JTEP Jurnal Keteknikan Pertanian,
Vol. 13 No. 4, p 613-626, 2025
P-ISSN 2407-0475 E-ISSN 2338-8439

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.013.4.613-626

Wood Waste Charcoal Briquettes: Physical and Thermal Characteristics Based on Particle Size and Wood Type

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Article Info

Submitted: 5 October 2025
Revised: 23 December 2025
Accepted: 29 December 2025
Available online: 14 January 2026
Published: December 2025

Keywords:
charcoal briquettes, briquette properties, particle size, wood waste biomass

How to cite:
Pamungkas, W. A., Yusuf, M. A., Teraka, M. (2025). Wood Waste Charcoal Briquettes: Physical and Thermal Characteristics Based on Particle Size and Wood Type. Jurnal Keteknikan Pertanian, 13(4): 613-626. https://doi.org/10.19028/jtep.013.4.613-626.

Abstract

The depletion of fossil fuel reserves and rising fuel costs have highlighted the need for alternative household energy sources. Biomass waste, particularly sawmill residues, has potential for conversion into solid fuel in the form of charcoal briquettes. This study evaluated the physical and thermal characteristics of charcoal briquettes produced from Bus wood (Melaleuca sp.) and Rahai wood (Acacia sp.) sawmill waste at particle sizes of 10, 30, and 60 mesh. Briquettes were produced through carbonization, size reduction, binder mixing, molding, and drying, followed by evaluation of physical and thermal properties. The results showed that Bus wood briquettes had a higher density (0.56–0.60 g/cm³) than Rahai wood briquettes (0.46–0.58 g/cm³). Moisture content ranged from 10% to 13%, with the highest value observed in Rahai briquettes at 60 mesh, which affected combustion stability. Thermal analysis indicated that Bus briquettes at 60 mesh achieved a high peak temperature (608 °C) and a high combustion time efficiency (92.31%), while Rahai briquettes exhibited a higher peak temperature at a coarser particle size (10 mesh, 604 °C). Overall, Bus briquettes with finer particle size showed favorable physical properties and combustion behavior. These findings indicate that Bus wood waste briquettes have potential for further development as household-scale solid fuel.

Doi: https://doi.org/10.19028/jtep.013.4.613-626

1. Introduction

Energy issues have become a strategic concern owing to the long-term depletion of fossil fuel reserves and increasing energy prices. This condition has encouraged the development of alternative energy sources, particularly for household-scale applications. Biomass waste has gained attention owing to its availability and potential for conversion into solid fuels.

Indonesia has considerable biomass resources derived from agricultural, plantation, and forestry residues (Lestari & Wulandari, 2025). One promising biomass source is wood processing waste, including sawdust and offcuts generated by sawmills, which can be converted into charcoal

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briquettes as an alternative solid fuel (Sotannde et al., 2010). The volume of sawmill waste in Indonesia is estimated to reach approximately 1.4 million m^3 per year (Malik, 2012). However, wood waste is often underutilized and disposed of through open burning or stockpiling, causing environmental concerns (Maurits et al., 2023; Rianto et al., 2019).

In Merauke Regency, South Papua Province, household cooking energy mainly relies on kerosene and liquefied petroleum gas (LPG), both of which are relatively expensive (Andika et al., 2024; Manupapami & Kurniati, 2022). Merauke has active timber industries that generate considerable wood-processing waste (Wahyuni & Sulistyo, 2016). Among the commonly utilized timber species are Bus wood (*Melaleuca* sp.) and Rahai wood (*Acacia* sp.), which are widely used as construction materials (Doloksaribu & Nababan, 2021). These residues represent a potential feedstock for the production of charcoal briquettes. As species identification was limited to the genus level, reported caloric values from the literature were used as references, ranging from 4,088 – 4,535 cal/g and 4,066 – 4,701 cal/g, respectively (Wahyuni & Sulistyo, 2016; Yuningsih et al., 2022).

