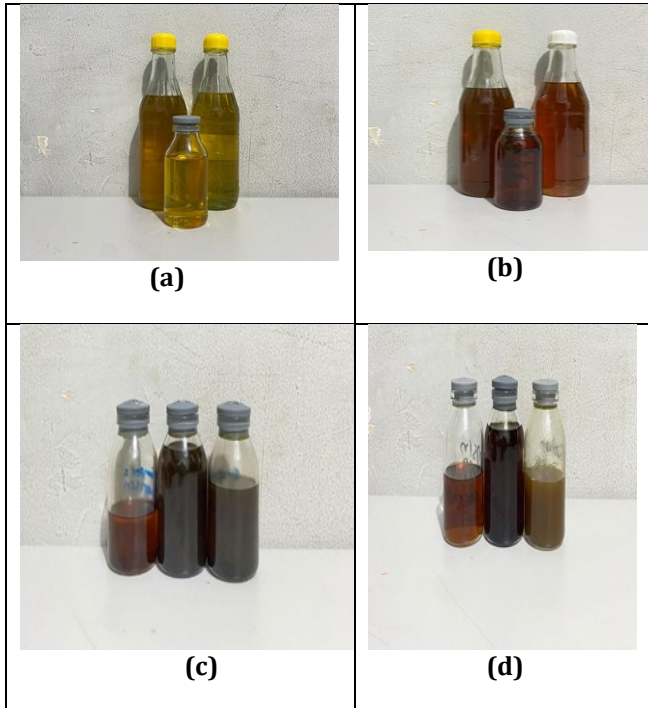


Fig. 4. The liquid products resulting from the pyrolysis process using mixed materials with PP:LDPE ratios of (a) 100 kg : 0 kg, (b) 70 kg : 30 kg, (c) 50 kg : 50 kg, (d) 30 kg : 70 kg

3.3 Characteristics of liquid products

The density of the liquid products is shown in Table 1. Based on Table 1, the composition of raw materials influences the density of the oil products. In other words, different PP:LDPE ratios will result in oil products with different densities. The product with the density closest to the SNI for gasoline is obtained at PP:LDPE ratio of 70 kg : 30 kg, namely 760 kg/m³. The SNI for gasoline is 715 - 770 kg/m³. Meanwhile, the PP:LDPE ratio of 70 kg : 30 kg results in kerosene with a density of 776.4 kg/m³ and diesel fuel with a density of 873 kg/m³. The density of PP and LDPE plastics and the process temperature affect the characteristic products. Polypropylene (PP) is a thermoplastic polymer having low heat stability, so it easily becomes soft at high temperatures or hardens again at low temperatures. LDPE plastic contributes density with a relatively high value because LDPE has more crystalline phases than PP. LDPE also has quite good thermal stability so it is difficult for carbon chain decomposition to occur in its constituent monomers (Yadav, 2020).

Then, the octane number test results show that the addition of LDPE can increase the octane number of the gasoline product. RON (Research Octane Number) values for mixed raw materials at various PP:LDPE ratios of 100 kg : 0 kg, 70 kg : 30 kg, 50 kg : 50 kg, and 30 kg : 70 kg are analyzed using the ASTM D613 method, namely 76.7, 78.9, 79.7, and 81, respectively. The standard octane number for conventional gasoline is 88. The difference in octane values between the gasoline obtained in this study

and the conventional gasoline is caused by the carbon chains that make up PP and LDPE and the addition of an octane booster to conventional gasoline (Akhbar, 2013). PP and LDPE plastics contain aliphatic and aromatic compounds in their carbon chains which can affect the octane value in the resulting gasoline products. It can be concluded that the addition of LDPE can increase the octane value of the gasoline product.

The higher the octane and cetane numbers in the gasoline, the smaller the knocking on the engine. When the fuel with too low an octane number is used, the fuel's ability to overcome knocking will be lower, so the pressure and temperature in the combustion chamber will increase rapidly, as a result, two high-pressure waves will be formed which collide in the engine cylinder or combustion chamber and produce knocking sound which, if it continues, can cause motor vehicle engine components to suffer damage.

The highest calorific value of gasoline, which is 10,926.3 cal/g, results from the PP:LDPE ratio of 100 kg :

0 kg. A comparison among the characteristics of the gasoline resulting from various PP:LDPE ratios is shown in Table 1.

Furthermore, based on the cetane number test results (Table 1), the cetane number of diesel fuel in this study which is closest to the cetane number of conventional diesel fuel is obtained at PP:LDPE ratio of 70 kg : 30 kg, which is 42. The difference in cetane number in each raw material composition is caused by the carbon chain and compound content in raw materials. A high cetane number will give an idea of the ability of the diesel fuel to ignite by itself (autoignition). The cetane number (CN) makes a major contribution to reducing exhaust emissions and can improve diesel engine performance (Nasution, 2010). Then, the best calorific value of diesel fuel is obtained at PP:LDPE ratio of 30 kg : 70 kg, namely 11,020.6 cal/g (Table 1).

Table 1. Characteristics of liquid pyrolysis products

Parameters	Standard test	Gasoline product				SNI for gasoline
		100 PP	70: kg pp:30 kg LDPE	50: kg pp:50 kg LDPE	30: kg pp:70 kg LDPE	
Density (kg/m ³)	ASTM D 1298	772	760	780	779	715-770
Octane number	ASTM D 163	76.7	78.9	79.7	81.4	88
Heating value	Bomb Calorimeter 6400	10,926.30	10,836.30	10,780.30	10,660.30	10,160-11,000
Parameters	Standard test	Diesel product				SNI for diesel
		100 PP	70: kg pp:30 kg LDPE	50: kg pp:50 kg LDPE	30: kg pp:70 kg LDPE	
Density (kg/m ³)	ASTM D 1298	874	873	884	882	835
Cetane number	ASTM D 163	37.2	42	38.9	36.5	48
Heating value	Bomb Calorimeter 6400	10,965.90	10,996.50	10,989	11,020.60	10,755-11,200
Parameters	Standard test	Kerosene product				SNI kerosene
		100 PP	70: kg pp:30 kg LDPE	50: kg pp:50 kg LDPE	30: kg pp:70 kg LDPE	
Density (kg/m ³)	ASTM D 1298	777.2	776.4	784	775.2	815-870

4. CONCLUSION

Differences in raw material composition in the pyrolysis process with PP:LDPE ratios of 100 kg : 0 kg, 70 kg : 30 kg, 50 kg : 50 kg, and 30 kg : 70 kg can affect the characteristics of the oil products. The best pyrolysis oil products (suitable with SNI standard) are obtained at PP:LDPE ratio of 70 kg : 30 kg. The density of the resulting gasoline, kerosene, and diesel fuel of 760 kg/m³, 776.4 kg/m³, and 873 kg/m³, respectively. The calorific value for the gasoline product is 10,836 cal/g and it for the diesel fuel product is 10,996.5 cal/g. The cetane number of diesel fuel is 42, while the octane number of gasoline is 78.9.

5. ACKNOWLEDGMENTS

The authors express gratitude to Universitas Sultan Ageng Tirtayasa and PT. Chandra Asri Petrochemical Indonesia for supporting this research.

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