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Pyrolysis Process of Organic Waste into Bio-Oil as an Alternative Fuel

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Abstract

One of the abundant potential energy sources in Indonesia is organic waste in the form of biomass waste, which amounts to 60% of the total waste in Indonesia. Organic waste from various parts of plants can be converted into fuel in the form of bio-oil through a fast pyrolysis process. The effectiveness of this process really depends on the temperature in the reactor and the type of material being processed. Therefore, the aim of this research is to study the effect of process temperature and type of raw material on yield and the quality of the bio-oil produced. The raw materials used are sawdust, rice husks, or mango plant leaves, which have been cut into pieces to a maximum size of 3 cm. Then the raw material is put into the pyrolysis reactor and heated to a temperature to be varied, namely 200°C, 300°C, 400°C, 500°C, and 600°C. This heating produce vapour, which is then condensed into liquid bio-oil, and be purified until it is equivalent to fuel oil, as well as non-condensable gas, which can also be used as an alternative fuel. The results of raw material analysis show that sawdust has lower water and ash content as well as a greater calorific value compared to rice husks and mango leaves. Meanwhile, the experiments show that in the pyrolysis process, the higher of the temperature have increased the yield of bio-oil produced, up to a temperature of 500°C, where the yield have decreased at even higher temperatures. The highest yield was achieved in the pyrolysis of sawdust at a temperature of 500°C, namely 30%. Meanwhile, for the heating value, the higher of the temperature have increased the heating value of the bio-oil. The highest heating value was obtained in sawdust pyrolysis at a temperature of 500°C, namely 1,35 joules per gram.

Keywords: *Organic waste, bio-oil, pyrolysis, yield, heating value, temperature*

1. Introduction

The main problem that is currently emerging in Indonesia is an energy crisis. The rapid growth of population and industrial development has led to an increase in fuel consumption. On the other hand, fuel production from petroleum (fossil fuel) is decreasing. This is due to the decline in oil reserves, which are no longer sufficient for national fuel needs.

In fact, the government has used various methods to overcome this energy crisis, including developing alternative energy as a replacement for crude oil. This is as stated in Government Regulation Number 79 of the Year 2014 concerning National Energy Policy [1] and Presidential Instruction Number 1 of the Year 2006 concerning the Provision and Utilization of Biofuels as Another Fuel [2]. Expected primary energy consumption in the form of coal, gas, and oil, can be replaced by other energy sources in accordance with the national energy mix plan, as is the convert to alternative energy.

However, the waste issue is also a significant concern that exists in modern civilization. The limited acreage of the final processing site (TPA) and the increasing waste generation over time, which rises in line with changes in lifestyle and population expansion, are issues that commonly come up. Therefore, there's a risk that municipal solid waste won't be handled properly. One type of waste that is very disturbing is organic waste. It is waste that is easily degraded by nature, such as leaves, twigs, food waste, and so on. The amount of this waste is very large and can cause foul odors and dangerous diseases if not managed properly. As a result, it's important to consider other uses of organic waste, like producing bio-oil by pyrolysis process as a source of energy.

Bio-oil, an emulsion with a smoke-like odor, is created by vapor condensation of material containing lignin, cellulose, hemicellulose, and other carbon components. The main components of bio-oil are carbon, hydrogen, and oxygen, with minor amounts of nitrogen and sulfur [3]. Bio-oil is a smoke-like liquid fuel produced from biomass such as wood, bark, paper, or other biomass. Bio-oil consists of carbon, hydrogen, and oxygen, with a small amount of sulfur content that can be eliminated. The largest organic components in bio-oil are lignin, alcohol, organic acids, and carbonyls. Apart from that, bio-oil has a calorific value that is greater than that of oxygenated fuels (such as methanol), and its value is only slightly lower compared to diesel oil and other fuel oils. This makes bio-oil an environmentally friendly fuel.

The development of bio-oil can replace hydrocarbon fuels in industry, such as combustion engines, boilers, static diesel engines, and gas turbines. Bio-oil is very effective as a substitute for diesel oil, heavy fuel oil, light fuel oil, and natural gas for various types of boilers. Therefore, the application of bio-oil as a substitute for fossil fuels and other products is very broad.