The quality and performance of charcoal briquettes are strongly influenced by several factors, including the biomass type, particle size, binder type, and compaction pressure. Finer particle sizes generally enhance briquette density and mechanical strength owing to improved interparticle contact (Abineno et al., 2025), whereas wood species and compaction pressure also play significant roles in determining the physical and thermal properties (Maurits et al., 2023; Mitchual et al., 2013). Starch-based binders are commonly used because of their low cost, biodegradability, and ability to improve briquette strength and calorific performance (Aransiola et al., 2019; Marreiro et al., 2021).

This study aimed to evaluate the physical and thermal characteristics of briquettes from Bus wood (*Melaleuca* sp.) and Rahai wood (*Acacia* sp.) sawmill waste at different particle sizes (10, 30, and 60 mesh). The results are expected to identify suitable material and particle size combinations that influence combustion performance, thereby supporting the future utilization of local wood waste as a household-scale energy source.

2. Material and Methods

2.1 Material and equipment

This study used Bus (*Melaleuca* sp.) and Rahai wood (*Acacia* sp.) sawmill waste obtained from a local sawmill in Kelapa Lima Sub-district, Merauke District, Merauke Regency, South Papua Province, as shown in Figure 1. Tapioca starch and water were used as the binding materials. Briquette production was conducted using basic equipment for carbonization, size reduction, sieving (10, 30, and 60 mesh), mixing, molding (manual hydraulic press), and drying. Physical and thermal characterizations were performed using standard laboratory equipment, including digital balances, ovens, and thermocouples.

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Figure 1. Bus wood waste (a) and Rahai wood waste (b) images.

The first stage of this study involved the production of charcoal briquettes, which began with open-air carbonization, followed by size reduction, sieving, binder preparation, mixing, molding, and natural sun drying. The subsequent stage evaluated the briquette characteristics, including mass, dimensions, density, moisture content, temperature, and combustion duration. Figure 2 illustrates the overall research procedure.

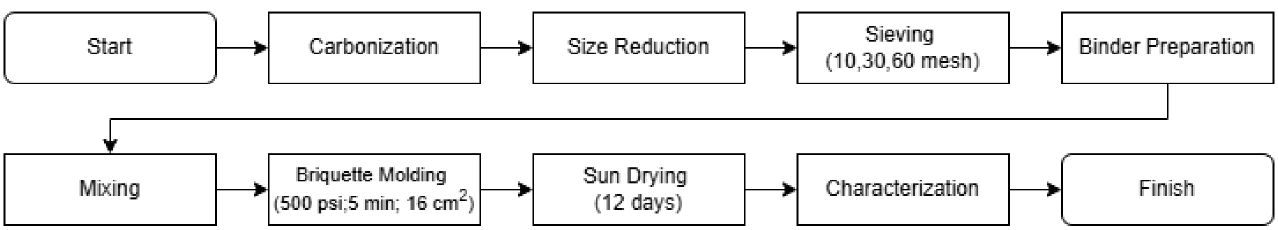

Figure 2. Research flowchart.

2.2 Charcoal preparation

Charcoal was produced using an open-air carbonization method under ambient conditions. Carbonization was conducted using an upright cylindrical metal plate as the combustion boundary. The wood waste was ignited from the center and manually turned to ensure uniform carbonization while preventing complete oxidation. Carbonization was continued for approximately 5 h until complete conversion to charcoal, followed by natural cooling.

2.3 Size reduction and sieving

Charcoal was manually ground using a pestle to produce uniform particles, thereby facilitating homogeneous mixing with the binder. The ground charcoal was subsequently sieved to obtain particle size fractions of 10, 30, and 60 mesh.

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2.4 Binder preparation

The binder was prepared by heating 800 ml of water, while 300 g of tapioca starch was dispersed in 200 ml of water. The starch suspension was added to boiling water and stirred until a homogeneous gel was formed, with the binder ratio kept constant throughout all treatments.

2.5 Binder-charcoal mixing

The binder gel was gradually added to 1 kg of charcoal and mixed manually using a stirrer, followed by hand kneading until a homogeneous briquette mixture was achieved. Each batch was prepared separately using 1 kg of charcoal following the same procedure.

