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The Effects of Distillation Temperature and Plastic Loading on the Improvement of Waste-Derived Bio-oil Properties

Herry Irawansyah[1*], Apip Amrullah[1*], Syafa'at Prayogi[1], Syahriza Alfahri[1]

[1]*Mechanical Engineering Department, Faculty of Engineering, Universitas Lambung Mangkurat, Indonesia*

Corresponding Authors E-mail: herryirawansyah@ulm.ac.id, apip.amrullah@ulm.ac.id

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Abstract

Since plastic and food waste are both types of non-lignocellulosic biomass, these must be handled and managed correctly to avoid pollution problems and damage to the environment. Bio-oil, made from recycled materials, including plastic and food waste, is one focus of these attempts. The co-pyrolysis method is being investigated in this study as a technique of recycling plastic waste and food waste to produce biofuels with reduced environmental impact. In terms of energy efficiency, bio-oil is unequal to other fuels like coal or natural gas because of its high acidity, high oxygen content, and low thermal stability. Therefore, a vacuum distillation process is required to improve bio-oil quality by adjusting the distillation temperature from 300 to 350 ^{O}C and the percentage of plastic waste used from 30 to 50%. The bio-oil was analyzed using a Gas Chromatography-Mass Spectrometer (GC-MS). The general compound showed that acids (60%) and alcohols (20%) were the most prevalent chemical compounds, followed by phenol (4%), aldehyde (14%), aliphatic (5%), Furan (14%), and ketones (11%) at maximum temperature (350 ^{o}C) for 30-50% plastic waste. Meanwhile, the final product is affected by temperature and plastic waste (PET) ratio factors. At 350 °C and a plastic waste addition of 50%, the highest bio-oil yield is 45%.

Introduction

The utilization of energy derived from oil and gas reserves requires community members to make an effort to meet their requirements for energy consumption. According to the ministry of energy and mineral resources republic of Indonesia [1], at the end of 2014, the total amount of oil reserves in the world was 170.1 billion barrels. In contrast, Indonesia only has proven oil reserves of 3.7 billion barrels, representing only 0.2% of the world's total oil reserves. Plastic waste is non-biomass waste that people, stores, and big businesses use daily. It is one of the types of waste that people throw away more than any other. People also throw a lot of discarded plastic into the water and soil, destroying nature to a greater extent. Because plastic waste is made of inorganic materials, it is hard for bacteria that intake dead things to decompose it. Hence plastic waste needs treatment and convert as potential useful energy resource. The conversion of biomass into energy has been accomplished using a variety of methods, including thermochemical, biochemical, and physicochemical methods. Thermochemical conversion is the most widely used method since it is fast and can treat mixture of different types of biomasses with no issues. For several years, pyrolysis has been considered the best option for producing bio-oil, char, and biogas by thermochemical conversion from biomass. Pyrolysis' principal by product is bio-oil, which can be utilized either as a low-grade fuel or as a high-energy feedstock for power generation after refinement.

Converting plastic into oil is one approach to dealing with plastic and inorganic waste has become clearer the benefits of pyrolysis, including its wide range of products, high efficiency, and environmental friendliness. The material decomposes into gas, bio-oil, and solid hydrocarbons during the pyrolysis process, which thermally decomposes organic molecules in an inert environment while anaerobically modifying their structure at a comfortable temperature (300-800 °C) Compared to paper waste and other biomass, plastic waste has a lower water content since it does not absorb water. Additionally, plastic has a calorific value comparable to fossil fuels like gasoline and diesel [2]. Plastic polymers can be divided into three primary categories: polypropylene, polyethylene, and polystyrene. High-density polyethylene and low-density polyethylene are the two types of this material. As a thermochemical conversion method, plastic waste pyrolysis has yet to reach its full potential. Pyrolytic oil is a liquid by-product that includes naphtha and other components that may be refined into valuable fractions [3]. Results in several research on the processing of plastic waste into liquid products suitable for use as fuel have been encouraging, suggesting that this technology is worth further exploring and developing [4].