Seeing the good prospects for bio-oil, the government has set an agenda for bio-oil development in Indonesia, as stated in the Bio-oil Milestones in the National Energy Management Blue Print 2006–2025 [4]. It is estimated that production capacity in 2025 will be 5.992 million kiloliters per year, with a cumulative investment of $553.78 million. Based on the energy blueprint, the development of bio-oil is absolutely necessary to achieve this target, especially in terms of providing appropriate and efficient technology to produce bio-oil through the pyrolysis process.

Pyrolysis is a chemical decomposition process that uses heating without the presence of oxygen. Pyrolysis is the technique of managing heat and pressure to thermally break down long chain polymer molecules into smaller, less complicated compounds. The procedure calls for high heat for a brief period of time without oxygen. The three main byproducts of pyrolysis are oil, gas, and char, all of which are useful to enterprises, particularly those in the manufacturing and refinery sectors [5] [6]. Char and vapours are produced during the four stages of the process, which are initiation, transfer, decomposition, and termination. Both condensable and non-condensable gases are included in these pyrolysis vapours. Condensation results in the formation of pyrolysis wax/oil, a complex mixture of each raw material type's thermal breaking products. [7]

One of the main factors that influence the pyrolysis process is the operating temperature in the reactor [8]. Good pyrolysis occurs at temperatures between 300°C and 500°C. The higher of pyrolysis temperature, the greater amount of bio-oil produced. However, above a temperature of 500°C, the product decomposition process occurs further into gas, so that the bio-oil produced will begin to decrease. In addition, the higher of process temperature, the greater the energy required for the pyrolysis process. Therefore, setting the right temperature will greatly influence the success and efficiency of the pyrolysis process.

2. Materials and Methods

Raw Material Preparation

The first stage of the research is the preparation of raw materials and auxiliary materials that will be used in the research. Before preparation, a survey was carried out at several potential locations as sources of raw materials. The raw material in the form of sawdust is obtained from several sawmills in Sleman Regency, especially from hardwood such as sengon wood. The raw material for rice husks is obtained from several rice mills in the Sleman Regency area. The raw materials for plant leaves are taken from the Tambakboyo Waste Recycling Location, especially mango plant leaves which are widely available in this area.

All raw materials are dried first in the sun for several days with the hope of getting dry raw materials (maximum water content 10%), and the size is made uniform with a maximum length of material of 3 cm. On the other hand, the catalyst in the form of natural zeolite (technical) was obtained from the "Alfa Kimia" chemical shop in the Yogyakarta.

Before use, the raw materials are first analyzed for chemical content at the Chem-Mix Pratama Laboratory, Bantul. Some of the parameters analyzed are water content, ash content, carbon content, volatile content, and heating value.

Equipment Preparation

Producing a pyrolysis tool begins with making an equipment design uses calculations based on mass and energy balances from the pyrolysis process of organic materials, which are implemented in a design drawing. After the drawing is complete, the equipment work process is carried out in the Engineering Workshop for 1 month.

The equipment that was used in this research is shown in Figure 1.

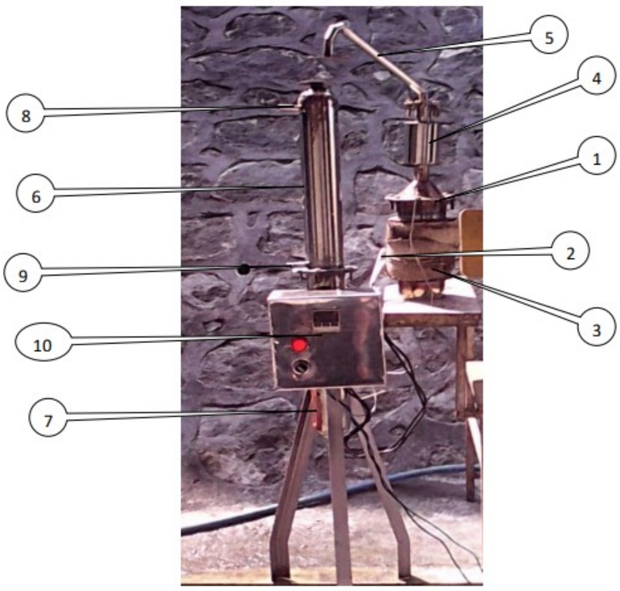

Figure 1. Pyrolysis Reactor Equipment

1. Pyrolysis reactor
2. Heating Elements
3. Isolator
4. Catalyst tube
5. Pirolysis vapour pipe
6. Condenser
7. Bio-oil storage
8. Water out
9. Water in
10. Temperature Controller

The series of available equipment is tested first without using a load to find out whether the equipment can function or not. If any part of the equipment does not function properly, it will be repaired, and if all parts function normally, the research will continue.

