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Coconut shell charcoal briquettes production using banana corm adhesive

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Abstract: The production of biomass-based briquettes from coconut shell charcoal and banana corm adhesive has been successfully carried out. This research aims to determine whether the banana corm may serve as an adhesive for briquette production from coconut shell charcoal. The concentration of banana corm utilized as adhesive is 10, 20, 30, 40, and 50%. For comparison analysis, this study also employed tapioca flour adhesive with the same concentration. The briquettes adhere to the SNI 01-6235-2000 standard for briquettes. The quality of briquettes is determined based on fixed carbon content and calorific value. The minimum standard calorific value and fixed carbon content are 5000 cal/g and 65%, respectively. Briquettes with a 90:10 ratio (coconut shell charcoal to banana corm adhesive ratio) had the highest calorific value of 7250 cal/g and fixed carbon content of 80.04%. In comparison, the tapioca flour adhesive provides a calorific value and fixed carbon content of 6995 cal/g and 81.09%, respectively. Furthermore, another indicator that determines briquette quality is the content of moisture, ash, and volatile matter. Briquettes with a 90:10 ratio possessed low moisture content (3.55%), ash content (6.45%), volatile matter content (9.96%), and burning rate (0.020 g/sec). This result indicates that the briquettes with a 90:10 ratio exhibit the greatest quality. Briquettes with banana corms adhesive have similar characteristics to tapioca flour, especially in terms of calorific value. As a result, the highlight of this research lies in offering banana corm, which has scientific contribution and future potential as an alternative adhesive in the briquetting process.

Keywords: Banana corm, adhesive, briquette, coconut charcoal

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INTRODUCTION

Recent research on alternative energy sources has involved a specific approach that incorporates biomass. Biomass is a natural resource that is generally considered waste and is often disposed of through combustion. However, biomass can still be used to produce useful resources [1]. Briquettes are charcoal sticks produced from the combustion of biomass materials such as wood, coconut shells, or agricultural waste [2]. Briquettes have several advantages, including a tidy design that leaves no residue on the hands, ease of ignition, and a low combustion rate [3]. Coconut shell charcoal is a raw material for briquette production. Coconut shells, as a by-product of coconut trees, contain carbon compounds that have good heat diffusion properties and energy production capabilities [4]. The process of making briquettes from coconut shell charcoal involves carbonization, filtering to produce homogeneous particle sizes, and finally mixing with a binder [5, 6].

The production of briquettes requires a binder to prevent disintegration [7]. Adhesives suitable for producing high-density briquettes include clay and molasses. Nonetheless, this adhesive produces a significant amount of smoke upon combustion [8]. The approach involves utilizing natural resources with adhesive characteristics, such as tapioca flour, to produce smokeless, durable briquettes that are resistant to damage during storage [9-12]. Palanisami et al. [13] conducted research utilizing tapioca flour as an adhesive for briquetting Gloriosa superba and turmeric leaf waste at a concentration of 20%. Their findings indicated that tapioca flour significantly influences a high calorific value of 15.64 MJ/kg, a high density of 1176.5 kg/m³, a prolonged burning time of 20-28 minutes, and an ignition time of 4 seconds.

Banana plants possess a brown stalk that encases a banana corm. The banana corm is the lowest part of the banana plant, characterized by its spherical and tuber-like appearance underground [14]. Banana corm contains a polysaccharide composition (amylose, which provides rigidity, and amylopectin, which causes stickiness), which makes it a potential novel source of flour [15]. According to Zhang et al. [16], banana corms contain 11.2% amylose and 66.16% amylopectin, while tapioca flour has 17% amylose and 83% amylopectin [17].

Since banana corm has a high flour content, it could be used as an adhesive in briquette production [18]. The novelty of this research is the use of banana corm as an alternative adhesive to replace tapioca flour in the production of coconut shell charcoal-based briquettes. The resulting briquettes are expected to have qualities comparable to or better than those of tapioca flour adhesives, particularly in terms of calorific value and fixed carbon content. For comparison, this study also investigated briquettes made with tapioca flour. Furthermore, the study's limitations included the use of kepok banana corm with charcoal and adhesive concentration ratios ranging from 90:10 to 50:50.

