Effect of Temperature on Pyrolysis Oil Using HDPE and PET Sources from Mobile Pyrolysis Plant

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Research

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Abstract

This research aims to study the effect of temperature on pyrolysis oil along with analyzing viscosity, density, proportion of pyrolysis products and performance of each condenser towers of pyrolysis high density polyethylene and polyethylene terephthalate. The results showed that the main product of high density polyethylene resin is liquid and the main product of polyethylene terephthalate resin is solid. The pyrolysis of high density polyethylene resin at 400, 425 and 450ºC produce the amount of oil 22.5, 27 and 40.5 L, respectively. The study found that the temperature at 450ºC was the temperature that give the best pyrolysis oil in the experiment. The viscosity was in the range of 3.287–4.850 cSt. The density was in the range of 0.668-0.740 kg/L. The viscosity and density were increased according to 3 factors: high pyrolysis temperature, number of condensers and longer sampling time. From the distillation at temperatures below 65, 65–170, 170–250 and above 250ºC, all refined products in each temperature range shows the amount of hydrocarbon compounds according to the boiling point.

1. Introduction

Energy is important to life and is one of the economic drivers. At present, Thailand has faced with energy problems because Thailand imports energy which affects the way of life and the overall economy of the country. Therefore, energy sustainability is one of Thai society’s problems that urgently need solutions. The utilization of energy from waste is an option that has been promoted by the government which has both direct and indirect benefits.

From the Pollution Control Department's pollution quantity survey in 2014, the amount of solid waste in Thailand is 26.17 million tons per year. There is only 19 percent correct disposal, resulting in accumulated waste up to 19.9 million tons per year. There is also an amount of old garbage accumulated more than 300 million tons and continuously increase every year. Considering the waste composition, there are generally about 18 percent of plastic waste, equivalent to 3.75 million tons per year and another 25.79 million tons from accumulated waste, which can be processed into pyrolysis oil.

Pyrolysis oil is the oil obtained from the processing of plastic waste. The processing rate is 500 liters per ton of plastic waste. The oil produced can be used to replace fuel oil and low cycle diesel. For this engineering project, we study the temperature of the pyrolysis process to produce oil from plastic pellets, testing the properties of oil obtained at each temperature, and increasing the purity of pyrolysis oil.

The objective of this research is to (1) study the proportion of pyrolysis oil in each temperature, (2) study the properties of pyrolysis oil obtained at each temperature, and (3) study the performance of each condensate tower.

2. Theories And Related Researches

A. Plastic

Plastics are synthetic organic compounds that are used to replace certain natural materials. The plastic is divided into 2 types: thermoplastic and thermosetting plastics. There are many types of thermoplastics, such as high density polyethylene (HDPE) with specific gravity values of 0.941–0.965 g/cm^3. HDPE has a melting point temperature of about 135ºC, with a linear molecular structure. There are also many types of thermosetting plastics. Polyethylene terephthalate (PET) is the one of them.

B. Pyrolysis Process

The pyrolysis process is the process of decomposition of various compounds or materials with medium heat (compared to other processes) at temperatures around 400–800ºC in an oxygen-free atmosphere or contain very small amount of oxygen.

In general, the products obtained from the pyrolysis process can be divided into 3 types according to the condition. The primary product can be gas, liquid (which has oil-like properties) and char. The ratio of obtained products depends on the processing conditions, such as temperature, heat rate, etc. The most preferred product is liquid or oil.

C. Oil Specifications and Testing

There are few characteristics of the oil that can be directly tested by the instrument, such as sulfur content, viscosity values, etc. In addition, most values are measured by using certain tests that use standards to determine, such as using the standards of ASTM (American Society for Testing and Material) or IP (Institute of Petroleum), etc. Chemical characteristics and physical properties of oil is a unique property of each type of oil that has different values. The properties tested are (1) flash point (2) viscosity (3) heating value and (4) specific gravity.

3. Chemicals, Equiment, And Methods

A. Chemicals

Chemicals used in this study were high density polyethylene resin from IRPC Company Limited, polyethylene terephthalate from Thai Chin Kong Industry Corporation Limited, liquefied petroleum gas, and liquid fuel.

