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Utilization of Coconut Shell and Coffee Grounds as Briquettes Using the Carbonization Method

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ABSTRACT: Biomass-derived briquettes are gaining attention as renewable energy carriers capable of reducing fossil fuel use and CO_2 emissions. This study evaluates the effect of composition ratio and carbonization time on the quality of briquettes produced from coconut shells and spent coffee grounds. Carbonization was conducted at 300 °C with residence times of 60–180 minutes, while composition ratios varied from 9:1 to 5:5 (w/w). Key performance indicators moisture, ash, volatile matter, fixed carbon, density, and calorific value were assessed against SNI 01-6235-2000 and international briquette standards. Results showed that a 9:1 ratio provided the highest calorific value of 27.09 $MJ.kg^{-1}$, while the optimal carbonization time was 90 minutes, yielding 27.21 $MJ.kg^{-1}$. These values meet both Indonesia and international standards. The novelty of this work lies not only in the dual valorization of coconut shells and coffee waste into high-quality solid fuel but also in their synergistic interaction: coconut shell provides calorific strength and structural rigidity, while coffee grounds enhance ignition, binding, and combustion stability. The findings not only establish process parameters for efficient briquette production but also demonstrate broader implications for renewable energy transition and the development of sustainable bioenergy export commodities.

Keywords: biomass briquettes; coconut shell; coffee grounds; carbonization; calorific value

1. Introduction

Briquettes are a form of renewable energy that can be used as an alternative energy source. Their primary function is typically as fuel for heating, cooking, and electricity generation. Briquettes are made from biomass charcoal; however, each type of biomass has different properties and characteristics that can affect its performance as a fuel—such as water content, ash content, volatile matter, density, fixed carbon, calorific value, and the processing method. These factors determine how effectively the briquettes function as a fuel. Coconut shell has been scientifically proven to be an excellent raw material for charcoal briquette production. Various studies have shown that briquettes made from coconut shell possess outstanding physical and chemical characteristics, making it an ideal choice for producing high-quality briquettes (Malik & Mukhtar, 2023). Coconut production in Indonesia reached 2.87 million tons in 2022, representing a 0.23% decrease compared to the previous year's output of 2.88 million tons, according to data from the Central Bureau of Statistics (BPS, 2021).

According to a study conducted by Zaenul amin et al., 2019, coconut shell has a calorific value of 31.90 $MJ.kg^{-1}$. Coffee grounds can be used as a mixing material in briquette production due to their high calorific value. Utilizing coffee waste for briquette making also adds a pleasant coffee aroma when the briquettes are burned. According to a report by the Central Bureau of Statistics (BPS), Indonesia's coffee production reached 786.2 thousand tons in 2022. Coffee grounds constitute approximately 50% of the total mass of raw coffee material. Despite the high production of coffee ground waste, it is still rarely utilized. According to a study by Elwina, 2022, the calorific value of 100% robusta coffee grounds is 24.61 $MJ.kg^{-1}$, while the calorific value of 100% arabica coffee grounds is 23.75 $MJ.kg^{-1}$. In a study conducted by Fakhri Ismail & Kurniawan Ronny (2022), the pyrolysis method yielded briquettes with a calorific value of 30.12 $MJ.kg^{-1}$. However, pyrolysis equipment requires significant investment and involves complex maintenance. In addition, the pyrolysis process is more intricate, requiring precise control and consuming a large amount of energy. Therefore, in this study, the carbonization method was chosen as it is considered more effective and easier for

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producing biomass briquettes. The resulting biochar has high quality featuring high carbon content and significant energy density. Moreover, the carbonization process generates minimal gas emissions, as it occurs in an oxygen-free environment.

2. Materials and Methods

The experimental work was designed to evaluate the influence of composition ratio and carbonization time on the quality of briquettes produced from coconut shells and spent coffee grounds. The methodology encompassed three main stages: (i) preparation of raw materials and adhesive, (ii) briquette production through mixing, molding, pressing, and drying, and (iii) characterization of physicochemical properties using established ASTM and SNI protocols.

2.1. Raw Materials

Coconut shells were collected from Rancaekek, West Java, and Arabica coffee grounds were sourced from Padalarang. Both materials were cleaned, then oven-dried at 100 °C until they reached a constant weight. The dried biochar was subsequently ground and sieved through a 60-mesh screen.

2.2. Adhesive preparation

The binder was prepared by mixing 8.5 g of tapioca flour with the feedstock, then adding 25 mL of hot water. The mixture was stirred thoroughly until it became uniform.

