Conversion Of Polystyrene Plastic Waste Using Thermal Pyrolysis Integrated with Bubble Cap Distillation Column

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**Abstract.** In Indonesia, the demand for plastic continues to increase by an average of 200 tons per year, resulting in environmental pollution. Therefore, a method is needed to deal with the problem of plastic production, one of which is the pyrolysis method. Pyrolysis is a chemical decomposition process using heating without the presence of oxygen. The products of pyrolysis are three types of products, namely solids (charcoal), gas (syngas) and liquid (pyrolysis oil). Pyrolysis has great potential to be developed in producing liquid fuel from plastic waste. The objective of this research is to convert polystyrene (PS) waste into liquid fuel to determine the effect of temperature and time on pyrolysis. The research was conducted by preparing 100 grams of polystyrene (PS) plastic raw material and putting it into the glass tube as a reactor. After that, turn on the vacuum pump, water pump and furnace. Then set the pyrolysis temperature according to the variables and the pyrolysis process is run according to the variable time with variable time. The variables used in this study are temperature variables of 350 ℃; 450 ℃; and 550 ℃ and pyrolysis time of 30; 60; 90; and 120 minutes. When the pyrolysis time was reached, the yield was measured every time according to the pyrolysis time variable used. This study can be concluded that the three parameters of pyrolysis influence can increase the yield production produced. The best condition for product yield pyrolysis oil was obtained at a temperature of 550°C, 120 minutes, which was 25.185% on tray 1 and 11.04% on tray 2. Then based on the results of the analysis, it is concluded that the type of fuel from PS pyrolysis is gasoline which can provide benefits for industrial and other needs.

**Keywords:** pyrolysis, plastic waste, polystyrene, bubble cap, fuel

# INTRODUCTION

Polystyrene waste is one of the biggest challenges in plastic waste management today. Polystyrene is a very popular plastic because it is lightweight, waterproof, and has good thermal insulation. Widely used in food packaging, disposable products, and various household appliances, polystyrene has a very long decomposition time, often reaching hundreds of years. This causes significant build-up in landfills and the natural environment, which creates ecological and aesthetic problems [1].

The widespread use of polystyrene in fast food packaging and single-use products increases the volume of non-degradable plastic waste. Polystyrene litter is often found on beaches, rivers and waterways, disrupting ecosystems and damaging wildlife habitats. Marine animals, such as fish and birds, often mistake small pieces of polystyrene for food, which can lead to death due to blockage of the digestive tract [2].

Burning polystyrene waste is not an environmentally friendly solution. The process produces harmful air pollution, including the emission of toxic gases such as styrene and benzene, which are human carcinogens. In addition, burning polystyrene can produce fine particles that negatively impact air quality and public health. Alternatives such as recycling still pose great challenges due to the complexity in the collection and processing of polystyrene waste [3].

Polystyrene recycling faces technical and economic constraints. It is often contaminated with food waste or other materials, making it difficult to recycle efficiently. In addition, the economic value of polystyrene recycling is relatively low, making it less attractive to the recycling industry [4]. As a result, only a small portion of polystyrene is reused, while most remains as waste.

Innovations in polystyrene waste management technologies are urgently needed to address this problem. One promising approach is pyrolysis, a thermal process that converts polystyrene into reusable liquid and gaseous fuels. Pyrolysis of polystyrene can produce high-value products such as pyrolysis liquid product, gas, and solid residue that can be further utilized. This method not only helps to reduce the volume of plastic waste, but also has the potential to provide economic value through the utilization of pyrolysis products [5].

Pyrolysis is a thermal process that involves heating organic materials in the absence of oxygen. This process breaks down long polymer chains into smaller molecules, producing products in the form of gases, liquids, and solids. Pyrolysis of polystyrene mainly produces styrene monomer, along with some other aromatic compounds. Higher pyrolysis temperatures tend to increase gas and liquid production, while lower temperatures produce more solid residue [6].

The pyrolysis process of polystyrene occurs through several stages of thermal decomposition. In the initial stage, the polymer chains start to break down at around 350-450°C, producing free radicals which then react further to form pyrolysis products. The optimal pyrolysis temperature for polystyrene is around 500-600°C, where styrene production reaches its peak [7].

Important variables in the pyrolysis process include temperature, pyrolysis time, and heating rate. Higher pyrolysis temperatures tend to increase the conversion of polystyrene into liquid and gaseous products but can also increase the formation of unwanted by-products. Longer pyrolysis time generally increases the yield of pyrolysis liquid products but may decrease the liquid product quality due to the formation of complex compounds 8. Quality parameters of pyrolysis liquid product using Handbook of Petroleum.