Main Experiment

This experiment was carried out by heating the three types of raw materials to a temperature determined according to the research variables, which will produce products in the form of bio-oil, charcoal and non-condensable gas. The research was conducted in the Production Process Laboratory, Faculty of Engineering, Universitas Proklamasi 45 Yogyakarta.

The main experimental process begins by inserting raw materials into the reactor, then the lid is installed and all heating, cooling and piping systems are tightened. After all the systems are installed properly, start heating to the desired temperature, and then hold it at that temperature for 1 hour. In this pyrolysis process, volatile matter will evaporate, flow through the pipe, continued to the condenser and condensate into a liquid product. Some of the non-condensable gas will be analyzed for its contents, while the other part will be burned through the gas flare pipe provided. After the pyrolysis process is complete, the equipment is turned off and allowed to stand until it approaches room temperature. After that, the lid is opened and the charcoal is taken out and placed in a place that is not damp and kept tightly so that water vapor from the surroundings is not absorbed into the charcoal.

Analysis of bio-oil products

The liquid product (bio-oil) obtained from the pyrolysis process is then measured in volume using a measuring cup. The results of measuring the volume of the liquid product will be used to calculate the product yield. Laboratory tests of liquid products are carried out by measuring their heating value at the Chem-mix Pratama Laboratory using a bomb calorimeter test. The bio-oil tested was 10 m^3, resulting from the pyrolysis of each research variable.

3. Results and Discussion

3.1. Research result

Laboratory test results of raw materials are as follows in table 1.

Table 1. Laboratory test results of raw materials

No.	Parameter	Unit	Sawdust	Rice Husk	Mango Leaves
1	Water content	%	2,89	3,81	3,32
2	Ash content	%	3,21	24,43	11,67
3	Volatile Matter Content	%	77,66	55,56	61,25
4	Fixed Carbon Content	%	16,23	16,19	23,75
5	Calorific Value	Joule/gram	20,41	13,78	17,75

Based on Table 1, it can be seen that the water content and ash content of sawdust are very small compared to mango leaves and rice husks. However, the volatile content of sawdust is greater than that of mango leaves and rice husks. For carbon content, mango leaves have a greater carbon content than sawdust and rice husks. Meanwhile, for the calorific value parameter, sawdust apparently has a large calorific value compared to leaves, mango, and rice husks.

The pyrolysis process was carried out first on sawdust with specified temperature variations, then continued with the pyrolysis of rice husks and mango leaves. The yield of bio-oil products produced from the sawdust pyrolysis process, rice husks, and mango leaves is shown in Table 2.

Table 2. The yield of bio-oil product in different temperature of pyrolysis process

No.	Temperature (^{0}C)	Sawdust	Rice Husk	Mango Leaves
1	200	25%	17%	21%
2	300	28%	19%	23%
3	400	29%	23%	25%
4	500	30%	23%	26%
5	600	30%	21%	24%

In addition, an analysis of the calorific value of the bio-oil products produced was carried out, as shown in table 3.

