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Utilization of PT INALUM Baking Filter Dust Waste and Coconut Shell Charcoal in Making Hybrid Briquettes

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ABSTRACT

The global energy crisis and dependence on fossil fuels require the search for renewable and environmentally friendly energy sources. The smelter industry of PT INALUM produces Baking Filter Dust (BFD) as waste, which can pollute the environment if not properly managed. Meanwhile, coconut shells, an abundant agricultural waste, hold potential as an alternative fuel. This research aims to develop hybrid briquettes from BFD and coconut shell charcoal, according to SNI No.01-6235-2000 standards. The study involved collecting and preparing BFD from PT INALUM and coconut shell charcoal, producing briquettes with varying ratios from 20% BFD: 80% charcoal to 80% BFD: 20% charcoal. The quality of the briquettes was tested through proximate and ultimate analyses, with characterization using XRF, FTIR, SEM-EDS, and TGA to determine elemental content, functional groups, structure, chemical composition, and thermal stability. The results indicated that briquettes with 60% BFD and 40% coconut shell charcoal exhibited the highest quality, with a calorific value of 6557.3 cal/g, fixed carbon content of 86.2%, ash content of 3.38%, moisture content of 3.22%, volatile matter content of 7.2%, and sulfur content of 0.47%. These briquettes meet SNI No.01-6235-2000 standards and provide a viable solution for managing industrial waste and supplying sustainable alternative fuel.

Keywords: Baking Filter Dust, Biomass, Coconut Shell Charcoal, Hybrid Briquettes, Renewable Energy

ABSTRAK

Krisis energi global dan ketergantungan pada bahan bakar fosil memerlukan pencarian sumber energi terbarukan dan ramah lingkungan. Industri smelter PT INALUM menghasilkan *Baking Filter Dust* (BFD) sebagai limbah, yang dapat mencemari lingkungan jika tidak dikelola dengan baik. Sementara itu, tempurung kelapa, sebagai limbah pertanian yang melimpah, memiliki potensi sebagai bahan bakar alternatif. Penelitian ini bertujuan untuk mengembangkan briket hibrida dari BFD dan arang tempurung kelapa, sesuai dengan standar SNI No.01-6235-2000. Penelitian ini melibatkan pengumpulan dan persiapan BFD dari PT INALUM serta arang tempurung kelapa, dengan pembuatan briket dalam berbagai rasio dari 20% BFD: 80% arang hingga 80% BFD: 20% arang. Kualitas briket diuji melalui analisis proksimat dan ultimate, serta karakterisasi menggunakan XRF, FTIR, SEM-EDS, dan TGA untuk menentukan kandungan unsur, gugus fungsi, struktur, komposisi kimia, dan stabilitas termal. Hasil penelitian menunjukkan bahwa briket dengan komposisi 60% BFD dan 40% arang tempurung kelapa memiliki kualitas tertinggi, dengan nilai kalor 6557.3 cal/g, kandungan karbon terikat 86.2%,

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kandungan abu 3.38%, kandungan air 3.22%, kandungan zat terbang 7.2%, dan kandungan sulfur 0.47%. Briket ini memenuhi standar SNI No.01-6235-2000 dan memberikan solusi yang efektif untuk mengelola limbah industri serta menyediakan bahan bakar alternatif yang berkelanjutan.

Kata kunci: Arang Tempurung Kelapa, Baking Filter Dust, Biomassa, Briket Hibrida, Energi Terbarukan

1. Introduction

The fulfillment of human needs for energy resources cannot forever rely on the existence of petroleum. Using biomass is a wise solution to address the current energy crisis problems. The scarcity and rising prices of oil will continue to occur due to its non-renewable nature. Therefore, it is necessary to balance this with the provision of alternative energy sources that are renewable, abundant, and cheap, making them affordable for the entire society [1]. Indonesia has many renewable alternative energy sources, including biomass or organic waste. Potential biomass includes agricultural waste, industrial waste, and domestic waste. For example, biomass can be converted and used as an alternative fuel by making briquettes. Briquettes have economic advantages because they can be produced simply, have a high calorific value, and are easily obtainable in Indonesia, making them competitive with other fuels [2].

Biomass is a renewable resource, and its energy is called renewable energy. The ideal type of biomass has lost its main product. The potential biomass in Indonesia that can be utilized for energy generation is available from agricultural, plantation, forest, industrial, and livestock waste. Biomass for energy has the highest value due to its renewable and sustainable characteristics, can be stored, replaced, and transported, has high availability, and is carbon neutral. Biomass-derived from waste (plantation, agricultural, forest, and livestock) and industrial waste can become an environmentally friendly alternative energy source because biomass comes from non-fossil organic materials that produce non-polluting CO_2 from combustion [3].

One type of biomass that can be used as a briquette mixture is baking filter dust (BFD) and coconut shell. The smelter industry PT. Indonesia Asahan Aluminium (INALUM) produces BFD as a by-product of the methylene blue (MB) adsorption process. Unfortunately, this BFD often becomes waste that can pollute the environment if not managed properly. A sustainable solution to utilize this BFD is to make hybrid briquettes. Coconut shell is a solid waste product from coconut processing, extracted from its meat to obtain coconut milk. Coconut shell is often used as fuel for household purposes. Indonesia is one of the largest coconut-producing countries in the world, with coconuts growing evenly in Java, Sumatra, Kalimantan, Sulawesi, and Irian Jaya [4]. Coconut shells used to make briquettes must be old, dry, and free of dirt, such as soil fibers or other impurities, as these will affect the pyrolysis process and the quality of the briquettes. Wet shells will produce too much smoke during carbonization [5]. The use of coconut shell briquettes is a solution to utilize alternative energy sources and reduce environmental pollution. Therefore, efforts are needed to increase public understanding and awareness of the production and utilization of coconut shell briquettes as a renewable energy substitute [6].