2.3. Briquette production

Coconut shells and spent coffee grounds were initially carbonized and subsequently blended at mass ratios of 9:1, 8:2, 7:3, 6:4, and 5:5 (w/w) for 60 minutes. Based on the optimal ratio identified at 60 minutes, a new experiment was conducted to evaluate the effect of carbonization duration at 60, 90, 120, 150, and 180 minutes. The starch binder was incorporated into the mixture, which was homogenized prior to molding. Briquettes were formed in a cylindrical die (5 cm diameter, 12.3 cm height) and compacted using a hydraulic press at 2 ton/cm² for 2 min. This compaction pressure lies within the range typically reported in briquetting studies (1–5 ton/cm²). The molded briquettes were subsequently oven-dried at 80 °C for 20 h to constant weight.

2.4. Characterization

The quality of the produced briquettes was evaluated through a series of standardized tests. The assessment included measurements of moisture content, ash content, density, volatile matter, calorific value, and fixed carbon. The obtained results were compared with the briquette quality criteria specified in SNI 01-6235-2000 and relevant international export standards.

3. Results and Discussion

This section explains the results of tests on briquettes made from coconut shell and coffee grounds. The tests evaluate the effects of mixture composition and carbonization time on briquette quality. These results enable identification of the combinations that yield the most suitable fuel-grade briquettes

3.1. Results of Briquette Characterization Test with Variations in Coconut Shell and Coffee Grounds Composition and a Carbonization Time of 60 Minutes

As shown in Figure 1, the content values ranged from 5.96% to 6.18%. The briquettes 5:5 sample (equal parts coconut shell and coffee grounds) showed the highest moisture content at 6.18%, while the 9:1 sample (with more coconut shell) had the lowest at 5.96%. Accordingly, all measured moisture contents complied with SNI (<8%) and were within export specifications for the United States (<6.2%) and Japan (6–8%).

This observation can be explained by the high lignin and carbon content, dense structure, and low moisture level of coconut shell. As noted by Pasaribu et al. (Pasaribu et al., 2024) who reported that coconut shell, classified as a hardwood, contains relatively higher lignin and lower cellulose than other biomasses, with a composition dominated by lignin, cellulose and hemicellulose. The high carbon concentration in coconut shell, containing 85-95% carbon (Silvia et al., 2023). Meanwhile, coconut shell exhibits a relatively high apparent density 702.1 kg.m^{-3} (Yusuf et al., 2020) Conversely, greater moisture content in the briquette matrix is associated with lower density (Anggraeni et al., 2021) Consistent with this relationship, formulations enriched in the denser coconut-shell fraction are expected to retain less moisture content. Moreover (Oktavian & Kartika, 2025) also reported that the moisture content can change depending on the chemical properties.

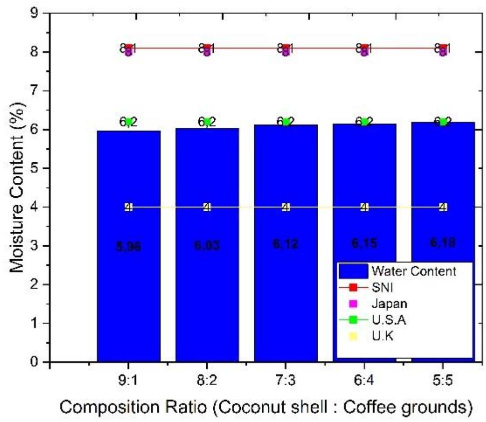

Figure 1. The Effect of Coconut Shell and Coffee Grounds Composition Variations on Briquette Moisture Content at a Carbonization Time of 60 Minutes

Ash content is another important way to judge briquette quality, besides water content. Ash is the non-combustible residue remaining after combustion and contributes zero energy. High ash content means the briquette has more impurities, less energy, and leaves more waste after burning. According to a study conducted by Febriana et al., 2023,

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briquettes made with 100% coconut shell composition had an ash content ranging from 7.45 %.

As shown in Figure 2, Ash content across all samples ranged from 1.27 to 4.31 %. All briquette samples satisfied SNI 01-6235-2000 (moisture < 8%) and were below the export moisture limits for Japan (< 3–6%), the United States (< 8.3%), and the United Kingdom (< 5.9%). Lower ash is generally associated with higher briquette quality, as mineral residues does not contribute to energy release. For fuel-grade briquettes, an ash content of ≤ 4 is commonly considered acceptable. Additionally, a low ash fraction generally correlates with a higher heating value, whereas ash-rich briquettes tend to generate more dust and co-pollutants and to diminish flame volume and overall combustion effectiveness (Teshome et al., 2024).