MATERIALS AND METHODS

Materials

The materials used were coconut shell, banana corm, tapioca flour, water, and benzoic acid.

Methods

Preparation of coconut shell charcoal

The coconut shell was sun-dried for two days to remove water and facilitate the briquetting process. The coconut shells were placed in a charcoal drum and burned to produce charcoal, which was then crushed and sieved using a 100-mesh sieve.

Preparation of Banana corm starch Adhesive

The banana corm is peeled, washed, cut into pieces, and sun-dried for two days. After that, the dried banana corm was crushed and sieved through a 100-mesh sieve. 100 g of banana corm flour was dissolved and stirred in boiling water until it formed a transparent and sticky gel.

Preparation of Briquettes

Coconut shell charcoal and banana corm flour adhesive in ratios of 90:10 (B1), 80:20 (B2), 70:30 (B3), 60:40 (B4), and 50:50 (B5) were mixed and then shaped using a cylindrical iron pipe with a diameter of 3 cm and a height of 7 cm. The solid material was then pressed using a briquette press machine for 3 minutes at a pressure of 340 mPa/psi to produce briquettes with a diameter of 3 cm and a height of 3 cm. Finally, the briquettes were dried at 60 °C for 24 h in an oven. The same process was also carried out with tapioca flour as a binder.

Calorific value testing of briquettes

The combustion furnace was calibrated using benzoic acid to ascertain the heat loss during combustion and employed as a correction factor. 5 g of benzoic acid were made into pellets, placed in the furnace, and subsequently burned. The calorific value is determined by combusting 20 grams of briquettes in a furnace until they smoulder. An aluminium pan with 1 L of water was set up on the furnace, and the weight of the pan together with the initial water temperature (T1) was observed. After all the coconut shell charcoal has turned to ash and no longer produces heat, the amount of ash residue and the final water temperature are calculated (T2). The calorific value of the briquette was determined using the equation:

$$Q = Q_w + Q_{al} + Q_{lose} \quad \text{(I)}$$

$$= (m_w \times C_w \times \Delta T_{br}) + (m_{al} \times C_{al} \times \Delta T_{br}) + \left(Q_{lose} \times \frac{\Delta T\ briquttes}{\Delta T\ benzoic\ acid}\right) \quad \text{(II)}$$

Q = Calorific value released (cal), w = water, br = briquette, al = aluminium, $\Delta T_{briquettes}$ = Change in water temperature with briquette combustion (T_2-T_1), $\Delta T_{briquettes}$ = Change in water temperature with benzoic acid combustion (T_2-T_1)

The calorific value was determined using the following equation:

$$\text{Calorific value of briquettes} = \frac{Q}{mb} \quad \text{(III)}$$

Q = Calorific value released (Cal), mb = weight of briquettes (g)

Calorific value testing was also conducted using a DSC (differential scanning calorimeter) instrument. The samples were weighed at 11.1 mg (briquettes with banana stump flour adhesive) and 16.9 mg (briquettes with tapioca starch adhesive), respectively, and then placed into an aluminium crucible, inserted into the chamber of the DSC instrument, and heated from 50 to 280 °C with a heating rate of 20 °C/minute.

Moisture content testing of briquettes

A 1 g sample was placed in an empty porcelain cup that had been previously weighed and heated in an oven at 105°C for 2 hours. The process was repeated until the weight remained constant. The sample was then cooled in a desiccator for 15 min and weighed after heating. The water content was calculated using the following equation:

$$\text{Water content (\%)} = \frac{(WS1 - WS2)}{Mass\ sample} \times 100\% \quad \text{(IV)}$$

WS_1 = weight of cup and sample before heating
WS_2 = weight after heating (g)

