Utilization of Biomass from Kerai Payung Trees and Waste Paper Through Pyrolysis Technology to Support the Zero-Waste Concept

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Article history:
Received: 25 October 2024 / Received in revised form: 14 January 2025 / Accepted: 15 February 2025
Available online 25 March 2025

ABSTRACT

Wisnuwardhana University is a private institution with a green campus environment surrounded by Kerai Payung trees. This environment produces organic waste from trees and inorganic waste such as used paper from campus activities. This study aims to achieve zero-waste processing by using pyrolysis technology to process campus waste, ensuring minimal residue. The experimental method involves comparing waste processing outcomes between conventional combustion and pyrolysis, the data was analyzed by comparing the results of pyrolysis with conventional combustion. The results of biochar from the pyrolysis process of used paper, Kerai Payung leaves, and nagging Kerai Payung tree are 76 g, 250 g, and 26 g. Then the results of ash from the pyrolysis process of used paper, Kerai Payung tree leaves, and nagging Kerai Payung tree are 23 g, 49 g, and 23 g. The results of liquid smoke from the pyrolysis process of used paper, Kerai Payung tree leaves, and nagging Kerai Payung tree are 75 mL, 50 mL, and 10 mL. Conventional combustion does not produce liquid smoke because the smoke from combustion is left to decompose in the air. This finding shows that pyrolysis is more effective than conventional combustion, because pyrolysis converts smoke into liquid, thereby reducing air pollution. In addition, the biochar and liquid smoke produced can be useful for agriculture and act as food preservatives, thus supporting sustainable waste management on campus.

Keywords: *Kerai Payung biomass, pyrolysis, waste paper, zero-waste*

I. Introduction

The environment of Wisnuwardhana University is known as a shady and beautiful area, with various types of trees planted around the campus, one of which is the Kerai Payung tree. The existence of these trees, although providing great benefits in creating a cool and comfortable atmosphere, also produces organic waste in the form of leaves and twigs that need to be managed. In addition to organic waste, daily activities on campus also produce waste paper from various administrative and learning activities. This waste is cleaned up every day by janitors, but its management is still carried out conventionally and is not optimal. Currently, the management of organic waste and paper is carried out by burning it in an open area. Processing in this way not only produces smoke that disturbs the comfort of students and the surrounding community, but also leaves behind combustion residue that is left to pile up in the corner of the field, making the campus environment look dirty and unpleasant to look at.

Several previous studies process campus waste and garbage into useful items. Research conducted by [1] who processed waste on the STKIP Kusuma Negara campus into teaching aids made from the utilization of used plastic bottles, plastic packaging waste, cardboard,

DOI: 10.17977/um016vv9i12025p014

and paper. In the study conducted by [2], on waste processing at the Hasanuddin University campus, the research proposed several improvements, including expanding waste sorting into four categories, implementing separate collection facilities, establishing a 3R (Reduce, Reuse, Recycle) waste processing station within the campus, and enhancing academic community participation through source-based waste. Another study conducted by [3] focused on waste processing at Semarang University to achieve an Eco Campus. This research resulted in a zero-waste management planning model incorporating a composting system, the 3R approach, and the development of a standard operating procedure (SOP) for campus waste management. The three studies share a similar waste processing model based on the 3R (Reduce, Reuse, Recycle) method. However, the approaches used remain conventional, such as repurposing waste into teaching aids or implementing basic waste separation systems. Building on this background and previous research, this study explores the use of pyrolysis technology as an innovative approach to achieving zero-waste management in the campus environment. By integrating pyrolysis technology, waste processing can be more effective in minimizing landfill disposal. Zero-waste is both a philosophy and a practical strategy aimed at eliminating waste from landfills and incinerators by promoting a circular economy, where resources are continuously reused. This concept is fundamentally based on three principles: reduce, reuse, and recycle. The pyrolysis method facilitates the conversion of biomass into solid, liquid, and gaseous products [4], [5]. As a promising technology, pyrolysis can transform solid waste into energy-rich products such as fuels and chemicals [6], [7]. This approach offers a sustainable solution for processing organic waste and paper, minimizing harmful emissions while contributing to a cleaner, healthier, and more environmentally friendly campus. This study aims to achieve zero-waste processing by utilizing pyrolysis technology to convert campus waste, specifically biomass from the Kerai Payung tree and used paper into useful products with minimal residue.