B. Equipment

Equipment used in this study were mobile pyrolysis system kit, gallon volume 4.5 liters, cyclone machine, two 12-inch wrench, diameter ½ inch hose (3 meters long), long spade, rice sacks, Brookfield viscometer DV-I +, pure distillation unit, and 3-position weighing scales.

C. Experimental Methods

1) Preparation of pyrolysis reactor

Preparation of pyrolysis reactors by cleaning the machine from sediment trapped inside. Opening the lid of the pyrolysis reactor from above with a wrench (Fig. 1(a)), then use a long spade to scrape off the sediment trapped inside the reactor (Fig. 1(b)). After that, use a cyclone to remove all sediment (Fig. 1(c)).

3) Preparation of the coolant

Water preparation for use in coolers by taking the remaining water out of the coolant tank Fig. 2(a) and add the new one into the tank Fig. 2(b) to be ready to use the coolant for mobile pyrolysis systems.

4) Adding raw materials

The plastic pellets used in the experiment are fed into the pyrolysis reactor as shown in Fig. 3.

5) Collecting pyrolysis oil samples
After the pyrolysis process is complete, oil samples will be collected at the 1st, 2nd, 3rd and 4th condensers respectively, as shown in Fig. 4(a), by opening the valve of the bottom filter of each condenser, in order to bring the pyrolysis oil that is condensed at that condenser in the pyrolysis oil refining process (Fig. 4(b)).
6) Mobile type pyrolysis equipment
Three-dimensional model of mobile type pyrolysis equipment shown in Fig. 5 (a) and (b) conveying plastic waste by waste conveyor (6) into the raw material shredding machine and into (15) pyrolysis reactor heating by using (13) heating furnace to system at a temperature of 400ºC. Over time, the plastic granules will become liquid and evaporate into gas flowing into (3) gas separator to enter (1) the main condenser and enter in (1) condense the 1st, 2nd, 3rd and 4th units and collect the oil samples at the exit of the 4 solid filters at the bottom of each condenser, keeping the temperature to 400ºC as For 10 minutes, then collect the oil samples again until complete 3 times every 10 minutes. After that, increase the temperature at the reactor to 425 and 450ºC. Experimenting the same method at the temperature of 400ºC.
D. Analysis
1) Oil refining set
The liquid product obtained from pyrolysis of high density polyethylene and polyethylene terephthalate distilled by the oil distillation kit as shown in Fig. 7 consists of (1) thermometer (2) three-way joints (3) round bottom bottles (4) heating furnaces (5) condensers (6) vacuum joints (7) apple shaped bottles that are distilled at low temperature ranges of lower than 65, 65–170, 170–250 and over 250ºC.
2) Viscosity analysis with Brookfield viscometer DV-I + at 40ºC by adding 1 mL of sample into the sample cup and returning to the viscometer. Adjust the cone with the adjustment ring to contact the liquid surface, and adjust the rotation of the machine to 20 RPM to measure viscosity. The result was reported on screen in centipoise (cP), then convert the unit to centistoke (cSt) from the Eq. (1)

$$\mu_{cSt} = \frac{\mu_{cP}}{\rho \times 1000} \quad (1)$$

where
μ_{cP} is the viscosity in centipoise (cP)
μ_{cSt} is the viscosity in centistoke (cSt)
ρ is the density of oil sample in gram per cubic meter (g/cm³)

3) Analysis of hydrocarbon compounds

Analysis of various hydrocarbon compounds in the pyrolysis oil by fractional distillation with 300 mL volume purity distillation equipment at temperature ranges of lower than 65, 65–170, 170–250 and more than 250ºC.

4. Results And Discussion

A. Fuel Properties

The 95 gasoline measured from the experiment with a density of 0.73 kg/L is lower than the standard, which is 0.741 kg/L. The viscosity of 0.72 cSt is in the standard range, which is 0.40–0.80 cSt.

