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Physical and Chemical Characterization of Briquettes Made from a Mixture of Butt Dust and Coconut Shell Charcoal Using Starch Binder

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ABSTRACT

The global energy crisis demands the development of alternative energy sources that are environmentally friendly and sustainable. One potential solution is the utilization of industrial waste and biomass into solid fuel in the form of briquettes. This study aims to evaluate the characteristics of briquettes made from industrial waste of PT. INALUM, namely butt dust, combined with coconut shell charcoal using starch as a binder. Five variations of butt dust and coconut shell charcoal compositions were tested, namely 100:0%, 80:20%, 60:40%, 40:60%, and 20:80%. Each variation was analyzed for ash content, moisture content, volatile matter, fixed carbon, density, and calorific value. The results showed that the raw material composition influenced the physical and chemical properties of the briquettes. Briquettes with a 100:0% ratio produced the best performance, with the highest calorific value of 9431.14 cal/g, density of 0.2324 g/cm³, ash content of 2.09%, moisture content of 4.22%, volatile matter of 11.0%, and fixed carbon of 82.7%. The addition of coconut shell charcoal tended to reduce calorific value and increase ash content. These findings confirm that butt dust has great potential as the main raw material for producing high-quality briquettes. Practically, the results support the utilization of industrial waste as an alternative energy source, contributing to national energy security while reducing environmental impacts.

Keywords: Biomass Briquettes, Butt Dust, Coconut Shell Charcoal, Physical and Chemical Properties, Sustainable Alternative Energy

ABSTRAK

Krisis energi global menuntut pengembangan sumber energi alternatif yang ramah lingkungan dan berkelanjutan. Salah satu solusi potensial adalah pemanfaatan limbah industri dan biomassa menjadi bahan bakar padat dalam bentuk briket. Penelitian ini bertujuan untuk mengevaluasi karakteristik briket yang dibuat dari limbah industri PT. INALUM, yaitu *butt dust*, yang dikombinasikan dengan arang tempurung kelapa menggunakan pati sebagai perekat. Lima variasi komposisi butt dust dan arang tempurung kelapa diuji, yaitu 100:0%, 80:20%, 60:40%, 40:60%, dan 20:80%. Setiap variasi dianalisis terhadap kadar abu, kadar air, zat menguap, karbon tetap, densitas, dan nilai kalor. Hasil penelitian menunjukkan bahwa komposisi bahan baku memengaruhi sifat fisik dan kimia briket. Briket dengan rasio 100:0% menghasilkan performa terbaik, dengan nilai kalor tertinggi sebesar 9431,14 kal/g, densitas 0,2324 g/cm³, kadar abu 2,09%, kadar air 4,22%, zat menguap 11,0%, dan karbon tetap 82,7%. Penambahan arang tempurung kelapa cenderung menurunkan nilai kalor dan meningkatkan kadar abu. Temuan ini menegaskan bahwa *butt dust* memiliki potensi besar sebagai bahan baku utama untuk menghasilkan briket berkualitas tinggi. Secara praktis, hasil penelitian ini mendukung pemanfaatan limbah industri sebagai sumber energi alternatif, yang berkontribusi terhadap ketahanan energi nasional sekaligus mengurangi dampak lingkungan.

Kata kunci: Arang Tempurung Kelapa, Briket Biomassa, *Butt Dust*, Energi Alternatif Berkelanjutan, Karakteristik Fisika dan Kimia

1. Introduction

The growing global demand for energy, driven by population growth, industrialization, and urbanization, has intensified the exploitation of fossil fuels such as coal, crude oil, and natural gas, which for decades have served as the backbone of energy systems due to their abundance and relatively low cost [1]. However, the finite nature of these resources and their adverse environmental impacts, including greenhouse gas emissions and pollution, have raised serious concerns regarding long-term energy security and sustainability [2]. In Indonesia, coal remains a dominant energy source owing to its vast reserves, yet its continued utilization requires more efficient and environmentally friendly strategies [3]. One promising approach to energy diversification is the conversion of coal-based industrial residues into alternative fuels. PT Indonesia Asahan Aluminium (PT. INALUM), which employs coal in the coking process to produce carbon anodes, generates waste in the form of butt dust, a fine black powder derived from the trimming of carbon anodes and combustion residues. With a fixed carbon content of up to 94.47%, butt dust is a promising candidate for solid fuel production. Despite PT. INALUM producing approximately 2 tons of butt dust daily, only 3–5% is recycled for re-anode production, leaving the majority underutilized and potentially harmful to the environment if unmanaged [4].