Hybrid briquettes are solid fuels made by mixing organic materials such as biomass (e.g., coconut shells, sawdust, or agricultural waste) with inorganic materials or industrial waste such as BFD from the smelter industry [7]. The primary purpose of making hybrid briquettes is to increase calorific value and combustion efficiency and reduce pollutant emissions compared to conventional briquettes [8]. Hybrid briquettes have several advantages over ordinary charcoal briquettes. First, hybrid briquettes generate higher combustion heat due to the higher energy content of their mixed materials [9]. Second, the smoke emissions produced are less, making them more environmentally friendly [3]. Third, the shape and size of hybrid briquettes are more uniform as they are made using special molds, allowing for design variations according to needs [10].

In addition, the process of making hybrid briquettes is quite simple and can be applied to household and small-scale industries. The adhesive commonly used is tapioca starch solution, which aids in the pressing and compression process of the briquettes [7]. The quality testing parameters for briquettes include moisture content, volatile matter content, ash content, sulfur content, fixed carbon content, and calorific value. These tests are essential to ensure that the produced briquettes meet quality and efficiency standards [8].

The production of hybrid briquettes must meet SNI No.01-6235-2000 standards, including a calorific value (minimum 500 cal/g), moisture content (maximum 8%), ash content (maximum 8%), volatile matter content (maximum 15%), and fixed carbon content (minimum 77%) [11]. Making hybrid briquettes is easy and can be carried out by home industries. These briquettes are a relatively economical alternative fuel and can be a choice for the general public, with raw materials that are easy to obtain and affordable. Briquettes are used for cooking and various other needs. Charcoal briquettes have several advantages over LPG gas and kerosene: safer, cheaper, and easier to use. With the high production of charcoal briquettes domestically, it is expected that new business opportunities will emerge, such as the manufacture of briquette stoves, which will automatically increase employment opportunities and improve the standard of living of the community as well as help the government reduce LPG gas imports.

2. Research Method

This research was conducted at the Healthy Briquette House of Mrs. Ir. Rena Arifah, M.Si, on Jl. Mandala, North Sumatra, Medan. The study was carried out through several stages, including collecting and preparing materials in the form of Baking Filter Dust (BFD) collected from PT INALUM and sieved using a 100 mesh sieve. Coconut shells were taken from coconut measuring shops, cleaned, and then burned in a furnace at a temperature of 850°C for 5 hours until they became charcoal, which was then crushed. BFD and coconut shell charcoal were mixed in various ratios (20% : 80%, 30% : 70%, 40% : 60%, 50% : 50%, 60% : 40%, 70% : 30%, 80% : 20%) and mixed with an adhesive from a tapioca flour solution. This mixture was then compacted using a high-pressure machine to form briquettes with 140 bars. The hybrid briquettes produced were then dried for 3 days under the sun, and the dried hybrid briquettes were tested for proximate and ultimate analysis to determine moisture content, ash content, carbon content, sulfur content, volatile matter, and calorific value according to the SNI No.01-6235-2000 standard. The best hybrid briquette test results were analyzed using XRF, FTIR, SEM-EDS, and TGA techniques to determine the elemental content, functional groups, structure, chemical composition, and thermal stability.

Moisture content was determined using the calculation formula of SNI 13-3477-1994:

$$M\ (\%) = \frac{m_2 - m_3}{m_2 - m_1} \text{ x } 100\ \% \tag{1}$$

Ash content was determined using the calculation formula of SNI 13-3478-1994:

$$A\ (\%) = \frac{m_3 - m_1}{m_2} \text{ x } 100\ \% \tag{2}$$

Volatile matter content was determined using the calculation formula of SNI 13-3999-1995:

$$VM\ (\%) = \frac{m_2 - m_3}{m_2 - m_1} \text{ x } 100\ \% - M \tag{3}$$

Fixed carbon content was determined using the calculation formula of SNI 13-3479-1994:

$$FC\ (\%) = 100\ \% - (M - A - VM)\% \tag{4}$$

The Calorific Value was determined using the calculation formula of ASTM D240:

$$\text{Nilai Kalor (kal/g)} = (T_2 - T_1 - 0{,}05)\ x\ Cv\ x\ 0{,}239 \text{ kal} \tag{5}$$

where M is moisture content (%), VM is volatile matter content (%), A is Ash Content (%), FC is fixed carbon content (%), m_1 is the weight of the crucible (g), m_2 is the weight of the crucible and charcoal before heating (g), m_3 is the weight of the crucible and charcoal after heating (g), T_1 is Temperature of cooling water before ignition (°C), T_2 is Temperature of cooling water after ignition final temperature (°C), Cv is specific heat of bomb calorimeter (73529.6 J/g°C) and 0.05°C is temperature rise due to igniter wire 0.05°C.

3. Results and Discussion

3.1. Proximate and Ultimate Tests of Hybrid Briquettes from Baking Filter Dust and Coconut Shell Charcoal

Table 1 shows the results of the proximate and ultimate tests of hybrid briquettes made from a mixture of Baking Filter Dust (BFD) and coconut shell charcoal with various composition ratios meeting the Indonesian National Standard (SNI) No.01-6235-2000. Data analysis shows that the ash content is relatively constant at around 4%, except for the 60%:40% ratio (BFD and coconut shell charcoal) which has the lowest ash content of 3.38%. The moisture content also varies between 3.22% and 4.75%, with the lowest value at the 60%:40% composition. This indicates that mixtures with a higher coconut shell content tend to have lower moisture content, which is desirable for briquette fuel. Furthermore, the highest carbon content was found in the 60%:40% ratio, reaching 86.2%, indicating high energy potential. Sulfur content varies slightly, with the highest value being 0.68% at the 80%:20% ratio. Volatile matter decreases with increasing BFD proportion, with the lowest value of 7.2% at the 60%:40% ratio. The calorific value or energy content also increases with the increasing proportion of BFD, with the highest value of 6557.3 cal/g at the 60%:40% ratio. These results indicate that 60% BFD and 40% coconut shell composition provides the best energy efficiency and combustion performance, making it the optimal choice for these hybrid briquettes.