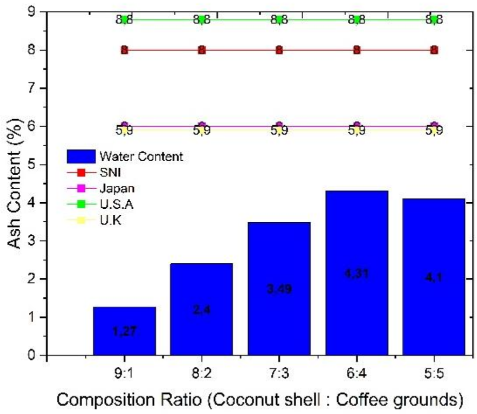

Figure 2. The Effect of Coconut Shell and Coffee Grounds Composition Variations on Briquette Ash Content at a Carbonization Time of 60 Minutes

The next characteristic tested was volatile matter, which includes substances in the briquette that quickly evaporate when burned. Figure 3 shows that adding more coffee grounds lowers the volatile matter in the briquettes. The values ranged from 8.73% to 13.57%. Therefore, all samples exhibited volatile-matter contents compliant with SNI 01-6235-2000 (<15%) and within export specifications for several countries, including the United States (<19.28%), the United Kingdom (<16.4%), and Japan (15–30%). Compared with Erdiyanto et al., 2024, which reported 29.87 to 55.12 % volatile matter for briquettes made from mixed spent coffee grounds, coconut shell charcoal and organic waste, the values obtained in this study are lower. The discrepancies between the findings of this study and previous research may be attributed to differences in the content of volatile compounds other than water present in the biomass feedstocks and binding materials (Kebede et al., 2022). Biomass primarily consists of cellulose and hemicellulose in them break down easily when heated. Their porous structure helps these materials let out even more gases when burned (Varkolu et al., 2025). Smaller particles release volatile matter more quickly due to more uniform heat distribution throughout their structure. In contrast, larger particles take longer to reach uniform internal temperatures, causing volatile compounds to remain trapped for a longer period. This slower release results in a higher overall volatile matter content in larger particles. (Abineno et al., 2025). Thus, reduced volatile content enhances combustion efficiency and lowers pollutant emissions (Wu et al., 2025).

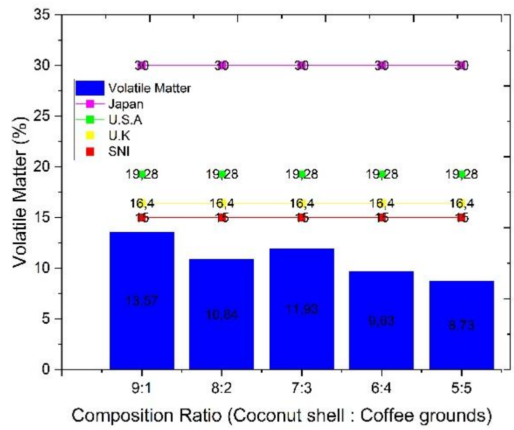

Figure 3. The Effect of Coconut Shell and Coffee Grounds Composition Variations on Briquette Volatile Matter at a Carbonization Time of 60 Minutes

Particle size plays a crucial role in determining the quality and performance of biomass briquettes. Smaller particles improve density by filling the gaps between larger particles, resulting in a more compact structure. In general, smaller particle sizes enhance briquette density, durability, and combustion efficiency, whereas larger particles can increase porosity and reduce overall performance. (Abineno et al., 2025).

According to a study conducted by Fish, 2020, the production of charcoal briquettes using 70% coconut shell resulted in a density value of 0.8 $g.cm^{-3}$. Figure 4 shows that the 9:1 sample achieved the highest density at 0.81 $g \cdot cm^{-3}$, whereas the 8:2 and 6:4 samples recorded the lowest values of 0.76 $g \cdot cm^{-3}$. Figure 4 shows that the 9:1 sample achieved the highest density (0.81 $g \cdot cm^{-3}$), whereas the 8:2 and 6:4 samples recorded the lowest values (0.76 $g \cdot cm^{-3}$). All briquette samples satisfied the SNI 01-6235-2000 density requirement (>0.447 $g \cdot cm^{-3}$) and remained below the export limits applied by the United States (<1.0 $g \cdot cm^{-3}$) and Japan (<1.2 $g \cdot cm^{-3}$). This result is consistent with the intrinsic properties of coconut shell, which is characterized by relatively high bulk and particle densities compared with other lignocellulosic biomasses (Kabir Ahmad et al., 2022).

Fixed carbon is a key factor influencing the energy efficiency and burn duration of charcoal. A higher fixed carbon content leads to greater heat production during combustion, making it more suitable for cooking and other thermal applications. Increasing the carbonization temperature helps remove more volatile compounds, thereby raising the fixed carbon content and enhancing combustion performance. In contrast, briquettes with lower fixed carbon content often contain higher levels of ash and volatile matter, which reduce their combustion efficiency and energy output (Mencarelli et al., 2025).

