

The Effect of Temperature Variation and Absorber Type on the Pyrolysis of Sawdust Using Microwaves

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Abstract

Biomass is a renewable and environmentally friendly energy source. However, its utilization is often inefficient, such as in direct combustion and biological processes. Pyrolysis, a method of heating biomass without oxygen, can enhance the value of biomass by producing gas, oil, and char. Microwave technology makes the pyrolysis process more efficient. This study varied the pyrolysis temperatures (350°C, 400°C, 450°C, 500°C) and used KOH and SiC as varied absorbers. KOH was chosen because it contains O and H elements that help absorb microwaves, while SiC is effective in improving heating efficiency. The results showed that pyrolysis at 350°C produced the highest biochar yield of 59.3% of the biomass weight. The highest bio-oil yield, 27.7%, was obtained at 400°C. Pyrolysis without an absorber demonstrated that sawdust cannot absorb microwaves effectively, as the temperature only reached around 200°C, which is insufficient for pyrolysis. SiC increased the temperature of the sawdust (between 200°C - 330°C) earlier than KOH. However, KOH led to higher bio-oil production than SiC. The findings suggest that absorber type and pyrolysis temperature significantly influence the efficiency and product distribution. Microwave-assisted pyrolysis with absorbers offers a promising method for converting biomass into valuable energy products, highlighting its potential for further development.

Keywords: Absorber, Microwave, Pyrolysis, Sawdust, Temperature

Introduction

Biomass is a renewable and environmentally friendly energy source with several advantages, such as abundant availability, widespread distribution, low cost, etc. These attributes make biomass the fourth-largest energy source today, after coal, petroleum, and natural gas (Kota et al., 2022). There are several processes for utilizing biomass, such as direct combustion, which is inefficient and produces significant pollution, and chemical and biological processes, which require a long time and result in limited yields (Arias et al., 2008; Medic et al., 2012; Pang, 2019). Other biomass conversion technologies are illustrated in Figure 1. One process with the potential to convert biomass into high-valued fuel is thermochemical conversion (Yang et al., 2024).

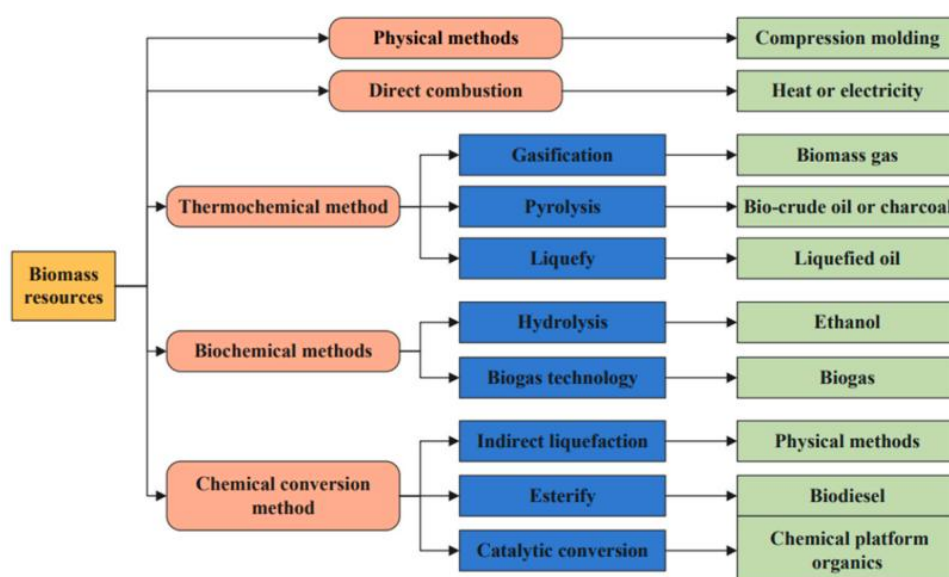


Figure 1. Biomass Conversion Technology (Yang et al., 2024)

The thermochemical process mentioned is divided into three types: gasification, pyrolysis, and hydrothermal liquefaction (HTL) (Ong et al., 2019). Table 1 shows that the pyrolysis process requires simpler conditions and produces a significant number of results. Therefore, pyrolysis is considered a promising technology for implementation (Yang et al., 2024), (Hasibuan, Qodri, Isa, et al., 2021).