Table 1. Results of Proximate and Ultimate Tests of Hybrid Briquettes from Baking Filter Dust and Coconut Shell Charcoal

Composition of Hybrid Briquettes from Baking Filter Dust and Coconut Shell	Ash Content (%)	Moisture Content (%)	Carbon Content (%)	Sulfur Content (%)	Volatile Matter (%)	Calorific Value (cal/g)
20 % : 80 %	4.69	4.67	77.94	0.50	12.7	5170.2
30 % : 70 %	4.74	4.26	78.9	0.52	12.1	5867.8
40 % : 60 %	4.88	4.37	79.55	0.53	11.2	6010.8
50 % : 50 %	4.11	4.75	79.64	0.56	11.5	6129.6
60 % : 40 %	3.38	3.22	86.2	0.47	7.2	6557.3
70 % : 30 %	4.21	4.10	80.59	0.64	11.1	6218.9
80 % : 20 %	4.12	4.25	80.33	0.68	11.3	6321.4

3.2. Ash Content Test

Figure 1 shows the ash content (%) of various hybrid briquette compositions consisting of a mixture of BFD and coconut shell charcoal, with the results as follows: the composition of 60% BFD and 40% coconut shell charcoal produced the lowest ash content (3.38%), while the composition of 40% : 60% produced the highest ash content (4.88%). A balanced ratio (50% : 50%) also showed good results, with an ash content of 4.11%. Increasing the proportion of baking filter dust above 60% tends to increase the ash content, indicating an optimal limit in using BFD to minimize ash content. Therefore, 60% : 40% can be considered the best composition for reducing ash content, whereas a mixture with more BFD and less coconut shell charcoal effectively reduces ash content.

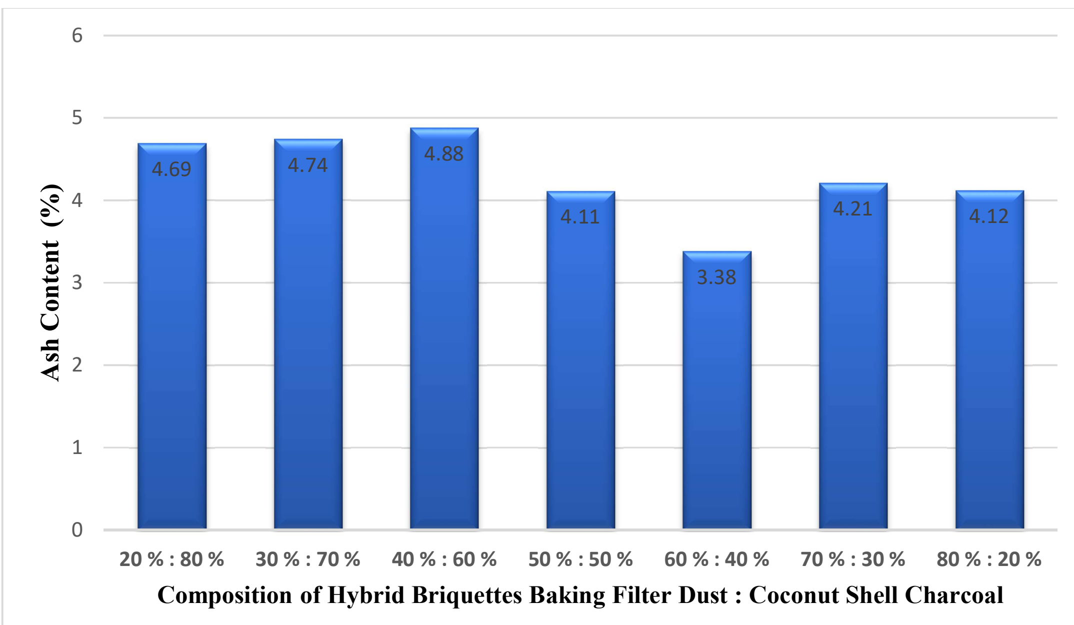

Figure 1. Ash Content of the fabricated hybrid briquettes.

3.3. Moisture Content Test

Figure 2 shows hybrid briquettes' moisture content (%) with various compositions between BFD and coconut shell charcoal. The graph shows that the highest moisture content is found in the 50%: 50% composition, with a value of 4.75%, while the lowest moisture content is in the 60%: 40% composition, with a value of 3.22%. The other moisture contents range from 4.67% to 4.1%, showing significant variation among the tested compositions. This data analysis indicates that differences in raw material composition affect the moisture content in hybrid briquettes. The 50%: 50% composition has the highest moisture content, which may indicate a stronger interaction between Baking Filter Dust and coconut shell charcoal in absorbing moisture. Conversely, the 60%: 40% composition shows the lowest moisture retention ability, which may suggest that a higher proportion of coconut shell charcoal reduces the capacity to absorb water. This provides important insights into determining the optimal composition for hybrid briquettes that can minimize moisture content, which is generally desired to improve combustion efficiency.

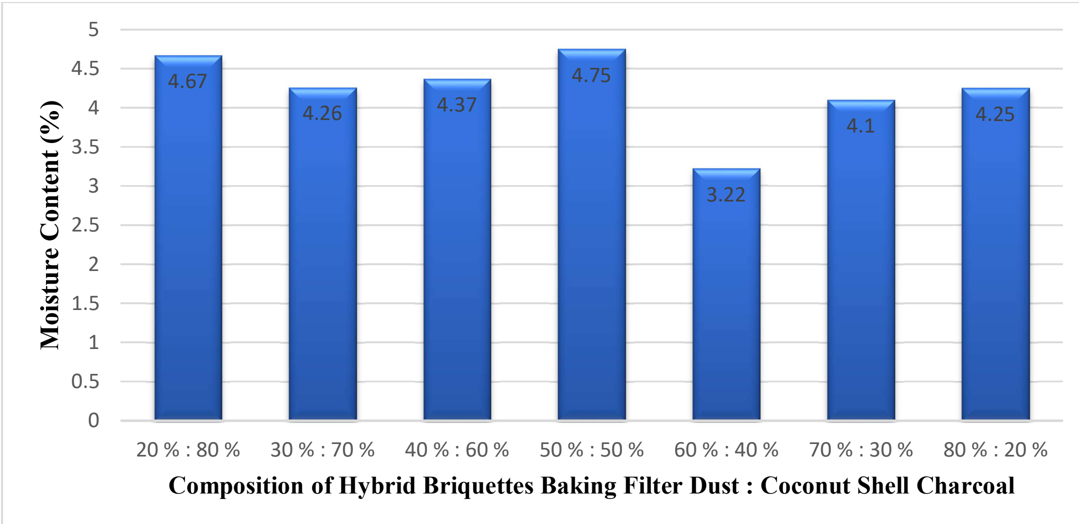

Figure 2. Moisture Content of the fabricated hybrid briquettes.