Density testing of briquettes

Determination of the density is done by measuring the mass (m), diameter (d), and height (h) of the briquettes. The density was calculated using the equation:

$$\text{Density } (\rho) = \frac{m}{v} \quad \text{(V)}$$

$$v = \frac{\pi}{4} d^2 \times h \text{ (volume of cylinder)} \quad \text{(VI)}$$

Ash content testing of briquettes

The empty porcelain cup was dried in an oven, weighed, and then 1 g of the sample was added. The sample was placed in a furnace at 600 °C for 3 hours until it had completely turned to ash. The ash was then cooled in a desiccator for 15 min, and the weight of the cup and ash was measured. The ash content was calculated using the equation:

$$\text{Ash content (\%)} = \frac{[WA1 - WA2]}{mass\ sample}\ x\ 100\% \quad \text{(VII)}$$

WA_1 = weight of cup and sample before heating (g)
WA_2 = weight after heating (g)

Volatile matter content testing of briquettes

1 g of sample was placed in an empty porcelain crucible that had been weighed beforehand, and then it was heated in a furnace at 950 °C for 7 minutes. The results were removed, cooled in a desiccator for 15 minutes, and weighed to determine the weight of the cup containing the sample after it had been heated. The volatile matter content was calculated using the equation:

$$\text{Volatile matter content (\%)} = \frac{[(WS1 - WS2)]}{mass\ sample}\ x\ 100\% - \text{water content} \quad \text{(VIII)}$$

WS_1 = weight of cup and sample before heating (g)
WS_2 = weight after heating (g)

Fixed carbon content of briquettes

The determination of the value of the fixed carbon content of briquettes is calculated based on the equation:

Fixed carbon content (%) = 100% – (water content + ash content + volatile matter content).

Briquette combustion rate

The burning rate of briquettes is determined based on the rate at which they burn and turn to ash. The duration is measured by burning the briquettes and then recording the time from when the briquettes start burning until they are completely burned or turned to ash.

RESULTS AND DISCUSSION

Calorific value analysis

The calorific value with water media is determined based on the amount of heat released by the briquette or the heat absorbed by water, the furnace, and the aluminium pan. The briquette furnace was initially calibrated using benzoic acid, which possesses a calorific value of 6318 cal/g. The use of banana corm adhesive (Table 1) reveals that the highest calorific value is found in briquettes with a 90:10 ratio (4231 cal/g). In comparison, the lowest calorific value is observed in briquettes with a 50:50 ratio (2827 cal/g). The results indicated that an increase in adhesive concentration corresponds to a decrease in calorific value. The usage of adhesive affects the moisture content, ash, volatile matter, and bound carbon, thereby impacting the calorific value of the briquette [4]. A comparable situation occurred with the use of tapioca starch adhesive, with a calorific value ranging from 2868 (50:50) to 4356 (90:10) cal/g.

Table 1. Calorific value of briquettes using water media and DSC instruments

No	Sample	Calorific value (cal/g)				
		Water media		DSC		SNI
		BC	TF	BC	TF	
1	B_1	4231	4356	7250	6995	>5000
2	B_2	3667	3835	6891	6695	
3	B_3	3477	3477	6704	6475	
4	B_4	3212	3102	6517	6291	
5	B_5	2827	2868	6236	6168	

Charcoal to adhesive ratio of 90:10 (B_1); 80:20 (B_2); 70:30 (B_3); 60:40 (B_4); 50:50 (B_5)
BC = Banana corm, TF = Tapioca Flour, SNI = Standard Nasional Indonesia

Table 2. The properties of briquettes using banana corms and tapioca flour adhesive

No	Sample	Briquettes properties													
		Moisture content			Ash content			Density		Volatile matter			Fixed carbon		
		BC	TF	SNI	BC	TF	SNI	BC	TF	BC	TF	SNI	BC	TF	SNI
1	B_1	3.55	3.46	≤8	6.45	6.43	≤8	0.41	0.44	9.96	9.02	≤15	80.04	81.09	>65
2	B_2	3.66	3.52		6.54	6.48		0.43	0.44	11.44	11.05		78.36	78.95	
3	B_3	3.80	3.69		6.61	6.54		0.43	0.45	13.44	13.50		76.15	76.27	
4	B_4	3.83	3.92		6.62	6.74		0.46	0.47	13.26	16.39		76.29	72.95	
5	B_5	4.08	4.09		6.68	6.80		0.50	0.47	15.07	17.21		74.17	71.90	