Table 1. Comparison of Pyrolysis, Gasification and HTL Technologies.

	Gasification	Pyrolysis	HTL
Conditions	600-1000°C	400-600°C	210-360°C Pressure: 10-25 MPa
Main Products	Gas	Oil or Carbon	Oil or Carbon
Main Catalysts	Mineral based AAEM based Nickel based	Zeolites Metals	Active carbon Al ₂ O ₃ , SiO ₂ , ZrO ₂ and zeolite

Pyrolysis is a thermochemical conversion process without oxygen, used to convert biomass into three main pyrolysis products: liquid (bio-oil), solid (biochar), and gas (Mufandi et al., 2023; Syamsiro et al., 2021). In practice, pyrolysis with conventional heating requires a long time to reach the desired temperature. As a result, the time needed to produce the three pyrolysis products is also extended (Hasibuan, Qodri, & Isa, 2021). Therefore, innovations in the heating system are necessary to accelerate the attainment of pyrolysis temperatures (Igliński et al., 2023).

The study uses a microwave oven as the heating device. Figure 2 illustrates the difference between conventional heating and microwave heating processes. Microwave heating, which occurs from the inside of the particles to the surface of the raw material, accelerates the heating process. As a result, the pyrolysis process can occur more quickly and efficiently, without heat loss due to conduction and convection within the reactor (Zhang et al., 2017).

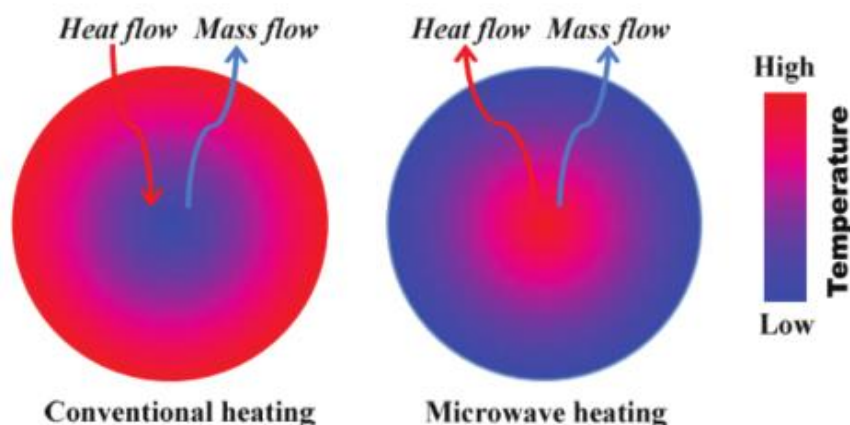


Figure 2. The Difference Between Conventional Heating and Microwave Heating (Zhang et al., 2017)

Research on the pyrolysis of biomass in the form of teak wood sawdust has been conducted by Gupta et al. (2019). The sawdust was collected from a local sawmill near the Indian Institute of Technology (Banaras Hindu University) campus in Varanasi, India. The sawdust was cleaned and dried until a constant weight was achieved, then sieved into mesh sizes 30-50, 50-70, and 70-90. The pyrolysis of sawdust was carried out at temperatures ranging from 400 to 700 °C, with nitrogen gas flowing at a rate of 150-240 ml/min (Mishra & Mohanty, 2022).

