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Research Paper

The Influence of Carbonization Temperature Variations on the Quality of Durian Peel-Based Bio-briquettes

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ABSTRACT: *The increasing global energy demand and environmental concerns necessitate the development of alternative energy sources. Durian peel, an abundant agricultural waste in Indonesia, presents significant potential for bio-briquette production due to its high cellulose and lignin content. This study investigates the effect of carbonization temperature on the quality of durian peel-based bio-briquettes. Carbonization was conducted at 300°C, 400°C, 500°C, and 600°C, with proximate analysis and calorific value determination performed according to SNI 01-6235-2000 standards. The results demonstrate that higher carbonization temperatures reduce moisture and volatile matter while increasing fixed carbon and calorific value. At 500°C, the bio-briquettes exhibited optimal properties, including moisture content (7.47%), volatile matter (13.54%), and a calorific value exceeding 5000 cal/g, meeting the SNI standard. However, ash content at this temperature (9.33%) slightly exceeded the standard (≤8%), highlighting a trade-off between energy efficiency and residual minerals. This study concludes that 500°C is the optimal carbonization temperature for producing high-quality bio-briquettes from durian peel, balancing energy output and combustion efficiency. Further optimization of the process is recommended to enhance fixed carbon content and minimize ash. These findings contribute to sustainable energy practices by transforming agricultural waste into a renewable energy resource, addressing both waste management and energy challenges.*

Keywords: *Durian peel, Biobriquettes, Carbonization, Calorific value, Sustainable energy*

1. INTRODUCTION

The escalating global energy demand, projected to grow by 1.6% annually until 2030, underscores the urgent need for sustainable energy solutions [1]. Overreliance on fossil fuels not only threatens resource depletion but also exacerbates environmental challenges such as climate change and air pollution [2]. Given these critical issues, the pursuit of alternative energy sources has emerged as a global priority. Among various options, biomass energy stands out as a promising solution due to its dual benefits. It is renewable, ensuring a sustainable supply, and addresses waste management challenges by converting organic waste materials into energy [3]. Unlike fossil fuels, biomass energy produces significantly lower carbon emissions, making it an environmentally friendly choice. The integration of biomass energy into the global energy portfolio not only diversifies energy sources but also promotes energy security and sustainability [4]. Among the various biomass materials, durian peel stands out as a high-potential resource due to its abundance

Durian, the fifth most-produced crop in Indonesia as of 2021, has 15–30% edible portions, while 50–60% of its weight is biomass waste, mainly consisting of peels and seeds [5]. East Java, producing an average of 131,000 tons annually, is a major contributor to this waste, which, if unmanaged, can cause environmental issues such as increased solid waste and unpleasant odors. Durian peel waste is rich in cellulose (50–60%) and contains around 5% lignin, making it a promising biomass material for energy conversion. It holds significant

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potential for transformation into biobriquettes with a calorific value of approximately 5189.128 cal/g [6]. This utilization not only addresses waste management issues but also contributes to sustainable energy production, offering a practical solution to environmental and energy challenges. The conversion of durian peel into biobriquettes not only helps in reducing waste but also contributes to sustainable energy practices by offering a renewable fuel source that can replace fossil fuel [7].

Biobriquettes derived from biomass waste have proven to be an efficient and environmentally friendly energy source [8]. Carbonization plays a crucial role in the production of high-quality biobriquettes. By heating biomass material to high temperatures in the absence of oxygen, carbonization causes chemical changes that reduce moisture and volatile components while concentrating the carbon content. This process not only increases the calorific value of the material but also improves its combustion efficiency. The carbonization process significantly influences the quality of the resulting briquettes [9]. A study by Saragih et al. resulted the optimum carbonization temperatures, ranging from 350-400 °C, produce briquettes with a high heating value of 5,605.75 cal/g and a low moisture content of 6.29%, making them highly efficient as a fuel source [10]. Bio-briquettes derived from biomass waste have proven to be an efficient and environmentally friendly energy source. During carbonization, the biomass undergoes chemical and physical transformations that significantly improve its fuel quality. Specifically, carbonization reduces the moisture content, volatile matter, and oxygen content while increasing the fixed carbon content [11].