Previous studies have reported the production of briquettes from biomass sources such as sawdust, rice husk, palm shell, and coconut shell, yielding favorable calorific values and mechanical properties [5]-[7]. Other works have explored blending agricultural residues with coal or charcoal to enhance combustion efficiency and reduce emissions [8]-[10]. However, very limited research has addressed the direct utilization of industrial carbon residues, particularly butt dust, in briquette production. Moreover, the potential of combining butt dust with coconut shell charcoal a widely available agricultural byproduct in Indonesia has not been systematically studied. Coconut shells, often discarded or openly burned, can in fact provide high calorific value and substantial fixed carbon when carbonized, making them highly suitable for fuel applications [11].

The integration of butt dust and coconut shell charcoal in briquette production therefore represents a strategic approach to combining the advantages of two distinct waste materials into a more efficient and environmentally friendly fuel. While butt dust contributes high carbon content and structural stability, coconut shell charcoal provides excellent calorific value and combustion properties, and the use of natural starch as a binder enhances the mechanical strength of the briquettes without synthetic additives. This study aims to characterize the physical and chemical properties of briquettes made from varying ratios of butt dust and coconut shell charcoal using starch as a binder. Parameters evaluated include moisture content, ash content, volatile matter, fixed carbon, density, and calorific value. The findings are expected to support sustainable energy initiatives while addressing the dual challenge of industrial and agricultural waste management, thereby contributing to Indonesia’s energy diversification and environmental goals.

2. Materials and Methods

2.1. Raw Material Preparation

The primary raw material, butt dust, was obtained from the Carbon Division of PT. INALUM, Kuala Tanjung, North Sumatra, in the form of fine powder. To achieve uniform particle size, the material was sieved through a 100-mesh screen, followed by characterization to determine its moisture content, ash content, volatile matter, fixed carbon, and calorific value. Coconut shells were collected from coconut vendors at traditional market in Medan. After cleaning to remove residual fibers and impurities, the shells were carbonized in a furnace at 400°C for 5 hours to produce charcoal. The resulting charcoal was then ground with a disk mill and sieved using a 100-mesh screen to ensure homogeneity of particle size. Starch powder, purchased from local traditional markets, was used as a natural binder. It was dissolved in water to form a viscous solution that facilitated even distribution within the raw material mixture.

2.2. Mixing Ratios

The sieved butt dust and coconut shell charcoal were weighed and blended according to predetermined mixing ratios of 100%:0%, 80%:20%, 60%:40%, 40%:60%, and 20%:80%. Each batch of raw materials weighed 100 grams in total, ensuring consistency across treatments and facilitating precise comparisons among variations.

2.3. Briquette Production Process

The blended materials were mixed with 10% starch binder (by weight of the total raw material). The binder solution was gradually added and stirred until a homogeneous mixture was obtained. Briquettes were then molded using a hydraulic press equipped with a cylindrical mold (5 cm in diameter and 7 cm in height) under a pressure of 140 bar. The molded briquettes were sun-dried for three consecutive days, with an average daily exposure of six hours, to reduce moisture content and enhance durability.

2.4. Sample Size Justification

A batch size of 100 grams was selected as it allowed for manageable processing during molding while maintaining material uniformity. This weight was also adequate to produce briquettes of standard dimensions suitable for characterization, thereby ensuring comparability across experimental treatments.

2.5. Replication and Statistical Validity

To enhance the reliability of results, each composition ratio was produced in triplicate. This replication minimized experimental bias and provided a sufficient data set for robust statistical analysis. The characterization data were subsequently analyzed using Analysis of Variance (ANOVA) to evaluate the effect of composition ratios on the physical and chemical properties of the briquettes. The results were presented in graphical form to highlight differences among treatments and identify the optimal formulation.

3. Results and Discussions

This study examines two primary raw materials used in briquette production: butt dust and coconut shell charcoal. Each material possesses distinct characteristics; therefore, it is necessary to conduct testing to determine their chemical and physical components, including moisture content, ash content, volatile matter, fixed carbon, and calorific value.