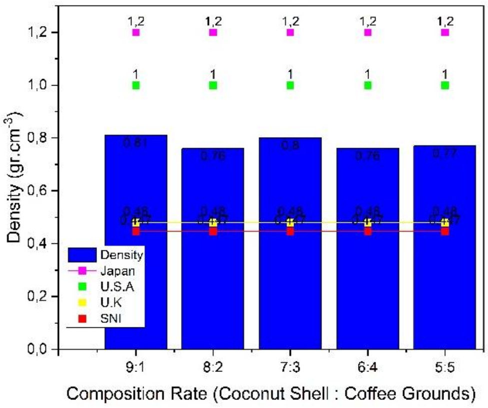

Figure 4. The Effect of Coconut Shell and Coffee Grounds Composition Variations on Briquette Density at a Carbonization Time of 60 Minutes

As shown in Figure 5, the fixed carbon test results ranged from 78.73 to 82.23%, with the lowest value observed in the 9:1 sample at 78.73% and the highest in the 6:4 sample at 82.23%. The fixed-carbon content of all samples was above the SNI requirement (77%) and aligned with commonly cited export standards—United States (>60%), Japan (60–80%), and United Kingdom (>75.3%).

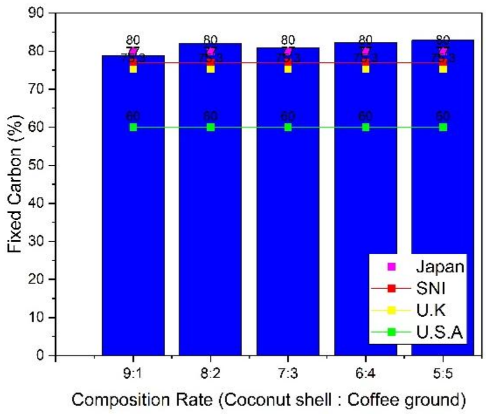

Figure 5. The Effect of Coconut Shell and Coffee Grounds Composition Variations on Briquette Fixed Carbon Value at a Carbonization Time of 60 Minutes

For comparison, Erdiyanto et al., 2024 reported 30 to 51 % for briquettes from spent coffee grounds, coconut-shell charcoal and organic waste, which generally retain higher volatile matter and ash, leading to lower fixed-carbon values. In related work, the briquette made from sawdust exhibited the highest fixed carbon content (41.75 ± 2.14%), which the authors attributed to strong interparticle bonding and a uniform particle-size distribution. These characteristics enhance densification, thereby increasing both the fixed carbon and the calorific value of the briquette. Additionally, the sawdust briquette produced a comparatively low ash yield (8.62 ± 3.66%) relative to other biomass fuels, indicating higher fuel reactivity and more efficient carbon conversion during combustion (Kebede et al., 2022). Calorific value shows how much energy a briquette can produce when burned. Briquettes with a high calorific value make more heat and are better for energy use.

Based on the calorific-value tests shown in Figure 6, the samples exhibited values of 26.201–27.094 MJ·kg⁻¹, with the highest value for the 9:1 composition (27.094 MJ·kg⁻¹) and the lowest for the 5:5 composition (26.201 MJ·kg⁻¹). All briquettes met SNI 01-6235-2000 (>20.920 MJ·kg⁻¹) and were within commonly applied export specifications, including the United States (26.062 MJ·kg⁻¹) and Japan (25.104–29.288 MJ·kg⁻¹). According to a study by Espina et al., 2023, he gross calorific value of raw coconut shells was reported as 30.79 MJ/kg^{-1}, highlighting their superior energy potential compared to other biomass residues such as spent coffee grounds, which have a lower calorific value of 23.957 MJ/kg^{-1} (Sołowiej et al., 2024). Although spent coffee grounds exhibit a lower calorific value (approximately 22.83–23.91 MJ.kg^{-1}) relative to coconut shell (>30.79 MJ.kg^{-1}) (Sołowiej et al., 2024;Espina et al., 2023).

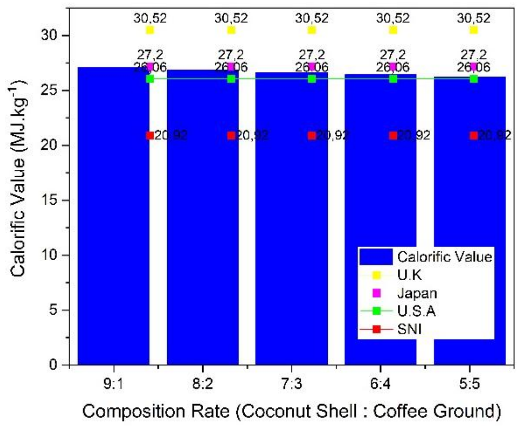

Figure 6. The Effect of Coconut Shell and Coffee Grounds Composition Variations on Briquette Calorific Value at a Carbonization Time of 60 Minutes

In contrast, the lower energy content of spent coffee grounds is balanced by their fine particle size and residual organic compounds, which contribute positively to briquette formation. Natural binding agents such as lignin, starch, and proteins found within plant biomass facilitate particle cohesion during briquette formation. Reducing particle size enhances the release and flow of these internal binders, increases surface area and contact points, and reduces the distance between particles. This improves mechanical interlocking and bonding strength. As a result, smaller particles promote better packing during compaction, leading to briquettes with higher apparent density, energy content, and mechanical durability. (Setter et al., 2021).