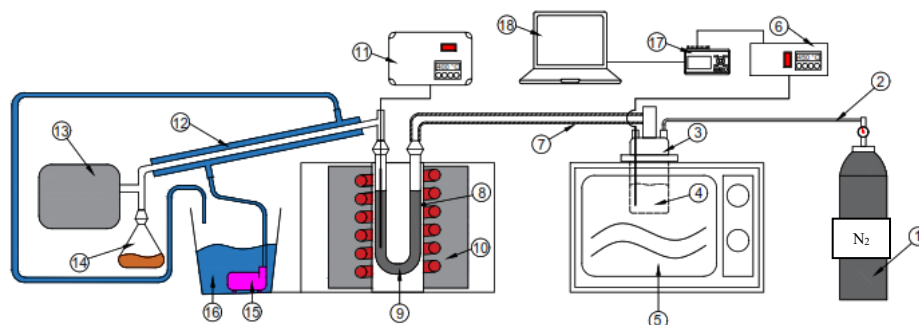
The experiments of teak wood sawdust pyrolysis in an inert atmosphere produced biochar (27.4%), bio-oil (48.8%), and pyrolysis gas (23.8%) at an optimal temperature of 600°C. The bio-oil, with a high calorific value (14.51-25.83 MJ/kg), can be used as synthetic liquid fuel. Biochar is suitable as an adsorbent in wastewater treatment. The pyrolysis gas has a good proportion of H₂, CH₄, CO, and CO₂ in the exit gas stream (Mamaghani et al., 2023). Teak sawdust pyrolysis is effective for waste minimization, waste treatment, and energy production (Gupta et al., 2019).

Research on pyrolysis using microwave heating has also been conducted by Fricler et al. (2023). The study utilized various feedstocks, including peanut shells, rice husks, sawdust, straw, and bran. The study compared the effects of feedstock particle size, types of absorbers used, and the percentage of mixtures. These variations were used to assess their impact on the quantity and quality of the primary pyrolysis products: gas, biochar, and bio-oil (Shrivastava et al., 2021).

The results showed that a particle size of 800 μm was optimal for producing bio-oil and gas. Larger particle sizes (1000-2000 μm) reduced the yield of gas and oil but increased the biochar yield. The biomass mixture of sawdust and straw produced a higher yield of combustible gas. The gas generated from this mixture contained CO, CH₄, and H₂ at 20-70% higher than those produced from other biomass mixtures (Fricler et al., 2023).

Materials & Methods

The research was conducted in the Energy Conversion Laboratory, Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada. The study aims to examine the effects of different pyrolysis temperatures and types of absorbers on the quantity of the products generated from the pyrolysis process. The heating mode used in this pyrolysis process uses microwave radiation with a power of 1250 watts. The material used is teak wood sawdust with a particle size of 0.25-0.5 mm and mass of 100 grams for each test. The study utilizes operating temperatures of 350°C, 400°C, 450°C, and 500°C, maintained for 15 minutes (de Almeida et al., 2022). The research also uses absorber types of KOH and SiC, each with a mass of 100 grams per trial. When testing two different types of absorbers, the pyrolysis temperature used was set to 400°C (Zhang et al., 2024). Figure 3 illustrates the schematic of the microwave-assisted pyrolysis research including its legends.



Legends:

- | | |
|---|---|
| 1. Nitrogen gas cylinder | 10. Conventional Oven |
| 2. Nitrogen gas line | 11. Thermocontroller of a conventional oven |
| 3. Reactor cover | 12. Condenser |
| 4. Glass reactor | 13. Tedlar bag |
| 5. Microwave oven | 14. Erlenmeyer flask |
| 6. Thermocontroller of a microwave oven | 15. Cooling water pump |
| 7. Pyrolysis gas insulation channel | 16. Cooling water |
| 8. Pipe U shape | 17. Data logger |
| 9. Catalyst | 18. Laptop |

Figure 3. Schematic Diagram of the of the Microwave-Assisted Pyrolysis Research

Results and Discussions

In order to determine the optimal variation in the pyrolysis of teak sawdust using microwaves, it is necessary to measure the amount of pyrolysis products, namely biochar, bio-oil, and gas (Makepa, 2023). The quantities of biochar and bio-oil are measured in mass units, while the amount of gas is calculated as the difference between the mass of the raw material and the masses of biochar and bio-oil produced (Sahoo et al., 2021). The temperature of 350°C produced the highest amount of biochar at 59.3% of the raw material's weight. Temperatures of 400°C, 450°C and 500°C yielded nearly similar amounts of biochar, at 58.5%, 58.1% and 53.2%, respectively. The highest bio-oil yield, 27.7%, was obtained at 400°C. All temperature conditions in this study utilized KOH as the absorber to assist the heating process. The discussion of the effects of each variation, both temperature and absorber type, is as follows.