II. Material and Methods

This method used an experimental research design. The location of the study was carried out at the Manufacturing Process Laboratory of Wisnuwardhana University, Malang. This research was conducted with 2 processes, namely the pyrolysis process and conventional combustion, with the same number of samples used, namely 420 g. The purpose of carrying out combustion in 2 different ways is to determine how effective the use of the pyrolysis process is in helping to reduce pollution [8] compared to the conventional combustion process, which is considered to pollute the surrounding air. The data obtained from the pyrolysis process were then analyzed by comparing the results of pyrolysis with conventional combustion.

1. Equipment Preparation Stages

The materials used were biomass from Kerai Payung trees (Figure 1) and used paper (Figure 2) located around the Wisnuwardhana University. Kerai Payung trees (*Filicium decipiens*) are one of the tree species that are widely used as greening plants in urban areas because they have a wide canopy and are adaptive to the environment. The biomass used was leaves and twigs from Kerai Payung trees. In addition to biomass, this research used paper from teaching and learning activities or administrative activities in the campus environment. As is known, paper has a high lignin content. The presence of lignin in the paper content allows the processing of used paper, which is processed into a mixture of plant fertilizers. Thus, lignin is the main source of organic material that is slowly damaged by fuminic acids found in the soil [9]. So, lignin can be used as a plant fiber strengthener. Waste paper was also chosen because improper processing of waste paper can be harmful to health. According to [10], the Cl content in paper products is harmful to humans. According to recent research, Cl in the pores of the human body can cause cancer, nervous system disorders, as well as clastogenic and endocrine disorders [10], [11].

Fig. 1. Kerai Payung tree biomass

Fig. 2. Waste paper

The collection of materials used for this research was obtained around the environment of Wisnuwardhana University Malang. Samples were collected according to the volume of the reactor tube, which was 420 g in each sample. In the biomass of the Kerai Payung tree, the leaves, twigs, and stems were separated. If the condition of the biomass and used paper is moist or wet, it will be dried for approximately 10 hours in the sun until a dry condition is obtained so that the combustion process can be carried out with pyrolysis.

Fig. 3. Pyrolysis unit

The obtained material was processed by a pyrolysis process. The pyrolysis tool used was the work of students from the practicum carried out in the manufacturing process laboratory (Figure 3). The pyrolysis unit consists of 3 main parts, namely the reactor (C), dust separator (D), and condenser (E). The pyrolysis unit is also equipped with a grinder (B), and leaf dryer (A). The capacity of waste that can be accommodated by the reactor is 420 g. While the dimensions for each unit in pyrolysis are written in Table 1.

Table 1. Dimensions of each unit in pyrolysis

	Tall (cm)	Diameter (cm)
A. Dryer (Dryer)	38	30
B. Grinder (Shredder)	38	30
C. Reactor	54	35
D. Dust Separator	89	21
E. Condenser	79	44

2. Combustion Stages (Pyrolysis)

The combustion process with pyrolysis occurs in the reactor tube. In the combustion process, charcoal and diesel are used as combustion media. Diesel is used to help create fire in the combustion process [12]. In the combustion process with pyrolysis, the temperature in the reactor tube is unstable, this is because the combustion medium uses charcoal so that pressure is needed from the LPG gas cylinder and compressor to help the charcoal burn continuously and also the reactor tube is not equipped with a flame regulator so that the temperature in the reactor tube cannot be controlled. The pyrolysis combustion process is only carried out in 1 cycle. The use of a pyrolysis unit is directly related to flammable materials such as diesel and LPG gas and the heat generated in the combustion process can injure the user's body, therefore to ensure user safety, safety glasses are used to protect the eyes when making fire so that the eyes are protected from heat and prevent eye pain, then the use of heat-resistant gloves to prevent hands from being exposed to heat during the combustion process, in addition to the use of masks to prevent smoke during the fire-making process from entering the respiratory tract, as one of the anticipations of fire during the combustion process, a Light Fire Extinguisher (LFE) has also been prepared.

