Thermal Pyrolysis of Polypropylene Plastic Waste into Liquid Fuel: Reactor Performance Evaluation

M Martynis, Mulyazmi, E Winanda and A N Harahap
Chemical Engineering Department, Bung Hatta University, Jl. Gajah Mada No. 19 Olo Nanggalo, Padang, West Sumatera, 25143, Indonesia
martynismunas@yahoo.co.id

Abstract. The amount of plastic waste is growing over years due to the vast applications of plastics in many sectors. Of the various processes that can be used to convert solid waste into fuels, the pyrolysis process has been identified as having significant potential. Pyrolysis thermally degrading long chain polymer molecules into smaller, less complex molecules, through heat and pressure with little or in absence of oxygen. In this study, a 125 dm³ pyrolysis reactor was designed and its performance was evaluated. The feedstock for the reactor was 1 kg polypropylene type of plastic waste and conducted at temperature of 250 °C, 300 °C, 350 °C and 400 °C, each process was carried out at 30 minutes and 60 minutes of operating time. The results showed that at a temperature of 400 °C, for a period of 60 minutes, a maximum yield of 88.86% liquid fuel was achieved. Obtained pyrolysis liquid fuel is comparable with the commercial fuel set by Indonesian Ministry of Energy and Mineral Resources. Furthermore, the viscosity and calorific value of liquid fuel produced are close to those of kerosene, meanwhile the density is close to the density of gasoline.

1. Introduction
A marvel of polymer chemistry, plastics has become parts of everyday consumer life and its production and consumption have increased drastically. Over 300 million tons are globally produced every year and the demand is expected to continue to rise [1]. Plastics are non-biodegradable polymers mostly containing carbon, hydrogen, and few other elements such as chlorine, nitrogen etc. [2]. Due to its non-biodegradable nature, the plastic waste contributes significantly to the problem of municipal waste management. The disposal of plastic by landfilling and incineration will lead to environmental pollution [3]. In a long term neither the landfilling nor the incineration solve the problem of wastes, because the suitable and safe depots are expensive, and the incineration stimulates the growing emission of harmful and greenhouse gasses e.g. NOx, SOx, COx [4]. Thus, in order to reduce plastic disposal to the landfill, recycling method is considered as another alternative to manage plastic waste.
Recycling has many types of techniques including pyrolysis, gasification, hydrolysis and etc. The carbon recycling by catalytic cracking is a better alternative approach to counter the increase of polymer waste, since they are environmentally friendly compared to disposal by landfilling and incineration. Moreover, it is possible to regain energy and fuel from recycling while reducing the consumption of natural resources [5].
The most attractive recycling technique to waste minimization that has been gaining interest recently is pyrolysis. Pyrolysis is the process involves the thermal degradation of biomass or long chain polymer
molecules performed in the absence of oxygen into a wide range of products [6] and involves the removal of volatile components such as hydrocarbon gases, tars and phenols [7]. This process is a part of de-polymerization, which is in contrast to the production of plastics, which uses polymerization from syngas and crude oil [8]. The pyrolysis of plastics yields on average 45-50% of liquid fuel, 35-40% of gasses and 10-20% of char, depending on the pyrolysis technology [9]. Plastic waste mainly consists of polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP) and polystyrene (PS) [10]. Fundamentally, different types of plastics have different compositions that normally reported in terms of their proximate analysis. Thus, different liquid fuel yield will be obtained when different types of plastic wastes undergo pyrolysis process. Table 1 summarizes the types of plastics and its application.