3.4. Carbon Content Test

Figure 3 above shows the carbon content (%) of hybrid briquettes with various compositions between BFD and coconut shell charcoal. The graph shows that the composition of 60% BFD and 40% coconut shell charcoal has the highest carbon content at 86.2%. Meanwhile, the lowest carbon content of 77.94% is found in the composition of 20% BFD and 80% coconut shell charcoal. The other compositions show carbon content ranging from 78.9% to 80.59%, with slight fluctuations among the different compositions. This data analysis indicates that increasing the proportion of BFD in the mixture significantly increases the carbon content in hybrid briquettes, particularly in the 60%: 40% composition. This is due to the higher carbon content in BFD compared to coconut shell charcoal.

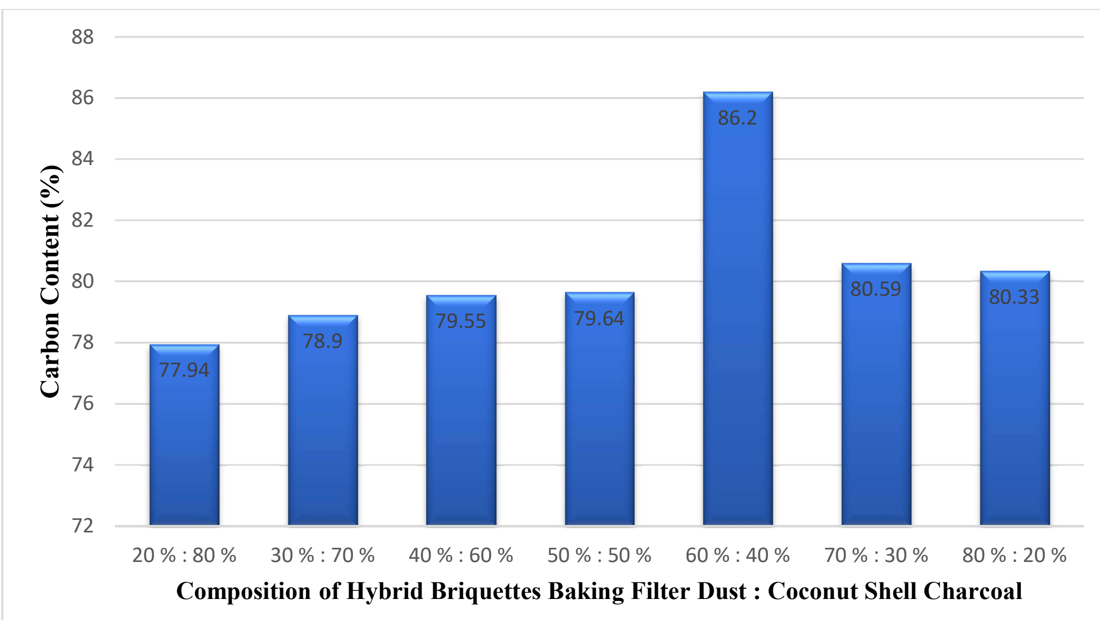

Figure 3. Carbon Content of the fabricated hybrid briquettes.

On the other hand, increasing the proportion of coconut shell charcoal seems to reduce the carbon content, as seen in compositions with a higher proportion of coconut shell charcoal. These findings are important for efficient briquette formulation, as higher carbon content is associated with better combustion performance and higher energy. Therefore, 60% BFD and 40% coconut shell charcoal can be considered the optimal composition for obtaining briquettes with high carbon content.

3.5. Sulfur Content Test

Figure 4 shows the sulfur content (%) of hybrid briquettes with various compositions between BFD and coconut shell charcoal. From the graph, it can be seen that the highest sulfur content is found in the composition of 80% BFD and 20% coconut shell charcoal with a value of 0.68%. Conversely, the lowest sulfur content is found in the composition of 60% BFD and 40% coconut shell charcoal, with a value of 0.47%. The other compositions show sulfur content ranging from 0.50% to 0.64%. This data analysis indicates that increasing the proportion of coconut shell charcoal in the mixture increases sulfur content in hybrid briquettes. This may be due to the higher sulfur content in coconut shell charcoal than BFD. Compositions with a balanced proportion of both materials, such as 50% : 50%, also show relatively lower sulfur content than those with a higher proportion of coconut shell charcoal. Therefore, a higher proportion of BFD could be a better choice to minimize sulfur content in briquettes. Reducing sulfur content is important because high sulfur can cause harmful gas emissions during combustion, making low sulfur content compositions more desirable to minimize environmental impact.

