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Potential of Woody Biomass from River Debris for Thermal Process Fuel

Potensial Biomassa Kayu dari Sampah Sungai sebagai Bahan Bakar Proses Termal

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ABSTRAK

Sampah perairan di Tempat Penampungan Sementara (TPS) Jakarta memberikan beban polusi yang signifikan akibat aktivitas manusia. Pemulihan energi menyajikan peluang untuk mendapatkan nilai dari puing-puing ini dan mencapai solusi limbah nol. Di antara komponen limbah di TPS Perintis, puing kayu dari puing-puing sungai di Jakarta mendominasi. Penelitian ini bertujuan untuk memproses puing kayu melalui proses termal di TPS Perintis. Penelitian ini menggunakan analisis hitungan beban di TPS Perintis dan melakukan pengujian laboratorium, termasuk analisis kadar air, analisis kadar abu, penentuan nilai kalor, dan *thermal gravimetric analysis* (TGA). Generasi harian sampah perairan di TPS Perintis rata-rata mencapai 7,164 m^3/hari atau 5,2 ton/hari, dengan puing kayu menyumbang 62,8% dari total. Puing kayu menunjukkan potensi pemulihan energi tertinggi di antara komponen limbah, dengan nilai kalor sebesar 16,43 kWh/kg atau 54.123,38 kWh/hari. Hasil uji TGA menunjukkan bahwa puing kayu dapat digunakan sebagai arang, dengan dekomposisi terjadi pada rentang suhu 200–500°C dan hasil sisa sebesar 14%. Temuan ini menyoroti kelayakan pemulihan energi dari puing kayu di TPS Perintis dan potensi untuk mengubahnya menjadi arang. Kesimpulan penelitian ini menekankan pentingnya penggunaan proses termal dalam mengelola puing-puing sungai, menyediakan solusi berkelanjutan untuk pengelolaan limbah dan pelestarian lingkungan.

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ABSTRACT

River debris at the Waste Temporary Shelter (TPS) Perintis Jakarta poses a significant pollution load resulting from human activities. Energy recovery presents an opportunity to derive value from this debris and achieve a zero-waste solution. Among the waste components at TPS Perintis, wood debris from river debris in Jakarta is predominant. This study aimed to process the wood debris through a thermal process at TPS Perintis. The research employed load count analysis at TPS Perintis and conducted laboratory testing, including moisture content analysis, ash content analysis, calorific value determination, and thermal gravimetric analysis (TGA). The daily generation of river debris at TPS Perintis averaged 7.164 m^3/day or 5.2 tons/day, with wood debris accounting for 62.8% of the total. Wood debris exhibited the highest potential for energy recovery among the waste components, with a calorific value of 16.43 kWh/kg or 54,123.38 kWh/day. The TGA test results indicated that wood debris could be utilized as charcoal, with decomposition occurring within the temperature range of 200–500°C and a residue yield of 14%. These findings highlight the feasibility of energy recovery from wood debris at TPS Perintis and the potential for its conversion into charcoal. The study's conclusions emphasize the significance of utilizing thermal processes for managing river debris, providing a sustainable solution for waste management and environmental conservation.

1. INTRODUCTION

1.1 Background

The coastal area is a transitional area between land and sea, where the characteristics of land and sea still influence each other. Jakarta City has large resource potential and beautiful environmental services and areas with big problems, including pollution (Martinez & Masron, 2020; Suryawan & Lee, 2023a). Pollution reduces the quality of the environment to be damaged and interferes with the survival of related resources, one of which is marine debris (Clayton et al., 2021). The problem of waste in the Indonesian seas can involve several factors, such as culture and government policies (Ain et al., 2021; Suhardono et al., 2023). The culture of the of people who are not all aware of environmental sustainability will throw garbage carelessly (Sewak et al., 2021, Suryawan & Lee, 2023b). Throwing trash directly into the river has detrimental consequences, as it pollutes the river water with waste that subsequently flows into the sea. (Verster & Bouwman, 2020).