The results of plastic waste fractionation have been put to better use, especially in transforming tar products (pyrolytic oil) into lubricating oil via the hydroisomerization technique. The step, while shorter than before, is nonetheless significant. Researchers armed with this knowledge will use food waste and other non-biomass materials to produce environmentally acceptable Fuel through the co-pyrolysis process for potential future usage. The pyrolysis bio-oil still contains char and water, which will affect the quality of the bio-oil produced. The quality of bio-oil can be improved by various processes, one of which is upgrading with a vacuum distillation process. The use of catalysts in the process of upgrading the quality of bio-oil has been widely carried out by previous researchers [2],[6–8] , but the improvement of the quality of bio-oil through the vacuum distillation process has not been widely carried out.

In order to enhance the quality of bio-oil made from microalgae by utilizing the pyrolysis extraction technique, Nam et al. [9] carried out study on the efficiency of vacuum distillation at temperatures ranging from 80 to 90 ° C [9]. It was revealed that using vacuum distillation as a technique for the physical separation of bio-oil improves the qualities of the distillate in an effective manner. This makes it possible for the distillate to be used as a transportation fuel after the components have been further combined or improved. Amrullah et al. [10] used pyrolytic bio-oil has been distilled using vacuum distillation process at temperatures of 96, 97, 98, 99, and 100 °C to create the volume of phenol-rich bio-oil quite concentrated [10]. Five various types of compounds were found. These were acids, aldehydes, furans, ketones, and phenols. Nevertheless, vacuum distillation applications to improve the quality of pyrolytic bio-oil from non-biomass have not been investigated, and no other references have been published. Therefore, as far author's knowledge, this is the first study on upgrading non-biomass bio-oil driven using vacuum distillation with high temperature. Therefore, this study aims to evaluate the effect of distillation temperature (300 and 350 ^{o}C) and plastic loading (30, 40, and 50%) on the characteristic of bio-oil produced from slow pyrolysis of non-biomass. The raw materials used in this research are food waste and non-biomass waste, such as plastic waste. Food waste is a type of biodegradable waste that comes from places like households, food processing plants, and the catering business.

Experimental Method

The bio-oil that was utilized in this investigation was obtained from the previous study through the slow pyrolysis of non-biomass at 600 °C [11]. After filtration, the bio-oil was kept at a temperature of 10 °C so that undesirable deterioration would not occur. The most recent and most relevant information can be found elsewhere [12]. The schematic process for vacuum distillation process is shown in Figure 1.

