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Characteristics and Thermal Stability of Biobriquettes Sub-Bituminous Coal and Coconut Shell (*Cocos nucifera*) Mixture

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Abstract

Low-grade coal, such as sub-bituminous, is characterized by low calorific value. In this context, combining coal (C) with coconut shell (CS) biomass can upgrade the quality. Therefore, this study aims to analyze the effect of feed ratio and carbonization temperature on improving the biobriquette quality. The processes included preparation, carbonization at 300°C and 400°C, variation in feed ratios, mixing, molding, and drying. Evaluation was conducted for proximate composition, calorific value, combustion rate, and thermal stability characteristics using Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA). The results showed that the biobriquette with 100CS contained 100% CS carbonized at 400°C. Furthermore, it had the best quality, with 5.05% moisture content, 1.83% ash content, 36.11% volatile matter, 57.01% fixed carbon, and a calorific value of 6,075 cal/g. These values met the Indonesian Ministry of Energy Regulation No. 47 of 2006. TGA–DTA analysis showed a total mass loss of 98–99% up to approximately 800°C, *featuring* the best thermal stability. Based on observation, 100% coconut shell (100CS) provided the best quality. This did not imply that hybrid composition was ineffective. For combustion performance tests, the highest combustion rate was recorded in a mixture of 50C: 50CS, namely 0.3005 g / min. The addition of coal to biomass briquettes aimed to improve combustion performance, specifically through increasing the combustion rate. This suggested that the briquettes are easier to ignite (easy ignition), and heat is generated more quickly. In conclusion, the mixture of coal and coconut shell is suitable for applications that require fast heating, such as cooking activities.

Keywords: Biobriquette; coconut shell; differential thermal analysis; sub-bituminous coal; thermogravimetric analysis

1. Introduction

Global energy demand is increasing alongside population growth and economic expansion. According to the World Energy Outlook 2023 report published by the International Energy Agency (IEA), global energy consumption is projected to rise by 2.2% in 2024. This value is nearly double the annual average of 1.3% from 2013 to 2023 [1]. Among fossil fuels, coal remains an important energy source and is classified into five ranks, including anthracite, bituminous, sub-bituminous, lignite, and peat. Sub-bituminous coal and lignite are characterized by relatively low calorific values, which limit the suitability for efficient energy generation. The use of these grades in power plants increases fuel consumption, handling requirements, and associated costs [2]. The high proportion of fine particles can generate dust during handling, while the relatively high volatile matter increases the risk of spontaneous combustion during storage. Ash content also influences the quality and performance of briquettes. Blending low-rank coal with biomass offers a potential method for improving the quality of the briquettes [3].

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Coconut shell, often regarded as agricultural waste, offers a potentially more sustainable alternative fuel source. Due to the high carbon content, it is an efficient fuel that can be used in applications ranging from power plants to household use. South Sumatra Province, which is among the largest coconut-producing regions, recorded coconut production of approximately 61,100 tons in 2024, according to data from the Central Statistics Agency (BPS) [4]. Coconut shell is also used as raw material in the production of briquettes and pellets for both household and industrial fuel needs. Briquettes, which serve as an alternative energy source, can be produced by combining coconut shells with coal. The quality is significantly influenced by factors such as carbonization temperature and the ratio of raw materials. Coal is combined with coconut shell biomass to improve the quality of the resulting briquettes [5].

Previous studies explored the use of various raw materials for the production of biobriquettes. Agricultural residues, such as coconut husks [5], rice straw with sugarcane leaves [6], as well as palm kernel [7] and peanut shells [8], offer promising alternatives as biomass feedstocks. These materials offer an affordable and sustainable energy solution, but the direct use is often hampered by challenges such as low density and high moisture content. Therefore, investigations have been conducted to explore alternative raw materials, such as coconut shell, which offers the advantages of high fixed carbon and high calorific value [9]. Mustain et al. [10] aimed to determine the effect of the mixture composition of bagasse and coconut shell charcoal. The results showed that the best briquette characteristics were obtained through a 30:70 composition of bagasse: coconut shell, with tapioca flour as the adhesive. The moisture, ash, volatile matter, and bound carbon contents, as well as the calorific value recorded, were 6.93%, 3.50%, 24.75%, 64.82%, and 5,995 cal/g, respectively. Yirijor et al explored coconut shell biobriquettes with cassava binder and corn flour. Biobriquettes made from dried coconut shell produced the highest fixed carbon of 70.79 % and HHV of 31.51 MJ/kg (7531 cal/g), while the boiling times ranged from 15 min to 36 min. The limitation of shorter boiling time is addressed by adding coal to the mixture [9].