Woody debris is commonly found along river-dominated margins, but it constitutes a relatively small portion of the sediment on the inner shelf in marine habitats. (Charles et al., 2022, 2014; Rabouille et al., 2008; Tesi et al., 2008). Serious challenges come from the problem of wastewater treatment and waste management, both of which can impact environmental damage, decrease aesthetics, and reduce comfort and health (Kerber & Kramm, 2022). The rate of waste generation from accommodation and eating places in tourist areas is increasing rapidly, which causes an increase in disease vectors, such as flies and rats. Marine debris in the sea can come from several waste factors, such as plastic waste, wood waste, metal waste, waste from organic materials, and a lot of other waste that can pollute the sea (Chen et al., 2019; Hayati et al., 2020).

Microbes can decompose organic matter, but each type of material has a different level of ease of decomposition. For example, newsprint, hemicellulose, and carbohydrates are easily degraded. On the other hand, wrapping paper, bamboo, fat, and protein is rather challenging to degrade. Meanwhile, wood, lignin, and plastic are almost wholly not degraded. The main advantage of hydrothermal technology is that processing municipal organic waste does not require a sorting or drying process. During the hydrothermal process, biomass is converted into a solid carbon product, bio briquettes, which can be used for various applications. Biobriquettes are an alternative to fossil fuels (Lucian & Fiori, 2017).

Hydrothermal treatment leads to a thermo-chemical process for decomposing materials containing charcoal, such as coal and biomass, with water under high temperature and pressure conditions (Khan et al., 2019; Kumar, 2022; Oktaviananda et al., 2017). The hydrothermal treatment temperature is lower with 200–230ºC for hydrothermal processes (Wang et al., 2021) than 250–550ºC for pyrolysis (Duarte et al., 2017) and 900–1200ºC for gasification (Korotkikh et al., 2016). In addition, biomass conversion occurs in a humid environment, so the moisture content of the feedstock is not a problem. For this reason, the hydrothermal method is suitable for treating biomass containing high water content of more than 50% wt water in fresh conditions (Oktaviananda et al., 2017).

One specific area of concern is the deposition of woody debris in marine habitats. Although woody debris is commonly observed along river-dominated margins, its presence, and effects on inner shelf sediments in marine environments still needed to be better understood. Addressing this knowledge gap is essential for comprehending the extent of ocean pollution and developing effective mitigation strategies. The motivation behind this research stems from the need to examine the novel aspects of woody debris deposition in marine ecosystems. While previous studies have focused on other types of marine pollutants, the specific contribution of woody debris to inner shelf sediments has received limited attention. Therefore, this research aims to explore the unique characteristics and implications of woody debris deposition, shedding light on its ecological significance and potential consequences for marine life. By providing a detailed analysis of this understudied aspect, this research seeks to contribute to the broader understanding of ocean pollution and foster innovative approaches to mitigate its impacts.

1.2 Objective

Proper handling of river debris is crucial in developing comprehensive waste management systems, including those for coastal tourism. Understanding the characteristics of wood debris is essential for designing appropriate processing methods, such as converting it into Refuse-Derived Fuel (RDF) pellets. Considering the significance of this topic, this study aims to investigate the properties of wood debris for potential RDF pellet production. The primary objective of this research is to determine the specific characteristics of wood debris that make it suitable for processing into RDF pellets. By analyzing the composition, moisture content, calorific value, and other relevant parameters, valuable insights can be gained regarding the potential energy recovery and waste management opportunities associated with wood debris. The findings of this study will contribute to the development of sustainable waste management systems, particularly in coastal tourism areas, where effective handling of river debris is crucial for environmental preservation.

2. METHOD

2.1 Location

The composition of wood debris is of particular interest for waste management systems, especially in the context of TPS Perintis, Jakarta (Figure 1). The measurement of waste generation and density plays a crucial role in understanding the composition of wood debris at this location. The load count analysis method is employed to assess the composition by measuring the total weight (w/w) of waste entering TPS Perintis. This information is essential for developing effective waste management strategies and identifying the potential for energy recovery or other forms of utilization. Accurate measurements of waste generation and density allow for a comprehensive understanding of the wood debris composition at TPS Perintis, facilitating informed decision-making and the implementation of sustainable waste management practices.