In addition, the relatively high volatile matter fraction promotes easier ignition (Oladosu et al., 2023), while their inherent porosity supports more uniform combustion and

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reduces instability during burning. Furthermore, The higher volatile matter in biomass makes it easier to ignite, resulting in a lower ignition temperature. (Liu et al., 2023).

3.2. Results of Briquette Characterization Test with Variation in Carbonization Time and a Coconut Shell and Coffee Grounds Composition (9:1)

Carbonization time can affect the moisture content of briquettes, which in turn influences their quality . Higher moisture content makes briquettes harder to ignite and lowers their calorific value, as less energy is produced (Akinbomi et al., 2025). The amount of water in a briquette also impacts its burning ability (Akinbomi et al., 2025); Lower moisture content increases the efficiency of briquettes, as less energy is required to evaporate water during combustion due to the low specific heat capacity of moisture (Pari et al., 2023). Higher carbonization temperatures were found to reduce the moisture content of hydrochar. Similarly, longer residence times during carbonization also led to lower moisture levels. (Nakano et al., 2024) As temperature increases, more volatile compounds are released, and amorphous carbon begins to convert into crystalline carbon. This transformation causes cracking and creates sparse regions within the biomass structure, leading to the development of more pores (Edeh et al., 2023).

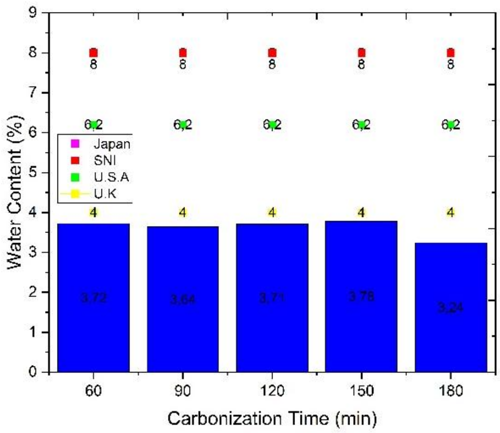

Figure 7. Effect of Carbonization Time Variation with a Coconut Shell and Coffee Grounds Composition (9:1) on the Water Content of Briquettes

Figure 7 shows that moisture content testing yielded values in the range of 3.24–3.78%. Accordingly, all measurements comply with SNI (<8%) and fall within export specifications for the United States (<6.2%), the United Kingdom (<34%), and Japan (6–8%). The highest moisture content was observed for briquettes carbonized for 150 minutes (3.78%), whereas the lowest was recorded at 180 minutes (3.24%). The moisture content of the briquettes showed minor variation but generally decreased. Owing to their high aromaticity and low O/C ratios (low polarity), both coconut-shell and SCG chars are relatively hydrophobic and thus retain little moisture after drying. This is because both coconut-shell char and SCG char are aromaticity (Rampe et al., 2021) (Torboli et al., 2024). Increasing the carbonization temperature simultaneously raises aromaticity and hydrophobicity while reducing polarity, demonstrating a direct link between condensed aromatic structures and water-repellent character (Luo et al., 2024).

Carbonization time can affect the ash content of briquettes and can influence their quality. Ash content is determined by the residue left from the briquettes after the combustion process. Ash content affects briquette quality; the higher the ash produced after burning, the lower the quality of the resulting briquette (Anis et al., 2024). The duration of the carbonization process affects the ash content in briquettes. The results in Figure 8 showed that ash content generally low with longer carbonization time. Ash content measurements ranged from 1.27 to 1.58 wt%. Ash ranged from 1.27 to 1.58 wt%, within SNI and export standards. The ash content in all samples was between 1.27% and 1.58%. This is due to the coconut shell's characteristically low ash content (± 0–2 %) (Ajien et al., 2023), by contrast, the ash content of spent coffee grounds is slightly higher (2.42%) (Jie et al., 2023). So, the overall inorganic drops and implicated that the measured ash goes down.