3.1. Results and Characteristics of Butt Dust

The butt dust used in this study was obtained from anode waste at PT INALUM, which is composed of coke, butt, and coal tar pitch as a binder [12]. The characterization of the butt dust included tests for moisture content, ash content, volatile matter, fixed carbon, and calorific value [13]. The results of the butt dust analysis are presented in Table 1.

Table 1. Characterization test results of butt dust.

No	Test Parameters	Characterization Results
1	Moisture Content (%)	0.58
2	Ash Content (%)	1.21
3	Volatile matter (%)	58.4
4	Fixed Carbon (%)	96.7
5	Calorific Value (cal/g)	11598.55

3.2. Results and Characteristics of Coconut Shell Charcoal

Coconut shells, or shell charcoal, were first cleaned to remove any fibers and attached impurities. The carbonization process was then carried out to convert the shells into charcoal. This was done by directly burning the coconut shells in a combustion furnace for approximately 6 hours at a temperature of 400°C until fully carbonized. The resulting charcoal was then ground using a disk mill, and to ensure uniform particle size, it was sieved using a 100-mesh screen. The test results for the coconut shell charcoal are presented in Table 2.

Table 2. Characterization test results of coconut shell charcoal.

No	Test Parameters	Characterization Results
1	Moisture Content (%)	6.08
2	Ash Content (%)	6.98
3	Volatile matter (%)	17.8
4	Fixed Carbon (%)	69.2
5	Calorific Value (cal/g)	9255.41

3.3. Characterization Results of Briquettes Made from a Mixture of Butt Dust Charcoal and Coconut Shell Charcoal

This study examined five distinct briquette compositions with mixing ratios of 100:0, 80:20, 60:40, 40:60, and 20:80, representing the proportions of butt dust charcoal to coconut shell charcoal. Photographs of these five variations are provided in Appendix 2 for visual reference. Each composition underwent a comprehensive series of tests to evaluate its physical and chemical properties, including moisture content, ash content, volatile matter, fixed carbon, and calorific value [13]. The detailed characterization results of the briquettes are summarized in the Table 3.

Table 3. Characterization test results of briquettes made from a mixture of butt dust charcoal and coconut shell charcoal.

Test Parameters	SNI 01-6235-2000	Composition Variations of Butt Dust Charcoal : Coconut Shell Charcoal (%)				
		100:0	80:20	60:40	40:60	20:80
Ash Content (%)	Max 8%	2.09	2.25	2.57	3.42	5.24
Moisture Content (%)	Max 8%	4.22	8.63	11.0	11.4	12.4
Volatile Matter (%)	Max 15%	11.0	16.0	21.9	32.4	32.5
Fixed Carbon (%)	Min 77%	82.7	73.1	64.6	52.8	49.8
Density (g/cm^2)	-	0.2324	0.2413	0.2509	0.2485	0.2401
Calorific Value (cal/g)	Min 5000	9431.14	10426.98	10091.44	10134.09	8611.04

Based on the test results shown in Table 3, the experimental results demonstrate that variations in the composition of butt dust charcoal and coconut shell charcoal exert a significant influence on the quality of the briquettes produced. Analysis of Variance (ANOVA) confirmed that mixing ratios had a statistically significant effect ($p < 0.05$) on moisture content, ash content, volatile matter, fixed carbon, density, and calorific value, underscoring the central role of raw material proportions in determining briquette performance.

The 100:0 composition (100% butt dust charcoal) exhibited the best overall quality. With an ash content of 2.09% and a relatively low moisture content of 4.22%, this formulation indicates efficient combustion potential. Furthermore, its calorific value reached 9431.14 cal/g, far exceeding the Indonesian National Standard (SNI) minimum requirement of 5000 cal/g. The fixed carbon level, as high as 82.7%, reflects superior combustion efficiency and extended burning duration, making this composition particularly suitable for sustainable energy applications. These findings are consistent with previous studies emphasizing the direct contribution of high carbon content to enhanced combustion stability and calorific performance [5]-[7].