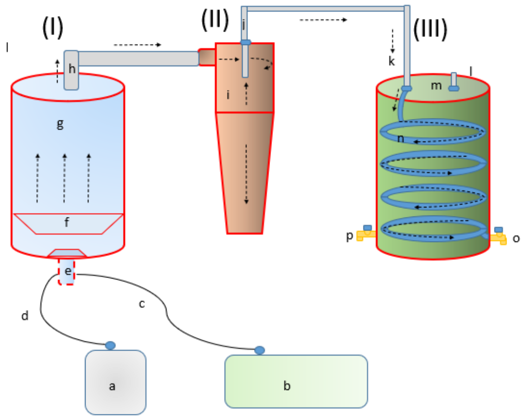
3. Stages of Pyrolysis Results Collection

The taking of the results of pyrolysis combustion cannot be done directly when the combustion process is complete, it takes approximately 5 hours to wait for the pyrolysis unit to be at normal temperature. The taking of the pyrolysis results is done by collecting ash, charcoal, and liquid smoke into a container that has been labeled. For the collection of ash and charcoal, because there is no separator between ash and charcoal in the condenser, it is necessary to separate it manually using a sieve to get ash. After the ash and charcoal are separated, then weigh and record the results of each component. As for smoke, the liquid is put into a measuring cup to find out how many mL of liquid smoke is obtained. The results of the pyrolysis are then analyzed by comparing them with the results obtained from the conventional process.

III. Results and Discussions

The utilization of Kerai Payung tree biomass and used paper has been carried out through a pyrolysis experiment process (Figure 4). The results will be described in the following results and discussion.

1. Pyrolysis System



a : Gas cylinders	i : Dust Sparator
b : Compressor	j : Out Pipe Dust Sparator
c : Compressor Hose	k : Pipe in (Gas) Condensor
d : Regulator Hose	l : Pipe in (Water) Condensor
e : Stove	m : Condensor
f : Burning Container	n : Spiral Pipe
g : Reactor Cylinders	o : Pipe Out (Bio Oil)
h : Reactor Tube Out Pipe	p : Pipe Out (Water)

Fig. 4. Pyrolysis scheme

The working system of pyrolysis technology involves several main stages that work sequentially to convert organic materials into products that have added value. The process begins with the collection of raw materials in the form of used paper and biomass from the Kerai Payung tree, which is then put into the reactor tube (I). In the reactor, the temperature is heated to reach the highest temperature in anaerobic conditions or in a state without air. This heating causes thermal decomposition of organic materials, which are then forwarded to the Dust Separator (II) and turned into liquid smoke. While biochar and ash are obtained in the reactor tube. The time used for the pyrolysis process was 90 minutes. The heating system in the pyrolysis technology uses a heating system from a gas stove connected to an LPG gas cylinder. In addition to using LPG gas to help push the heat evenly in the reactor tube, a compressor is also used. The pyrolysis process of each component will be explained below:

Pyrolysis System Each Component

a. Reactor Tube (Reactor)

