 ISSN XXXX-XXXX

Combustion Quality Analysis of Bio-Briquettes from Mixture of Coconut Shell Waste and Coal with Tapioca Flour Adhesive

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ARTICLE INFO

Article history
Received June10, 2023
Revised July 1, 2023
Accepted July 4, 2023

Keywords
Bio-briquette
Coal
Coconut shell waste
Molding screw system
Tapioca flour

ABSTRACT

Agroindustry residues can be utilized as a resource for alternative energy sources such as bio-briquettes. Using agro-industry residue is also a solution to reduce pollution caused by biomass waste in the environment. This article highlights the combustion quality analysis of biomass waste in the form of bio-briquettes with binding materials prepared from tapioca flour. The biomass used is a mixture of coconut shell charcoal and coal to improve the quality of the bio-briquettes. In this study, bio-briquettes were manufactured using a screw press system. The combustion quality of bio-briquettes with various percentage compositions (0:100, 25:75, 50:50, 75:25, 100:0) of coconut shell charcoal and coal was investigated, i.e., moisture content, ash content, combustion rate, and calorific value. Results show that the calorific value of most bio-briquettes produced in this study was higher than the standard calorific value according to SNI Standard No.1/6235/2000 (≥ 5,000 cal/gr). The optimum composition to produce bio-briquette with good quality based on the standard is 75:25 (coconut shell charcoal: coal), which had a moisture content of 7.6325%, ash content of 6.9697%, combustion rate of 0.1833 gr/min, and caloric value of 5833.78 cal/gr.

1. Introduction

Indonesia is known as one of the world's largest producers of agricultural commodities, such as coconut, palm oil, cocoa, coffee, and spices. Agricultural industries generated a significant amount of residues that were primarily untreated. These residues cause a serious disposal problem and may lead to environmental pollution. Meanwhile, global energy demand is rising every year as the growth of the population is also increasing. The current use of fossil fuels causes significant exploitation of fossil fuels such as oil and coal, and the need for energy consumption is growing every year, while the natural resources that produce energy are shrinking because these energy sources cannot be renewed [1]. To reduce our dependence on fossil fuels, alternative energy sources, for example, biomass, are needed. Biomass energy is the oldest form of energy used since human civilization began. Biomass energy still plays an important role today, especially in rural areas [2], [3].

As mentioned before, biomass, such as agroindustry wastes, can be utilized as a resource for alternative energy sources such as bio-briquettes. Based on its availability, coconut shell is the potential to be used as a renewable energy source and is very appropriate to be developed in Indonesia [4]. Using biomass waste is also a solution to reduce pollution in the environment. Biomass waste can be used as a fuel source by converting it into charcoal and processing it into briquettes. Briquettes are much easier to use and relatively inexpensive compared to firewood. It also has a high heating or calorific value but a low level of ash content. Usually, briquettes are locally produced near the supplier and consumer for everyday use [5], [6].

In addition to biomass briquettes, bio-coal briquettes can be used as other energy sources. Bio-coal briquettes are a mixture of briquettes derived from biomass and coal. There are plenty of coals in Indonesia to meet alternative energy needs for the next 150 years. The process of making briquettes from biomass and coal has been carried out by [7]. It was reported that coal produces emissions between SO_2 and NO, which can be reduced. It also generated less smoke and ash when compared to burning coal alone. According to [8], manufacturing briquettes from a mixture of coal and biomass also provides a longer combustion time and high heating temperature than briquettes from coal or biomass only. This study uses coal as a source of hydrocarbons and coconut shell charcoal as a source of biomass. An adhesive is needed as a binding material, such as tapioca flour, to stick the raw materials together. Tapioca flour is selected in this study because it is abundantly available, affordable, and easy to obtain [9].

During the combustion of bio-briquettes, the reaction between carbon and oxygen to form carbon monoxide and carbon dioxide happened on the surface of the particles as stated in Equations (1) to (4) below:

$$C + \frac{1}{2}O_2 \rightarrow CO_2 \quad (1)$$

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 \quad (2)$$

$$C + CO_2 \rightarrow 2CO \quad (3)$$

$$C + H_2O \rightarrow CO + H_2 \quad (4)$$

Some factors affect the characteristics of bio-briquette combustion [10], [11] such as:

1. The burning rate of bio-briquettes and the content of volatile compounds are proportional. The higher the combustion rate, the higher the volatile compounds. The rate of combustion can be known by Equation (5):

$$(-rA) = -\frac{dmA}{dt} = km_A^n \quad (5)$$

2. If the combustion process reaches a high calorific value, the combustion temperature will be increased, and the optimum temperature will be extended.
3. If the density of bio-briquettes is high, the combustion rate will be slower.