In contrast, increasing the proportion of coconut shell charcoal, particularly in the 20:80 composition, resulted in a marked decline in quality. The moisture content rose to 12.4%, exceeding the SNI maximum threshold, thereby reducing combustion efficiency. The volatile matter content also increased substantially to 32.5%, more than double the SNI limit of 15%, leading to less stable combustion and potentially higher emissions. Although this composition still satisfied the minimum calorific value requirement (8611.04 cal/g), its overall performance was significantly lower than the 100:0 composition. These results corroborate earlier research showing that elevated volatile matter levels can compromise combustion stability while increasing emission levels [8]-[10].

The highest density was recorded in the 60:40 composition at 0.2509 g/cm^3, indicating enhanced compaction with increasing coconut shell content. However, density alone does not fully correlate with combustion quality, as elevated moisture and volatile matter levels can offset the benefits of higher compaction.

From a practical perspective, these findings carry important implications for both industrial and agricultural waste utilization. Firstly, employing 100% butt dust charcoal offers a high-value pathway for recycling industrial carbon residues into premium alternative fuels. Secondly, while coconut shell charcoal holds promise as a supplementary material, its use must be carefully optimized to prevent quality degradation. Overall, integrating butt dust and coconut shell charcoal into briquette production supports energy diversification strategies while simultaneously addressing waste management challenges, aligning with Indonesia's broader goals for sustainable energy transition.

3.4. Ash Content

In the combustion process, there is a residue that no longer contains carbon, referred to as ash. Silica is the main component of ash that negatively affects the calorific value of briquettes [14]. The high ash content causes the quality of the briquettes to decrease. This occurs because the high ash content can lower the calorific value of charcoal briquettes. The ash content produced in this study is shown in Figure 1.

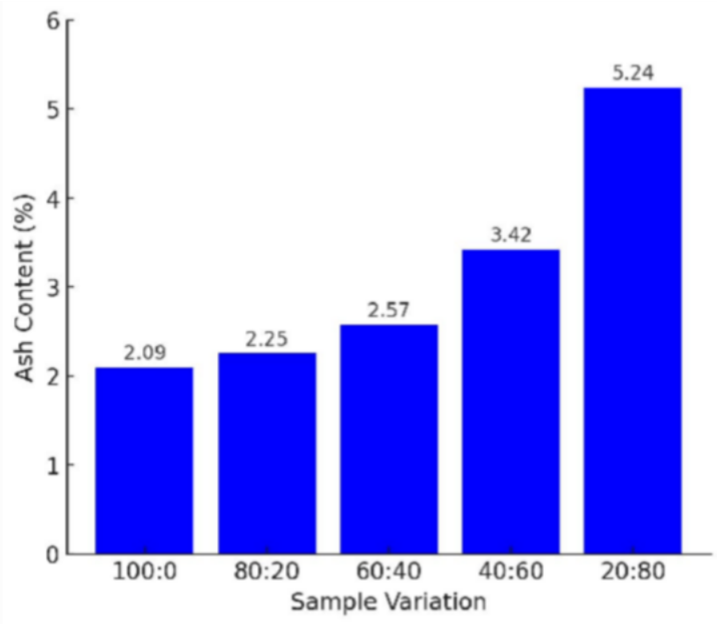

Figure 1. Graph of briquette ash content test results.

In Figure 1, it can be seen that the ash content in each sample variation increased as the proportion of coconut shell charcoal increased. The variation with a composition of 100:0 (100% butt dust charcoal) showed the lowest ash content, which was 2.09%. Next, the variations with 80:20 and 60:40 had slightly higher ash contents, 2.25% and 2.57%, respectively. In the 40:60 variation, the ash content increased to 3.42%, and in the 20:80 variation (80% coconut shell charcoal), the ash content reached 5.24%, the highest ash content among all sample variations. This increase in ash content indicates that adding more coconut shell charcoal in the briquette mixture results in a higher ash residue after combustion. Although the 100:0 variation shows the lowest ash content, the variations with more coconut shell (20:80 composition) tend to show an increase in ash content, which may affect the combustion efficiency and the combustion residue of the briquettes.

The amount of coconut shell charcoal added to the briquette mixture causes an increase in the briquette's ash content. This is influenced by the initial testing of the raw materials, where coconut shell charcoal has a higher ash content than butt dust charcoal. Coconut shell charcoal contains 6.98% ash, while butt dust charcoal only contains 1.21%. Additionally, the ash content is also influenced by the type of binder used [8]. Ash content is directly proportional to the amount of inorganic material present in the materials used in the production of charcoal briquettes. The inorganic substances found in the briquettes come from butt dust, starch, and coconut shells, such as silica (SiO_2), MgO, Fe_2O_3, AlF_2, MgF_2, and Fe [15].