The reactor tube is the main component in the pyrolysis system, which functions as a place where combustion or the pyrolysis process occurs. The reactor tube has a crucial role in ensuring the success and efficiency of the pyrolysis process. The material used for the reactor tube is heat-resistant steel coated with refractory bricks and cement. Refractory bricks and cement are considered to be able to help retain the heat in the reactor tube, and refractory bricks can also distribute the heat in the tube. The reactor tube is also coated with paint to prevent rust and corrosion, paint can form a layer that prevents direct contact between iron and environmental factors such as water, air, and chemicals. This reduces the risk of corrosion (rust), which occurs due to the oxidation reaction of iron with oxygen and moisture. Inside the reactor tube is also equipped with a container for combustion (sand) which is useful as a container for charcoal and raw materials to be burned. The order of arrangement in the reactor tube, at the very bottom, is charcoal, which is used as a combustion medium, then above the charcoal, there is a nest as a place to burn biomass. The volume of biomass that can be accommodated in the reactor tube is 420 g (Data from the Manufacturing Process Laboratory, Wisnuwardhana University). During the pyrolysis process in the reactor tube, thermal decomposition of raw materials occurs to produce gas and charcoal. In the pyrolysis process, pressure regulation is carried out using a tap connected to the compressor and gas cylinder, the purpose of pressure regulation is to ensure efficiency and safety during the pyrolysis process. In the pyrolysis process of biomass and waste paper, the temperature in the reactor tube has different variations and tends to decrease at each time interval. Figure 5 shows the temperature measured in the reactor tube with an interval of 18 minutes, the temperature is measured with a thermocouple thermometer to determine the temperature in the reactor tube. From the results of temperature measurements, it was found that the temperature in the reactor tube during the pyrolysis process tended to decrease, and the highest temperature did not reach the ideal number for the pyrolysis process. According to [13], [14], pyrolysis is a thermal decomposition process of organic materials at a temperature of 350 - 550 °C. The reactor tube lacks a temperature controller, causing a temperature drop inside. Only the gas pressure entering the reactor can be regulated. Additionally, the tube is minimally coated with cement and refractory stone, and the combustion medium—charcoal—depletes over time. As a result, the combustion flame cannot be evenly distributed within the reactor.

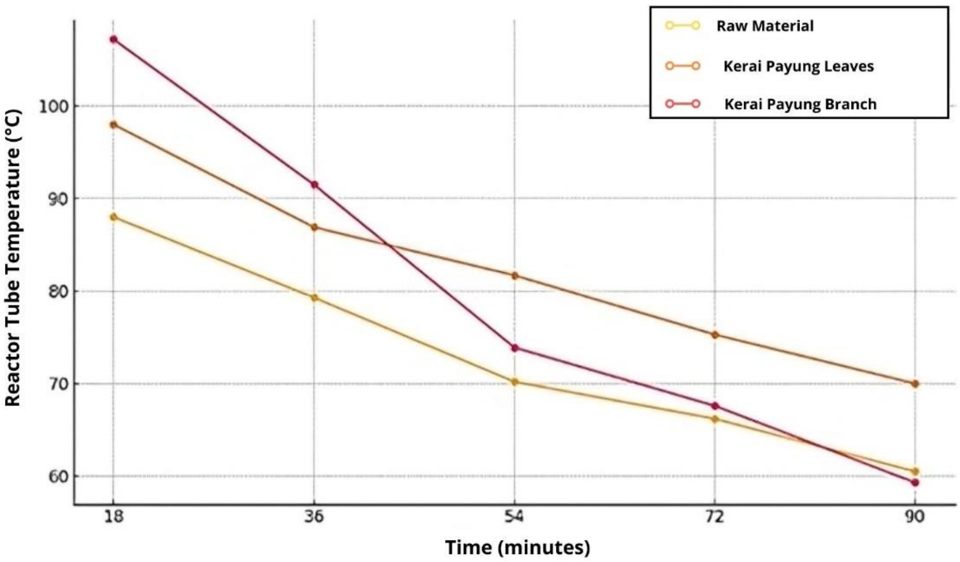


Fig. 5. Temperature line diagram of the reactor

b. Dust Separator

In the dust separator, pyrolysis gas carrying dust particles enters at high speed into a cone-shaped chamber. The centrifugal force generated by the gas flow forces the solid particles to move to the outer wall of the dust separator and down to the bottom to be collected, while the cleaner gas exits from the top. In the dust separator, the product that should be produced is ash particles carried by the smoke from combustion in the reactor, the main function of the dust separator is to separate the ash carried by the 1smoke so that when it enters the condenser, the clean smoke does not contain any ash at all. In reality, the dust separator produces liquid smoke because the smoke from the reactor tube lacks sufficient heat pressure to reach the condenser. As a result, the smoke becomes trapped in the dust separator, mixing with dust on its walls before condensing into liquid smoke. The results of the temperature measurements are presented in the form of a line diagram, which can be seen in Figure 6.