Rahman et al [11] optimized the production of pure sub-bituminous coal briquettes from South Sumatra mines through an oven drying process at 105°C for 5 hours, with a 6% tapioca binder and a molding pressure of 200 kg/cm². This process aimed to produce household briquettes with moisture content, shatter index, stable calorific value, and combustion time of <8%, >95%, 5,500-5,800 cal/g, and >90 minutes, respectively. This meets the requirements of the Minister of Energy and Mineral Resources Regulation No. 20/2012. The calorific value of low-rank sub-bituminous coal is the weakness that needs to be improved by biomass mixture with coconut shell charcoal. The novelty of this study lies in the optimization of hybrid briquettes produced using low-grade sub-bituminous coal from Tanjung Enim, South Sumatera, and coconut shell biomass by investigating the combined effects of carbonization temperature and raw material ratio on the quality. Unlike previous publications that commonly focused on biomass or coal briquettes separately, this study integrates locally available low-rank coal and coconut shell waste as a composite solid fuel to improve calorific value, reduce ash-related quality limitations, and enhance the overall combustion characteristics. It also made a specific contribution by using coconut shell waste from South Sumatra as a regional biomass resource, thereby supporting both low-grade coal upgrading and agricultural waste valorization.

The quality of briquettes is influenced by factors such as carbonization temperature, as well as the ratio and composition of raw materials. The carbonization temperature can increase calorific value and mechanical strength. Using an appropriate proportion of coconut shell waste can optimize production, enhance briquette quality, reduce coconut plantation waste, and provide a more sustainable energy source. This study contributes to improving briquette quality through the utilization of coconut shell and coal mixtures and to exploring alternative energy solutions to meet Indonesia's growing energy demand. The objective is to evaluate the effect of combustion temperature and feed ratio on the quality of coal and coconut shell briquettes in relation to requirements of Indonesian National Standard SNI 01-6235-2000 [12] and Ministry of Energy Regulation No. 47 of 2006 [13].

2. Research Methods

2.1. Tools and Materials

The materials in this study were organic biomass waste in the form of coconut shell and sub-bituminous coal obtained from a mining center very near Palembang, such as Tanjung Enim in Palembang, South Sumatra. Tapioca flour was

adopted as a binding agent, while the equipment used was a 50 mesh sieve, porcelain dishes, a furnace, beakers, a hot plate, aluminum pans, a mortar, an analytical balance, an oven, a spatula, and a dropper pipette.

2.2. Carbonization Process

The dried coconut shell was carbonized in a furnace at two different temperatures, namely 300°C and 400°C, for 2 hours each. After being removed from the furnace, the biochar was ground in a mortar and sieved through a 50 mesh sieve.

2.3. Mixing with Binder

The carbonized raw material was grounded in a mortar and sieved through a 50 mesh sieve. Coconut shell charcoal (CS) and sub-bituminous coal (C) were mixed in predetermined ratios of 0%:100%, 25%:75%, 50%:50%, 75%:25%, 100%:0% with labels 100C, 25CS:75C, 50CS:50C, 75CS:25C, and 100CS. Tapioca flour was added as a binder at 15% of the total weight for each ratio, then the mixture was stirred until homogeneous.

2.4. Briquette Molding

The mixture was molded using a molding machine, and the briquettes were weighed to determine the initial weight. The briquettes were dried in the oven at a temperature of 110°C, then weighed to determine the final weight. Analysis was conducted for several characteristics, such as proximate composition including moisture content, ash content, volatile matter content, fixed carbon content, and calorific value. Combustion rate and thermal stability were also evaluated using Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA).