Charcoal to adhesive ratio of 90:10 (B_1); 80:20 (B_2); 70:30 (B_3); 60:40 (B_4); 50:50 (B_5)
BC = Banana corm, TF = Tapioca flour, SNI = Standard Nasional Indonesia

The calorific value of briquettes is determined using the Differential Scanning Calorimeter instrument. A DSC instrument is used to measure the heat flow into or out of a sample as it's heated or cooled. The results revealed that those incorporating banana corm adhesive at a ratio of 90:10 exhibited an elevated calorific value of 7250 cal/g. In contrast, the caloric value of tapioca flour is 6995 cal/g. SNI 01-6235-2000 specifies that the minimum calorific value of briquettes is 5000 cal/g. This study concluded that banana corm can be utilized as an adhesive in briquette production, meeting the Indonesian National Standard. Anis et al. [4] investigated briquette production using various adhesives, i.e tapioca flour, cassava flour, and modified cassava flour, yielding calorific values of 7040, 7003, and 7181 cal/g, respectively. This finding indicates that the use of banana corm adhesive has a higher calorific value than other adhesives due to the banana corms containing high amylopectin, which helps bind the charcoal particles together to improve the density of the briquette. Furthermore, the banana corm adhesive has a good ability to absorb water, resulting in a lower moisture content and a higher calorific value [16].

The heat value, as determined by DSC instrument analysis, is higher than that of water media. For example, in sample B1 with water media, the heat value produced is 4231 cal, while with the DSC instrument, it is 7250 cal. The result is due to the DSC instrument being able to quantify the total amount of heat energy absorbed or released. In contrast, calculations using water media only determine the amount of heat released based on the heat generated when heating the water and the pan.

Moisture content analysis

Table 2 presents the properties of briquettes made from banana corms and tapioca flour adhesive. The moisture content of the briquettes increased with higher concentrations of adhesive. It aligns with Mao et al. [19], which indicates that a higher concentration of adhesive leads to an increased amount of water entering and being retained in the pores of charcoal. Furthermore, the adhesive's presence increases the density of the briquettes. The moisture content results from the narrower pores associated with higher briquette density. Upon drying, water becomes trapped within the pores, rendering water evaporation difficult [20].

Briquettes utilizing banana corm adhesive have a moisture content ranging from 3.55% to 4.08%. It is in agreement with SNI 01-6235-2000, which states that the maximum moisture content of briquettes is 8%. In comparison to tapioca starch adhesive with a moisture content of 3.46 – 4.09%, both adhesive types exhibit comparable moisture levels.

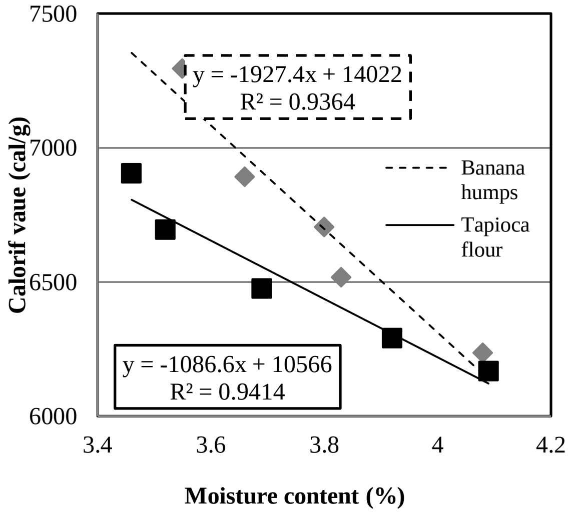

Figure 1. The correlation of calorific value with the moisture content of briquettes

Nonsawang et al. [17] used tapioca starch, cassava peel, and cassava tubers as adhesives for briquette production from coconut shells and found that the briquettes had moisture contents of 3.48%, 4.35%, and 6.40%, respectively. Tapioca starch has a lower moisture content due to its starch form, whereas cassava comes in its natural form of peel and tubers, which have a higher water content.