The kerosene measured from the experiment with a density of 0.800 kg/L is lower than the standard, which is 0.807 kg/L. The viscosity of 1.19 cSt is lower than the standard, which is 1.24 cSt.

The diesel fuel measured from the experiment with a thickness of 0.814 kg/L is lower than the standard, which is 0.837 kg/L. The viscosity of 3.44 cSt is in the standard, which is 1.80–4.10 cSt.

B. Effects of Temperature Changes of Pyrolysis with HDPE and PET by Mobile Pyrolysis Reactor

1) Effects of temperature changes on sampling.

It was found that the products obtained from pyrolysis of high density polyethylene produce liquid products more than from the pyrolysis of polyethylene terephthalate, which is essentially gas and solid. The high density polyethylene plastic breaks down at lower temperature than polyethylene terephthalate plastic. The pyrolysis of high density polyethylene and polyethylene terephthalate at the temperature of 400, 425 and 450ºC produce the oil 22.5, 27 and 40.5 L, respectively. It was found that the temperature at 450ºC is the temperature that produce the most amount of pyrolysis oil in this experiment.

2) Effects of Temperature Change on Sampling Time

From the density analysis of pyrolysis of high density polyethylene and polyethylene terephthalate at the temperature of 40ºC, it was found that the density values at 400, 425 and 450ºC are 0.668, 0.67 and 0.672 kg/L, respectively. The densities of each condenser are 0.672, 0.69, 0.7063 and 0.7102 kg/L, respectively. Considering the difference sampling time of 10 minutes, the densities are 0.672, 0.722 and 0.729 kg/L, respectively. The density has increased significantly according to the temperature of the pyrolysis, the collecting samples from each condenser, and for a longer collecting time.

From the viscosity analysis of pyrolysis of high density polyethylene and polyethylene terephthalate, at temperatures of 400, 425 and 450ºC, the viscosities are 3.287, 3.289 and 3.297 cSt, respectively. Considering each condenser, the viscosities are 3.297, 3.350 and 3.366 cSt, respectively. For the sampling time of 10 minutes, the viscosities are 3.297, 4.599 and 4.725 cSt, respectively. The viscosity has increased according to the temperature of the pyrolysis, the collecting samples from each condenser, and a longer period of collecting time.

To increase the purity of the liquid products obtained from pyrolysis of high density polyethylene and polyethylene terephthalate at various temperature ranges. It was found hydrocarbon compounds with C5-C7 at temperature lower than 65ºC. Hydrocarbon compounds with C6–C12 were found at temperature range of 65–170ºC. The C10–C14 were found at temperature range of 170–250 ºC. Finally, at above 250ºC, there was C14–C19 hydrocarbon.

3) Results of Purification by Distillation

The amount of pyrolysis oil obtained from the purity of distillation at various temperatures of the distillation in the first sample collecting at the temperature range of lower than 65, 65–170, 170–250 and more than 250ºC are gasoline, kerosene and diesel with volumes of 60, 90 and 39 mL, respectively. In the second sample collecting, 10 minutes after the first one, at the temperature range of lower than 65, 65–170, 170–250 and more than 250ºC, it was found gasoline, kerosene and diesel with volumes of 55, 70 and 29 mL, respectively.

In the second sample collecting, 20 minutes after the first one, at the temperature range of lower than 65, 65–170, 170–250 and more than 250ºC, it was found gasoline, kerosene and diesel with volumes of 47, 75 and 31 mL, respectively. Immediately collecting sample when the temperature reaches the specified point, the distillation product increases the volume of gasoline, kerosene and diesel.

5. Conclusion

Main products of high density polyethylene resin are liquid and polyethylene terephthalate resin is solid. 450ºC was the temperature that give the best pyrolysis oil in the experiment. The viscosity and density were increased according to 3 factors: high pyrolysis temperature, the number of condensers and longer sampling time. All refined products in each temperature range shows the amount of hydrocarbon compounds according to the boiling point.

Declarations

- Ethical Approval and Consent to participate

Dr. Ruktai Prurapark is a corresponding author, the other authors are his researchers team.