2.6 Molding and pressing

The briquette mixture was placed into the mold and compacted by applying vertical pressure from the top using a manual hydraulic press. A compaction pressure of 500 psi was applied and maintained for 5 min, as shown in Figure 3. The applied pressure was calculated based on the square cross-sectional area of the mold (4 × 4 cm, corresponding to 16 cm^2). After pressing, the bottom plate of the mold was removed, and the formed briquettes were ejected downward from the mold.

For each wood type and particle size combination, 16–18 briquettes were produced for physical and thermal characterization. A smaller number of briquettes was obtained for the 60 mesh samples due to occasional breakage during demolding.

Figure 3. Briquette molding process (a) and briquettes after molding (b).

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2.7 Briquette drying procedure

After molding, the briquettes were placed on metal trays and dried under direct sunlight. Sun drying was conducted under ambient environmental conditions according to the production schedule. The drying process was conducted daily from 08:00 to 16:00 local time. During the drying period, the briquettes were periodically turned to promote uniform moisture removal from them. Drying was continued for 12 days until the briquettes reached a stable mass before further characterization.

2.8 Characterization of charcoal briquettes

The characteristics of charcoal briquettes included parameters such as density, moisture content, combustion temperature, and combustion duration. The density was determined from the ratio of briquette mass to total volume, as calculated using Equation 1.

$$\rho = \frac{m}{V} \quad (1)$$

Where: ρ = density of a charcoal briquette (g/cm^3), m = mass of a charcoal briquette (g), and V = volume of a charcoal briquette (cm^3).

Approximately 5 g of charcoal briquette sample was dried in an electric oven at 105 °C for 24 h. The oven-dry mass was measured using a digital balance, and the moisture content was determined using Equation 2:

$$MC = \frac{W1-W2}{W1} \text{ x } 100 \quad (2)$$

Where: MC = moisture content of the charcoal briquette (%), W_1 = initial mass of the briquette (g), and W_2 = oven-dry mass of the briquette (g).

The combustion characteristics were evaluated based on the temperature variation from ignition to complete ash formation. The briquettes were ignited simultaneously indoors under ambient conditions using a small amount of commercial ignition fluid applied to the bottom surface as an aid for ignition. Only one briquette per replicate was directly ignited, and no forced airflow was applied to the system. For each treatment, nine briquettes (three replicates) were arranged upright between two perforated metal trays in a face-to-face configuration (Figure 4).

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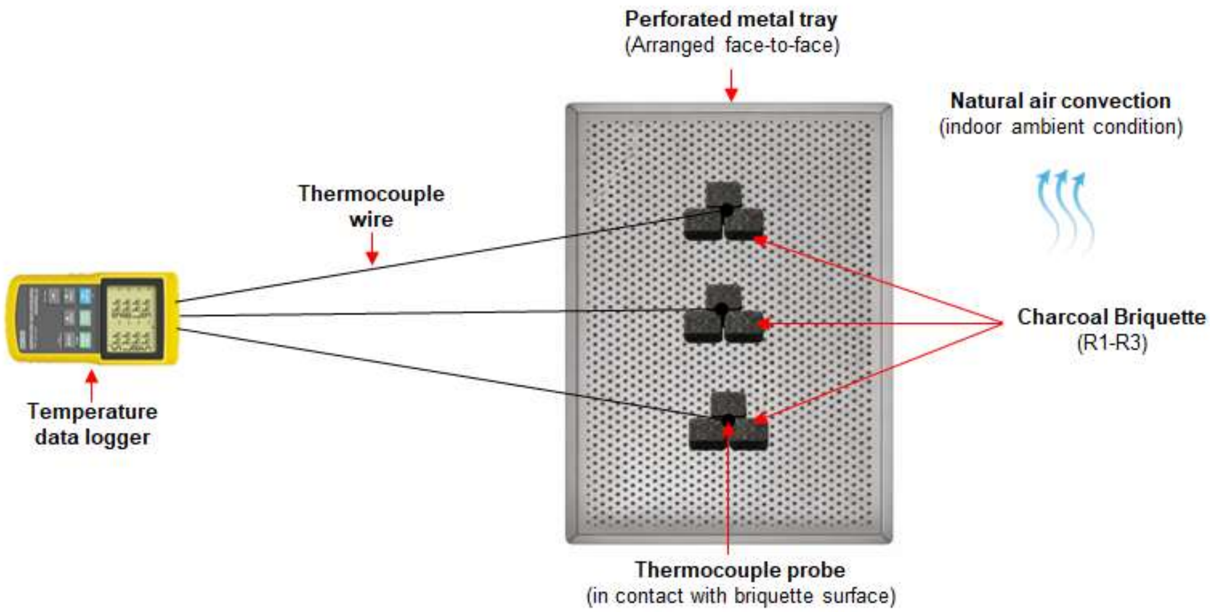

Figure 4. Schematic of the combustion test setup (top view).