3.5. Moisture Content

The quality of charcoal briquettes is greatly influenced by their moisture content. The calorific value will increase if the moisture content of the briquettes is low. In this study, the moisture content obtained is presented in Figure 2. In Figure 2, it shows that the moisture content in various briquette sample variations increases as the proportion of coconut shell charcoal in the briquette mixture increases. The briquette variation with a composition of 100:0 (100% butt dust charcoal) has the lowest moisture content, which is 4.22%. Then, in the 80:20 variation, the moisture content slightly increases to 8.63%. The moisture content continues to rise in the 60:40 variation, with a moisture content of 11%, and in the 40:60 variation, the moisture content increases to 11.4%. The variation with a 20:80 composition (80% coconut shell charcoal) shows the highest moisture content, which is 12.4%.

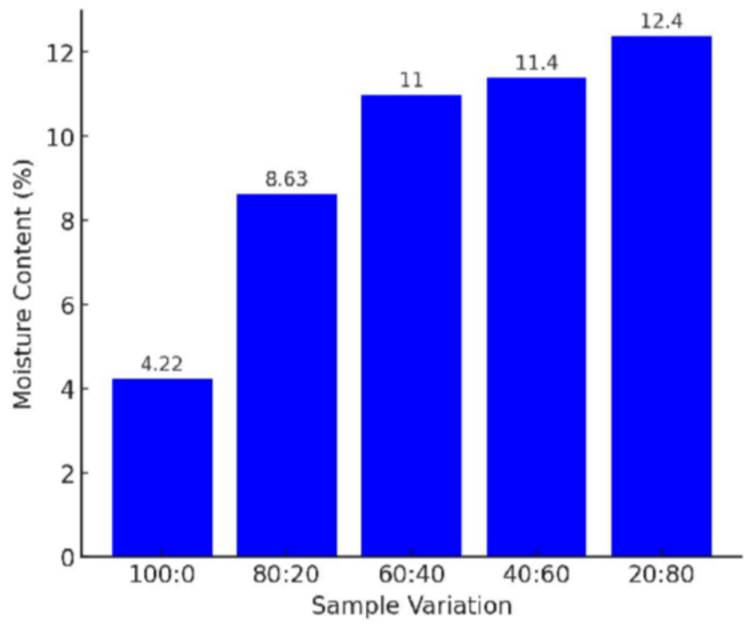

Figure 2. Graph of briquette moisture content test results.

Figure 2 shows a fundamental increase in moisture content as the proportion of coconut shell charcoal increases. This is due to the higher moisture content in the biomass and its higher water absorption capacity compared to butt dust, which has a lower moisture content. This is consistent with the initial tests of the raw materials, which show that coconut shell charcoal has a moisture content of 6.08%, while butt dust has a moisture content of 0.58%. Therefore, the 20:80 variation has higher moisture content compared to other variations. Similarly, the high moisture content is also caused by the addition of starch as a binder.

This increase in moisture content indicates that the higher the proportion of coconut shell charcoal in the briquette mixture, the higher the moisture content in the briquette. Higher moisture content in the briquettes can affect combustion efficiency because briquettes with higher moisture content tend to require more energy to evaporate the water before optimal combustion can occur. Therefore, the 100:0 variation (100% butt dust charcoal) shows the best performance in terms of moisture content, with a low humidity level and more efficient combustion.

3.6. Volatile Matter

Substances that evaporate due to heating as a result of the decomposition of materials in charcoal, other than water, are referred to as volatile matter. High volatile matter in charcoal briquettes produces more smoke when the briquettes are burned [14]. The volatile matter results are presented in Figure 3.