- Availability of supporting data

All data in this paper is already included in this paper.

- Competing interests

The authors declare that they have no conflict of interest.

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Figures

(a) (b) (c)

Figure 1

Preparation of pyrolysis reactor (a) Opening the lid of a pyrolysis reactor (b) Using metal spade to scrape off any remaining sediments and (c) Extracting excess sediments and any remaining solid from previous operating sessions using Cyclone machine.

(a) (b)

Figure 2

Preparation of the coolant (a) Taking remain water out of the coolant tank and (b) Adding new water into the tank.

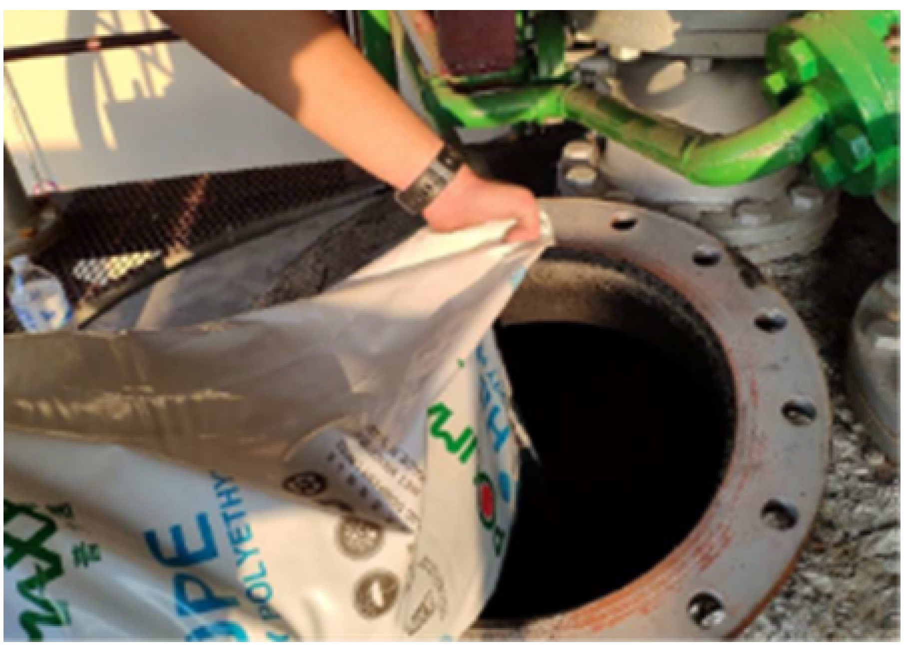

Figure 3. Adding raw materials.

Figure 3

Adding raw materials.