### Table 1. Types of plastics, symbol and applications

| Types of plastics                     | Symbol | Applications                                                                 |
|--------------------------------------|--------|-----------------------------------------------------------------------------|
| Polyethylene terephthalate (PET)     | ![PET] | Beverage bottles, medicine jars, rope, clothing and carpet fiber           |
| High-density polyethylene (HDPE)     | ![HDPE] | Containers for milk, motor oil, shampoos and conditioners, soap bottles, detergents, and bleaches |
| Polyvinyl chloride (PVC)             | ![PVC] | All kinds of pipes and tiles                                               |
| Low-density polyethylene (LDPE)      | ![LDPE] | Cling-film, sandwich bags, squeezable bottles, and plastic grocery bags   |
| Polypropylene (PP)                   | ![PP]  | Lunch boxes, margarine containers, yogurt pots, syrup bottles, prescription bottles, plastic bottle caps, plastic cup |
| Polystyrene (PS)                     | ![PS]  | Disposable coffee cups, plastic food boxes, plastic cutlery and packing foam |
| Polyethylene Acrylonitrile butadiene styrene (ABS) | ![ABS] | Baby bottles, compact discs, and medical storage containers |
| Polyamide (PA) or Nylons             | ![OTHER] |                                                                               |
| Polystyrene terephthalate (PBT)      |        |                                                                               |

Different researchers have studied the effect of temperature and the type of reactor on the pyrolysis of plastic wastes. According to previous research, there are some cases where a high amount of liquid fuel yield, more than 80 wt % could be produced in the pyrolysis of individual plastic. Santaweesuk and Janyalertadun [11] studied pyrolysis process of various types of plastic found in the municipal landfill in Thailand. The results showed that PP was converted into 80% liquid fuel, LDPE to 73% liquid fuel, HDPE to 70% liquid fuel, and mixed plastic to 46% liquid fuel. Miandad et. al. [12] examined the outcomes of different types of plastic waste such as PS, PE, PP and PET on the yield from each type of
plastic and product quality from the pyrolysis process. The plastic waste of PS type showed maximum yield of liquid fuel (80.8%) with minimum amount of gases (13%) and char (6.2%) in comparison with other types of plastic. Another research was conducted to produce liquid fuel from PP type of plastic waste and successfully obtained heavy fuel with carbon number of C_4 to C_{35} which similar to fuel grade oil [13].

In 2010 Indonesia produced 46 million tons of waste with 11% being of plastic waste [14]. Thus, pyrolysis can be an alternative method to recycle this amount of plastic waste. Therefore, this research aims to obtain liquid fuels resulted from pyrolysis of plastic waste (PP type) that is safe for humans and environment with heating value and fuel quality that meet standardized-compliant.

2. Experimental section

2.1. Materials

Plastic cup wastes (polypropylene type) were collected from Bung Hatta University campus area, cleaned and dried. The dried plastic wastes were cut into small square shaped pieces (about 5 cm side). The pyrolysis setup consists of batch reactor made of stainless steel as shown in Figure 1.

![Pyrolysis reactor setup](image)

1. Reactor
2. Furnace
3. Thermometer
4. Pressure Gauge
5. Condenser
6. Hot water flow out
7. CoL water flow in
8. Condensate flow out

Figure 1. Pyrolysis reactor setup

The experimental setup consist of a batch reactor with capacity of 125 dm³. The reactor was covered with 5 mm insulation jacket made of low alloy steel to avoid heat loss. It was placed on an LPG gas burner and was connected to the condenser and separating system.

2.2. Pyrolysis process

1000 g of plastic cup sample was loaded into the reactor in each pyrolysis reaction. A thermocouple was then placed in the reactor and heated with gas burner while the temperature was maintained between 250 to 400 °C according to the variable for 30 and 60 minutes. The condensable liquid products were collected through the condenser and the volume was measured. After pyrolysis, the char left was weighed and the gaseous product was calculated. The yield of liquid fuel was determined by dividing the collected material by the weight of feeding plastics.

2.3. Analysis

The calorific value of the obtained liquid fuel was performed using Bomb Calorimeter. A small container contains the pyrolysis liquid fuel sits submerged in a container of water, and ignition wires start the combustion. The bomb calorimeter will measure the heat that is released by the reaction, calculated as
calorific value. Furthermore, the physical properties of pyrolysis liquid fuel, such as density and kinematic viscosity, were also measured.