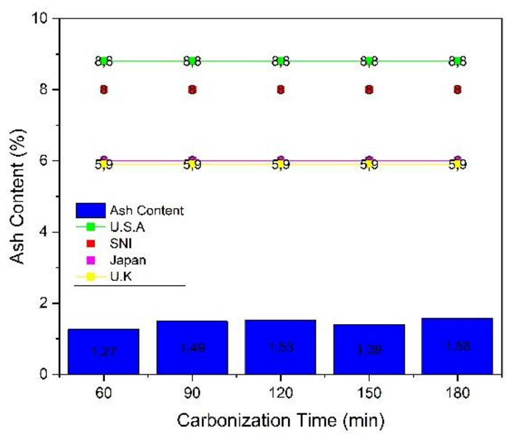

Figure 8. The Effect of Carbonization Time Variation with a Coconut Shell and Coffee Grounds Composition (9:1) on the Ash Content of Briquettes

One of the important factors that influences the composition and quality of briquettes is the duration of carbonization. Carbonization time can affect the volatile matter content of the briquette and may influence the quality of the briquette (Nurhalim et al., 2024). Volatile matter can be observed from the amount of smoke produced; the higher the volatile matter content, the more smoke will be generated (Anisa et al., 2025). Increasing the proportion of rice husk charcoal in the briquette raises its volatile matter content. While high volatile matter improves flammability and makes the briquette easier to ignite, it also shortens the burning duration. In general, higher volatility leads to greater reactivity and faster combustion. (Fachruzzaki et al., 2025).

Figure 9 shows that the longer the carbonization time, the lower the volatile matter in the briquettes. The test results ranged from 8.28% to 13.57%. Volatile matter was 8.28–13.57%, meeting SNI (<15%) and the U.S., U.K., and Japan export limits. This could result in the conversion of lignin-derived volatiles into more condensed products. Recent lignin-pyrolysis studies show that, given the significant influence of pyrolysis temperature and residence time, more severe conditions lead to greater transformation of phenolic monomers into light gases. Whereas active aromatic species present in bio-oils are transformed into biochar through repolymerization (Lu & Gu, 2022). Carbonization studies on coconut-shell briquettes indicate that extending the holding time reduces volatile matter and increases fixed carbon; for example, a 135 min hold at 400 °C lowered volatile matter to 25.65 % and raised fixed carbon to 71.55 % (Rusnadi et al., 2025).

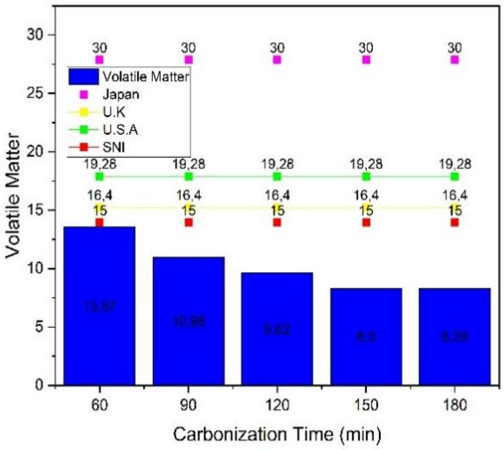

Figure 9. The Effect of Carbonization Time Variation with a Coconut Shell and Coffee Grounds Composition (9:1) on the Volatile Matter Content of Briquettes

The duration of carbonization is one of the factors that can affect briquette quality; the longer the carbonization time, the better the briquette quality, as it results in lower volatile matter and moisture content. (Mulyadin & Tanggasari, 2024). Briquette density is influenced by the uniformity of particle size and material composition. Additionally, the type and proportion of binder used also significantly affect the final density. (Gahana et al., 2025). Higher density typically indicates a more solid and durable briquette, often resulting from smaller particle sizes and stronger interparticle bonding. (Nurhilal et al., 2025). During carbonization, the release of volatile compounds forms pores and increases the effective surface area, which enhances ion storage capacity. However, if the carbonization time is too long, it can cause pore collapse, reducing both porosity and surface area (Patil et al., 2025).

Figure 10 shows densities of 0.74–0.77 g·cm⁻³, exceeding the U.K. export specification (0.48 g·cm⁻³) and surpassing the SNI threshold (>0.447 g·cm⁻³). These results indicate that the apparent density decreases and then remains relatively constant even as the hold time is extended. As temperature increases, the internal energy of the material also rises, allowing molecular segments to move and deform(Börcsök & Pásztory, 2021). This behavior arises because heating increases molecular motion and slighty further apart, thereby lowering density.

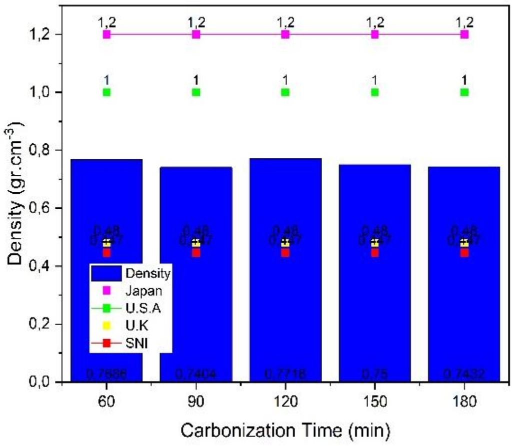

Figure 10. The Effect of Carbonization Time Variation with a Coconut Shell and Coffee Grounds Composition (9:1) on the Density Value of Briquettes.