Figure 1. Research location at TPS Perintis, Jakarta

2.2 Data Collection

Data collection was carried out for eight days (from 15–22 January 2019) as stated in SNI 19-3964-1994 regarding sampling and measuring the composition of waste generation TPS Perintis. Understanding the waste composition generated at TPS Perintis allows for effective waste management planning. By knowing the types and quantities of waste components, appropriate strategies can be developed to handle, treat, and dispose of the waste efficiently and environmentally friendly. Knowledge of waste composition helps determine the resources required for waste management. It enables allocating personnel, equipment, and infrastructure based on the types of waste generated. This ensures that resources are utilized optimally, leading to improved waste management practices. Determining the composition of waste can unveil opportunities for recycling and recovery of valuable resources. Spesific waste components may be suitable for recycling, reusing, or transforming into energy sources such as, RDF (Refuse-Derived Fuel) pellets. Understanding the composition allows for identifying and implementing appropriate recycling and recovery methods, contributing to a more sustainable waste management system.

Measurement of water content through a drying process with the help of a tool in the form of an oven with a temperature of 105°C. The analytical method used in measuring water content is ASTM D.3173 Water content in RDF. The total residue from the combustion of RDF is also known as ash. Silica compounds contained in the ash can reduce the heating value of RDF (Putri & Sukandar, 2013). Calculation of the ash content of RDF using the ASTM D.3174 standard. Detailed proximate analysis can be used with the Thermogravimetric Analyzer (TGA 701) ASTM D 7582-10. The study includes inherent moisture, fixed carbon, ash, and volatile matter. The calorific value of fuel is the maximum amount of heat energy released by a fuel through a complete combustion reaction per unit mass or volume. Therefore, analysis of the calorific value of a fuel is intended to obtain data on the heat energy that fuel can liberate by the occurrence of a reaction or combustion process (Table 1).

3. RESULT AND DISCUSSION

3.1 Debris Generation and Composition

River debris generation at TPS Perintis for seven days had an average value of 7.164 m^3/day or 5.2 tons/day (Figure 2). People use rivers for garbage disposal. Several reasons cause residents to throw garbage into the river. First, throwing garbage into the river is considered more practical and accessible (Kaur et al., 2018; Knickmeyer, 2020; Kumar and Bharadvaja, 2019). The lack of facilities for throwing garbage around the river has become a culture (Michiani & Asano, 2019).

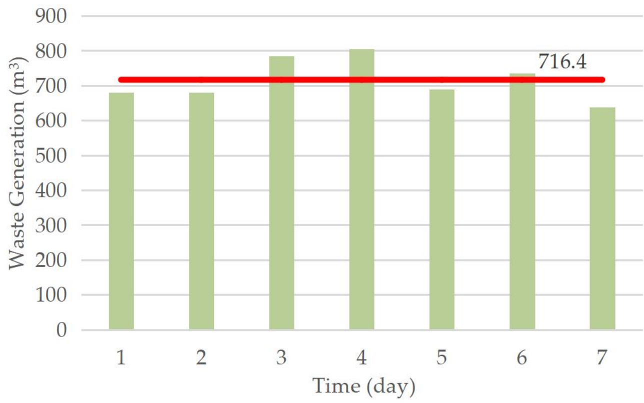

Figure 2. Measurement Results of River Debris Generation at TPS Perintis, Jakarta

Table 1. RDF characterization method

Parameter	Standard	Explanation
Calorific Value	ASTM D5865-13	This standard specifies the test method for determining the gross calorific value of solid fuels using the bomb calorimeter method.
Water Content	ASTM D.3173	This standard provides a test method for determining the moisture content of solid fuels by the air-oven drying method.
Ash Content	ASTM D.3174	This standard describes the test method for determining the ash content of solid fuels, including RDF, through a gravimetric procedure.
Thermogravimetric Analyzer (TGA 701)	ASTM D 7582-10	The ASTM standard ASTM D7582-10 provides a test method for determining the weight percent volatile content, fixed carbon content, and ash content of solid fuels using a thermogravimetric analyzer (TGA). This standard can be used to analyze RDF samples' thermal decomposition and behavior.