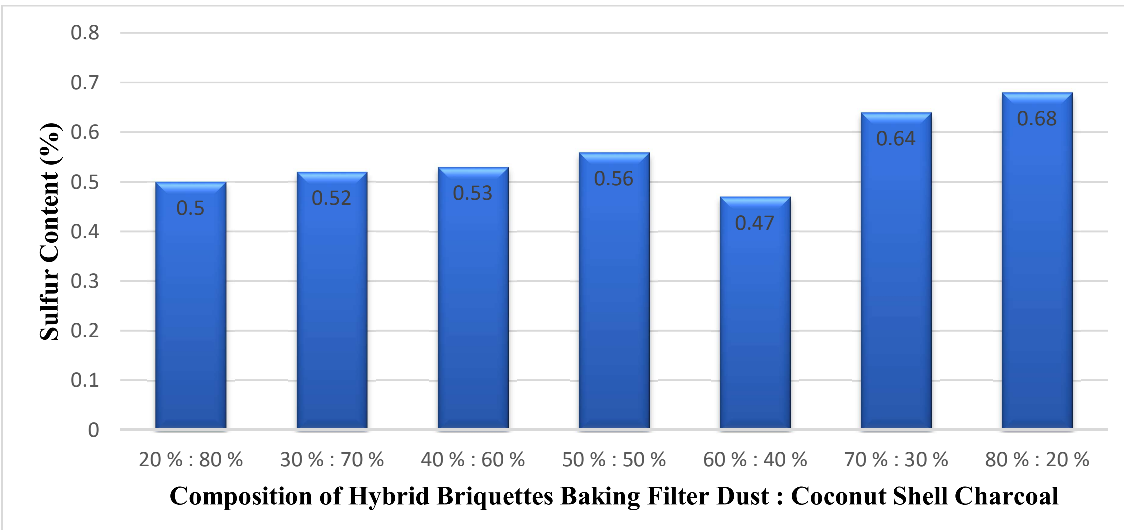

Figure 4. Sulfur Content of the fabricated hybrid briquettes.

3.6. Volatile Matter Test

Figure 5 shows the percentage of volatile matter in hybrid briquettes with various compositions between BFD and coconut shell charcoal. From the graph, it can be seen that the composition with the highest volatile matter is 20% BFD and 80% coconut shell charcoal with a value of 12.7%, while the lowest is the composition of 60% BFD and 40% coconut shell charcoal with a value of 7.2%. The other compositions show volatile matter values ranging from 11.1% to 12.1%. This data analysis indicates that increasing the proportion of coconut shell charcoal in the mixture increases the volatile matter value in hybrid briquettes. This may be due to the more volatile characteristics of coconut shell charcoal compared to BFD. The composition of 60% BFD and 40% coconut shell charcoal, which shows the lowest volatile matter value, becomes the optimal choice for reducing volatile matter content. Lower volatile matter is generally desired because it can increase combustion stability and reduce emissions of unburned gases, resulting in more efficient and environmentally friendly combustion. Therefore, a higher proportion of BFD in the mixture can provide significant benefits regarding the performance and environmental impact of the produced briquettes.

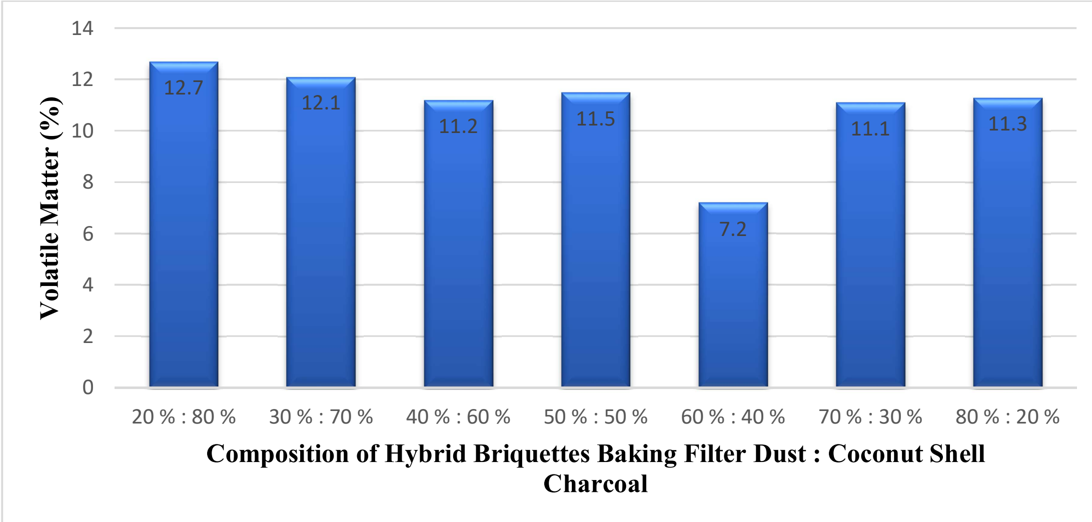

Figure 5. Volatile matter of the fabricated hybrid briquettes.

3.7. Calorific Value Test

Figure 6 shows the calorific value (cal/g) of various compositions of hybrid briquettes consisting of BFD and coconut shell charcoal in varying percentages. Each mixture has a different combination, ranging from 20%:80% to 80%:20%. From the graph, it can be seen that the mixture composition with the lowest calorific value is 20% BFD and 80% coconut shell charcoal with a value of 5170.2 cal/g. Meanwhile, the highest calorific value is found in the composition of 60% BFD and 40% coconut shell charcoal, with a value of 6557.3 cal/g. The analysis shows that as the percentage of BFD in the briquette composition increases, the calorific value tends to increase until it reaches a peak at 60%:40% composition, then decreases even though the percentage of BFD continues to increase. This may be due to the calorific properties of each raw material having a certain optimum point in the mixture, where beyond this point, the addition of one material no longer provides a significant increase in calorific value or even decreases it. Compositions that provide high calorific values indicate better energy efficiency potential, which is important for briquette combustion applications in industry or households. Therefore, compositions with a higher proportion of BFD, such as 60%:40%, show better energy efficiency, which is important for fuel applications requiring high calorific output. A high calorific value means the briquettes can produce more heat when burned, which is useful for heating or energy generation. Therefore, a higher proportion of BFD in the mixture is recommended to obtain briquettes with optimal calorific value.