The correlation between the calorific value of briquettes and moisture content is such that increased moisture content results in a decreased calorific value of the briquettes. Conversely, the calorific value of briquettes rises with a decrease in the concentration of adhesive employed. Figure 1 illustrates that briquettes with a 90:10 ratio exhibit excellent qualities, characterized by a lower moisture content and higher calorific value compared to the tapioca starch adhesive.

Ash content analysis

Table 2 demonstrates the correlation between increasing ash content and higher adhesive concentration. The presence of adhesive results in an increased ash content in the briquettes. Briquettes made with banana corm adhesive exhibit an average ash content ranging from 6.45% to 6.68%. The same result is observed, with briquettes made from tapioca starch as an adhesive exhibiting an ash content of 6.43 to 6.8%. The ash content produced adheres to SNI 01-6235-2000, which specifies a maximum. Ash content of 8% for briquettes. Figure 2 demonstrates that an improvement in ash content is associated with an increase in the calorific value of the briquettes. According to Kipngetich et al. [8], a high ash content can diminish the calorific value, as the briquettes will rapidly convert to ash, thereby shortening the combustion process. In contrast, a reduced ash level in the briquettes correlates with an elevated calorific value. Briquettes with a 90:10 ratio are of higher quality because they possess a low ash content and high calorific value.

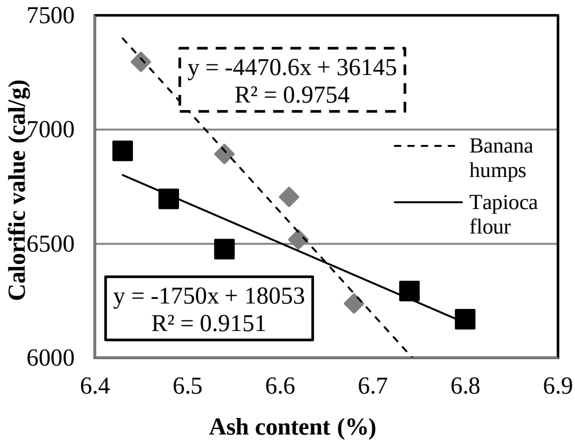

Figure 2. The correlation of calorific value with the ash content of briquettes

Density analysis

Density is a parameter that determines the quality of briquettes, which is influenced by the particle size of the briquettes. Briquettes with a small particle size have a larger number of particles, causing the small amount of water contained in the pores and a higher density [21,22]. The density of briquettes with banana corm adhesive in Table 2 are 0.409 (90:10);

0.433 (80:20); 0.438 (70:30); 0.464 (60:40); and 0.535 g/cm^3 (50:50). This is in accordance with Lu et al. [12] which states that the effect of adhesive concentration on briquette density is that the higher the concentration of adhesive, the stronger the bond between particles, so that the charcoal particles will be strongly bound together, causing higher density. The densities of briquettes with tapioca starch adhesive are 0.437 (90:10), 0.445 (80:20), 0.455 (70:30), 0.470 (60:40), and 0.475 g/cm³ (50:50).