2.5. Proximate Analysis

2.5.1. Moisture content measurement

Moisture content or inherent moisture (IM) is a measurement of the water content in a sample that has been dried and powdered. Equation 1 can be used to determine moisture content. The mass of the weighing bottle and cap was recorded as m1 (g), while m2 (g) represented the mass of the weighing bottle, cap, and sample before heating. The mass of the weighing bottle, cap, and sample after heating was recorded as m3 (g).

$$IM = \frac{m2-m3}{m2-m1} x\ 100\% \quad \textbf{.....(Equation 1)}$$

2.5.2. Ash Content Measurement

Ash content is the remaining inorganic substances contained in briquettes. It primarily originates from the inherent impurities in the raw material and can be determined using Equation 2. The mass of the empty cup was recorded as m1 (g), while m2 (g) represented the mass of the empty cup and sample before ashing. The mass of the empty cup and sample after ashing was recorded as m3 (g).

$$AM = \frac{m3-m1}{m2-m1} x\ 100\% \quad \textbf{.....(Equation 2)}$$

2.5.3. Volatile Matter Content Measurement

Volatile matter content refers to substances that can evaporate due to the decomposition of compounds remaining in the briquette, other than water. Its content can be determined using the Equation 3. The mass of the weighing bottle and cap was recorded as m1 (g). The mass of the weighing bottle, cap, and sample before heating was recorded as m2 (g), while m3 (g) represented the mass of the weighing bottle, cap, and sample after heating.

$$VM = \frac{m2-m3}{m2-m1} x\ 100\% \quad \textbf{.....(Equation 3)}$$

2.5.4. Fixed Carbon Content

Fixed carbon content is the amount of pure carbon contained in the briquette. The fixed carbon content can be determined using the following Equation 4. IM represented Inherent Moisture (%), AC represented Ash Content (%), and VM represented Volatile Matter (%).

$$FC = 100\% - (IM + AC + VM) \textbf{ .(Equation 3)}$$

2.5.5. Calorific Value

The products were analyzed using a bomb calorimeter to obtain the heating value.

2.5.6. Combustion Rate

The flame test was conducted to determine the time required for the briquettes to burn down to ash.

2.5.7. Thermogravimetric Analysis (TGA)

TGA measures the change in the mass of a sample when heated or cooled in a controlled atmosphere. It is used to evaluate thermal stability, decomposition, oxidation, and volatile content. TGA measures both heat flow and weight changes in a material as a function of temperature or time in a controlled atmosphere from room temperature to 1500˚C

2.5.8. Differential Thermal Analysis (DTA)

DTA is a thermoanalytical method that measures the temperature difference between a sample and an inert reference as both are subjected to a controlled heating or cooling program. It is widely used to identify materials, quantify phase transitions, and study chemical reactions.

3. Results and Discussion

3.1. Proximate Analysis of Briquettes

The proximate analysis of the briquettes with coconut shell charcoal (CS) and sub-bituminous coal (C) ratios of 0%:100%, 25%:75%, 50%:50%, 75%:25%, and 100%:0% was labelled 100C, 25CS:75C, 50CS:50C, 75CS:25C, and 100CS. Every sample was analyzed to determine IM, ash content, volatile matter, fixed carbon, and calorific value using ASTM and ISO standards of ASTM D.3173M-17A, ASTM D.3174-2018, ISO-562:210(E), ASTM D.3172-02 (11), and ASTM D.5865M-2019, respectively. The results of this study are presented in Table 1.

3.2. Moisture Content

Moisture content reflects the amount of water retained in briquettes after drying and curing. Figure 1 shows that carbonization at 300 °C produced moisture contents of 9.55%, 7.50%, 7.07%, 5.18%, and 5.05% for the 100C, 25CS:75C, 50CS:50C, 75CS:25C, and 100CS samples, respectively. At 400 °C, the corresponding values were 9.50%, 8.55%, 7.71%, 6.53%, and 6.56%. Overall, increasing the carbonization temperature reduced the moisture content in most samples. The 100 °C sample showed a slight increase at 400 °C compared with 300 °C. This behavior may be attributed to the development of pores and cracks at elevated temperatures, which can increase the hygroscopicity of the material and promote moisture reabsorption [14]. Although heating generally facilitates moisture removal, excessive temperatures may alter the pore structure and increase the material's affinity for water. Low moisture content is desirable because it increases calorific value and improves combustion efficiency.