a. Effect of Temperature Variations

The temperature variation in the pyrolysis process of teak sawdust using microwaves affects the resulting products, which include biochar, bio-oil, and gas. Figure 4 shows the amounts of pyrolysis products for each temperature variation. An increase in temperature during the pyrolysis process leads to a decrease in the amount of biochar produced. At lower temperatures, such as 350°C, the biochar yield is higher compared to bio-oil and gas. This occurs because the thermal decomposition process is not yet fully completed, leaving much of the biomass unconverted into volatile compounds (Chan et al., 2014). The biochars obtained at these temperatures are shown in Figure 5. The biochar produced at these temperatures has an oily texture, and not all of it is black, indicating that the biomass has not been completely carbonized and still contains many unconverted organic compounds. The darker products indicated that carbon content in the solid fuel was getting higher (Surono et al., 2020)

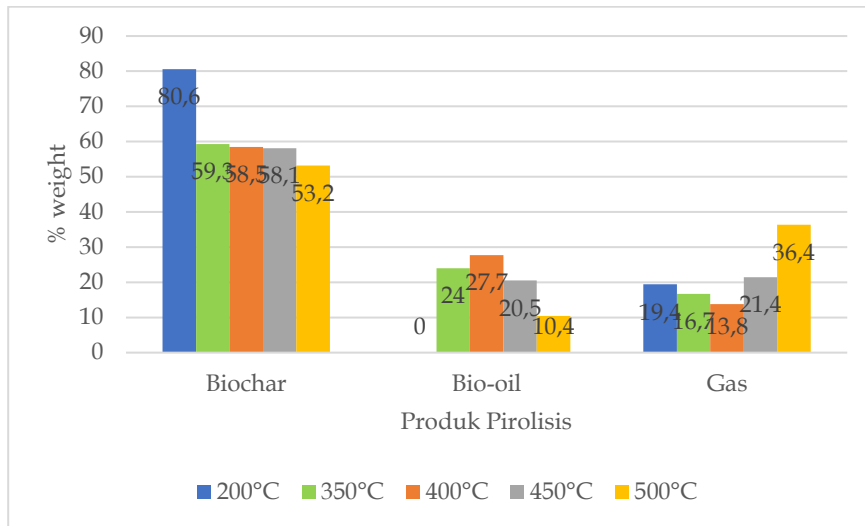


Figure 4. Biochar, Bio-Oil and Gas Products in Varying Pyrolysis Temperatures

Increasing the temperature results in a decrease in the amount of bio-oil produced. This reduction occurs because higher temperatures generate more gas, causing the pyrolysis gas flow rate to increase and preventing the gas from condensing into bio-oil. The bio-oil produced is shown in Figure 6. The 400°C temperature yields the highest amount of bio-oil, accounting for 27.7% of the biomass weight.