This study aims to test the combustion quality of bio-briquette manufactured from a mixture of coconut shell charcoal and coal with tapioca flour adhesive using a screw system press. Some analyses were applied to test the performance of the bio-briquette, namely moisture content, ash content, combustion rate, heating value, and ignition test. After being tested, the bio-briquettes' quality was investigated to determine the optimum condition.

2. Research Methodology

2.1. Materials

The biomass waste material used in this study was coconut shell charcoals (roughly crushed with maximum water content 15%) collected from Giwangan Traditional Market, Yogyakarta, while coal was obtained from Kalimantan. An adhesive or binding material was prepared by mixing tapioca flour and water with a ratio of 1:3.

2.2. Briquette preparation

The manufacturing process of bio-briquette was carried out as following steps:

- Coconut shell charcoal and coal as raw materials were ground into a size of 60 mesh. The grinding process of raw materials is shown in Figure 1.

(a) (b)

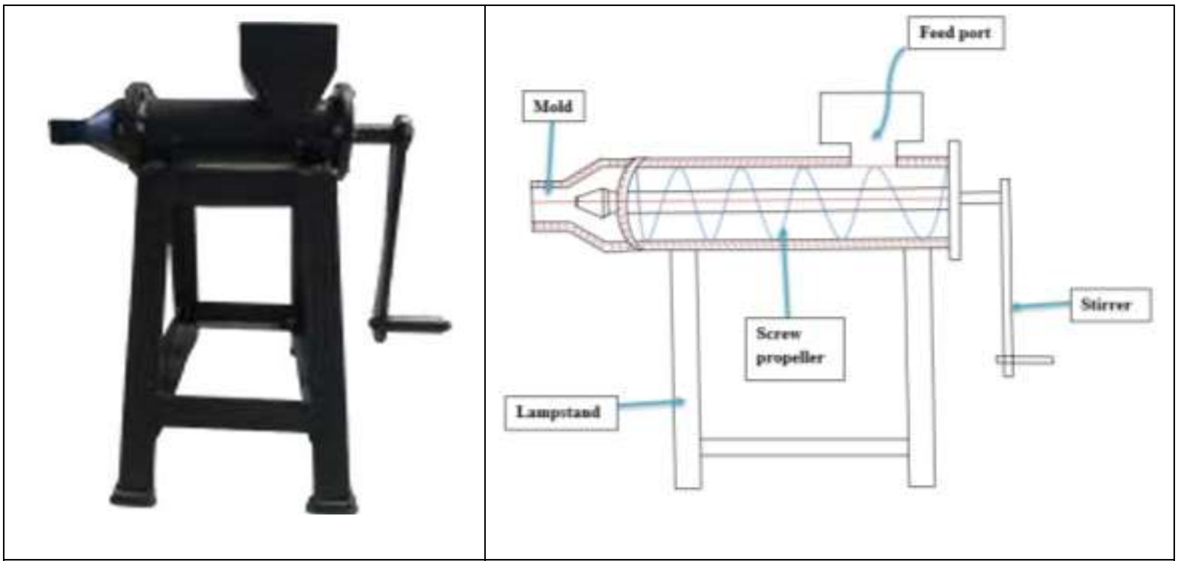
Figure 1. Raw materials: (a) before and (b) after the grinding process

- Both raw materials were mixed to produce bio-briquettes with tapioca flour solution as an adhesive. The mixture ratio of raw materials in bio-briquette (coconut shell charcoal: coal) is presented in Table 1.

Table 1. Composition of raw materials (%w) in bio-briquette

Variation	Composition (coconut shell charcoal: coal)
Bio-briquette 1	0:100
Bio-briquette 2	25:75
Bio-briquette 3	50:50
Bio-briquette 4	75:25
Bio-briquette 5	100:0

- The bio-briquette dough was inserted into the printed press (screw press system as shown in Figure 2) and cut into the desired size. The wet bio-briquette was weighed first before drying.



(a) (b)

Figure 2. Screw press briquette: (a) machine, (b) scheme

- The printed bio-briquette samples were dried using the sun-drying method. The bio-briquette samples were continuously weighed daily to determine the constant dry weight. It took 3–5 days to get completely dried samples. After the pieces were dried, the quality of bio-briquettes was investigated through several tests.
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2.3. Analysis

2.3.1. Moisture content

This test is carried out to determine the water content of the bio-briquette sample.

$$Moisture\ content\ (\%) = \frac{M_D}{M_W - M_D} \times 100\% \quad (6)$$

where: M_W = wet mass basis of bio-briquette (gram)
M_D = dry mass basis of bio-briquette (gram)