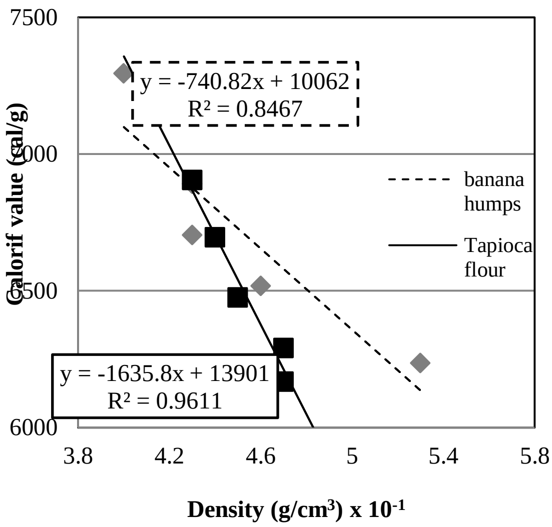

Figure 3. The correlation of calorific value with the density of briquettes

The composition of the adhesive material affects the density difference between the two types of adhesives. The use of banana tubers produces briquettes with high density due to their high amylopectin content. The relationship between the calorific value and density of briquettes, as shown in Figure 3, indicates that a decrease in density is correlated with an increase in calorific value. However, high-density briquettes have a low calorific value due to their high adhesive content, which results in high water, ash, and volatile matter content, thereby reducing the calorific value [23,24].

Volatile matter content analysis

The evaluation of volatile matter content was conducted to quantify the volatile compounds present in the briquettes at 950 °C. Table 2 shows that the volatile matter content ranges from 9.96% (90:10) to 15.07% (50:50). According to SNI 01-6235-2000, the maximum volatile matter content in briquettes is 15%; therefore, the production of briquettes utilizing banana corm adhesive adheres to the standard. Briquettes with tapioca starch adhesive have a relatively similar moisture content, ranging from 9.02% (90:10) to 17.21% (50:50). The amount of volatile matter is influenced by the temperature and duration of the pyrolysis process during charcoal treatment. Ziezio et al. [25] state that a temperature range of 100-400 °C facilitates the drying and evaporation of moisture content. Thus, at temperatures between 400 and 600 °C, the pyrolysis of volatile substances occurs, resulting in the formation of carbon charcoal.

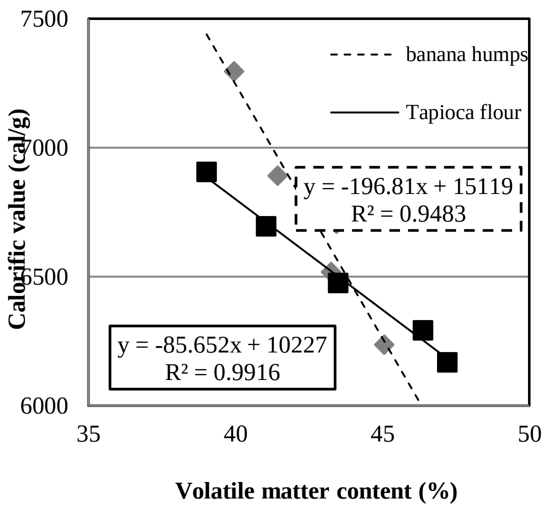

Figure 4. The relations of calorific value with the volatile matter of briquettes

The presence of adhesive also affects the quantity of volatile matter. Banana corm adhesive does not undergo pyrolysis, resulting in a high content of volatile matter. This aligns with the findings of Suryaningsih et al. [26], which indicate a correlation between increased adhesive amount (without pyrolysis) and elevated volatile matter content. Figure 4 illustrates an inverse relationship between calorific value and volatile matter content, indicating that higher volatile matter in briquettes is associated with a reduction in calorific value. Inversely, a decrease in volatile matter correlates with an increase in calorific value. This result is attributed to the low concentration of vaporized matter, which leads to a high bound carbon in the product, thereby generating increased energy (heat) and producing a higher calorific value.

Fixed carbon content analysis

Table 2 presents the fixed carbon value of the briquettes with banana corm adhesive of

80.04% (90:10), 78.36% (80:20), 76.15% (70:30), 76.29% (60:40), and 74.17% (50:50). These results show that the higher the concentration of adhesive, the lower the fixed carbon. Briquettes with the highest fixed carbon content are obtained when using an adhesive concentration of 10% (80.04%). According to SNI 01-6235-2000, the minimum fixed carbon content in briquettes is 65%. Briquettes prepared using tapioca starch adhesive have fixed carbon of 81.09% (90:10), 78.95% (80:20), 76.27% (70:30), 72.95% (60:40), 71.90% (50:50). The fixed carbon content generated between the two adhesives is relatively similar, meaning that banana corms can be used as an alternative adhesive to replace tapioca starch.