Table 1. Proximate analysis results of coconut shell (CS) and sub-bituminous coal (C)

T (ºC)	Sample	Inherent Moisture (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (cal/g)
300	100C	9.50	4.28	53.75	32.47	4,523
300	25CS :75C	8.55	2.93	49.47	39.05	5,058
300	50CS :50C	7.71	2.09	45.23	44.97	5,343
300	75CS: 25C	6.53	1.68	41.84	49.95	5,655
300	100CS	6.56	4.00	37.26	46.78	5,919
400	100C	9.55	4.58	55.75	32.87	4,543
400	25CS :75C	7.50	2.44	45.10	44.96	5,460
400	50CS :50C	7.07	2.60	47.20	43.13	5,501
400	75CS: 25C	5.18	1.97	40.03	52.82	5,554
400	100CS	5.05	1.83	36.11	57.01	6,075
	SNI	≤ 8	≤ 8	≤ 15	≥ 77	≥ 5,000
	ESDM MINISTERIAL REGULATION	≤ 15	≤ 10	≤ 15	≥ 77	4,400

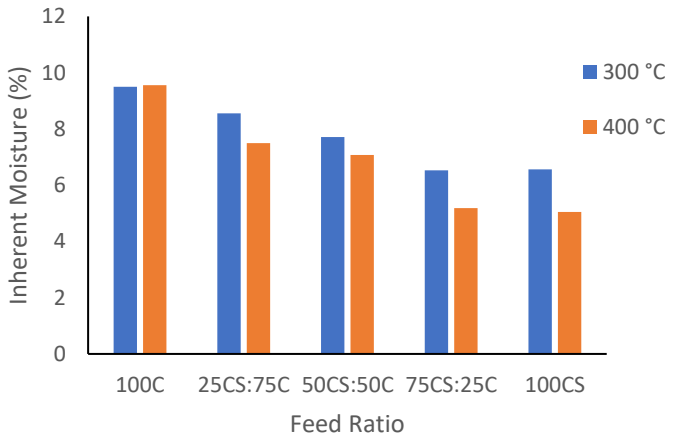

Figure 1. The Effect of feed ratio coconut shell (CS): sub-bituminous coal (C) and carbonization temperature on biobriquette's inherent moisture

Figure 1 shows that the moisture content at carbonization temperatures of 300 and 400 °C presents a fluctuating pattern. This variation is influenced by differences in the physical properties and pore structures of the raw materials. Coal is hydrophilic and contains predominantly closed micropores, which trap water and hinder evaporation at lower carbonization temperatures [9]. In contrast, coconut shell had a more open pore structure and larger pore volume, facilitating moisture release during heating [15]. Consequently, increasing the coconut shell proportion generally results in lower moisture content. Formulations with a higher coal proportion tend to retain more moisture. According to Ministry of Energy and Mineral Resources Regulation No. 47 of 2006, the maximum allowable IM content of briquettes is ≤15%, while SNI 01-6235-2000 specified a limit of ≤8%. All briquette formulations evaluated in this study complied with both requirements.

3.3. Ash Content

Ash content represents the incombustible inorganic mineral residue remaining after combustion. A lower value, preferably below 8%, generally reflects higher briquette quality [14]. As shown in Figure 2, carbonization at 300 °C led to ash contents of 9.40%, 2.93%, 2.09%, 1.68%, and 4.28% for the 100C, 25CS:75C, 50CS:50C, 75CS:25C, and 100CS samples, respectively. At 400 °C, the corresponding values were 4.28%, 2.44%, 2.60%, 1.97%, and 1.87%.

Based on Figure 2, the higher ash content from the combustion process at a temperature 400 °C led to lower quality of the briquettes due to a reduction in the calorific value [9]. Higher carbonization temperatures generally increase the relative ash content of the briquettes. This is because increasing temperature promotes the decomposition of volatile matter, releasing organic compounds and water vapor as gases and consequently increasing the relative concentration of non-combustible mineral ash [16].

The ash content of briquettes increased alongside the coal ratio. This is because coal has a higher inorganic mineral content compared to coconut shell. It contains compounds such as SiO_2, Al_2O_3, Fe_2O_3, calcium, and magnesium, which are heat-stable and non-combustible, thereby remaining as ash residue after carbonization [17]. Coconut shell has a low mineral content (±0.6%) and is dominated by organic compounds that easily decompose into gas and carbon [18]. Therefore, the proportion of coal is directly proportional to the ash content produced. The PERMEN ESDM No. 47 of 2006, established by the Ministry of Energy and Mineral Resources of the Republic of Indonesia, stated that the maximum ash content limit is ≤10%. All briquette samples in Figure 2 complied with this standard.