The impact of temperature on carbonization is profound, influencing both the physical and chemical properties of the resulting biochar or hydrochar. Fixed carbon content tends to increase at higher temperatures, up to 300 °C, as demonstrated in studies Ryu et al. on hydrochars derived from empty fruit bunches and animal manure [12]. Similarly, a study by Krysanova et al. the calorific value of carbonized materials improves with rising temperatures, such as bio-coal from peat, which increased in energy content from 20.2 to 28.03 MJ/kg as the temperature rose from 160 to 230 °C [13]. In terms of chemical composition, higher temperatures lead to a reduction in volatile matter, thereby increasing the stability and energy density of the biochar [14]. Additionally, elevated temperatures promote the formation of aromatic structures, enhancing the thermal stability of the carbonized products [15] [16]. This highlights the importance of optimizing carbonization temperatures to achieve the desired balance between fuel efficiency, stability, and environmental impact.

Therefore, finding the optimal temperature for carbonization is essential for producing high-quality, energy-efficient bio-briquettes. This study investigates the impact of carbonization temperature variations on the calorific value of bio-briquettes produced from durian peel. By analyzing the physical and chemical properties of bio-briquettes at different temperatures, this research aims to identify the optimal carbonization temperature that maximizes calorific value, enhances energy sustainability but also promotes waste utilization as a resource for renewable energy.

2. MATERIALS AND METHOD

2.1 Materials and equipment

Durian peels sourced from Wonosobo, East Java, were pre-treated by cleaning and drying to reduce moisture content to 16.35%. Additional materials included tapioca flour and aluminum foil. The equipment used in this study comprised a 60-mesh sieve, hydraulic press, analytical balance, drying oven, furnace, and bomb calorimeter. A pyrolysis reactor was utilized for thermal processing, while a bomb calorimeter was employed for calorific value analysis. Additional tools included cups and instruments for proximate analysis to evaluate sample composition.

2.2 Carbonization Process

Durian peels were carbonized in a cylindrical pyrolysis reactor at 300°C, 400°C, 500°C, and 600°C. The carbonization process was monitored to maintain consistent temperature and ensure complete thermal decomposition. The carbonization process was carried out using the pyrolysis method. Dried durian peels were placed in a cylindrical reactor with a drum-like structure measuring approximately 100 cm in height and 60 cm in diameter. The carbonization reactor is shown in Figure 1.

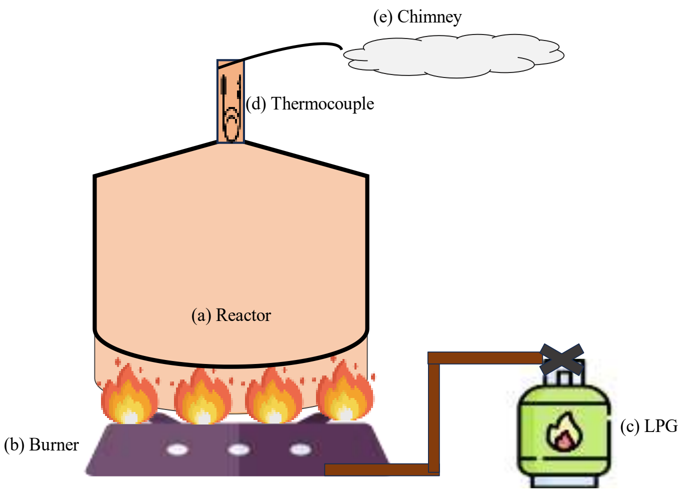

Figure 1. Pyrolysis reactor

The reactor consists of a charring chamber, a chimney, and a heating chamber at the bottom. The charring chamber indirectly combusts biomass using heat from sources such as a wood-fired furnace. The reactor is gradually heated to an initial temperature of 300°C using a controlled heat source, such as a gas or electric heater, to ensure uniform heat distribution. Once the temperature reaches 300℃, carbonization begins and is maintained for 2–3 hours, with the temperature monitored using a thermocouple.

Subsequently, the temperature is incrementally increased to 400°C, 500°C, and 600°C, with gradual adjustments to ensure the pyrolysis process remains optimal. After completing the carbonization process at the highest temperature (600°C), the reactor is slowly cooled in a sealed condition to prevent direct air contact, which could lead to oxidation.