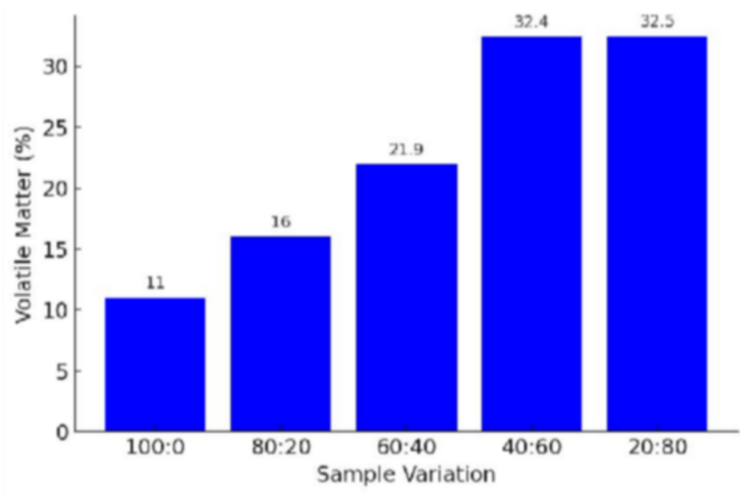

Figure 3. Graph of briquette volatile matter test results.

In Figure 3, the 100:0 composition variation (100% butt dust charcoal) shows the lowest volatile matter content, which is 11%. As the proportion of coconut shell charcoal is added, the volatile matter content increases gradually. The 80:20 composition variation has a volatile matter content of 16%, while the 60:40 composition variation shows a further increase to 21.9%. In the 40:60 variation, the volatile matter content reaches 32.4%, and in the 20:80 composition variation (80% coconut shell charcoal), the volatile matter content is slightly higher, at 32.5%. This increase in volatile matter content indicates that adding coconut shell charcoal to the briquette mixture increases the content of volatile substances, which can affect the combustion characteristics of the briquettes. The more coconut shell charcoal is added, the higher the volatile matter content in the briquettes. This suggests that variations with a higher proportion of coconut shell charcoal, such as 40:60 and 20:80, tend to produce briquettes with faster combustion properties, but this may affect combustion stability. In contrast, the 100:0 composition variation, which contains more butt dust charcoal, shows lower values in the volatile matter parameter, indicating a more controlled and longer-lasting combustion.

The perfection of the carbonization process determines the amount of volatile matter. Imperfections in the carbonization process lead to an increase in volatile matter. The duration of carbonization and temperature also affect the volatile matter content; the higher the temperature during carbonization, the lower the volatile matter content will be [14].

3.7. Fixed Carbon

The presence of ash and the content of volatile substances affect the amount of fixed carbon content. Low ash content and low volatile matter content result in an increased fixed carbon content. A good charcoal briquette is expected to have a high fixed carbon content [16]. The results of the fixed carbon test in this study are presented in Figure 4.

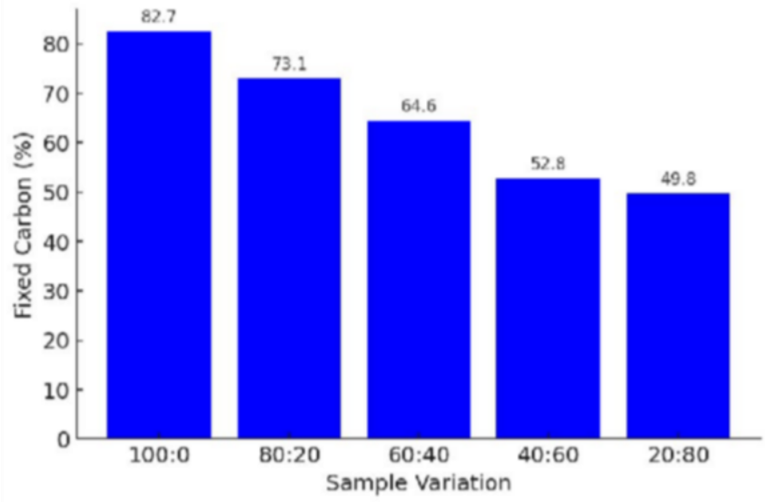

Figure 4. Graph of briquette fixed carbon test results.