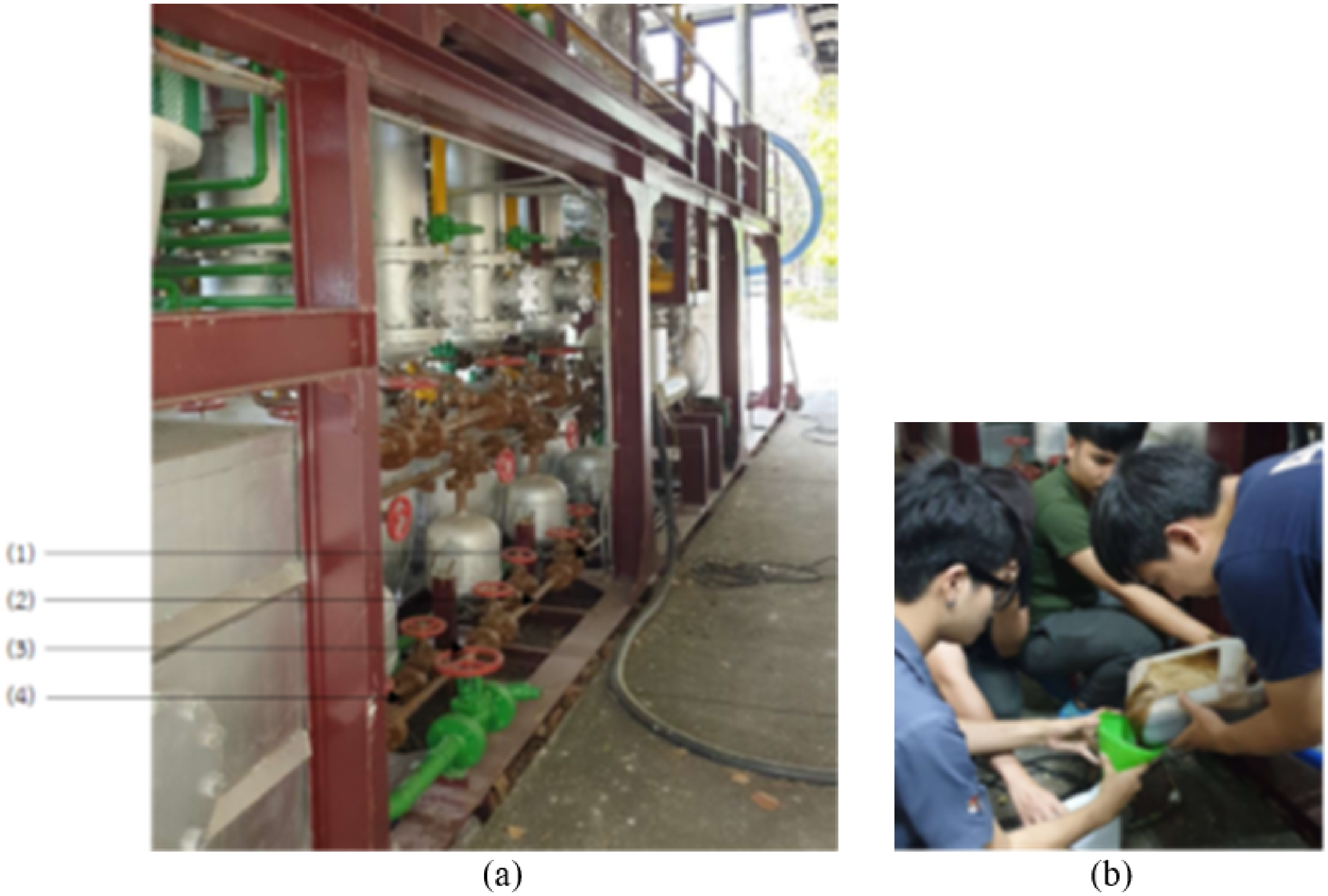

Figure 4

Collecting pyrolysis oil samples (a) 4 collecting areas and (b) Collecting the condensed pyrolysis oil.