The fixed carbon level depends on how much moisture, ash, and volatile matter are present in the material (Qanitah et al., 2023).Therefore, the fixed carbon content of the resulting briquettes is influenced by the levels of ash, volatile matter, and moisture content. (Crisdiantoro et al., 2025). A higher presence of moisture, ash, or volatile matter in the material leads to a lower fixed carbon content (Yana & Amborowati, 2024).

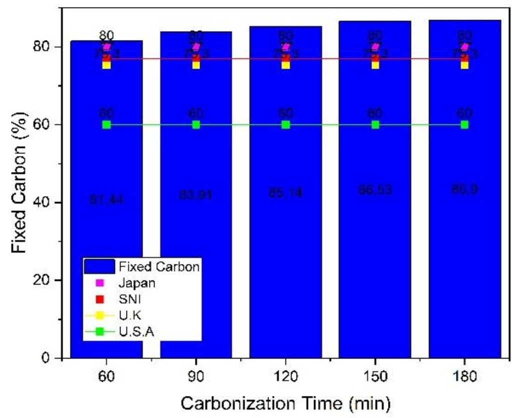

Figure 11. Effect of Carbonization Time Variation with a Coconut Shell and Coffee Grounds Composition (9:1) on the Fixed Carbon Content of Briquettes.

Figure 11. shows that the longer the carbonization time, the higher the fixed carbon content in the briquettes. This is because more volatile matter is removed as carbonization time increases. The fixed-carbon content ranged from 81.44% to 86.90%, meeting both Indonesian and export

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standards; the maximum (86.90%) occurred at 180 min of carbonization, and the minimum (81.44%) at 60 min. Consistent with general biochar characteristics, higher carbonization temperatures and longer holding times increase aromaticity and reduce polarity. These factors interact significantly and play a key role in determining both proximate and ultimate properties, including fixed carbon content. (Wijitkosum, 2023). A higher processing temperature reduces the volatile matter content of hydrochar, which in turn leads to an increase in fixed carbon percentage (Jie et al., 2023).

Calorific value shows how much energy a briquette gives when burned, and it's a key measure of briquette quality (Imam Ardiansyah et al., 2022). Calorific value is a key indicator of charcoal briquette quality. The higher the calorific value, the better the quality of the briquette. This value is influenced by the moisture and ash content of the charcoal briquette. (Irbah et al., 2022). Carbonization time has a significant effect on the calorific value of briquettes. Extended carbonization at higher temperatures specifically at 400 °C for 135 minutes reduces moisture content, ash content, and volatile matter, which in turn increases the calorific value of the briquette (Rusnadi et al., 2025), However, if carbonization time is too long or the temperature exceeds 600 °C, the briquette may degrade excessively, turning into ash. At such conditions, the biochar structure breaks down, leading to rapid carbon loss, increased ash content, and a reduction in overall carbon yield (Cárdenas-Aguiar et al., 2023) and high ash content can negatively impact the calorific value of briquettes. therefore, as ash content increases, the calorific value generally decreases. (Rashif et al., 2024).

In Figure 12, Calorific values were 25.99–27.21 $MJ.kg^{-1}$. All met SNI (>20.92 $MJ.kg^{-1}$), fit U.S. (>26.06 $MJ.kg^{-1}$) and Japan (25.10–29.29 $MJ.kg^{-1}$) export ranges, but not the U.K. (>30.52 $MJ.kg^{-1}$). The calorific value exhibited an increasing trend up to 90 minutes of carbonization, followed by a decline at longer residence times. This behavior can be attributed to the sequential thermal degradation of the main lignocellulosic components of biomass. Thermogravimetric analysis (TGA) has shown that these constituents decompose over distinct temperature ranges: hemicellulose typically degrades between 220–315 °C, cellulose between 300–400 °C, and lignin over a much broader range of 150–900 °C. (Waters et al., 2017). Hemicellulose, composed of simpler sugar units, decomposes at lower temperatures (220–315 °C), releasing volatile compounds. Cellulose breaks down at slightly higher temperatures (315–400 °C), while lignin due to its complex aromatic structure decomposes more gradually between 350–500 °C, significantly contributing to biochar formation (Loc & Phuong, 2025).

At 90 minutes of carbonization, the balance between volatile matter removal and carbon enrichment reaches its optimum, producing the maximum calorific value (27.21 $MJ.kg^{-1}$). Prolonged residence times (120–180 minutes), however, promote secondary degradation reactions, excessive devolatilization, and partial oxidation of the remaining carbon matrix. These processes increase ash content and decrease fixed carbon, thereby lowering the calorific value. Patil et al., (2025) reported that excessive carbonization degrades the carbon framework, leading to reductions in both energy density and specific capacitance, as prolonged heating causes structural collapse and the loss of active carbon. Similarly, Cárdenas-Aguiar et al., (2023) found that extended residence times (3 hours) at high temperatures (600 °C) during the production of vineyard-pruning biochar increased ash content and caused carbon loss, ultimately lowering the fixed carbon content and energy potential of the biochar.