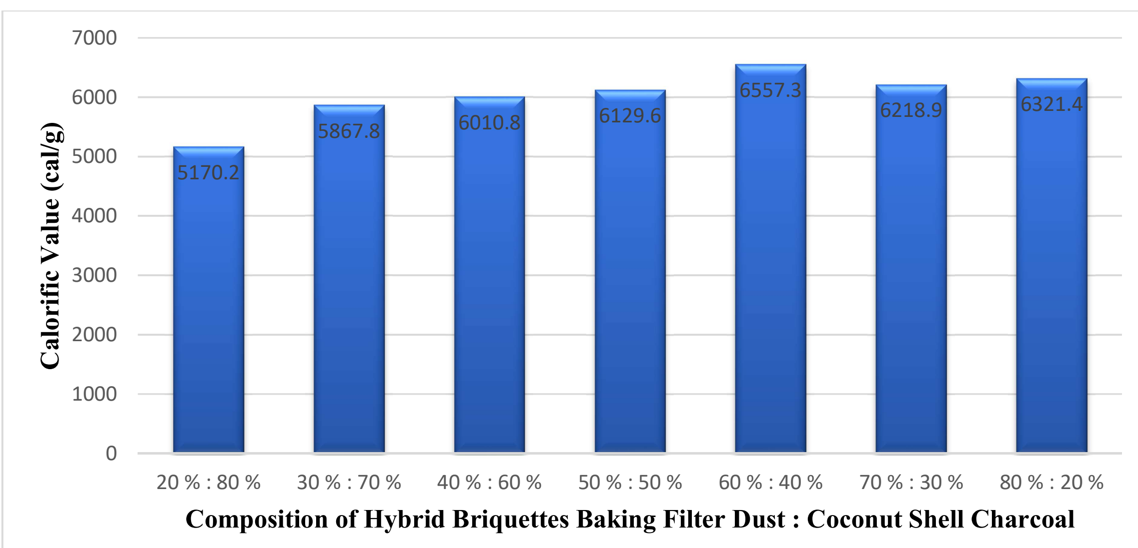

Figure 6. The calorific value of the fabricated hybrid briquettes.

3.8. Characterization FTIR Test Results of Hybrid Briquettes from BFD and Coconut Shell Charcoal

The following are the results of Fourier Transform Infra-Red (FTIR) characterization of hybrid briquette samples with a composition of 60%: 40%, shown in Figure 7.

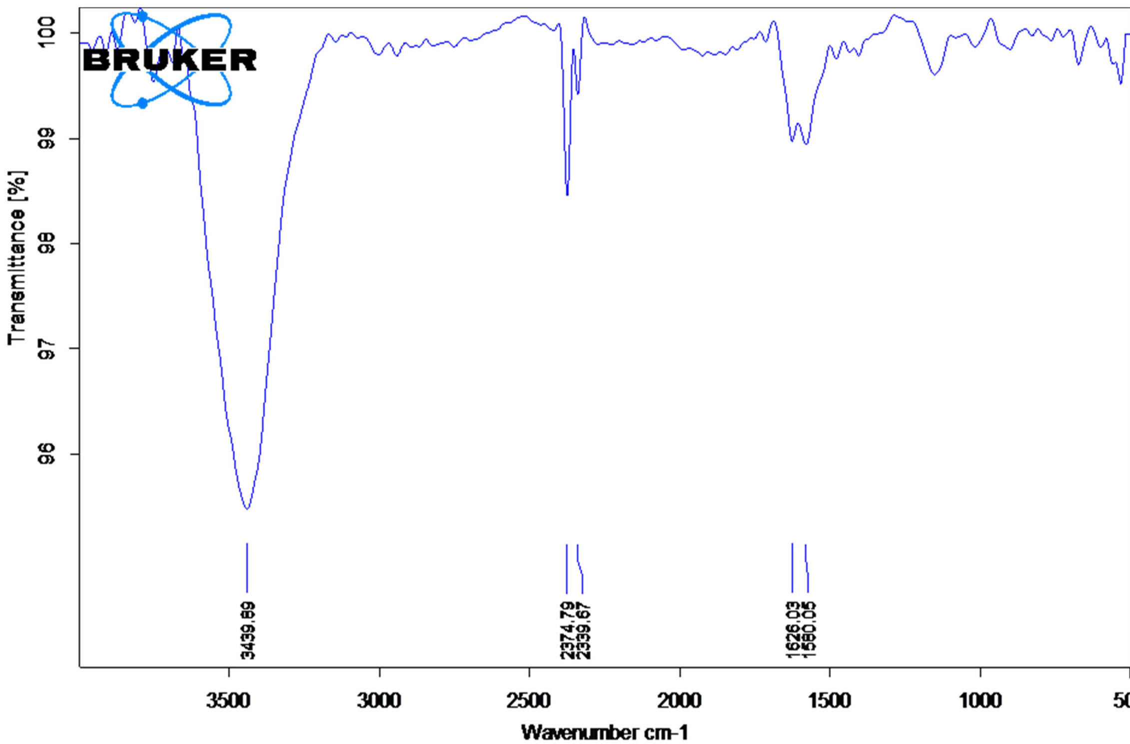

Figure 7. Characterization FTIR test results of hybrid briquettes from BFD and coconut shell charcoal composition 60% : 40%.

The Figure 7 above displays the FTIR (Fourier Transform Infrared) spectrum of the hybrid briquette sample with a 60%:40% composition, measured in the wavelength range from 4000 cm^{-1} to 400 cm^{-1}. FTIR is a spectroscopic technique used to obtain information about molecular structure based on the absorption of infrared energy by chemical bonds in molecules. In this spectrum, absorbance intensity is displayed on the y-axis, while wavelength or wavenumber (in cm^{-1}) is shown on the x-axis. The spectrum shows several major peaks indicating the presence of specific functional groups in the sample. The largest peak is observed around 3400 cm^{-1}, which is typically associated with O-H stretching vibrations, either from hydroxyl groups (–OH) in alcohols or water, indicating the presence of hydrogen bonds or moisture in the sample. Other significant peaks appear around 2920 cm^{-1} and 2850 cm^{-1}, characteristic of C-H stretching vibrations from alkanes, indicating the presence of aliphatic hydrocarbon chains in the sample. In the region around 1700 cm^{-1}, there is a sharp peak indicating C=O stretching vibrations, characteristic of carbonyl groups that could originate from aldehydes, ketones, or carboxylic acids. The peak at around 1600 cm^{-1} can be associated with C=C stretching vibrations in alkenes or aromatic rings. Additionally, peaks in the region around 1500 cm^{-1} to 1450 cm^{-1} are often associated with C-H or C=C bending vibrations in aromatic compounds. The region between 1300 cm^{-1} and 1000 cm^{-1} typically shows C-O stretching or O-H bending vibrations, which can indicate the presence of alcohols, esters, or ethers. This analysis provides a comprehensive overview of the various types of chemical bonds and functional groups present in the sample, which is essential for the identification and characterization of the chemical components in the sample.