3.4. Volatile Matter

Volatile matter content reflects the number of compounds that have not been evaporated during carbonization. A low value signified better briquette quality due to the production of less smoke during combustion, while a high content tends to increase smoke emissions. This parameter is influenced by the composition of the materials and the non-combustible compounds in the briquettes [19]. A high volatile matter content reflects a lower carbon content, leading to more smoke, easier ignition, but a shorter burning time.

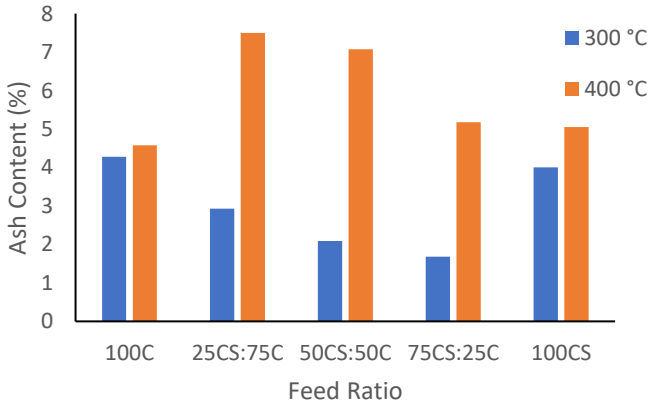

Figure 2. The Effect of feed ratio coconut shell (CS): sub-bituminous coal (C) and carbonization temperature on biobriquette's ash content

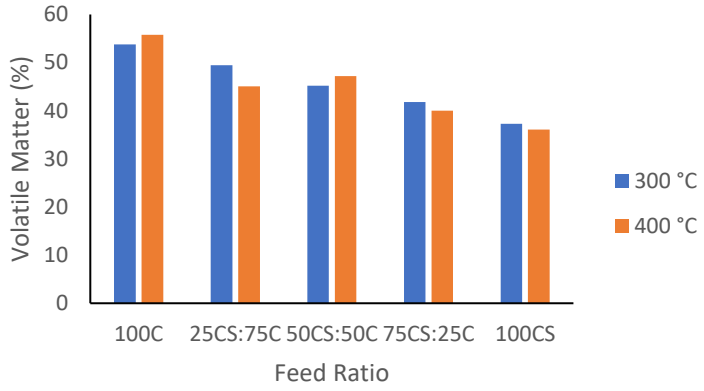

Figure 3. The Effect of feed ratio coconut shell (CS): sub-bituminous coal (C) and carbonization temperature on biobriquette's volatile matter

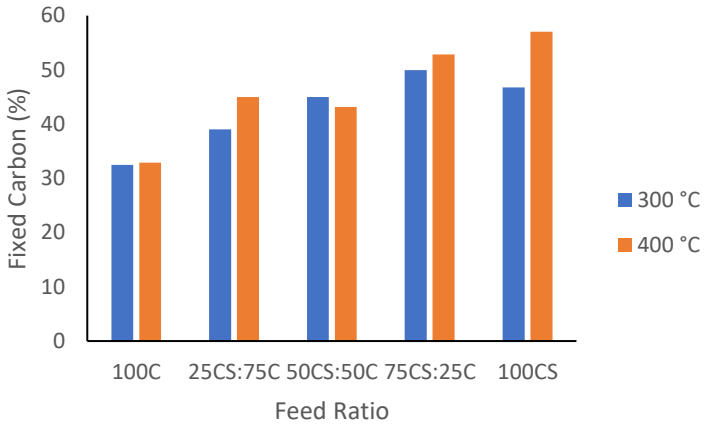

Figure 4. The Effect of feed ratio coconut shell (CS): sub-bituminous coal (C) and carbonization temperature on biobriquette's fixed carbon