There are two main types of waste, namely, biodegradable and non-biodegradable. Waste made from natural materials, such as food waste, is biodegradable (Velvizhi et al., 2020). This means that rain and animals, such as worms, can destroy the species. On the other hand, non-biodegradable waste is made of synthetic materials that take longer to decompose. Based on the observations, the waste found in the TPS Perintis is difficult to decompose, and it consists of four main components: wood, plastic, metal, and styrofoam, with proportions of 62.8%, 33.5%, 0.6%, and 3.1%, respectively (as shown in Figure 3). Another crucial element that affects the weight is the type of marine debris. In the Bali study (Suteja et al., 2021), they discovered that, despite their low abundances (2.3% for glass and 7.8% for wood), the glass and wood categories considerably contributed to the weight of marine debris. According to the findings of another study conducted on 17 beaches in Admiralty Bay in Antarctica, particles of processed wood were the most prevalent type of marine debris throughout the coastline (47.3%) (Anfuso et al., 2020). The lumber likely came from research and exploration facilities (both historical and industrial), as well as vessels that had been abandoned (Sander et al., 2009). According to the findings of Honorato-Zimmer et al., (2019), the differences in the predominant types of marine debris found on the beach are directly related to the activities in the area.

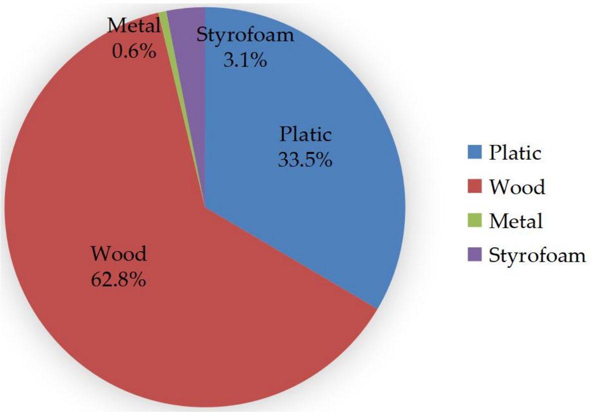

Figure 3. Results of River Debris Composition Measurements at TPS Perintis, Jakarta

The generation of wood debris at TPS Perintis is significant, with a daily production rate of 3,294.18 kg/day. This indicates a substantial amount of wood debris being deposited at the site daily. Moreover, wood debris constitutes a considerable proportion of the overall waste composition at TPS Perintis, accounting for approximately 62.8%. This high percentage highlights the dominance of wood debris compared to other waste components in the area. Understanding wood debris's generation rate and composition is crucial for waste management planning and decision-making processes. It emphasizes the need to develop specific strategies for handling, processing, and potentially utilizing this substantial amount of wood debris. Effective wood debris management can reduce pollution, promote resource recovery, and implement sustainable waste management practices in TPS Perintis and similar environments.

3.2 Energy Recovery Potential

Energy is the primary sector in the Indonesian economy today and will take on a more significant role in the future (Maulidia et al., 2019), providing foreign exchange, absorbing labor, preserving energy resources, national development, and regional development. The energy situation in Indonesia is inseparable from the world energy situation (Dwipayana et al., 2021). The increasing world energy consumption creates an opportunity for Indonesia to look for alternative energy sources to meet its needs (Sharvini et al., 2018). For this reason, it is necessary to identify which waste composition can be utilized as an energy resource. Our findings show that the most potential waste is wood debris (Table 2).

To calculate the potential energy recovery from wood debris, you would need to multiply the waste generation rate of wood debris by its calorific value. The formula is as follows:

Potential Energy Recovery =
Waste Generation Rate of Wood Debris x Calorific Value of Wood Debris………………………………………………. (1)

For example, the waste generation rate of wood debris at TPS Perintis is 3,294.18 kg/day, and the calorific value of wood debris is 16.43 kWh/kg.