The main product of polystyrene pyrolysis is pyrolysis oil, which can be used as fuel or raw material for chemical industry. The produced gases, such as methane and hydrogen, can be used as energy sources. The remaining solid residue can be further processed or used as filling material. Pyrolysis oil from polystyrene has similar characteristics to light crude oil, so it has the potential to be refined into various fuel products [9]. Therefore, research on termal pyrolysis connected to a bubble cap distillation column from polystyrene waste is very important to support the development of more efficient and environmentally friendly waste management technologies.

# MATERIALS AND METHODS

## Materials

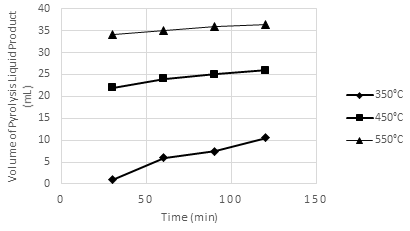
### The raw material used in this research is polystyrene plastic waste in the form of food containers. The polystyrene was cut into small pieces measuring ±2 mm² to speed up the pyrolysis process. The variables used in this study are temperature and time. Where the temperature variable is at 350ºC, 450ºC and 550ºC while the time variable is at 30, 60, 90 and 120min.

## Methods

A series of thermal pyrolysis devices connected to a bubble cap distillation column with 2 outputs (trays). The heater used in this research tool is a furnace. For the thermal pyrolysis process, 100gr of polystyrene plastic waste that has been cut into small pieces is put into the glass reactor. Then the glass reactor that has been filled with raw materials is put into the furnace. The process takes place according to the specified temperature and time variables. The pyrolysis liquid product condensed in tray 1 (first) and tray 2 (second) was collected and analyzed. The analyses conducted in this study were liquid product yield, density, specific gravity, °API and GC-MS analysis of liquid product.

# Results and discussion

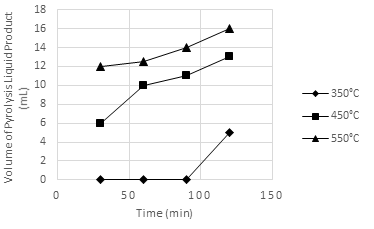
## Volume of Pyrolysis Liquid Product



**FIGURE 1.** Relationship Between Pyrolysis Time and Temperature Variables on The Volume of Liquid Product in Tray 1

Figure 1 above explains the relationship between the variables of temperature, temperature and the volume of liquid product from pyrolysis (pyrolysis oil) of polystyrene plastic waste in tray 1. The graph shows that at a temperature of 350°C for 30min produces 1mL of pyrolysis oil, 60min produces 6mL, 90min produces 7.5mL and 120 min produces 10.5mL. At 450°C for 30min, the pyrolysis oil produced 22mL, 60min produced 24mL, 90min produced 25mL and 120min produced 26mL. Meanwhile, at 550°C for 30min, the pyrolysis oil produced 34mL, 60min produced 35mL, 90min produced 36mL and 120min produced 36.5mL.

The volume of liquid product from pyrolysis (pyrolysis oil) of polystyrene plastic waste in tray 1 is at a temperature of 550ºC for 120 min of 36.5mL. This is due to the increased gas production that will be condensed with an increase in temperature and pyrolysis time. High temperatures tend to produce more liquid products with simpler compositions, as the polystyrene polymer decomposes more effectively [10]. Longer pyrolysis processes can produce better quality liquid products, as there is more time to break down complex polymers into simpler, easily separable compounds. The degradation of polystyrene will be complete at the optimal temperature and time [11].

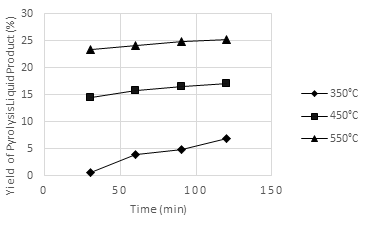


**FIGURE 2.** Relationship Between Pyrolysis Time and Temperature Variables on The Volume of Liquid Product in Tray 2

Figure 2 above explains the relationship between the variables of temperature, temperature and the volume of liquid product from pyrolysis (pyrolysis oil) of polystyrene plastic waste in tray 2. The graph shows that at 350°C for 30, 60 and 90min it does not produce pyrolysis oil but at 120 min it produces 5mL of pyrolysis oil. This is due to the large amount of gas condensed into pyrolysis oil in tray 1 and gas that has not been condensed will condense in tray 2. At a temperature of 450°C for 30min produced 6mL of pyrolysis oil, 60min produced 10mL, 90min produced 11mL and 120min produced 13mL. Meanwhile, at 550°C for 30min, the pyrolysis oil produced 12mL, 60min produced 12.5mL, 90min produced 14mL and 120min produced 16mL.