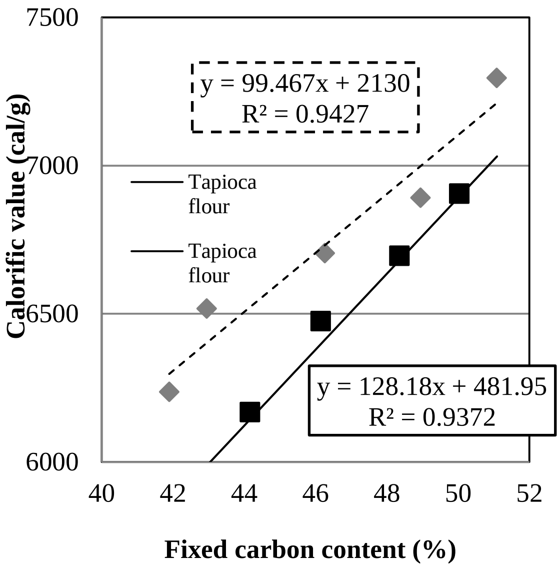

Figure 5. The relations of calorific value with the fixed carbon content of briquettes

Figure 5 shows the relationship between fixed carbon content and the calorific value of briquettes. The higher the fixed carbon content, the greater the calorific value. Briquettes with a ratio of 90:10 are considered the optimum quality briquettes due to their high fixed carbon content and high calorific value. Research by Anis et al. [4] indicates that fixed carbon content is another parameter used to determine the quality of briquettes, where a higher fixed carbon content corresponds to better-quality briquettes.

Burning rate analysis

The burning rate of a briquette is the rate at which the briquette burns to ash per second. The briquette burning rate is influenced by the quantity of briquettes consumed and the time required for the particles to reduce to ash [27]. Moreover, high-bound carbon (high fixed carbon) possesses powerful intermolecular connections that result in extended combustion [28]. The burning rate of the briquettes with banana corm adhesive was 0.020 g/sec (90:10), 0.016 g/sec (80:20), 0.015 g/sec (70:30), 0.012 g/sec (60:40); and 0.011 g/sec (50:50). The findings indicate that an increase in adhesive concentration correlates with a decrease in the burning rate of the briquettes.

Similarly, the burning rate of briquettes with tapioca starch adhesive was 0.022 g/sec (90:10); 0.018 g/sec (80:20); 0.014 g/sec (70:30); 0.012 g/sec (60:40); 0.010 g/sec (50:50). The comparison between the two adhesives showed that the briquettes with tapioca starch had a higher burning rate at ratios of 70:30; 60:40 and 50:50, while at ratios of 90:10 and 80:20 the briquettes with banana corm starch adhesive had a higher burning rate. The optimum condition of briquettes, based on calorific value and fixed carbon content (Table 2), indicates that briquettes with a ratio of 90:10 have the optimum quality. Furthermore, based on the briquette burning rate test on briquettes with a 90:10 ratio, banana corm adhesive is found to be superior to tapioca starch.

CONCLUSION

The production of briquettes from coconut shell charcoal using banana corm adhesive has been successfully carried out. The results show that the lower the concentration of adhesive used, the higher the calorific value and fixed carbon content produced. Meanwhile, the lower the water content, ash content, and volatile matter content, the higher the quality of the briquettes produced. Briquettes with optimal quality were obtained at a ratio of coconut shell charcoal to banana corm of 90:10. The quality of the briquettes produced has properties similar to those of briquettes using tapioca flour as an adhesive; therefore, it can be concluded that banana corm can be used as an alternative substitute for tapioca flour as an adhesive in briquette production. The limitations of this study are the lack of testing of the mechanical strength of the briquettes and their direct application. Furthermore, for future research, studies on the compressive strength, stability, and efficiency of briquettes are a priority, which can then be used as a reference to determine the quality of coconut shell charcoal briquettes produced with banana corms.

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