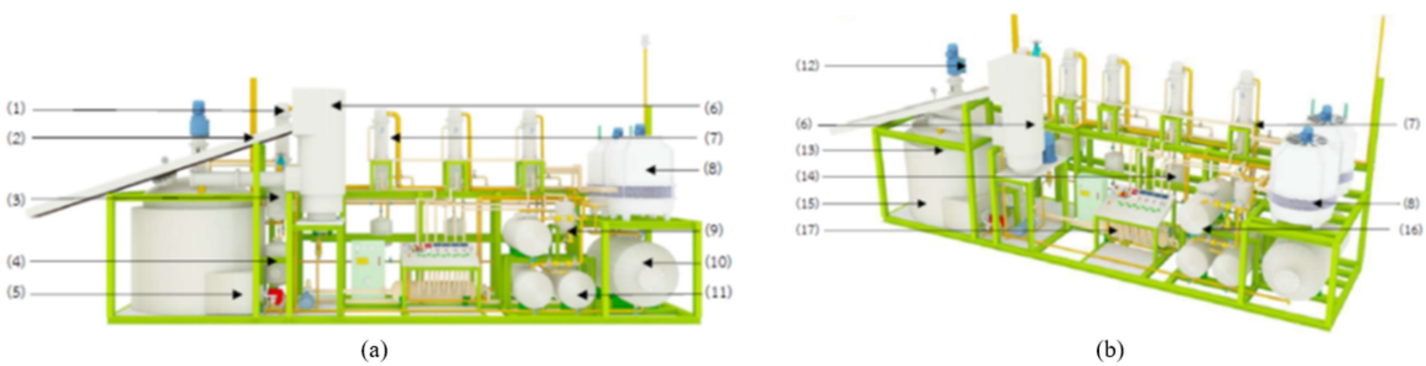

Figure 5

Three-dimensional model of the mobile pyrolysis equipment set Three-dimensional model of the mobile pyrolysis equipment set when (a) and (b) consists of (2) waste conveyor belt (3), (9) gas separator (4) gas storage tank (5) machine Burn (6) Sub-machine (7) Condenser (8) Cooling machine (10) Cooling

water tank (11) Pyrolysis oil storage tank (12) Gear motor stirring set (15) Reactor (14) Product filters (13) Kilns (16) Pyrolysis oil storage tanks and (17) Coolant.

Figure 6

Mobile type pyrolysis equipment set.

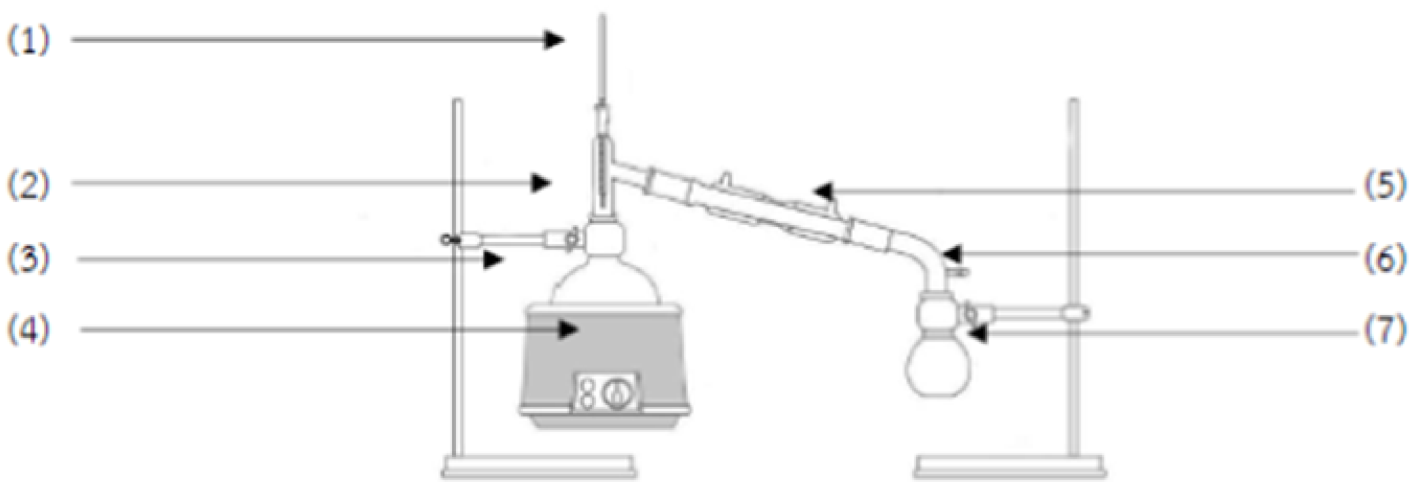

Figure 7

The distillation unit consists of (1) thermometer (2) three-way joint (3) round bottom bottle (4) heating furnace (5) condenser (6) vacuum coupling and (7) Erlenmeyer flask.