In Figure 4, the changes in fixed carbon content in the briquettes produced from five different composition variations of butt dust charcoal and coconut shell charcoal are shown. The 100:0 composition variation (100% butt dust charcoal) has the highest fixed carbon content, which is 82.7%. As the proportion of coconut shell charcoal is added to the mixture, the fixed carbon content decreases gradually. The 80:20 composition variation has a fixed carbon content of 73.1%, and the 60:40 composition variation shows a lower fixed carbon content of 64.6%. In the 40:60 variation, the fixed carbon content further decreases to 52.8%, and the 20:80 composition variation (80% coconut shell charcoal) shows the lowest fixed carbon content of 49.8%. The decrease in fixed carbon content as the proportion of coconut shell charcoal increases indicates that the higher the proportion of coconut shell charcoal, the lower the fixed carbon content in the resulting briquettes. The high fixed carbon content in the 100:0 variation suggests that these briquettes have the potential for more efficient and longer- lasting combustion, as fixed carbon is the main component that generates energy during the combustion process. On the other hand, in variations with a higher coconut shell charcoal content, such as the 20:80 composition, although the fixed carbon content is lower, these briquettes can still serve as an effective alternative energy source, even though their combustion efficiency may slightly decrease.

3.8. Density

To measure the mass per unit volume of an object, a density test is conducted. The size and homogeneity of the briquette components affect the density values. Density testing has been carried out on all briquette sample variations. The results of the briquette density tests for all variations are shown in Figure 5.

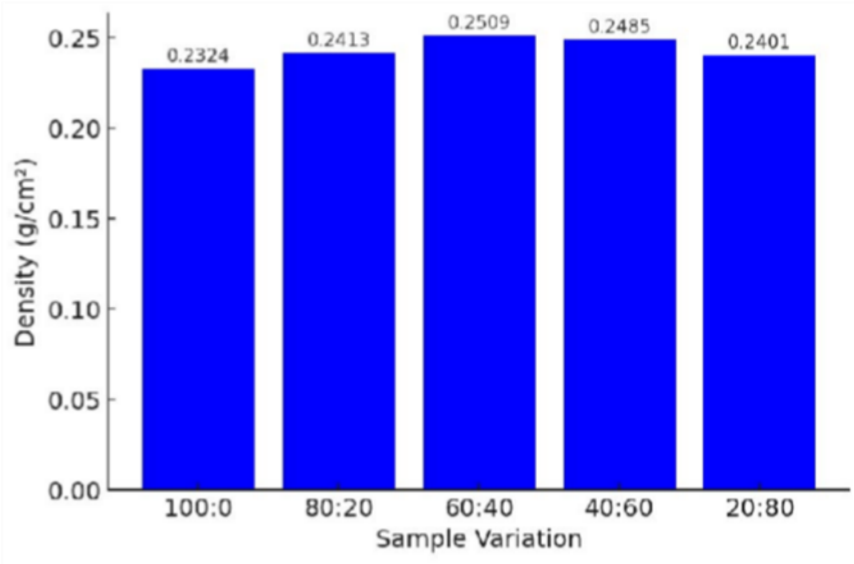

Figure 5. Graph of briquette density test results.

In Figure 5, it can be seen that the density of the briquettes remains relatively constant across all sample variations tested. The briquette variation with a 100:0 composition (100% butt dust charcoal) has a density of 0.2324 g/cm², which is slightly lower compared to the other variations. The 80:20 composition variation shows a density of 0.2413 g/cm², while the 60:40 composition variation has a density of 0.2509 g/cm², the highest density among all sample variations. In the 40:60 variation, the density slightly decreases to 0.2485 g/cm², and the 20:80 composition variation shows a density nearly the same as the 100:0 variation, at 0.2401 g/cm². Although there is a slight variation in density across the samples, the differences are not significant, which suggests that adding a higher proportion of coconut shell charcoal does not have a major effect on the briquette's density. Overall, the density of the briquettes in all sample variations lies within a relatively similar range, with small fluctuations between 0.2324 and 0.2509 g/cm². This indicates that the variation in the composition of butt dust charcoal and coconut shell charcoal does not significantly impact the briquette density, suggesting that all briquette variations have nearly uniform compression.

3.9. Calorific Value

To determine the combustion heat value generated by charcoal briquettes, the calorific value calculation is conducted [14]. The most important quality parameter for charcoal briquettes as a fuel material is the calorific value, making it a key determinant of the quality of the produced charcoal briquettes. The raw materials used also have a significant impact on the calorific value. Butt dust has a higher calorific content than coconut shell charcoal. The results of the calorific value tests for the five variations of the briquettes are presented in the diagram in Figure 6.