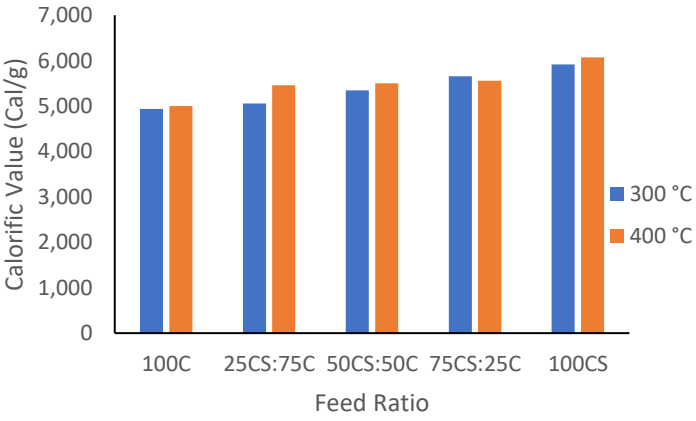

Figure 5. The Effect of feed ratio coconut shell (CS): sub-bituminous coal (C) and carbonization temperature on biobriquette's calorific value

Based on Figure 3, the volatile matter content of the biobriquettes did not meet the standard set by PERMEN ESDM No. 47 of 2006, which is ≤15%. All tested samples had values ranging from 36–53%, failing to meet the applicable standard. In addition to temperature, another influencing factor is the raw material ratio [20]. In the context of solid fuels, volatile matter plays a crucial role in ease of ignition and combustion characteristics [21]. Biobriquettes with a higher proportion of sub-bituminous coal feature higher volatile matter content due to the presence of oxygen-containing groups and easily decomposable light hydrocarbons. Meanwhile, coconut husks possessed better thermal

stability, which led to lower volatile matter content. The density of the briquettes during the molding process is also critical, as a structure that is too dense can hinder the release of volatile gases from within the pores of the material. This contributed to a final volatile matter content higher than expected [22].

3.5. Fixed Carbon Content

A high fixed carbon content increased the briquette's heat output and extended the burning time [23], as well as contributed to minimal smoke. Based on Figure 4, a carbonization temperature of 400°C produced a higher fixed carbon content compared to 300°C. At 400ºC, the values ranged from 32.87% - 57.01%, with the highest observed in 100CS, while at 300 ºC the values ranged from 32.37% - 49.97%. The trend identified in Figure 4 shows that an increase in carbonization temperature enhanced the fixed carbon content. The increase in fixed carbon content was associated with a higher calorific value of the briquettes, as the decomposition of volatile compounds resulted in a greater relative proportion of carbon [24].

The low fixed carbon content under 77% was influenced by high levels of volatile matter. This corresponds with the study conducted by Suwankamnoed et al [20], where high levels of volatile matter contributed to low carbon content, and vice versa. Similarly, as ash content increased, the carbon content decreased. The 100C briquette, composed entirely of coal, had the lowest fixed carbon content at 32.47%. The condition is related to the characteristics of the coal, particularly the relatively high ash and moisture content. This suggested that briquette quality tends to decline as moisture, ash, and volatile matter content increase.

A higher proportion of coconut shell, as in 100CS, leads to higher fixed carbon content compared to a mixture where coal is more dominant. This may be attributed to the high lignocellulosic content of coconut shell, consisting of 33.30% lignin and 27.31% cellulose, which decomposes during carbonization and forms a denser carbon structure, thereby increasing the fixed carbon fraction [25]. According to Ministry of Energy and Mineral Resources Regulation No. 47 of 2006, high-quality biobriquettes should have a fixed carbon content of ≥ 77%.

3.6. Calorific Value

The calorific values obtained from mixtures of coconut shell and sub-bituminous coal biobriquettes ranged from 4,523 to 6,075 cal/g. Based on Figure 5, the highest value was obtained for briquette 100CS carbonized at 400ºC, while the lowest was recorded in the coal ratio. At a furnace temperature of 400°C, a higher calorific value was recorded than at 300°C.

Increasing the carbonization temperature reduces the moisture content of the biobriquettes, thereby elevating the calorific value [26]. Briquettes with a higher proportion of sub-bituminous coal record low calorific value due to high moisture content and volatile matter, which reduce combustion efficiency. Conversely, briquettes containing a higher proportion of coconut shell exhibited higher calorific values, particularly when carbonized at 400°C. This could be attributed to increased release of volatile components, which enhanced the amount of fixed carbon [27].