2.3.2. Ash content

Ash content is a material that does not burn after a complete combustion process. The less ash left means, the better the bio-briquette produced.

$$Ash\ content\ (\%) = \frac{M_A}{M_D} \times 100\% \quad (7)$$

where: M_A = mass of ash (gram)
M_D = dry mass basis of bio-briquette (gram)

2.3.3. Combustion rate

Combustion rate is the reduction of bio-briquette weight per unit of time during combustion.

$$Combustion\ rate = \frac{B}{t} \quad (8)$$

where: B = mass of bio-briquette before combustion (gram)
t = combustion time (minutes)

2.3.4. Calorific value

Calorific value is the energy produced by the complete combustion of bio-briquette.

$$Calorific\ value = ((T_2 - T_1) - 0.5) \quad (9)$$

where: T_1 = temperature before combustion (°C)
T_2 = temperature after combustion (°C)

2.3.5. Flame test

The flame test is carried out to determine the characteristics of the bio-briquette during the combustion process. The tests investigate:

1. The ease or difficulty of burning bio-briquettes
2. The length of time required for bio-briquettes to burn (minutes)
3. Height of the resulting flame (cm)
4. The color of flame produced by the bio-briquettes (red/yellow/blue)
5. The length of time the flame lasts until the bio-briquettes run out (minutes)
6. The hardness of the bio-briquettes
7. The physical form of bio-briquettes in wet and dry conditions

3. Results and Discussion

3.1. Bio-briquettes' shape and properties

Bio-briquettes from the coconut shell charcoal and coal mixture have been successfully made using a screw press system. After being printed, bio-briquettes were dried using a sun-drying method for four days. Figure 3 and Figure 4 shows the drying process of bio-briquettes from various composition until the final product is thoroughly dried and the bio-briquettes sample is ready to be bested.

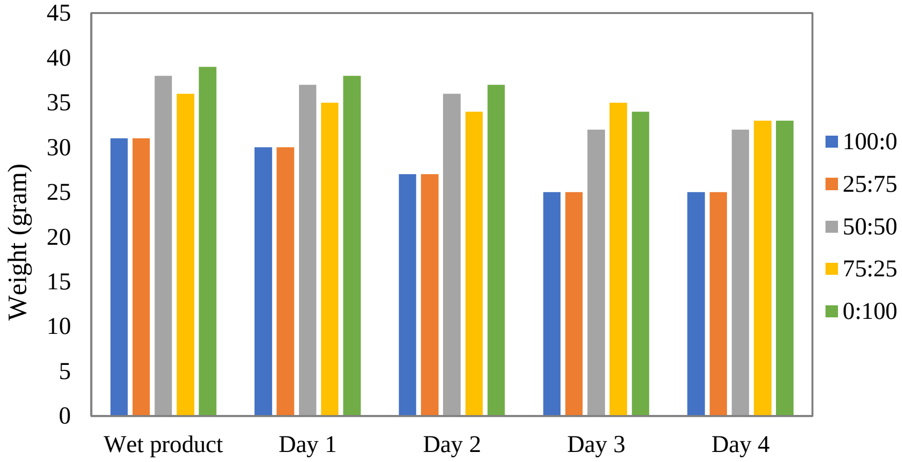
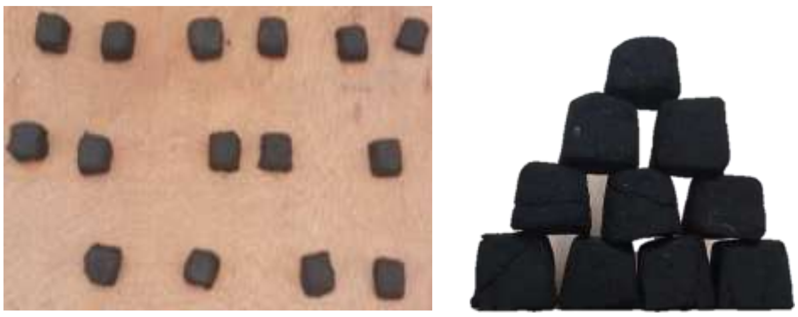


Figure 3. Weight of bio-briquettes from various compositions during the drying process



(a) (b)

Figure 4. Bio-briquettes from the mixture of coconut shell charcoal and coal: (a) during the drying process, (b) dried bio-briquettes product ready to be tested

The results of printed bio-briquettes were of good quality, as they are not too hard when threading the tool and are not runny. The time required for printing also took a short time. The resulting briquette product has no holes, despite a few coarse grains from the raw material. It can be seen in Figure 5.