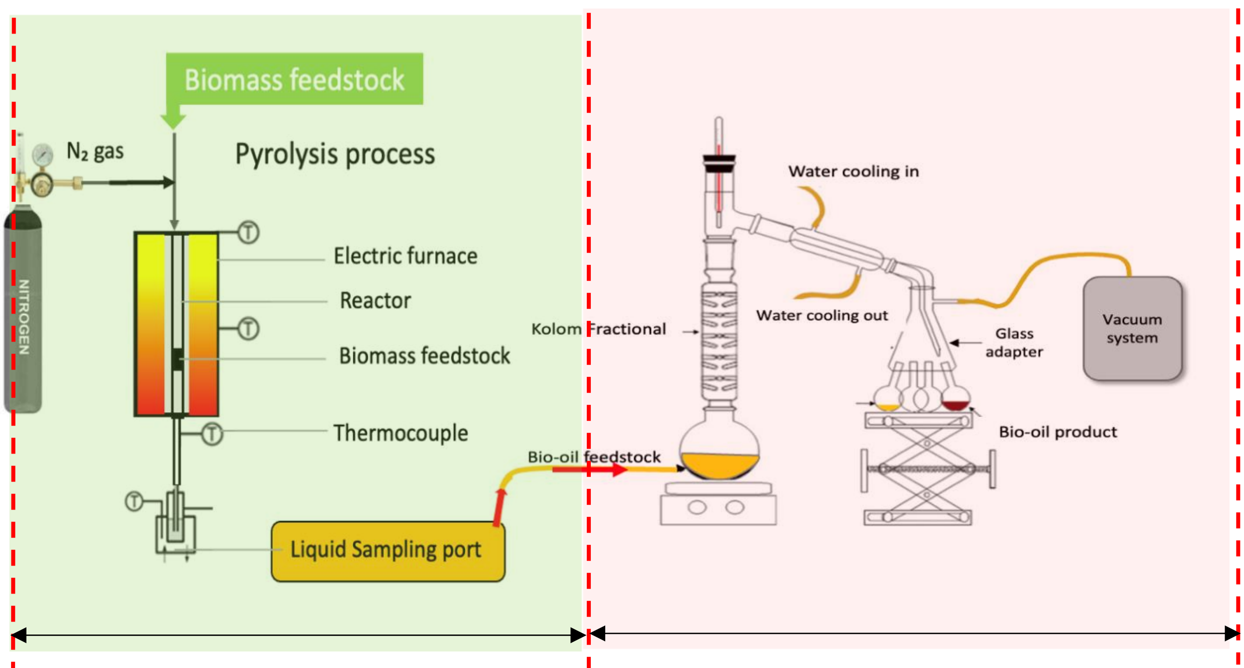

Figure 1. The schematic for the vacuum distillation process.

In this study, the effects of varying the distillation temperature (300 and 350 ^{o}C) and plastic loading (30, 40, and 50 wt%) on bio-oil quality are examined. The plastic waste used was PET waste and food waste used from households, food processing, and catering industry. Table 1 depicts the distribution of the various treatment types. The bio-oil products that were obtained after the distillation process were then characterized using GC-MS analyzer with Rtx-5MS-coated capillary column for a GC-MS (QP-2010). A total of 1 mL of the sample was dissolved in methanol and injected into the column. The GC-MS temperature was started at 150 ^{o}C , and maintained for 5 min. Then the temperature was increased to 300 ^{o}C. Each compound was then identified using a standard solution.

Table 1. Experimental conditions

Sample No.	Plastic waste (PET) loading (%)	Temperature distillation (^{o}C)	Holding Time (min)
1.	30	300 and 350	120
2.	40	300 and 350	120
3.	50	300 and 350	120

Result and Discussion

Effect of temperature and plastic loading on bio-oil yield.

Figure 2 shows the bio-oil yields from the distillation process at various temperatures (300 and 350 ^{o}C) as well as plastic loading. The percentage of bio-oil for each temperature was in the range of 40-48%. The distribution of bio-oil products, which range from solid to liquid to gaseous, was significantly influenced by temperature. It was observed that increasing temperature from 300-350 ^{o}C resulted in the percentage of bio-oil increase from 30-38% at 300 ^{o}C and 40-48% at 350 ^{o}C. The maximum 48% bio-oil yield was observed at 350 ^{o}C. This might be because the lignin molecules are fortified when high temperatures are used to generate liquid hydrocarbons [13].