3.9. Characterization XRF Test Results of Hybrid Briquettes from BFD and Coconut Shell Charcoal

The following are the results of X-Ray Fluorescence (XRF) characterization of hybrid briquette samples with a composition of 60% : 40% which can be shown in Table 2.

Table 2. Compound content of hybrid briquette samples from BFD and coconut shell charcoal composition 60% : 40%.

Al_2O_3 (%)	CaO (%)	Fe_2O_3 (%)	K_2O (%)	MgO (%)	Na_2O (%)	SiO_2 (%)	MnO (%)	ZnO (%)
0.502	5.84	25.1	43.3	2.91	4.71	3.70	0.487	0.163

Table 2 shows the chemical compound of briquette samples made from BFD (BFD) and coconut shell charcoal in the composition 60% : 40%. From the given data, K_2O is the largest component with a percentage of 43.3%, followed by Fe_2O_3 at 25.1%. The high presence of K_2O indicates that this material likely has strong alkaline properties, which can affect the combustion characteristics and chemical stability of the briquettes. The significant Fe_2O_3 content suggests that the sample also contains a high amount of iron, which can enhance the mechanical properties and thermal conductivity of the briquettes. Other components such as CaO (5.84%), Na_2O (4.71%), and MgO (2.91%) also contribute in considerable amounts. CaO and MgO can act as fluxes in the combustion process, aiding in ash binding and improving combustion performance. SiO_2 with a value of 3.70% contributes to the mechanical strength and thermal stability of the briquettes. Other elements like Al_2O_3, MnO, and ZnO are present in smaller amounts, but they remain important in determining the overall properties of these briquettes. The presence of various metal oxides indicates that briquettes made from BFD and coconut shell charcoal have a complex chemical composition, giving them potential applications in various industries, including energy and metallurgy.

3.10. Characterization SEM EDS Test Results of Hybrid Briquettes from BFD and Coconut Shell Charcoal

Figure 8 shows the results of Scanning Electron Miscroscope (SEM) characterization of hybrid briquette samples with a composition of 60% : 40% which can be shown in Figure 8.

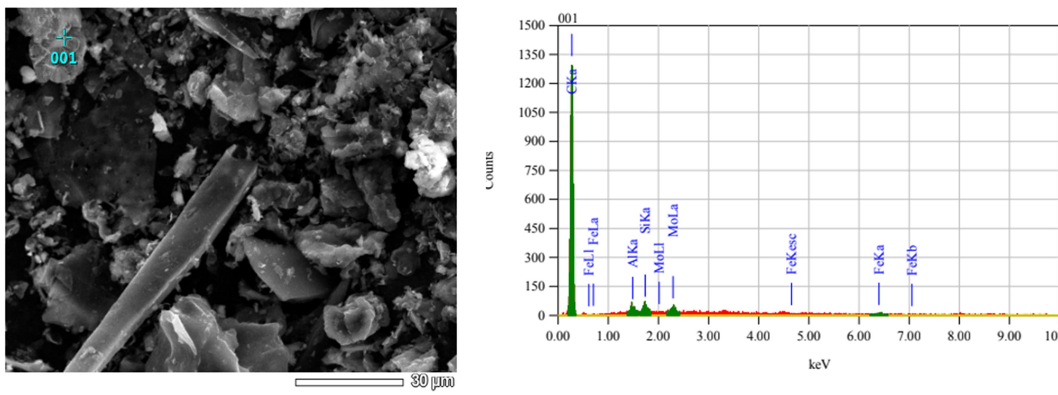

Figure 8. Characterization SEM test results of hybrid briquettes from BFD and coconut shell charcoal composition 60% : 40%.

The image consists of two parts: the top shows a scanning electron microscope (SEM) image, and the right side shows an energy-dispersive X-ray (EDS) spectrum. In the SEM image, the material's surface is displayed at high magnification, revealing a rough and heterogeneous morphological structure. The visible particles have various shapes and sizes, indicating uneven distribution. The scale size of 30 µm shown indicates that these particles are within the micrometer size range. This structure may indicate that the material has undergone complex physical or chemical processes, resulting in fractures, gaps, and uneven surfaces. This SEM image provides visual information about the texture and topography of the material's surface, which can aid in further analysis of the material's mechanical and physical properties. The EDS spectrum at the right side of the image shows the elemental composition analysis of a specific point marked "001" on the SEM image. This spectrum identifies characteristic peaks representing the elements present in the material. The largest peak appears around 0.9 keV, indicating the presence of iron (Fe) with the Lα line, while the peaks around 6.4 keV and 7.0 keV indicate the presence of iron with the Kα and Kβ lines, respectively. This suggests that iron is a major component of this material. Other peaks appear around 1.5 keV and 2.0 keV, indicating the presence of aluminum (Al) and silicon (Si). Additionally, there are small peaks around 2.3 keV and 2.6 keV, indicating the presence of molybdenum (Mo) and possibly other trace elements. This EDS analysis provides quantitative information about the chemical composition of the material's surface, which is important for determining the characteristics and potential applications of this material. For example, the dominant iron composition suggests that this material may have magnetic properties or high mechanical strength, while the presence of aluminum and silicon may affect hardness and corrosion resistance.