The volume of liquid product from pyrolysis (pyrolysis oil) of polystyrene plastic waste in tray 2 is at a temperature of 550ºC for 120min of 16mL. This happens because the temperature and time of pyrolysis affect the volume of condensed pyrolysis oil. The heavier fraction will be condensed in tray 2 so that the syngas discharged is not too much and already does not contain heavy fractions [12,13].

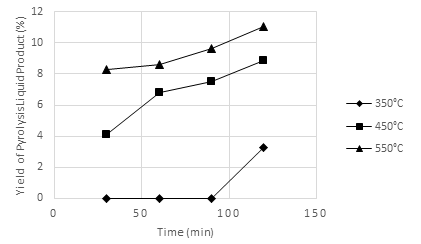
## Yield of Pyrolysis Liquid Products



**FIGURE 3.** Relationship Between Pyrolysis Time and Temperature Variables on Liquid Product Yield in Tray 1

From figure 3, it can be seen the effect of temperature and time of the pyrolysis process on the yield of pyrolysis oil in tray 1. At 350°C for 30min, the pyrolysis oil yield was 0.65%, 60min was 3.9%, 90min was 4.875% and 120min was 6.825%. At a temperature of 450°C for 30min produces pyrolysis oil by 14.52%, 60min by 15.84%, 90min by 16.5% and 120min by 17.16%. While at a temperature of 550°C for 30min produced pyrolysis oil of 23.46%, 60min of 24.15%, 90min of 24.84% and 120min of 25.185%.

The highest pyrolysis oil yield is at a temperature of 550°C with a pyrolysis time of 120min at 25.185%. This is due to the large volume of pyrolysis oil produced from the condensation of pyrolysis gas in tray 1. The higher pyrolysis temperature can make it easier to break polymer bonds in polystyrene waste to be simpler [14]. The increase in temperature is also followed by an increase in the duration of the pyrolysis time. So, it can be a factor in the efficiency of the pyrolysis process of polystyrene into pyrolysis oil [15].



**FIGURE 4.** Relationship Between Pyrolysis Time and Temperature Variables on Liquid Product Yield in Tray 2

From figure 4, it can be seen the effect of temperature and time of the pyrolysis process on the yield of pyrolysis oil in tray 2. At 350°C for 30, 60 and 90min, no pyrolysis oil was produced so that the yield was 0% while at 120min it was 3.26%. Then at a temperature of 450°C for 30min produced pyrolysis oil of 4.092%, 60min of 6.82%, 90min of 7.502% and 120min of 8.866%. While at a temperature of 550°C for 30min produced pyrolysis oil of 8.28%, 60min of 8.625%, 90min of 9.66% and 120min of 11.04%. The highest pyrolysis oil yield was at 550°C with a pyrolysis time of 120min at 11.04%. This is because the volume of condensed pyrolysis oil in tray 2 is not as much as in tray 1 [16,17].

## Density, Specific Gravity and ºAPI Against Fuel Type

Density is a measure of the mass per unit volume of a substance or material. In the context of fuels, density describes how dense or light the fuel is. Density is closely related to fuel type as it determines various characteristics, such as calorific value (the amount of energy that can be produced from combustion), viscosity (ease of flow), and thermal stability [18]. Examples of high-density fuels include diesel and others. Specific gravity is the ratio of the density of a substance to the density of water at the same temperature and pressure. It is a relative measure of the weight of fuel molecules compared to water. API degree is a measure of the relative specific gravity of liquid fuels, which is commonly used to classify crude oil and its derivatives [19]. API values are given in degrees, where crude oils with API degrees greater than 10 will float in water, while those less than 10 will sink. By considering these three factors together, the liquid products resulting from the pyrolysis of polystyrene in this study can be related to determine the characteristics and potential applications of different types of fuels.