2.3 Bio-briquette Production

The production process began with cooling the carbonized material from the pyrolysis reactor to room temperature to prevent oxidation. The material was then ground to a particle size of $\leq$ 2 mm and sieved using a 60-mesh sieve to ensure uniformity. The sieved material was mixed with a 10% tapioca binder by weight, using a mechanical mixer for homogeneity.

The mixture was molded into cylindrical briquettes (50 mm diameter, 20 mm height) using a hydraulic briquette press at 200 MPa pressure, ensuring structural integrity and low porosity. The molded briquettes were dried in an oven at 105°C for 24 hours to achieve moisture content < 8%, enhancing their calorific value and combustion properties. Finally, the dried briquettes were cooled and stored in sealed containers to maintain quality.

2.4 Analysis

Proximate analysis evaluates biomass quality by measuring moisture content (MC), volatile matter (VM), ash content (AC), and fixed carbon (FC**)** following SNI 01-6235-2000. The calorific value was determined using a bomb calorimeter.

MC: The sample is weighed, dried in an oven at 105°C until a constant weight is achieved, and reweighed.

$$MC\ (\%) = \frac{W_0 - W_1}{W_0} x100 \quad \text{..........................(1)}$$

Where :

W_0 = Initial weight of the sample (gram)

W_1 = Weight of the sample after drying (gram)

VM: The sample is heated at 950°C in the absence of oxygen for 7 minutes, and the loss in weight is measured

$$VM\ (\%) = \frac{W_0 - W_1}{W_0} x100 \quad (2)$$

Where :
W_0 = Weight of the dried sample (gram)
W_1 = Weight of the residue after heating at 950°C (gram)

AC: The sample is heated at 750°C until all combustible materials are burned off, leaving only ash.

$$AC\ (\%) = \frac{W_{ash}}{W_{dry}} x100 \quad (3)$$

Where :
W_{ash} = Weight of the ash residue (gram)
W_{dry} = Weight of the dried sample (gram)

FC: Solid combustible residue remaining after the removal of moisture, volatile matter, and ash

$$FC\ (\%) = 100 - (MC + VM + AC) \quad (4)$$

3. RESULTS AND DISCUSSION

3.1 Mass of Material After Carbonization

The purpose of carbonization in the production of durian peel-based bio-briquettes is to enhance energy content and improve the combustion properties of biomass. After carbonization at temperatures of 300°C, 400°C, 500°C, and 600°C, the weight of the material was measured, as shown in Figure 2.

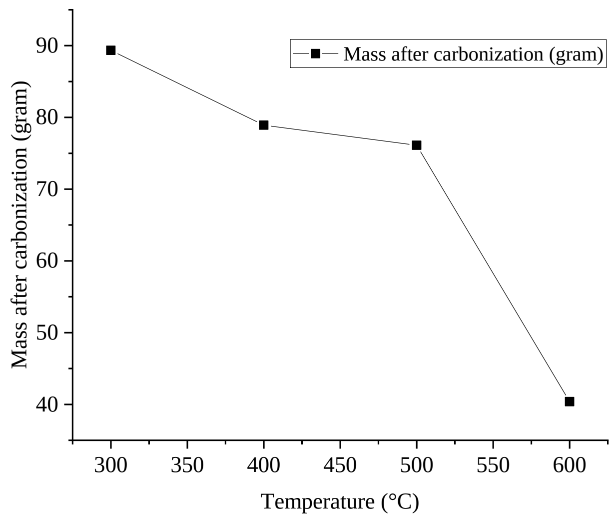

Figure 2. Effect of carbonization temperature on the mass of carbonized durian peel

The mass reduction observed in carbonized durian peel as the carbonization temperature increases highlights the significant role of thermal decomposition in biomass processing. At lower carbonization temperatures, such as 300°C, the remaining mass of the durian peel was approximately 89.34%, indicating minimal decomposition of biomass components. However, as the temperature increased to 400°C and 500°C, the mass decreased significantly, corresponding to 11.88% and 4.32%, respectively. The sharp decline observed between 500°C and 600°C, with the mass reducing from 76.11% to 40.39%, reflects the extensive loss of volatile compounds, primarily due to the breakdown of hemicellulose, cellulose, and partial lignin structures [17, 18].