The temperature was measured using a thermocouple probe positioned in direct contact with the briquette surface and recorded at 5-minute intervals using a temperature data logger. The combustion duration parameters (t_{sample} and t_{max}) and peak temperature were determined from the resulting temperature-time profiles.

Because the thermal efficiency, burning rate, and ash composition were not quantitatively evaluated, the combustion effectiveness was assessed using the combustion time efficiency as a comparative parameter.

The effective combustion duration (t_{sample}) was defined as the time interval between the moment when the combustion temperature first reached approximately 300 °C and the moment when it declined back to approximately 300 °C. Accordingly, the onset of the effective combustion phase was set as t=0 at the first attainment of 300 °C, regardless of the absolute time elapsed since ignition.

The total combustion duration (t_{max}) was defined as the time from ignition to complete ash formation. The combustion time efficiency (ηt) was calculated as the ratio of t_{sample} to t_{max} using Equation 3.

$$\eta t = \frac{t_{sample}}{t_{max}} \text{ x } 100 \quad (3)$$

Where: ηt = combustion time efficiency (%), t_{sample} = effective combustion duration corresponding to the active combustion phase (min), and t_{max} = total combustion duration (min).

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2.9 Statistical analysis

The experimental data were analyzed using two-way ANOVA at a 95% confidence level ($\alpha = 0.05$). Briquette mass and density were measured using 16-18 replicates per treatment, while moisture content was determined using six replicates per treatment. The combustion temperature data were analyzed descriptively and presented as temperature-time profiles.

3. Results and Discussion

3.1 Physical properties of charcoal briquettes

The charcoal briquettes produced in this study had a rectangular block shape with a length and width of 4 cm each and a variable height of approximately 4–5 cm, as shown in Figure 5. The average briquette mass varied among particle sizes and wood types, ranging from 38.44 g (10 mesh) to 45.42 g (60 mesh) for Bus briquettes and from 34.84 g (10 mesh) to 47.62 g (60 mesh) for Rahai briquettes. Statistical analysis showed that wood type, particle size, and their interaction had a significant effect on briquette mass ($p < 0.05$), indicating that the effect of particle size on briquette mass differed between Bus and Rahai wood types. The physical characteristics of the charcoal briquettes are presented in Table 1.