Table 3. The calorific value of bio-oil product in different temperature of pyrolysis process

No.	Temperature (^{0}C)	Sawdust	Rice Husk	Mango Leaves
1	200	1,12	1,12	1,17
2	300	1,23	1,13	1,19
3	400	1,29	1,17	1,21
4	500	1,31	1,29	1,23
5	600	1,35	1,33	1,25

3.2. Discussion

The influence of temperature on bio-oil yield is shown in the figure 2

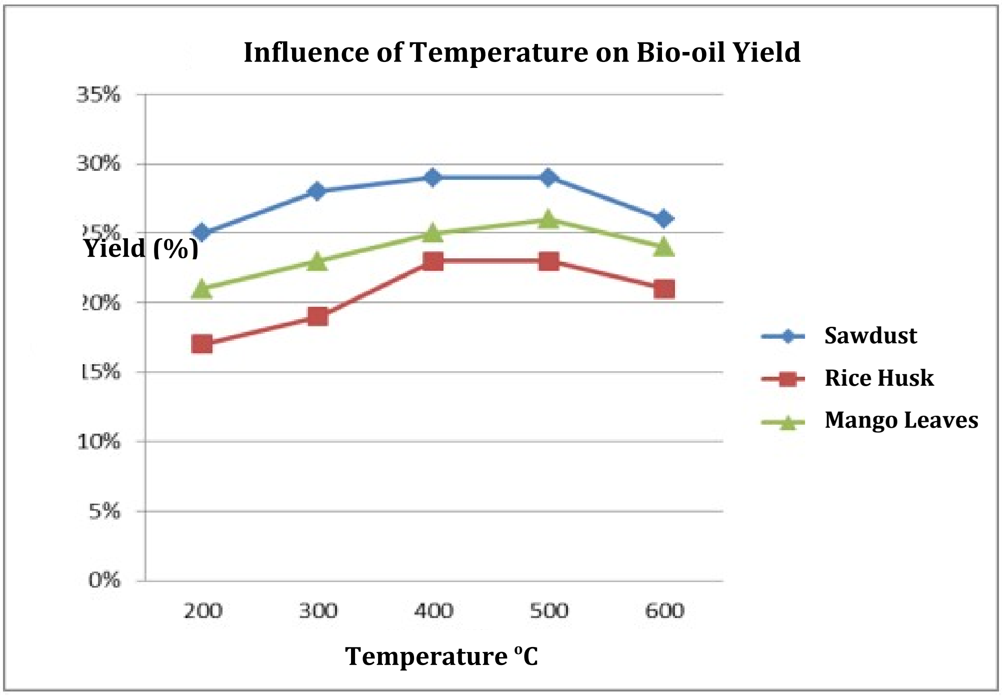

Figure 2. The effect of temperature on bio-oil yield

Based on Figure 2, it can be seen that the higher reaction temperature has increased the yield of bio-oil and reached maximum conditions at 500 °C. However, if the temperature is higher (600 °C), there is a decrease in the amount of bio-oil produced due to the secondary reaction of organic compounds in the bio-oil into gas that cannot be condensed [9].

From Figure 2, it can also be seen that the yield of bio-oil from sawdust pyrolysis is higher than that of rice husks and mango leaves. This is because the ash content of mango leaves and rice husks used is higher, which will reduce the amount of bio-oil produced. The highest bio-oil yield was obtained in the sawdust pyrolysis process at a temperature of 500 °C, namely 30%, and the lowest bio-oil yield was in the rice husk pyrolysis process at a temperature of 200 °C, namely 17%.

The effect of temperature on bio-oil calorific value is shown in the figure 3.