Coconut shell has a relatively high carbon content and calorific value, which can be attributed to the lignin-rich chemical structure [27]. Increasing the coconut shell proportion in the briquette formulation enhanced the calorific value at both carbonization temperatures of 300 and 400 °C. The highest value was recorded for the 100CS sample at 400 °C, reaching 6,075 cal/g. This result is consistent with the higher calorific value of coconut shell charcoal, which ranges from approximately 6,500 to 7,600 cal/g [9], compared to 4,500–5,000 cal/g for sub-bituminous coal [28].

3.7. Combustion Rate

The combustion rate shows how fast energy is released from the fuel during combustion, typically expressed in grams per minute (g/min) or kilograms per hour (kg/h). It is influenced by several key factors, such as the particle size of the raw material, airflow velocity, combustion temperature, moisture content, and the volatile matter content in the briquettes [27].

Table 2 shows that the highest combustion rate was 0.3005 g/min for the 50CS:50C sample carbonized at 300 °C, while the lowest was 0.1628 g/min for the 75CS:25C sample carbonized at 400 °C. A higher combustion rate generally corresponded to a higher peak temperature because faster oxidation released more thermal energy within a shorter period. In contrast, a lower combustion rate promoted gradual heat release, producing a more stable temperature profile but a lower peak temperature.

A high volatile matter content promotes rapid ignition, while a low fixed carbon content shortens the slow-burning phase, increasing the combustion

rate and reducing the overall burning time. The shortest combustion time was observed for the 50CS:50C sample, which contained 45.23% volatile matter and 45.97% fixed carbon. The relatively similar proportions of these components may have promoted rapid ignition and sustained combustion. A balanced combustion rate and heat distribution can support stable and efficient heating [28].

3.7. Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) Result

Analysis was conducted to observe the thermal degradation behavior and energy changes in the sample during gradual heating. The TGA curve provides information on mass changes resulting from evaporation and thermal decomposition processes. Meanwhile, the DTA curve shows the endothermic and exothermic phenomena occurring within a specific temperature range.

The analysis was conducted to evaluate the thermal degradation behavior and mass changes of the briquettes during gradual heating. Based on the TGA results for the 100CS sample carbonized at 400 °C (Figure 6), the purple curve indicates that the initial mass of approximately 6.4 mg remained relatively stable up to 300 °C, suggesting good thermal stability at lower temperatures. The slight mass loss below 100 °C can be attributed to the evaporation of free or adsorbed moisture. The most substantial mass loss occurred between 330 and 580 °C, corresponding to the primary decomposition of organic and volatile components. For biomass-based briquettes, this stage is generally associated with the degradation of cellulose, hemicellulose, lignin, and other reactive components [27]. Above 580 °C, the mass remained relatively stable up to 800 °C, signifying that most readily decomposable and volatile components had been removed, leaving thermally stable inorganic residues such as ash and minerals. The relatively stable mass at higher temperatures shows the good thermal stability of the briquette against further degradation.

Table 2. Combustion performance of coconut shell (CS) and sub-bituminous coal (C) biobriquettes

T (°C)	Sample	Combustion Rate (g/min)
300	100C	0.2207
300	25CS:75C	0.2385
300	50CS:50C	0.3005
300	75CS:25C	0.1945
300	100CS	0.2369
400	100C	0.2001
400	25CS:75C	0.1924
400	50CS:50C	0.1838
400	75CS:25C	0.1628
400	100CS	0.2252