These findings align with established principles of biomass pyrolysis, where temperatures above 400°C initiate the significant degradation of volatile organic compounds. Temperature range is critical for reducing volatile matter while enhancing fixed carbon content, making the resulting bio-briquettes more energy-dense and suitable for combustion applications [19]. Similarly, Cheng et al. [20] observed that fixed carbon content increases sharply between 500°C and 600°C due to the removal of moisture and volatile components, corroborating the results of this study.

In conclusion, the observed mass reduction between 500°C and 600°C underscores the importance of selecting appropriate carbonization temperatures to maximize bio-briquette quality. The findings indicate that this range facilitates the formation of a fixed carbon-rich structure, enhancing energy density while reducing volatile matter [21]. However, trade-offs, such as increased ash content, must be carefully managed to ensure efficient and sustainable bio-briquette production [2]. Further comparative studies across different biomass types and carbonization conditions will help refine these parameters, advancing the development of high-quality biofuels for diverse applications.

3.2 Proximate Analysis Results

Proximate analysis is a chemical analysis method used to identify the content of raw materials at a carbonization temperature of 500 °C. Table 1 presents the values of moisture content, volatile matter, ash content, and fixed carbon of durian peel Bio-briquettes.

Table 1. Proximate Test Results of Durian Peel Bio-briquettes at 500 °C Carbonization Temperature

Parameter	Value (%)	SNI (%)
Moisture content	7.47	≤ 8
Volatile matter	13.54	≤ 15
Ash content	9.33	≤ 8
Fixed carbon	67.76	≥ 77

Table 1 shows the results of the proximate analysis of durian peel charcoal at a carbonization temperature of 500 °C, including moisture content, volatile matter, ash content, and fixed carbon. The moisture content decreased significantly, from 16.35% in the initial durian peel charcoal to 7.47% after carbonization at 500 °C.

At this temperature, the carbonization process caused significant changes in the structure and composition of the material, resulting in substantial mass reduction. Volatile components such as water, hemicellulose, and most of the cellulose underwent thermal decomposition, leaving a more stable carbon residue [18]. This temperature is considered optimal for producing Bio-briquettes with high carbon content, offering better combustion efficiency and higher calorific value [22]. The moisture content of the durian peel charcoal complies with SNI 01-6235-2000 standards at 7.47%. This study concludes that carbonization effectively reduces the moisture content in bio-briquettes. Lower moisture content enhances the calorific value of the bio-briquettes.

The percentage of material weight that volatilizes due to the decomposition of compounds still present in the charcoal is referred to as volatile matter [23]. High volatile matter content in Bio-briquettes leads to increased smoke production during combustion. The volatile matter content of durian peel charcoal was found to be 13.54%. The volatile matter content of bio-briquettes is influenced by the duration and temperature of carbonization. Longer carbonization processes and higher temperatures result in the evaporation of more volatile compounds [24]. Based on the test results, the volatile matter content of this bio-briquette meets the SNI 01-6235-2000 standard of ≤ 15%. Volatile matter negatively correlates with carbon content, and vice versa. Durian peel bio-briquettes demonstrate good combustion and ignition capabilities [25]. The findings indicate that carbonization influences the volatile matter content of bio-briquettes, with higher carbonization temperatures increasing volatile matter content.

The ash content of bio-briquettes represents the residual minerals that do not combust during the combustion or pyrolysis process. Higher ash content in briquettes reduces their calorific value [26] [27]. The test results show that the ash content of durian peel Bio-briquettes was 9.33%. Ash content is affected by impurities in the raw material, which result in high mineral content in the bio--briquettes. The test results reveal an ash content of 9.33%, which exceeds the SNI 01-6235-2000 standard of ≤8%. Impurities such as SiO_2, Al_2O_3, Fe_2O_3, CaO, and alkali compounds that cannot combust or oxidize contribute to the high ash content [9].