3. Results

3.1. Effect of temperature on pyrolysis liquid fuel yield

The yield of liquid fuel in this experiment is shown in Figures 2 and 3.

Figure 2. The effect of temperature on pyrolysis liquid fuel yield at 30 minutes

For each experiment, more amount of pyrolysis liquid fuel was acquired at higher temperature of 400 °C compared to that of lower temperatures, as shown in Figure 2 and Figure 3. The oil and gas constituted major product as compared to the char fractions. The recovery of condensable fraction (liquid fuel) increased with gradual increase of temperature. A maximum of 88.86% of the liquid fuel has been obtained at temperature of 400 °C. The maximum yield of char 5.2% was obtained at the temperature of 250 °C. With the increasing of temperature, the gas yield is decreased. Contrarily, from low to high temperature, the liquid fuel yield increases resulting in a decrease of char yield. As a result, the pyrolysis process showed an inverse ratio between solid yields (char) and liquid products (oil). It is due to the fact that the higher the pyrolysis temperature, the components in the plastic cup wastes would be decomposed sharply. As more components were decomposed, the char production is lessened and the oil produced is rising.

The effect of reaction time is also shown in Figure 2 and Figure 3. At the same temperature and same amount of polypropylene, more pyrolysis liquid fuel was observed at 60 minutes because longer reaction time resulted in further cracking of polypropylene into liquid fraction. The maximum liquid fuel
obtained at temperature of 400 °C and 60 minutes of reaction time with the yield of liquid fuel, char, and gas were 88.86%, 1.84% and 9.3%, respectively. This result is comparable to those by another researcher. Sommani et. al. investigated the cracking process of used vegetable oil mixed with polypropylene plastic waste in the presence of activated carbon and able to obtained maximum of 79.69% liquid fuel at temperature of 430 °C and ratio of used vegetable oil and polypropylene of 30 : 70 (wt %) [15].

![Pyrolysis products: (a) liquid fuel, and (b) char](image)

**Figure 4.** Pyrolysis products: (a) liquid fuel, and (b) char

### 3.2. Pyrolysis liquid fuel physical properties

The physical properties of liquid fuel obtained in this study is summarized in table 2 and 3.

| Time (minutes) | Temperature (°C) | Density (kg m\(^{-3}\)) | Kinematic Viscosity (mm\(^2\) s\(^{-1}\)) |
|---------------|-----------------|--------------------------|------------------------------------------|
| 30            | 250             | 790.3                    | 1.2773                                   |
|               | 300             | 803.9                    | 1.0540                                   |
|               | 350             | 796.0                    | 1.4589                                   |
|               | 400             | 793.5                    | 1.3876                                   |
|               | 250             | 781.9                    | 1.0229                                   |
|               | 300             | 780.6                    | 0.9889                                   |
|               | 350             | 795.7                    | 1.2618                                   |
|               | 400             | 796.9                    | 1.5398                                   |

| Parameter                     | Unit                  | Pyrolysis Liquid Fuel | Gasoline (RON 88)* | Diesel Fuel* | Testing Method (ASTM) |
|-------------------------------|-----------------------|-----------------------|--------------------|--------------|-----------------------|
| Density                       | kg m\(^{-3}\)         | 796.9                 | 715 - 780          | 815 – 860    | D 1259                |
| Kinematic viscosity           | mm\(^2\) s\(^{-1}\)   | 1.5398                | not mentioned      | 2.0 – 4.5    | D 445                 |
| Calorific value               | MJ kg\(^{-1}\)       | 44.95                 | min. of 44.56      | min. of 42.7 | D 240                 |

* standard designed by Indonesian Ministry of Energy and Mineral Resources
The produced liquid fuel density after 60 minutes of pyrolysis process was increase with the increasing of temperature. According to Table 3, the density of pyrolysis liquid fuel (796.6 kg/m$^3$) meet the standard designed by Ministry of Energy and Mineral Resources for gasoline (RON 88) but slightly lower compared to the diesel fuel, which range between 815 and 860 kg/m$^3$. It should be noted that density affects the level of engine power. In terms of density, all values seem comparable with the commercial standard value for both gasoline (RON 88) and diesel fuel. Furthermore, the kinematic viscosity is another important parameter that affects the performance of diesel fuel as it represents the resistance of fuel to flow. The viscosity of pyrolysis liquid fuel obtained at 400 °C was 1.5398 mm$^2$/s, which is lower than the standard quality for diesel fuel.