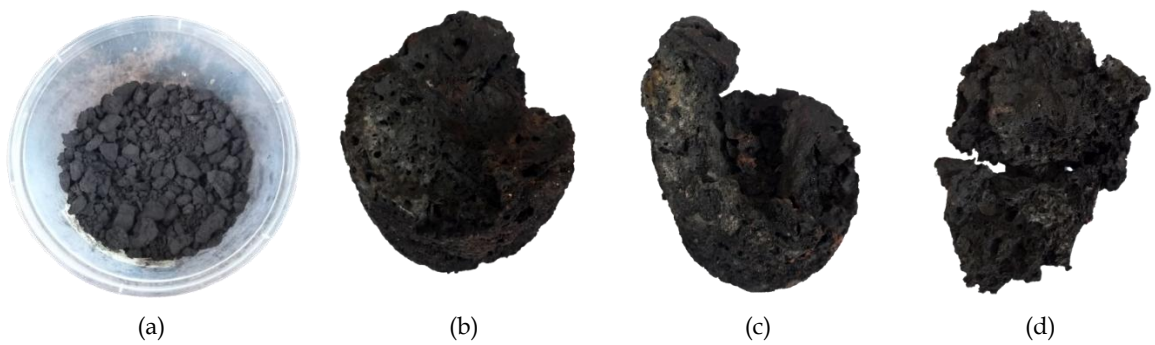


Figure 5. Biochar at Temperature Variations (a) 350°C, (b) 400°C, (c) 450°C, and (d) 500°C

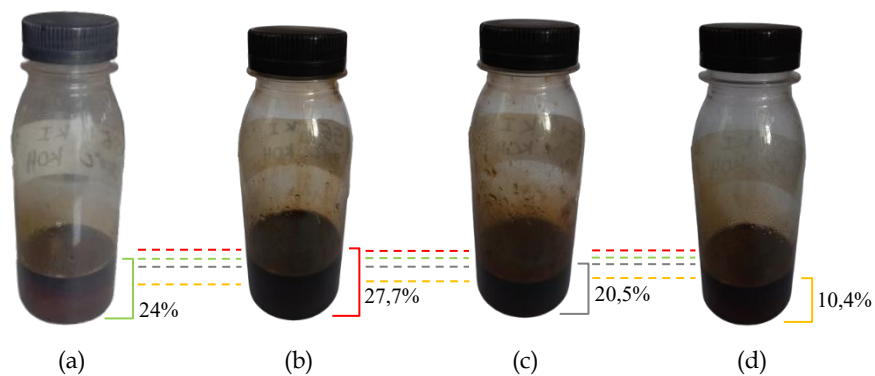


Figure 6. Bio-Oil at Temperature Variations (a) 350°C, (b) 400°C, (c) 450°C, and (d) 500°C

b. Effect of Absorber Variations

Before adding an absorber to absorb microwave radiation, the biomass was first heated without using an absorber. In the pyrolysis experiment without an absorber, teak sawdust could not absorb microwave energy effectively. As a result, the biomass did not reach the required temperature for pyrolysis and only achieved about 200°C. The low temperature prevented the devolatilization process, resulting in no bio-oil production. Figure 7 shows that pyrolysis without an absorber does not yield bio-oil due to the absence of the devolatilization process.

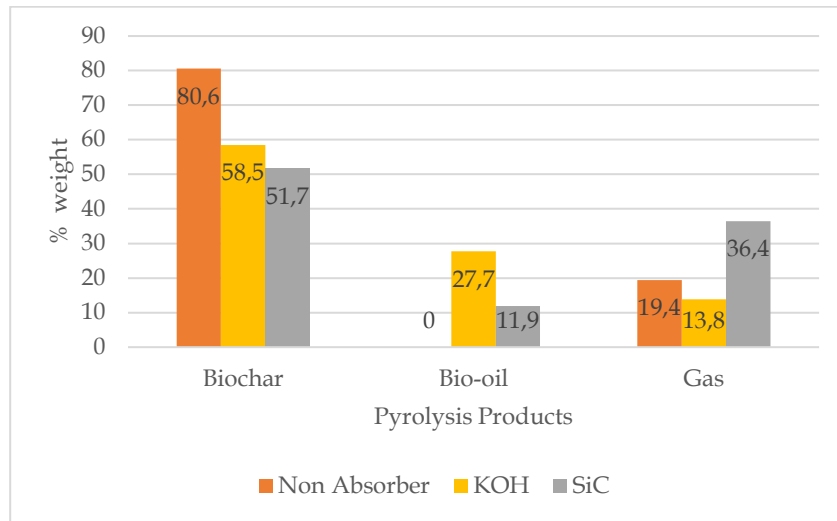


Figure 7. Biochar, Bio-Oil and Gas Products in Absorber Variations at Pyrolysis Temperature 400°C

An absorber is required to effectively absorb microwave radiation and heat the biomass. Both types of absorbers, KOH and SiC, have been proven to increase the biomass temperature. The KOH absorber enhances bio-oil production, particularly at a temperature of 400°C. Additionally, the KOH absorber reaches the pyrolysis temperature faster than the SiC absorber.