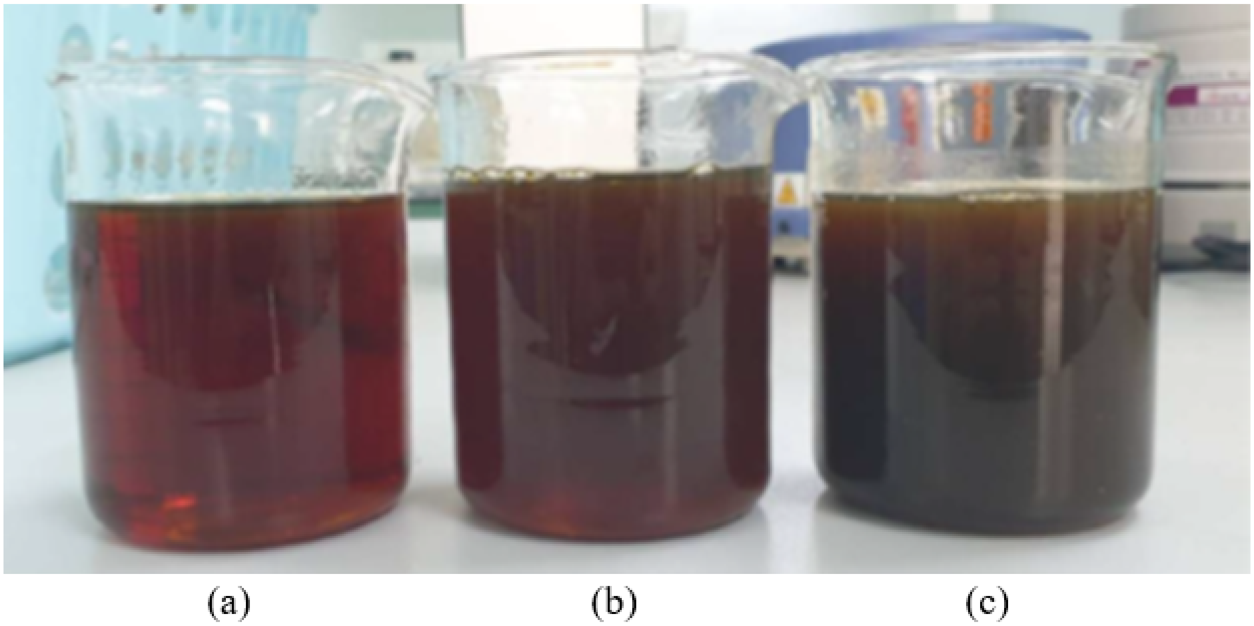

Figure 8

The products obtained from pyrolysis of high density polyethylene plastic pellets when (a) liquid products from the 1st sample collecting (b) liquid products from the 2nd sample collecting, and (c) the liquid product from the 3rd sample collecting.

Figure 9

The products obtained from pyrolysis of polyethylene terephthalate plastic pellets.