Fixed carbon in the bio-briquette testing is closely related to calorific value, as it affects volatile matter and carbonization temperature. Higher carbonization temperatures cause more volatile components and moisture in the raw material to decompose and evaporate, leaving more fixed carbon [27]. The fixed carbon content also influences the combustion rate of Bio-briquettes. Bio-briquettes with high fixed carbon content have a longer burn time and shorter ignition time [28]. According to SNI 01-6235-2000 standards for charcoal briquettes, the allowable fixed carbon value is >77%. The results of this study indicate that the fixed carbon content did not meet the SNI standard. Further research is necessary to optimize the process and improve the fixed carbon value of durian peel bio-briquettes.

3.3 Calorific Value of Durian Peel Bio-briquettes

The calorific value of bio-briquettes significantly affects their quality. This is because the calorific value is highly influenced by moisture content; lower moisture content and higher calorific value facilitate easier ignition of the bio-briquettes [9]. As shown in Figure 3, the calorific value of bio-briquettes at a carbonization temperature of 500 °C meets the SNI 01-6235-2000 standard, which requires a minimum of ≥5000 cal/gram. This compliance indicates that the carbonization process at this temperature is optimal for achieving a high-quality product. Carbonization at elevated temperatures reduces the moisture content and eliminates volatile compounds, thereby concentrating the carbon content in the material. The resulting increase in fixed carbon proportion directly contributes to the higher calorific value [13].

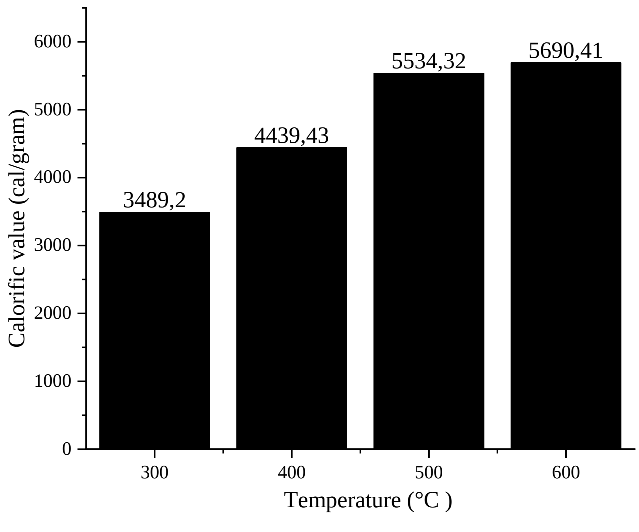

Figure 3. Calorific Value of Durian Peel Bio-briquettes at Various Carbonization Temperatures (cal/gram)

Moreover, the moisture content not only affects the calorific value but also impacts the carbonization process itself. During carbonization, lower moisture levels accelerate the thermal decomposition of organic compounds in the raw material, resulting in a more efficient conversion to carbonized products [29]. This efficiency ensures that the energy retained within the material is maximized, leading to bio-briquettes with superior energy output. Additionally, the relationship between carbonization temperature and calorific value highlights the need for precise control during production. Higher carbonization temperatures generally lead to a reduction in volatile matter and an increase in fixed carbon, which are desirable traits for bio-briquettes [30].

However, excessive temperatures may lead to energy losses and structural degradation of the material, emphasizing the importance of maintaining an optimal temperature range.

In conclusion, the interplay between moisture content, carbonization conditions, and calorific value underscores the importance of careful process optimization in bio-briquette production. By minimizing moisture content and operating within the optimal carbonization temperature, it is possible to produce bio-briquettes that not only meet standard specifications but also deliver enhanced combustion efficiency and energy performance.

4. CONCLUSIONS

This study highlights the significant influence of carbonization temperature (300°C–600°C) on the quality of durian peel bio-briquettes, impacting properties such as moisture, volatile matter, ash content, fixed carbon, and calorific value. An optimal temperature of 500°C was identified, yielding bio-briquettes with high calorific value (meeting SNI standards of ≥5000 cal/gram) and acceptable moisture (7.47%) and volatile matter (13.54%). However, ash content (9.33%) and fixed carbon (67.76%) require further improvement to fully comply with SNI standards. Higher temperatures enhanced energy content but increased ash levels, presenting challenges for combustion efficiency. Optimizing raw material pre-treatment and carbonization processes can address these issues. This research underscores the potential of durian peel bio-briquettes as a renewable energy source and highlights the need for future studies to explore advanced techniques for improving efficiency and sustainability.

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