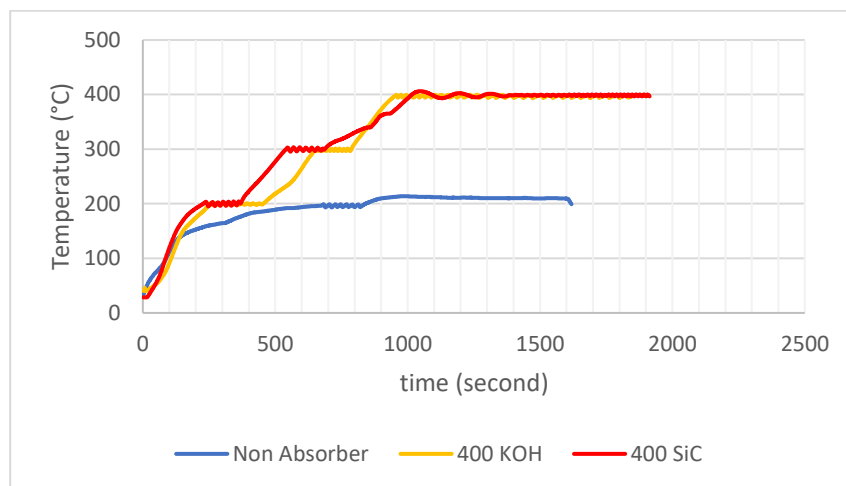


Figure 8. Pyrolysis Temperature Changes

The change in pyrolysis temperature with different absorbers can be seen in Figure 8. The SiC absorber reaches between 200°C - 330°C more quickly, but the KOH absorber reaches 400°C around one minute earlier than SiC. Figure 9 shows the biochar produced from pyrolysis using and without using an absorber. Pyrolysis without using an absorber only reaches a temperature of 200°C. The temperature is too low to produce gas or bio-oil. Most of the resulting product was biochar, which remained brown in color and had not fully converted into charcoal (Figure 9a). The biochar produced with the KOH absorber clumps together and sticks between particles (Figure 9b), while the biochar produced with the SiC absorber forms separate grains (Figure 9c), distinct from the raw material and the absorber.



Figure 9. Biochar (a) Non-Absorber, (b) KOH Absorber, and (c) SiC Absorber

The bio-oil produced from pyrolysis using two different types of absorbers can be seen in Figure 10. The darker color of the bio-oil from KOH absorber (10a) is believed to indicate a higher carbon content, similar to that found in biochar. The KOH absorber variation produces more bio-oil (27.7%) compared to the SiC absorber variation (11.9%) as shown at Figure 7.



Figure 10. Bio-Oil (a) KOH Absorber, and (b) SiC Absorber

The SiC absorber produces biochar that is separated and in the form of granules. This biochar is easy to separate from the absorber. At 400°C, some of the biochar remains brown in color, indicating that some of the biomass has not been properly decomposed. At temperatures of 450°C and 500°C, the black color is more evenly distributed throughout the biochar. The bio-oil produced with the SiC absorber is lower compared to the KOH absorber. This indicates that using SiC results in gas that is not fully condensed.

Conclusions

Based on the results of the study on the effect of temperature variations and absorber types in the pyrolysis of sawdust using microwave, the following conclusions can be drawn:

- At 350°C, the highest amount of biochar is produced, accounting for 59.3% of the feedstock weight.
- The highest yield of bio-oil is achieved at 400°C, with 27.7% of the feedstock weight.
- Both absorbers increase biomass temperature, but the KOH absorber reaches 400°C around one minute faster than the SiC absorber.
- The bio-oil produced using the KOH absorber has a greater quantity and darker color compared to the bio-oil produced using the SiC absorber.

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