Table 3 shows the results of Energy Dispersive Spectroscopy (EDS) characterization of hybrid briquette samples with a composition of 60% : 40%, as shown in Table 3.

Table 3. Elemental Content of EDS test results hybrid briquette samples from BFD and coconut shell charcoal composition 60% : 40%.

Element	(keV)	Massa %	Error %	Atom %
C	0.277	94.42	0.08	98.54
Al	1.486	0.91	0.18	0.42
Si	1.739	0.99	0.18	0.44
Fe	6.398	1.26	0.67	0.28
Mo	2.293	2.41	0.47	0.32

The EDS analysis results show the elemental composition of the hybrid briquette sample with the following elements: Carbon (C) dominates with a mass of 94.42% and an atom percentage of 98.54%, indicating that the main material of the sample is carbon-based, such as charcoal or carbon black. Aluminum (Al) and Silicon (Si) are present in small amounts, with masses of 0.91% and 0.99% and atom percentages of 0.42% and 0.44%, respectively, possibly originating from alumina (Al_2O_3) or silica (SiO_2). Iron (Fe) has a mass of 1.26% and an atom percentage of 0.28%, indicating the presence of metal inclusions or iron oxides in the sample. Molybdenum (Mo) is present in an amount of 2.41% mass and 0.32% atom percentage, possibly originating from metallic phases or molybdenum compounds. These elements show that the briquette sample has a complex chemical composition with carbon as the main component and significant contributions from aluminum, silicon, iron, and molybdenum. The high carbon content indicates that this material has properties that support its application as briquette fuel or carbon composite. At the same time, the presence of aluminum, silicon, iron, and molybdenum can enhance the material's mechanical strength, thermal stability, and durability.

3.11. Characterization TGA Test Results of Hybrid Briquettes from BFD and Coconut Shell Charcoal

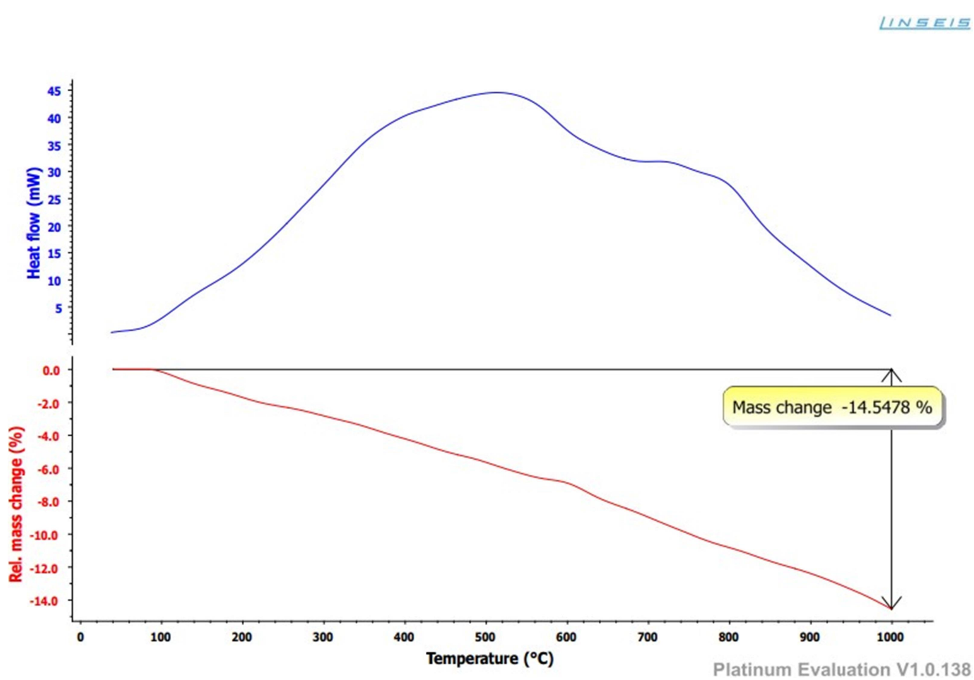

Figure 9. Characterization TGA test results of hybrid briquettes from BFD and coconut shell charcoal composition 60%: 40%.

The results of the Thermo Gravimetric Analysis (TGA) characterization of hybrid briquette samples with a composition of 60%: 40% are shown in Figure 9. Figure 9 depicts the results of thermogravimetric analysis (TGA) of a sample when heated up to 1000°C. The X-axis represents temperature in degrees Celsius (°C), while the left Y-axis shows the heat flow rate (mW/mg), and the right Y-axis shows the relative mass change (%) of the sample. The blue curve on the graph shows the TGA results, which depict the changes in heat flow within the sample as it is heated. From the graph, it can be seen that there is an increase in the heat flow rate, peaking at around 500°C before decreasing again to reach a stable condition at around 900°C. This increase may indicate an endothermic process, such as the sample's decomposition or melting of a component. After the peak, the decrease in the heat flow rate suggests an exothermic process caused by crystallization or the formation of a new phase. The red curve shows the TGA results, illustrating the change in the sample's mass relative to temperature. This graph shows a constant mass loss from around 100°C to 900°C, with a total mass change of -14.5478%. This mass loss may be due to the evaporation of water or organic volatiles at lower temperatures, followed by the decomposition of organic or inorganic materials at higher temperatures. The combination of TGA data provides a deeper understanding of the thermal processes occurring in the sample during heating.

4. Conclusion

The research results show that briquettes with a composition of 60% BFD and 40% coconut shell charcoal have the best quality, with a carbon content reaching 86.2% and a calorific value of 6557.3 cal/g. BFD as a briquette raw material has been proven to increase the briquettes' carbon content and calorific value, while coconut shell charcoal helps reduce moisture content and volatile matter. Characterization analysis shows that these briquettes have a solid structure and thermal stability. The use of tapioca flour adhesive also helps improve the briquette's strength. From these results, it can be concluded that combining BFD and coconut shell charcoal is an effective solution for producing high-quality and environmentally friendly hybrid briquettes.

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