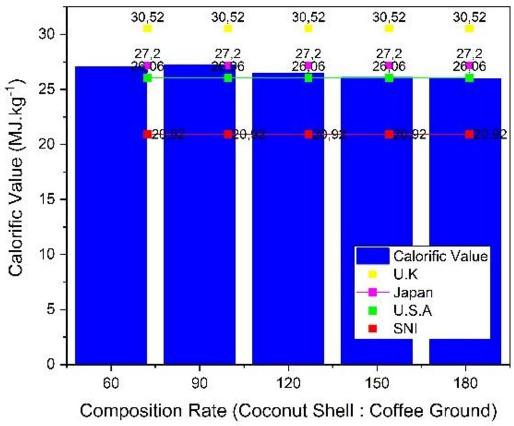

Figure 12. Effect of Carbonization Time Variation with a Coconut Shell and Coffee Grounds Composition (9:1) on the Fixed Carbon Value of Briquettes.

The CS–SCG briquettes produced in this study exhibited a calorific value of approximately 27 MJ kg^{-1}, comparable to that of mid-grade commercial briquettes commonly found in Indonesia. Typically, locally manufactured briquettes possess calorific values in the range of 21–31 MJ kg^{-1} (Berkarindo, 2025; Djavacoal, 2025; RibalBriquette, 2025). Increasing the fixed carbon content while reducing ash levels is therefore crucial to achieving the higher calorific values required to meet international briquette quality standards.

The results are compared with other biomass briquettes made from rice husk, coconut shell, sawdust/wood residues, and palm kernel shell (PKS), as shown in Table 1. The key properties—calorific value (CV), volatile matter (VM), fixed carbon (FC), and ash determine fuel quality. Higher FC and lower ash generally lead to higher CV, since FC provides energy while ash lowers combustion efficiency. The CS–SCG briquettes show moderate CV compared to coconut shell and PKS because of their lower FC and higher ash content. Their VM is similar to sawdust briquettes, indicating good ignition behavior. The binder used here serves only as an adhesive and has little effect on the fuel properties.

Table 1. Comparative Evaluation of Properties of Biomass Briquettes

Feedstock	CV (MJ.kg^{-1})	VM (%)	FC (%)	Ash (%)	Binder
Coconut Shell + Cinnamon sawdust (Madhusanka et al., 2025)	26.07-31.60	14.00-24.60	63.20-78.30	1.80-3.30	Cassava peel/Giant taro/starch /Pine resin
Coconut Shell + Spent Coffe Ground (The Present Study)	27.09-25.98	8.28-13.57	81.44-86.90	1.27-1.58	Tapioca Flour
Rice Husk + Coconut Shell (Jamilu Tanko et al., 2020)	14.77-17.85	-	-	27-36	Comart Starch
Coconut Shell + Sawdust (Fatimah et al., 2023)	21.51-26.74	49.89-68.57	8.74-33.79	-	Tapioca Flour
Palm Kernel Shell + Wood Sawdust + Coffee Grounds (Salim et al., 2024)	21.38-22.67	-	6.14-6.89	0.78-1.27	Starch
coconut shell + organic waste (Erdiyanto et al., 2024)	14.93-19.4	29.87-55.12	30.43-51.87	5.62-10.88	Tapioca Flour

4. Conclusions

This study demonstrated that a 9:1 blend of coconut shell to spent coffee grounds, carbonized at 300 °C for 90 minutes, yields briquettes with optimal fuel characteristics featuring a high calorific value of 27.21 MJ/kg, low moisture content (3.64%), low ash (1.49%), and high fixed carbon (83.91%). These results comply with both the Indonesian SNI 01-6235-2000 standard and relevant international specifications, confirming the potential of this formulation as an efficient and sustainable biofuel. Compared to conventional pyrolysis, the carbonization method employed in this study offers a simpler, more cost-effective, and energy-efficient alternative, making it especially suitable for small-scale and community-based biomass processing initiatives. The process requires minimal equipment, produces fewer emissions, and generates high-quality char ideal for briquette production. The integration of coconut shell and spent coffee grounds exemplifies an innovative dual-valorization strategy for managing Indonesia's abundant agricultural residues. Coconut shell contributes high calorific value and structural strength, while spent coffee grounds improve ignition properties and binder uniformity. This synergy results in briquettes that are both environmentally friendly and economically viable. These findings offer a practical model for scaling up briquette production using local resources. By optimizing carbonization parameters and feedstock ratios, this approach can be adapted for rural enterprises, promoting energy self-sufficiency and supporting Indonesia's transition toward renewable energy.

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