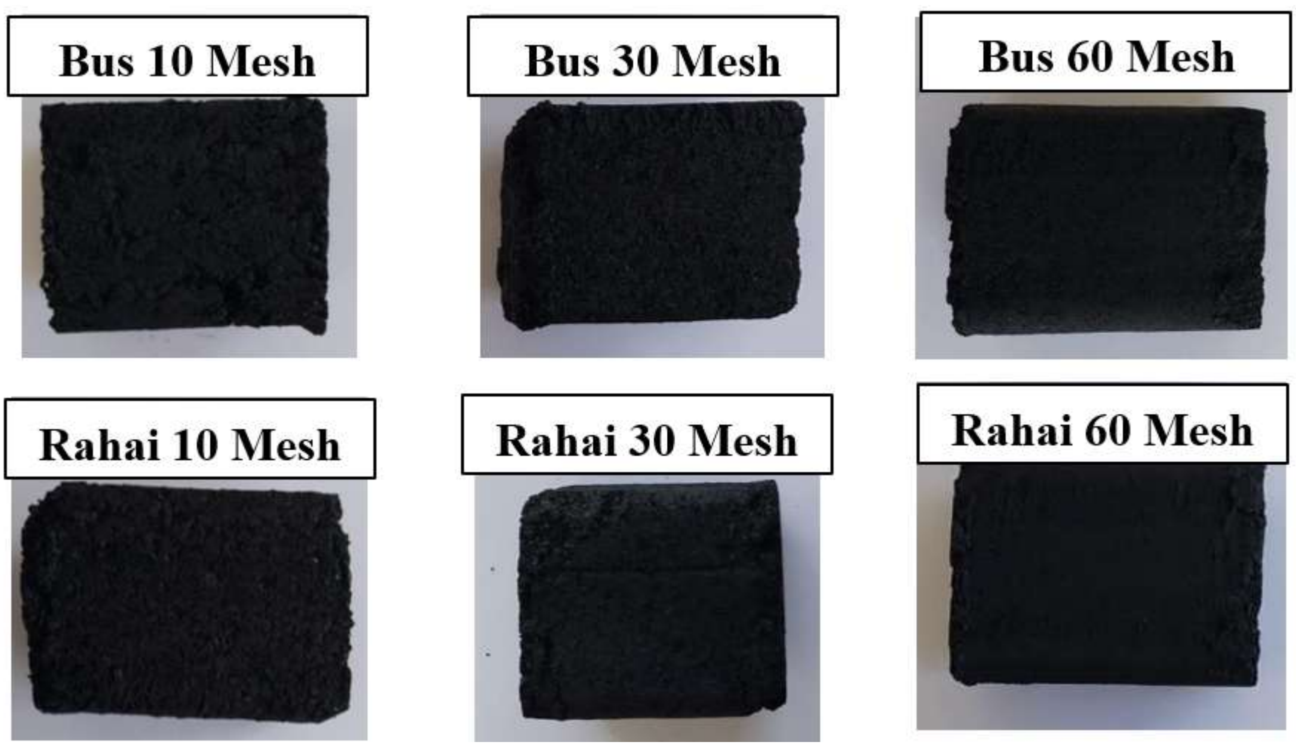

Figure 5. Charcoal briquettes from Bus and Rahai wood waste at different particle sizes.

3.2 Density of charcoal briquettes

The data in Table 1 showed that the density of charcoal briquettes from Bus wood waste ranged from 0.56 to 0.60 g/cm³. Briquettes made from Rahai wood had a lower density, ranging from 0.46 to 0.58 g/cm³. Statistical analysis revealed that wood type, particle size, and their interaction significantly affected the briquette density ($p < 0.05$).

The Bus briquettes had a relatively stable density across particle sizes, whereas the Rahai briquettes showed a marked increase in density with decreasing particle size. Although Bus and Rahai woods may differ in their natural wood densities, the significant interaction between wood type and particle size indicates that the influence of wood type on briquette density is strongly dependent on particle size. This suggests that the densification behavior is governed not only by the inherent material properties but also by particle rearrangement and packing efficiency during compaction, particularly for finer particles (Abineno et al., 2025; Sihombing et al., 2020).

Table 1. Physical properties of charcoal briquettes from Bus and Rahai wood waste.

Wood Type	Particle Size (Mesh)	Mass (g)	Volume (cm³)	Density (g/cm³)	Moisture Content (%)
Bus	10	38.44 ± 2.79	64.05 ± 1.15	0.60 ± 0.040	10.91 ± 0.824
	30	38.53 ± 2.13	69.04 ± 2.77	0.56 ± 0.038	10.37 ± 0.665
	60	45.42 ± 1.91	76.66 ± 3.76	0.59 ± 0.030	10.25 ± 0.822
Rahai	10	34.84 ± 2.82	75.54 ± 2.27	0.46 ± 0.029	10.43 ± 0.876
	30	33.40 ± 1.75	65.57 ± 1.37	0.51 ± 0.026	10.65 ± 0.587
	60	47.62 ± 2.46	81.60 ± 0.75	0.58 ± 0.030	12.88 ± 1.759

The significant interaction between wood type and particle size indicates that the influence of particle size on briquette density varied between Bus and Rahai woods. Although Bus wood has a higher intact wood density (627–879 kg/m³) than Rahai wood (615 kg/m³) (Doloksaribu & Nababan, 2021), the results suggest that the effect of intrinsic wood density on briquette density was modulated by particle size and compaction behavior rather than acting independently.