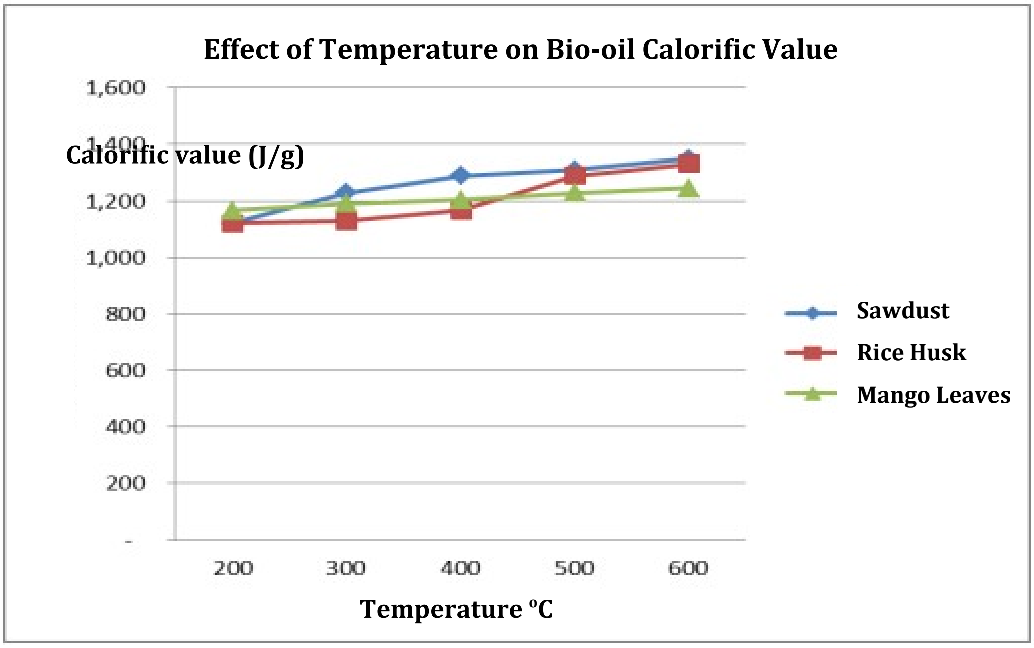

Figure 3. The effect of temperature on bio-oil calorific value

Based on Figure 3, it can be seen that the higher reaction temperature has increased the calorific value of bio-oil, although this is not too significant. This is because the phenol compounds formed increase as the temperature increases, while the oxygenate compounds decrease, so the calorific value will increase [10]. From Figure 2, it can also be seen that the calorific value of bio-oil from the pyrolysis of organic materials does not differ significantly from one material to another. The highest calorific value is shown in bio-oil resulting from sawdust pyrolysis at a temperature of 600 °C, namely 1,35 joules per gram.

4. Conclusion

Based on the results of the research that has been carried out, the following conclusions can be drawn:

1. The higher the reaction temperature, the higher the yield of bio-oil produced, with a maximum limit of 500°C. If the temperature is higher, the bio-oil produced is reduced. The highest yield was obtained in bio-oil resulting from sawdust pyrolysis at a temperature of 500°C, namely 30%.
2. The higher the reaction temperature, the calorific value of the bio-oil produced increases, but not too significantly. The highest calorific value was obtained in bio-oil resulting from the pyrolysis of sawdust at a temperature of 6000 °C, namely 1,348 joules per gram.

References

[1] Government of Indonesia, Government Regulation Number 79 of the Year 2014 concerning National Energy Policy. Jakarta, 2014.

[2] Government of Indonesia, Presidential Instruction Number 1 of the Year 2006 concerning the Provision and Utilization of Biofuels as Another Fuel. Jakarta, 2006

[3] D. S. Fardhyanti and A. Damayanti, Analysis of Bio-Oil Produced by Pyrolysis of Coconut Shell, *International Journal of Chemical and Molecular Engineering*, Vol:11, No:9, 2017 .

[4] Government of Indonesia, Presidential Regulation Number 5 of the Year 2006 regarding National Energy Management Blueprint 2006-2025. Jakarta, 2006

[5] S. Sharuddin, F. Abnisa, W. M. A. W. Daud, and M. K. Aroua, A Review on Pyrolysis of Plastic Wastes, *Energy Conversion and Management*, vol. 115, p. 308–326, 2016.

[6] M. S. Cahyono, Pengaruh Jenis Bahan pada Proses Pirolisis Sampah Organik menjadi Bio-Oil sebagai Sumber Energi Terbarukan, *Jurnal Sains dan Teknologi Lingkungan*, vol. 5, no. 2, pp. 67-76, 2013.

[7] Fivga A, Dimitriou I, Pyrolysis of plastic waste for production of heavy fuel substitute: A techno-economic assessment, Energy (2018), doi: 10.1016/j.energy.2018.02.094..

[8] Klass, D.L.. Biomass for Renewable Energy, Fuels, and Chemicals. Entech International Inc., London. 1990.

[9] Bridgewater. Biomass Fast Pyrolysis. Aston University, Birmingham, 2007.

[10] Amutio, dkk. 2012. Influence of Temperature on Biomass Pyrolysis in A Conical Spouted Bed Reactor. *Journal Resources, Conservation and Recycling* 59, pp.23-31, 2012.