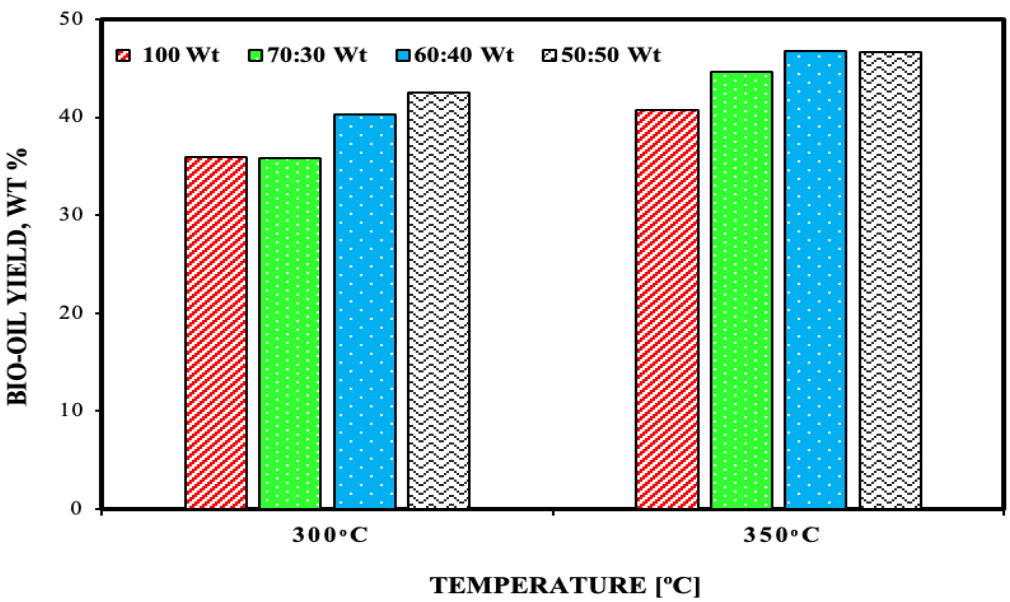

Figure 2. Bio-oil yield at temperatures of 300 and 350 ^{o}C

The results of this study are in line with the research conducted by Amrullah et al. [11], who revealed that the increase in temperature is related to the partial loss of volatiles which thermally breaks down into low-molecular-weight organic liquids and gaseous products due to thermal degradation of lignocellulosic biomass. Another study revealed that higher distillation temperatures caused cracking of the main lignin molecule, which could produce liquid hydrocarbons [14]. The different plastic loading was observed to affect bio-oil yield. The percentage of bio-oil improved in parallel with the percentage of plastic loading and temperature. Bio-oil production with different plastic loading (30, 40, and 50%) reached 40-48% at 350 ^{o}C. Increasing the plastic waste ratio in the raw material enhanced the bio-oil percentage and affected reduced solid products. This result agreed with the previous study by Amrullah et al. [11], who observed that 70 wt% of plastic waste loading resulted in high bio-oil yield (± 50%), with the solid and gas yield of 12, and 28 %, respectively [11]. This could be due to the lack of ash in plastic waste and the influence of ash on biomass [15].

Effect of temperature and plastic loading on bio-oil properties.

Bio-oil waste has studied the instrument for its chemical composition in order to gain knowledge about the bio-chemical oil's complexity and the GC method's constraints. Results from GC/MS analyses of upgraded (distilled) bio-oil samples at several temperatures are displayed in Figure 3.

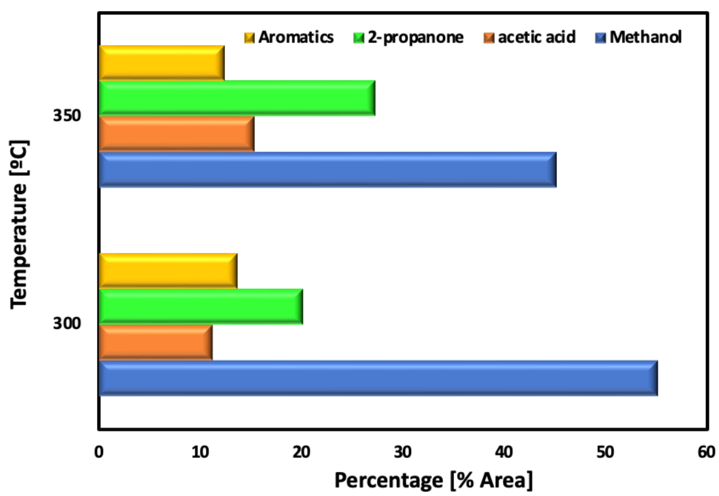

Figure 3. Representative results of GC/MS analysis at temperatures of 300 and 350 ^{o}C