3.3 Moisture content of charcoal briquettes

According to Sunardi et al. (2019), moisture content plays a significant role in briquette quality, especially in terms of energy performance and ignition. The variations in moisture content with particle size were not consistent across the materials in the current study (Table 1). Statistical analysis showed that wood type, particle size, and their interaction significantly affected the briquette moisture content ($p < 0.05$).

For Bus briquettes, the moisture content decreased from 10.91% to 10.25% and only slightly changed with the particle size. The behavior of Rahai briquettes was different; at the finest particle size, where the moisture content reached 12.88%, a discernible increase was observed. This contrast is consistent with variations in the properties of raw materials. Compared to Bus wood, Rahai wood has a higher porosity and lower natural density, which promotes moisture retention (Glass & Zelinka, 2010). The porous structure of charcoal allows it to reabsorb moisture even after carbonization (Antal & Grønli, 2003; Bao et al., 2021).

3.4 Combustion temperature of charcoal briquettes

Figure 6 shows the combustion temperature profiles of Bus briquettes with different particle sizes. Briquettes from finer particles, particularly those with a 60 mesh size, reached higher peak temperatures and exhibited a more sustained high-temperature profile than those produced from coarser particles.

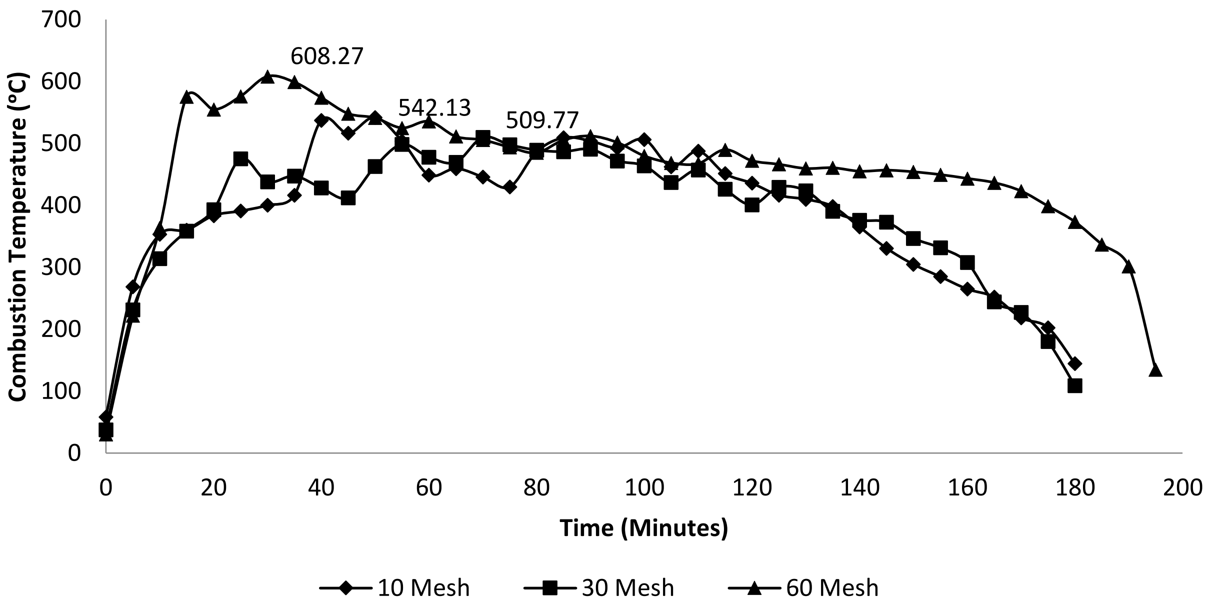

Figure 6. Combustion temperature profiles measured at the surface of Bus briquettes.

Bus briquettes made from 60 mesh particles reached the highest peak temperature (608.27 °C), whereas briquettes with particle sizes of 10 and 30 mesh reached peak temperatures of 542.13 °C and 509.77 °C, respectively. This trend indicates that finer particle sizes tend to generate higher combustion temperatures than coarser particle sizes. All Bus briquettes, regardless of particle size, reached combustion temperatures within the range of 300-600 °C reported in the literature (Yusuf et al., 2023).