**TABLE 1.** Determination of density, specific gravity and ºAPI in relation to fuel type

| Temp (ºC) | Tray 1 | | | | Tray 2 | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ρ | S.g | °API | Type of Fuel | ρ | S.g | °API | Type of Fuel |
| 350 | 0.65 | 0.71 | 66.58 | Gasoline | 0.652 | 0.72 | 65.97 | Gasoline |
| 450 | 0.66 | 0.73 | 63.58 | Gasoline | 0.682 | 0.75 | 57.28 | Gasoline |
| 550 | 0.69 | 0.76 | 55.1 | Gasoline | 0.69 | 0.76 | 55.10 | Gasoline |

Table 1 above shows the relationship between specific gravity, specific gravity and °API which is then compared to the criteria for fuel types in the Handbook of Petroleum Product Analysis [20]. Tray 1 at 350°C has a density of 0.65, specific gravity of 0.71 and API of 66.58. For a temperature of 450°C has a density of 0.66, a specific gravity of 0.73 and an API of 63.58 while a temperature of 550°C has a density of 0.69, a specific gravity of 0.76 and an API of 55.10. So, if the results of pyrolysis oil in Tray 1 are associated with the criteria for fuel types in the Handbook of Petroleum Product Analysis the results are close to the criteria for gasoline fuel [21].

For Tray 2, the temperature of 350°C has a density of 0.652, specific gravity of 0.72 and °API of 65.97. For a temperature of 450°C has a density of 0.682, a specific gravity of 0.75 and an API of 57.28 while a temperature of 550°C has a density of 0.69, a specific gravity of 0.76 and an API of 55.10. So, if the results of pyrolysis oil in Tray 2 are related to the criteria for fuel types in the petroleum product analysis guidebook the results are close to the criteria for gasoline fuel [22].

## GC-MS Analysis Results of Pyrolysis Liquid Products

The liquid product from the pyrolysis of polystyrene without catalyst was analyzed by gas chromatography-mass spectrometry GC-MS is a method of separating organic compounds that uses two methods of compound analysis, namely gas chromatography (GC) to analyze the number of compounds quantitatively and mass spectrometry (MS) to analyze the molecular structure of the analyte compound [23]. In the GC-MS results of liquid products without using catalysts, the data obtained consisted of 103 compounds detected by GC-MS, but several peaks were taken which had a large percentage, which can be seen in table 2.

**TABLE 2.** GC-MS Analysis Results of Polystyrene Pyrolysis Liquid products in Tray 1

| No | Peak | Component | % Area |
| --- | --- | --- | --- |
| 1 | 5 | C8H8 | 51.59 |
| 2 | 8 | C10H16 | 2.66 |
| 3 | 26 | C11H14O2 | 3.9 |
| 4 | 31 | C12H18O | 5.18 |
| 5 | 52 | C3H8O | 6.64 |
| 6 | 59 | [C15H15N](https://pubchem.ncbi.nlm.nih.gov/#query=C15H15N) | 8.69 |
| 7 | 60 | [C12H16](https://pubchem.ncbi.nlm.nih.gov/compound/Benzene_-_1_3-dimethyl-3-butenyl) | 3.59 |
| 8 | 78 | C14H10 | 1.49 |
| 9 | 100 | [C10H18](https://pubchem.ncbi.nlm.nih.gov/#query=C10H18) | 2.45 |
| 10 | - | Others | 13.81 |
| Total | | | 100 |

Table 2 above shows the results of GC-MS analysis for polystyrene pyrolysis liquid products without the use of catalysts, the most is the styrene (C8H8) area component 51.59%. The high styrene component in the pyrolysis liquid product is because there are still many polymer bonds that have not been optimally and completely degraded, causing the yield of polystyrene pyrolysis liquid product to be not large [24]. The fuel has compounds including alkanes, aromatic compounds and some olefin compounds [25]. From the results of GC-MS analysis obtained compounds from C5 - C15 which show the constituent components of gasoline fuel.

# CONCLUSION

# This research aims to utilise polystyrene plastic waste into fuel by thermal pyrolysis method integrated with bubble cap distillation. From this study, the highest pyrolysis oil yield was obtained at a temperature of 550°C for 120 min of 36.5mL with a yield of 25.185% in tray 1 and 16mL in tray 2 with a yield of 11.04%. Liquid products from pyrolysis (pyrolysis oil) in trays 1 and 2 were analysed for density, specific gravity, °API and GC-MS analysis when compared to the criteria for fuel types in the petroleum product analysis guidebook, the results are close to the criteria for gasoline fuel. Where the constituent components of pyrolysis oil consist of alkane compounds, aromatic compounds and some olefins as well as the constituent components of fuel.

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