Figure 3 shows the effect of temperature on the bio-oil properties as a result of upgrading by the vacuum distillation process. It is seen that when the distillation temperature is increased, methanol is the dominating product with an increase of about 15%. At a temperature of 300 ^{o}C, the percentage of methanol reaches 45% area and increases at a temperature of 350 ^{o}C with a percentage of 55.2% area. The increase in methanol is possible due to changes in the structure of lignin and hemicellulose during the acetic acid production process [13] . So the percentage of acetic acid decreases, followed by an increase in the percentage of methanol and 2-propanone. In addition to the effect of temperature on the bio-oil properties resulting from the upgrading process, in this study, the effect of adding plastic waste was also studied and analyzed for the chemical components contained in it using a GC/MS analysis tool. The data from the GC/MS bio-oil test results from the pyrolysis results with variations in the addition of plastic waste are shown in Figure 4 below.

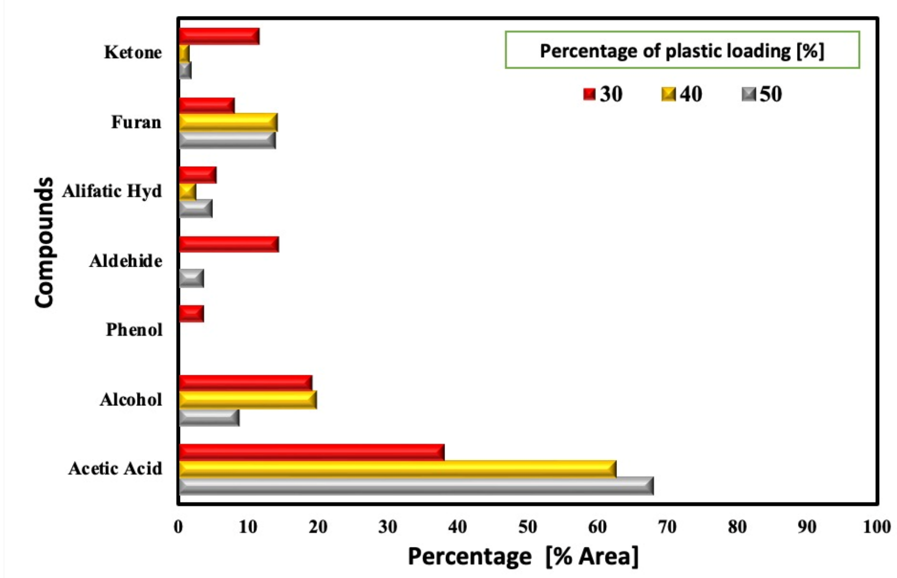

Figure 4. Representative results of GC/MS analysis at a temperature of 300 ºC with variations in the addition of plastic waste

Figure 4. shows that the addition of plastic waste has an effect on the properties of the bio-oil produced. It can be seen from the results of the GC-MS test that it is dominated by acid and alcohol content. These results are consistent with previous research conducted by Z. Wang et al. [16], which revealed that the addition of plastic (LDPE) was able to increase the percentage of bio-oil which was dominated by alcohol content [16]. Similar results were also found in research conducted by Mohan et al. [17], which revealed that the addition of plastic waste would increase the dominance of phenol, alcohol, and acid in bio-oil produced from the co-pyrolysis process [17].

Conclusion

The resulting product is influenced by the temperature and plastic waste ratio.The maximum bio-oil produced was 45%, with 50% plastic waste at 350 ºC. This upgrading process has a positive impact by observing the various chemical constituents of bio-oil. The content of chemical compounds in bio-oil after upgrading with the vacuum distillation method shows that the dominating compounds are acid and alcohol compounds ranging from 60% (acid) and 20% (alcohol), followed by other chemical compounds such as phenol (4%), aldehydes (14%), aliphatic (5%), Furans (14%), and ketones (11%).

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