The experimental calorific value of pyrolysis liquid fuel (44.95 MJ/kg) meet both standard for gasoline (RON 88) in addition to diesel fuel and were considered high for energy utilization. Additional analysis in characterizing the exact components of pyrolysis liquid fuel by Gas Chromatography-Mass Spectrometry analysis (GC-MS) and another fuel properties analysis (Cetane Number, Cetane Index, Octane Number, flash point etc.) were required for better understanding of pyrolysis liquid fuel properties.

4. Conclusions
The pyrolysis of polypropylene plastic waste was performed in a batch reactor at varied temperature of 250 °C, 300 °C, 350 °C, and 400 °C. The maximum pyrolysis liquid fuel of 88.86% was obtained at temperature of 400 °C after 60 minutes of reaction. The pyrolysis process showed an inverse ratio between char (solid yields) and fuel (liquid products). The density of pyrolysis liquid fuel produced meet the commercial standard value for both gasoline (RON 88) and diesel fuel. However, the kinematic viscosity of pyrolysis liquid fuel obtained at 400 °C was 1.5398 mm$^2$/s, which is lower than the standard quality for diesel fuel. Moreover, the calorific value of pyrolysis liquid fuel meet both standard for gasoline (RON 88) as well as diesel fuel. Further analysis in characterizing the exact components of pyrolysis liquid fuel by Gas Chromatography-Mass Spectrometry analysis (GC-MS) and another fuel properties analysis (Cetane Number, Cetane Index, Octane Number, flash point etc.) were required for better understanding of pyrolysis liquid fuel properties.

References
[1] Valavanidis A 2016 Scientific Reports 1–39.
[2] Grigore M E 2017 Recy. 2 1–11.
[3] Triassi M, Alfano R, Illario M, Nardone A, Caporale O, Montuori P 2015 Int. J. Environ. Res Public Health 1216–36.
[4] Lee K H and Shin D H 2003 Korean J. Chem. Eng. 20 89–92.
[5] Habayaran J B, Njemon M, Abdulnasir R, Neksumi M, Yahaya M, Sylvester O D, Joseph I, Okoro L, Agboola B, Uche O, Jahng W J 2017 Int. J. Sci. Eng. Res. 8 1193–02.
[6] Strubinger A, Oliveros A R, Araque M A, Guerra J 2017 Chem. Eng. Trans. 57 19–24.
[7] Bungay V C 2017 Chem. Eng. Trans. 56 193–8.
[8] Olufemi A S and Olagboye S A 2017 Int. J. Petrochem. Sci. Eng. 2 252–7.
[9] Wong S L, Ngadi N, Abdullah T A T, Inuw I M 2015 Renew. Sust. Energ. Rev. 50 1167–80.
[10] Sonawane Y B, Shindikar M. R., Khaladkar M Y 2015 Int. Res. J. Environ. Sci. 4 24–8.
[11] Santaweesuk C, and Janyalertadun A 2017 Int. J. Environ. Sci. Dev. 8 168–173.
[12] Miandad R, Barakat M A, Aburizaiza A S, Rehan M, Ismail I M I, Nizami A S 2016 Int. Biodeterior. Biodegrad 1–14.
[13] Sarker M and Rashid M M 2014 Am. J. Environ. Energy Power Res. 2 1–10.
[14] Jambeck J P, Geyer R, Wilcox C, Siegler T R, Perryman M, Andrady A, Narayan R, Law K L 2015 Sci. 347 768–771.
[15] Sommani P, Mankong N, Vitidsant T, Lothongkum A W 2013 ASEAN Eng. J. Part B 4 16–24.