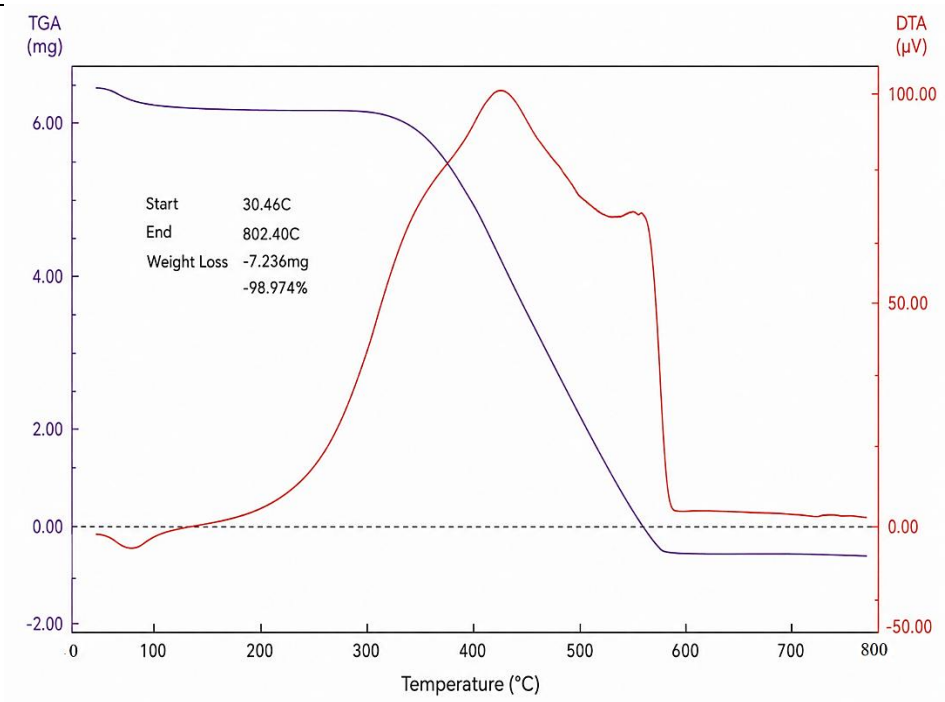

Figure 6. Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) results of the 100CS briquette with 400 °C carbonization temperature

The DTA curve (red line) provides information regarding thermal energy changes during the heating process. At temperatures below 100°C, a small drop peak suggests an endothermic process caused by the evaporation of water or moisture adsorbed onto the sample. From approximately 250°C, the DTA signal rises to form an exothermic peak with maximum intensity in the 430–450°C range. Based on the characteristics of the Shimadzu DTG-60 instrument, this positive peak signifies heat release during decomposition. This exothermic reaction coincides with the region of greatest mass loss on the TGA curve, reflecting the decomposition of organic components at these temperatures [29]. After reaching its maximum intensity, the DTA signal gradually decreased to approximately 550 °C, suggesting a decline in the rate of decomposition. Between 570°C and 590°C, the DTA curve drops sharply toward the baseline, signifying the completion of the primary decomposition process. At temperatures above 600°C, it remains relatively flat, with no significant changes in thermal energy. The briquette has reached thermal stability to release heat in an exothermic state over a wide temperature range of 100-450°C, which signifies good behavior of solid fuel.

4. Conclusion

In conclusion, carbonization temperature and raw material ratio significantly influenced the quality and performance of the biobriquettes. The 100CS formulation carbonized at 400 °C featured the best overall fuel properties, with a moisture content of 5.05%, ash content of 1.83%, volatile matter of 36.11%, fixed carbon of 57.01%, and calorific value of 6,075 cal/g. The moisture content, ash content, and calorific value met the requirements of Indonesian National Standard SNI 01-6235-2000, which specifies limits of <8%, <8%, and >5,000 cal/g, respectively. However, the volatile matter and fixed carbon contents did not meet the specified requirements. The relatively high volatile matter may contribute to faster ignition and combustion. The proximate properties also satisfied the requirements of Ministry of Energy and Mineral Resources Regulation No. 47 of 2006. TGA–DTA analysis showed a total mass loss of approximately 98–99% up to 800 °C, confirming the favorable thermal stability of the prepared biobriquettes. Although the 100% coconut shell (100CS) formulation had the best overall fuel quality, the hybrid briquette should not be overlooked. In particular, the 50C:50CS composition achieved the highest combustion rate (0.3005 g min^{-1}). This suggests that blending coconut shell with sub-bituminous coal offers improved combustion performance while retaining satisfactory fuel properties.

AI Usage Statements

The authors declare that no generative artificial intelligence (AI) tools were used in the writing, editing, analysis, or any part of the preparation of this manuscript. All content was conceived, written, and finalized solely by the authors without the assistance of AI technologies.

CRediT Authorship Statement

Rizka Wulandari Putri: Writing–Original draft, Writing-Review, Conceptualization, Methodology, Supervision, and Visualization **Rahmatullah**: Project administration, **Selpiana**: Validation and Investigation, **Nyayu Gandasari**: Methodology, Formal analysis, and Data curation. **Salsabillah Nur Fazrin**: Methodology, Formal analysis, and Data curation **Alek Al Hadi:** Validation, and Investigation. **Muhammad Haviz**: Software.

Declaration of competing interest

The authors declare there are no conflict of interest

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