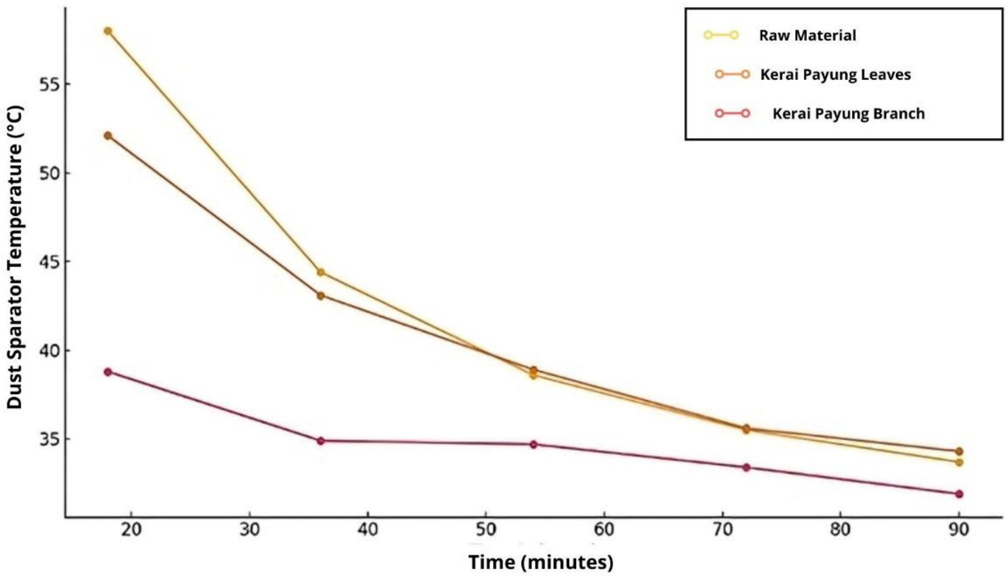


Fig. 6. Temperature line diagram on dust separator

Based on Figure 6, the temperature in the dust separator can be seen. The temperature in the dust separator tends to be low, so the presence of liquid smoke in the dust separator is caused by the low temperature, which causes a lack of heat pressure to carry the smoke up to the condenser.

2. Comparison of Pyrolysis and Conventional Combustion Results

Visually, conventional combustion is considered to cause air pollution that is detrimental to the surrounding community. With these problems, pyrolysis can be used as an alternative for environmentally friendly waste processing. The results of pyrolysis and conventional combustion that have been collected are then analyzed by comparing pyrolysis combustion with conventional combustion. Figure 7 shows a comparison of the results between pyrolysis combustion and conventional combustion.

Based on the results of data collection from pyrolysis combustion and conventional combustion, several differences were found. The amount of biochar from the pyrolysis process of used paper was 76 g, then the biochar results from the pyrolysis of Kerai Payung leaves were 250 g, and the biochar results from the pyrolysis process of twigs were 26 g. Then the ash results from the pyrolysis of used paper were 23 g, then the ash results from the pyrolysis of Kerai Payung leaves were 49 g, and the ash results from the pyrolysis of twigs were 23 g. The results of liquid smoke in the pyrolysis process of used paper were 75 mL (77 g), Kerai Payung leaves were 50 mL (49 g) and branches were 10 mL (6 g). While in conventional combustion, the biochar produced from used paper was 5 g, Kerai Payung leaves were 24 g and Kerai Payung branches were 7 g. The ash results in the conventional combustion process for used paper were 135 g, Kerai Payung leaves were 22 g, and Kerai Payung ranches were 41 g. The most visible difference is in the liquid smoke, conventional combustion does not produce liquid smoke because the smoke from conventional combustion is not contained in a closed room and spreads into the atmosphere, causing air pollution. Then it can be seen that the results of the pyrolysis process biochar are more, namely a total of 352 g from 3 raw materials processed compared to the results of biochar in the conventional process which if totaled is only 36 g, and vice versa in conventional combustion the ash results are more with a total of 198 g compared to the ash results in pyrolysis which is a total of only 35 g, this is because pyrolysis is carried out in conditions of minimal or no oxygen (anaerobic), so that organic material does not burn completely. Instead, it undergoes thermal decomposition, producing biochar as the main product. In conventional combustion, the material is fully oxidized due to excess oxygen, so that most of the organic material burns to ash.