The combustion temperature profiles of the Rahai briquettes with different particle sizes (10, 30, and 60 mesh) are shown in Figure 7. Briquettes produced from 10 mesh particles reached the highest peak temperature (604.03 °C), followed by 60 mesh (590.63 °C) and 30 mesh (528.10 °C) briquettes. This non-monotonic trend suggests that the combustion behavior of Rahai briquettes is influenced

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by a combination of particle packing and oxygen availability, rather than particle size alone (Aransiola et al., 2019; Mencarelli et al., 2025; Qi et al., 2022).

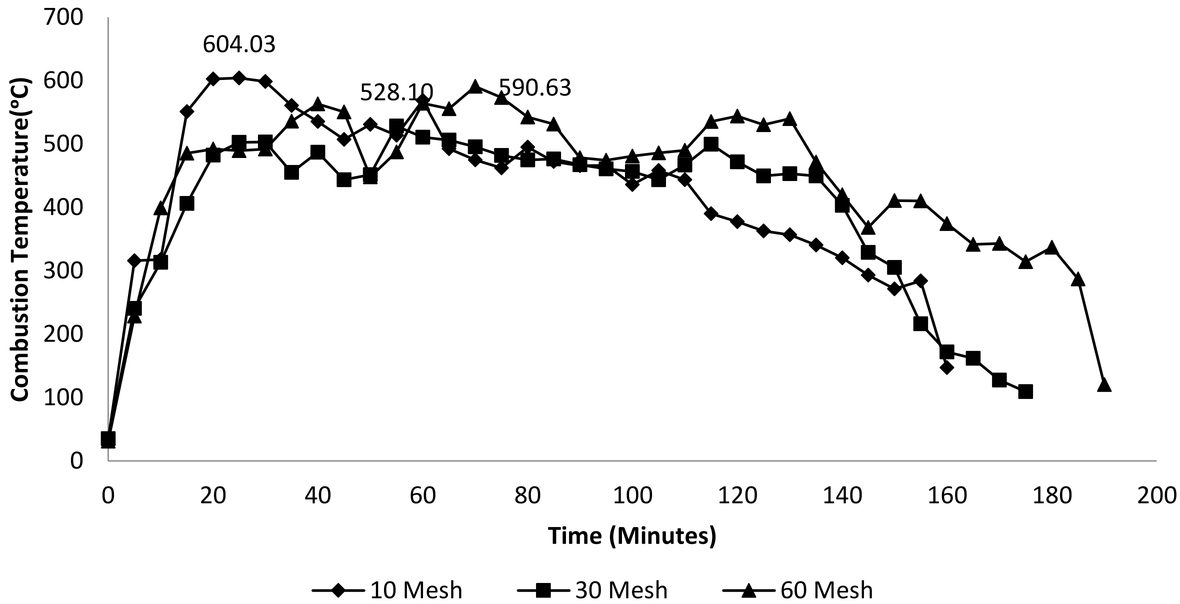

Figure 7. Combustion temperature profiles measured at the surface of the Rahai briquettes.

At the 10 mesh particle size, Rahai briquettes exhibited relatively higher peak temperatures, which may be associated with their lower density and larger interparticle voids, allowing oxygen to penetrate more easily during combustion. In contrast, briquettes produced from finer particles (60 mesh) benefited from a larger reactive surface area, although increased compaction may have partially limited the oxygen diffusion. The intermediate particle size (30 mesh) exhibited lower peak temperatures, which is consistent with its intermediate mass and density values, suggesting that neither oxygen availability nor particle contact was optimal at this size.

Despite these differences, all Rahai briquettes across the three particle sizes (10, 30, and 60 mesh) reached combustion temperatures comparable to those reported for open-air briquette combustion under similar experimental conditions, including peak temperatures of approximately 600 °C (Yusuf et al., 2023).

3.5 Combustion duration of charcoal briquettes

The peak combustion temperatures and duration characteristics of the Bus and Rahai briquettes with different particle sizes are presented in Table 2. For Bus briquettes, particle size was associated with differences in the duration of the effective combustion phase, defined by a minimum temperature of 300 °C. Briquettes made from finer particles (60 mesh) exhibited the longest effective combustion duration (180 min), followed by those made from 30 mesh (150 min) and 10 mesh (140 min). This finding is consistent with previous studies reporting that finer particles supported a more

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sustained effective combustion phase before the transition to burnout (Abineno et al., 2025; Qi et al., 2022).