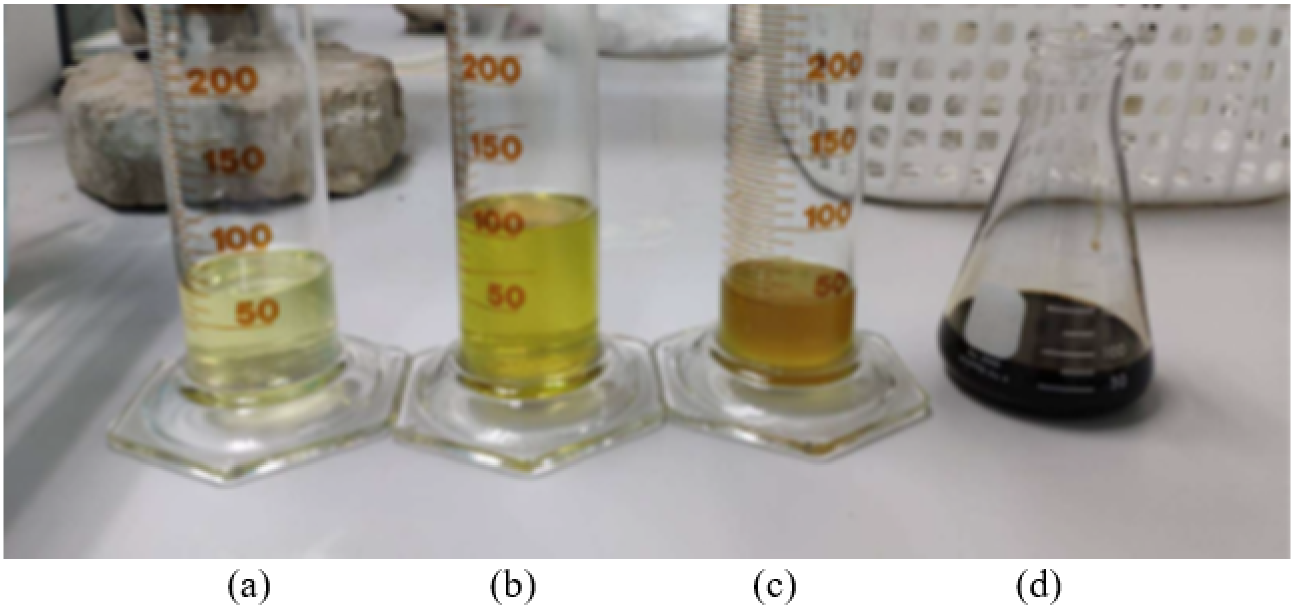

Figure 10

Products obtained from distillation of high density polyethylene at the temperature range of (a) lower than 65, (b) 65–170, (c) 170–250 and (c) more than 250ºC.

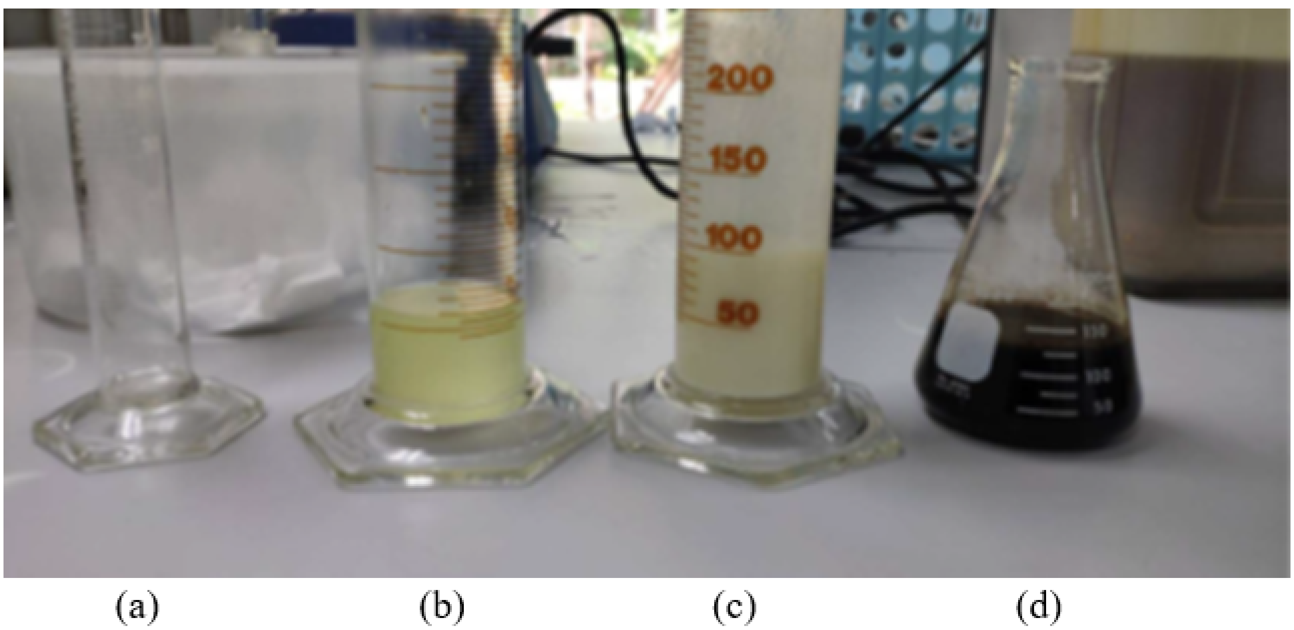

Figure 11

Products obtained from distillation of polyethylene terephthalate at the temperature range of (a) lower than 65, (b) 65–170, (c) 170–250 and (c) more than 250ºC.