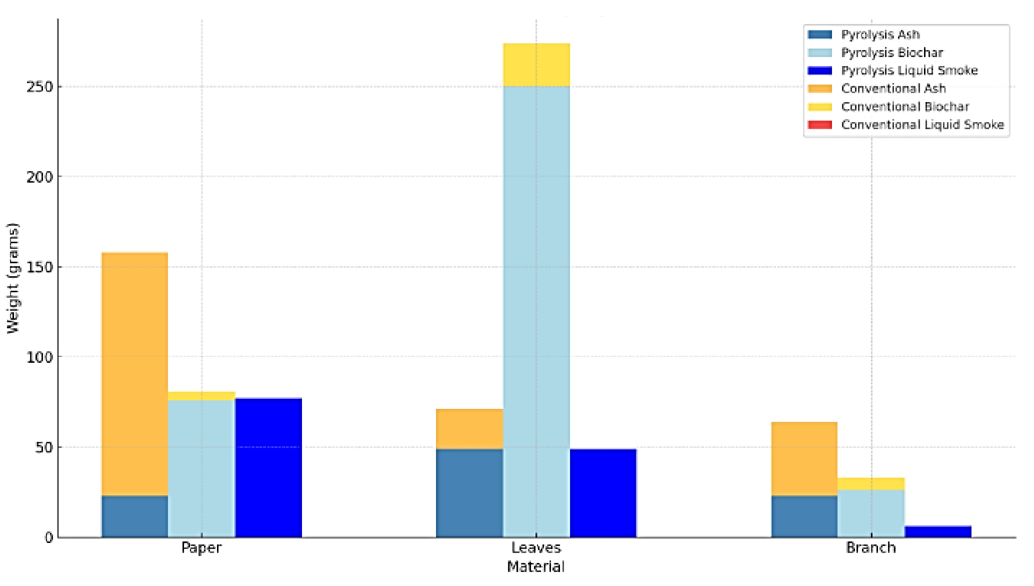


Fig.7. Bar chart comparison of pyrolysis results with conventional combustion results

Pyrolysis products can be utilized for various purposes. Liquid smoke from pyrolysis combustion has benefits as a food preservative and biopesticide. The type of biomass and the concentration of liquid smoke play an important role in determining the sensitivity and inhibition of antibacterial activity [15]. Grade 3 liquid smoke is used in rubber processing and wood preservatives to make them resistant to termites, grade 2 liquid smoke is intended as a food preservative with a smoked taste, and grade 1 liquid smoke is used as a food preservative with the best quality [16], [17]. Biomass originating from agricultural and plantation waste can be utilized optimally in the form of charcoal briquettes, thereby reducing environmental pollution [18]. Furthermore, biochar can be utilized as a wastewater filter. According to [19], the addition of biochar has a more significant positive effect on removing suspended solid particles from water compared to dissolved solids. Biochar has been widely used in sustainable agricultural production systems due to its various advantages, such as increasing soil porosity and reducing soil mass density, high recalcitrant carbon content that supports soil carbon sequestration, high cation exchange capacity that can contribute to reducing N leaching, increasing soil fertility and crop yields [20]-[22]. This biomass is pyrolyzed to form stable solid products and returned to the soil for long-term storage [23], [24]. It has been shown that the carbon content of biochar is stably stored in the soil after 100 years [25], [24]. Silica contained in wood ash, which is in crystalline form, does not have pozzolanic properties to react during cement hydration [26]-[28]. Increased compressive strength in self-compacting concrete by using fly ash from the combustion of olive agricultural residue pellets to replace limestone filler [29], [28]. Other studies investigating cement substitution with fly ash showed an increase in the viscosity and yield stress of cement paste [28], [30], [31].