Based on Table 2, the total combustion duration of the Bus briquettes showed limited variation among the particle size (180-195 min). However, the time required to reach the target temperature differed substantially. The 30 mesh Bus briquettes required the longest time to reach the peak temperature (70 min), whereas the 60 mesh briquettes reached the peak temperature more rapidly (30 min). These differences suggest that the particle size affects the heat development dynamics during the early stages of combustion, even though the overall burnout time is relatively similar.

Table 2. Peak Combustion temperature and duration of charcoal briquettes.

Wood Type	Particle Size (Mesh)	Peak Temperature (°C)	Time to Peak Temperature (min)	Effective Combustion Duration (min)	Total Combustion Duration (min)
Bus	10	542.13 ± 38.54	50	140	180
	30	509.77 ± 61.81	70	150	180
	60	608.27 ± 89.68	30	180	195
Rahai	10	604.03 ± 83.30	25	135	160
	30	528.10 ± 60.06	55	140	175
	60	590.63 ± 49.73	70	170	190

In Rahai briquettes, the combustion duration also varied with particle size but exhibited a different pattern than that of Bus briquettes. The effective combustion duration increased from 135 min (10 mesh) to 170 min (60 mesh), whereas the total combustion duration ranged from 160 to 190 min. Finer Rahai briquettes required a longer time (approximately 70 min), compared to 25 min for 10 mesh briquettes. This delayed temperature rise is likely associated with their higher moisture content (12.88%), which requires additional energy for water evaporation during the initial combustion stage before stable flaming combustion can be established (Ismayana & Afriyanto, 2011; Yuniarti et al., 2025).

3.6 Combustion time efficiency

The combustion time efficiency increased with decreasing particle size for both Bus and Rahai briquettes, indicating that finer particles resulted in a greater proportion of the total combustion duration occurring within the active combustion phase (Table 3). Bus briquettes with a particle size of 60 mesh exhibited a relatively high combustion time efficiency (92.31%), reflecting a more sustained active combustion phase relative to the total combustion time. A similar trend was observed for Rahai briquettes, although the increase in combustion time efficiency was less pronounced, reaching 89.47% at 60 mesh. This difference may be associated with the higher initial moisture content of the Rahai briquettes, which influenced the combustion behavior. All combustion

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tests were conducted until complete ash was formed. Combustion time efficiency (ηt) represents the relative duration of active combustion rather than the fuel burnout degree or ash yield.

Table 3. Combustion time efficiencies of Bus and Rahai briquettes.

Wood Type	Particle Size (Mesh)	Combustion Time Efficiency (%)
Bus	10	77.78
	30	83.33
	60	92.31
Rahai	10	84.38
	30	80.00
	60	89.47

3.7 Research limitations and practical applications

This research was conducted on a laboratory scale, and several limitations should be considered when interpreting the results. Variability may arise from sun drying and manual mixing, which can affect the moisture distribution and combustion behavior. However, all treatments were processed and tested using the same procedure, allowing for consistent comparisons. For applications beyond the laboratory scale, practical implementation in this study refers to the standardized and repetitive use in small-scale or community-based production, rather than mass production. Therefore, controlling the particle size, drying method, and material uniformity is essential to maintain the relevance of laboratory-scale combustion characteristics under practical conditions.

4. Conclusion

This study demonstrated that wood type and particle size affect the physical properties and combustion characteristics of charcoal briquettes. Briquettes made from Bus wood waste showed higher density and more stable combustion than those made from Rahai wood waste. The most favorable performance was observed for Bus briquettes with a particle size of 60 mesh, which exhibited higher peak temperatures and longer active combustion durations. In contrast, the combustion performance of the Rahai briquettes was more influenced by the particle size and moisture content. These results indicate that controlling the particle size and moisture content plays an important role in improving briquette performance and supports the potential use of Bus wood waste for household-scale solid fuel applications.

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