Potential Energy Recovery =
3,294.18 kg/day x 16.43 kWh/kg ………………..………...(2)

Table 2. Results of River Debris Characterization and Energy Recovery Opportunities for Each Component

Waste Composition	Waste Generation (kg/day)	Water Content (%)	Ash Content (%)	Caloric Value (kWh/kg)	Potential Energy Recovery (kWh/day)
Plastic	1,757.89	2.14	4.42	22.45	39,464.63
Wood	3,294.18	3.37	7.21	16.43	54,123.38
Metal	33.45	0.00	100.00	0.00	0.00
Styrofoam	162.39	2.35	3.41	19.53	3,171.48

To calculate the potential energy recovery, multiply the waste generation rate of wood debris by its calorific value. The result will give you the daily energy value in kilowatt-hours (kWh). Regarding the relationship to other river debris components, such as plastic, metal, and styrofoam, the calculation of potential energy recovery would follow the same principle. We need to determine the waste generation rate of each respective component and its corresponding calorific value. Applying the formula mentioned above, you can calculate the potential energy recovery for each component separately. This approach allows for comparing the energy potential among different types of river debris. It provides insights into which waste component has the highest energy recovery potential and helps prioritize resource allocation and waste management strategies accordingly. Biomass comprises hemicellulose, cellulose, and lignin (Chen et al., 2018). Wood has ash content usually less than 1% (Pettersen, 1984). Another advantage of biomass is its low-cost technology than other energy sources (Suryawan et al., 2022; Yan et al., 2020; Zahra et al., 2022). This condition can occur because the amount is very abundant and is generally a waste from a community activity. However, with a calorific of 16.43 kWh/kg, the energy it contains still has very potential to be utilized, especially to generate heat energy.

3.3 Thermal Gravimetry Process

Plant biomass, a composite material primarily comprised of hemicellulose, cellulose, and lignin, is an ideal renewable resource for generating heat and power via thermochemical processes such as fixed bed gasification (Burhenne et al., 2013). This is because plant biomass is a material that is predominantly comprised of these three components (Yang et al., 2006). The availability of biomass feedstock for the thermochemical conversion processes is becoming increasingly limited, particularly in areas with a high population density like Jakarta. This is especially the case in regions with a high demand for bioenergy and biomaterials, both of which require increasing amounts of biomass (Burhenne et al., 2013). The primary components of wood biomass are hemicellulose (24%), cellulose (35–55%), and lignin (10–25%) (Nanda et al., 2013). The decomposition of hemicellulose and the release of various volatiles, while the cellulose and lignin fractions remain almost unaffected (Acharya & Dutta, 2016).

The carbonization process with TGA shows a process of heating organic waste at specific temperatures with a limited air supply. The carbonization process is carried out to release some organic chemicals and leave a residue consisting of pure carbon. Only water content is released at a temperature of 50–150˚C (Sari et al., 2022; Sarwono et al., 2021; Shehap et al., 2014). It can be seen in Figure 4 that the decrease in water content is only 0.21%. This is certainly different from the proximate results because the waste is entered based on the dry weight in the TGA test. At a temperature of 200–500ºC, a carbonization process begins, namely decomposition or partial decomposition of wood debris. At a temperature of 250ºC, the water contained in the raw material comes out into steam, so the writing process takes time quickly. The color of the charcoal produced is shiny black, and the charcoal becomes like coal powder after being pulverized.

4. CONCLUSION

The TPS Perintis produces river debris an average of 7.164 m^3/day or 5.2 tons/day. Of all these out, 62.8% were wood flotsam and jetsam. In recovery, the potential energy recovery of wood debris has the highest chance compared to other waste components at the TPS Perintis, which is 16.43 kWh/kg or 54.123.38 kWh/day. The TGA test results show that wood debris also could be made into charcoal. Where the decomposition of wood debris occurs at 200–500°C with a residue yield of 14%. This study highlights the significance of wood debris in the waste composition at TPS Perintis. The research identifies the high potential for energy recovery from wood debris and its suitability for conversion into charcoal. These findings provide valuable insights for waste management strategies, emphasizing the importance of considering wood debris as a valuable resource for sustainable waste management practices and potential utilization opportunities.

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