In Figure 6, it shows the calorific value generated by various briquette sample variations made from a combination of butt dust charcoal and coconut shell charcoal. The 100:0 composition variation (100% butt dust charcoal) produces a calorific value of 9431.14 cal/g. The 80:20 variation shows a slightly higher calorific value, which is 10426.98 cal/g. The calorific values for the 60:40, 40:60, and 20:80 compositions are 10091.44 cal/g, 10134.09 cal/g, and 8611.04 cal/g, respectively. From this graph, it can be observed that the 100:0 composition variation has a relatively high calorific value, but variations with a higher proportion of coconut shell charcoal (80:20 and 40:60 compositions) show a slight increase in calorific value. This indicates that adding coconut shell charcoal to the briquette mixture can enhance the energy content that can be produced per unit mass of the briquette. However, the 20:80 composition variation, which contains more coconut shell charcoal, shows a decrease in calorific value to 8611.04 cal/g. Although it still meets the acceptable calorific value standards for use as fuel, the calorific value in this variation is lower compared to others. This may be due to the lower fixed carbon content in the mixture with a higher proportion of coconut shell charcoal. Overall, the highest calorific value is found in the 80:20 composition variation, which contains 80% coconut shell charcoal, indicating that this composition ratio provides the optimal result in terms of the energy produced.

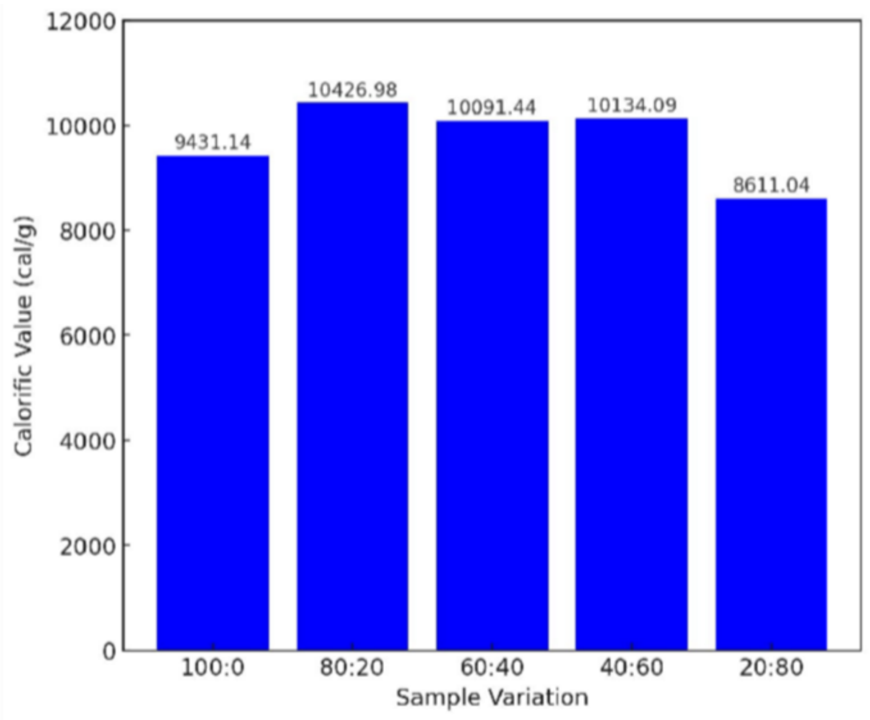

Figure 6. Graph of briquette calorific value test results.

4. Conclusion

The results of this study demonstrate that variations in the mixing ratio of butt dust charcoal and coconut shell charcoal significantly affect both the physical and chemical properties of briquettes. Increasing the proportion of coconut shell charcoal leads to higher density and a fluctuating yet generally rising calorific value. On the other hand, higher coconut shell content increases moisture, ash, and volatile matter, while reducing fixed carbon content. These findings suggest that optimal formulations must carefully balance the two materials to maximize energy performance while maintaining compliance with quality standards.

For future research, scalability tests under industrial production conditions and combustion performance evaluations in real-world applications are recommended. Such efforts would provide deeper insights into the practical potential of these briquettes as a sustainable alternative energy source, particularly in supporting Indonesia's clean energy transition and integrated waste management strategies.

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