The pyrolysis process is considered to have several significant advantages compared to the composting process, making it an attractive method for organic waste processing. First, pyrolysis is a thermochemical process that takes place in conditions with no or minimal oxygen, with a relatively short reaction time, taking only a few hours to decompose organic matter. In contrast, composting is a biological process that relies on the activity of microorganisms and takes weeks to months to break down organic matter naturally. This time efficiency makes pyrolysis more suitable for large-scale waste processing needs or in situations that require rapid handling. Second, pyrolysis produces a variety of useful products, such as biochar, pyrolysis liquid (including liquid smoke), and ash. These products have wide applications. Biochar, for example, can be used as a soil improver because of its ability to increase water and nutrient retention, as well as store carbon for the long term. Pyrolysis liquid can be used as fuel or further processed for various industrial purposes. Meanwhile, the resulting ash can be used in the manufacture of fertilizers or construction materials. In contrast, composting generally only produces compost, which although useful as an organic fertilizer, has relatively limited applications. Third, pyrolysis has the ability to process various types of organic waste, including waste that is difficult to decompose through composting. Examples include wood, leaves with high fiber, or other biomass waste that has a solid structure and is resistant to microbial decomposition. This makes pyrolysis more flexible and can handle waste with more diverse characteristics, making it more suitable for complex waste treatment scenarios.

3. Limitation

Several important things that need to be considered to understand the scope and limitations of the results obtained. First, this study only focuses on waste processing in the campus environment using the pyrolysis process. Although this method is effective for processing certain waste, the research has not included an in-depth analysis of the chemical content or molecular structure of the pyrolysis results, such as biochar, ash, and liquid smoke. This analysis is important to determine the potential for further application of pyrolysis products, such as for improving soil quality, alternative fuels, or other uses. Second, the pyrolysis unit used has not met the optimal standards to produce maximum results. For example, the reactor tube used is not equipped with a pressure regulator that can increase the temperature in a controlled manner. This condition can affect the efficiency of the pyrolysis process and the quality of the products produced, so the results may not reflect the full potential of the pyrolysis method if carried out with more sophisticated equipment, in addition, the capacity of the pyrolysis unit used is limited to a small scale so that capacity needs to be increased so that it can be used on a large scale. Third, the type of waste used is limited only to biomass from Kerai Payung trees and used paper. These limitations make it difficult to generalize the results to other types of waste, such as agricultural waste, organic household waste, or industrial waste. As a result, the benefits and flexibility of the pyrolysis method in handling various types of waste cannot be concluded comprehensively. Fourth, the study did not include an environmental impact analysis of the application of the pyrolysis method. In fact, evaluation of exhaust emissions, potential environmental pollution, or contribution to overall waste reduction are very important to ensure the sustainability of this method. Without such an analysis, it is difficult to determine whether this pyrolysis method is truly environmentally friendly and feasible for widespread application. These limitations indicate that further research with a wider scope, both in terms of tools, materials, and impact analysis, is needed to strengthen the results and provide more significant benefits.

IV. Conclusions

Combustion with the pyrolysis process occurs in limited air spaces. Pyrolysis relies on charcoal as a combustion medium, which leads to uncontrolled temperatures that decrease over time as the charcoal depletes. The pyrolysis unit has three main components: the condenser, which generates liquid smoke; the dust separator, which filters dust from the smoke before it enters the condenser; and the condenser itself, which produces liquid smoke. Pyrolysis produced biochar, ash, and liquid smoke. From used paper, Kerai Payung leaf tree, and Kerai Payung branch, biochar yields were 76 g, 250 g, and 26 g; ash yields were 23 g, 49 g, and 23 g; and liquid smoke yields were 75 mL, 50 mL, and 10 mL, respectively. Pyrolysis products have various uses. Liquid smoke can preserve food, act as a biopesticide, and protect wood. Biochar aids in wastewater treatment and improves soil fertility, while wood ash and fly ash enhance concrete and serve as cement substitutes. Compared to composting, pyrolysis is faster and produces versatile by-products. Limitations of this study include a focus on campus waste without analyzing the chemical composition of pyrolysis results, suboptimal pyrolysis units, limited types of waste studied, and no environmental impact analysis. Recommendations for future research include analyzing the chemical composition of pyrolysis results, improving pyrolysis units with pressure regulators, expanding waste types studied, and conducting environmental and economic feasibility analyzes to scale the technology.

Acknowledgement

The authors would like to thank the "Laboratory of Manufacturing Process" Wisnuwardhana University Malang Indonesia for supporting the experimental works.

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