(a) (b) (c) (d) (e)

Figure 5. Results of bio-briquettes with various compositions (coconut shell charcoal: coal): (a) 0:100, (b) 25:75, (c) 50:50, (d) 75:25, (e) 100:0

3.2. Moisture Content

Moisture content is the water content in bio-briquettes. The moisture content of bio-briquettes from various compositions can be seen in Table 2.

Table 2. The moisture content of bio-briquette from coconut shell charcoal and coal with various composition

Composition (%w) (coconut shell charcoal: coal)	Moisture content (%)
0:100	8.0049
25:75	6.0671
50:50	7.1825
75:25	7.6325
100:0	6.5356

The quality standard of bio-briquettes in this study was achieved from moisture content results. According to SNI Standard No.1/6235/2000, the maximum value for moisture content is 8%. All variations of bio-briquettes produced were below 8% (average value: 7.0845%), except for the composition of 0:100 (coconut shell charcoal: coal). Table 2 shows that the lowest moisture content was obtained by bio-briquette with a mixture of 25% coconut shell and 75% coal.

3.3. Ash Content

After the combustion of bio-briquettes, the residue left from burning bio-briquettes is referred to as ash, an inorganic substance. SNI Standard No.1/6235/2000 stated that the ash content of good-quality briquettes should be below 8%. The lower the ash content, the better the briquettes produced. The results of ash from the bio-briquettes after combustion can be seen in Figure 6, while the ash content is shown in Table 3.

(a) (b) (c)

Figure 6. Results of ashes from the combustion of bio-briquettes

Table 3. Ash content of bio-briquette from coconut shell charcoal and coal with various composition

Composition (%w) (coconut shell charcoal: coal)	Ash content (%)
0:100	7.6000
25:75	10.6667
50:50	10.3125
75:25	6.9697
100:0	10.6061

Table 3 shows that bio-briquettes that meet the standards are found in variations 0:100 and 75:25, while the ash content from other variations was still too high (>8%). One of the factors for the high ash content is tapioca flour which is still too much, or the ash content in the raw material is relatively high. It can also be due to the high adhesive ratio. If the ash content is still high, the crust produced during combustion can reduce the quality of briquettes.

3.4. Combustion Rate

The combustion rate is the weight loss per unit of time during combustion. The result from the combustion rate analysis of the bio-briquettes is shown in Table 4.

Table 4. Combustion rate of bio-briquette from coconut shell charcoal and coal with various compositions

Composition (%w) (coconut shell charcoal: coal)	Combustion rate (gr/min)
0:100	0.1701
25:75	0.2415
50:50	0.1621
75:25	0.1833
100:0	0.1833

Bio-briquette with the highest combustion rate was obtained from the mixture of coconut shell and coal with a composition of 25:75 which yielded a rate of 0.2415 gr/min, while bio-briquette with the lowest combustion rate was found in the variation of 50% coconut: 50% coal at 0.1621 g/minute.

3.5. Calorific Value

The calorific value is the heat or energy produced by complete combustion. According to [3], the calorific value produced from a briquette is expressed as a heating value. The higher the specific gravity of a material, the higher the calorific value will be obtained. The calorific value of bio-briquettes is one of the important parameters to determine their quality. The higher the calorific value, the better the briquettes. The calorific value from bio-briquettes in this study is shown in Table 5.

Table 5. The calorific value of bio-briquette from coconut shell charcoal and coal with various compositions

Composition (%w) (coconut shell charcoal: coal)	Calorific value (cal/gr)
0:100	5,714.70
25:75	5,274.22
50:50	5,778.78
75:25	5,833.78
100:0	4,515.20

Based on Table 5, calorific values from bio-briquettes with all various compositions were above 5,000 cal/gram, except for the composition 100:0. According to SNI Standard No.1/6235/2000, bio-briquette with good quality should have a calorific value more than 5,000 cal/gram, which means almost all bio-briquettes produced in this study (composition of 0:100, 25:75, 50:50, and 75:25) fulfilled the standard. The highest calorific value is achieved by a bio-briquette sample with the composition of 75% coconut shell charcoal: and 25% coal (5,833.78 cal/gram), and the lowest calorific value is obtained by a bio-briquette sample with the composition of 100% coal (4,515.20 cal/gram). Coconut husks and shell has been reported as material with high calorific value, thus it affects the final calorific value from the mixture. The high calorific value properties mean this briquette is suitable for alternative fuels [12], [13], [14].

3.6. Flame Test

The flame test is conducted to determine the characteristics of the bio-briquette samples in terms of the combustion process. The flame test consists of (i) a physical and (ii) a burning test.

3.6.1. Briquette Physical Test

The physical test consists of testing the properties of bio-briquettes such as shape, hardness, hardening time, printout condition, product compactness, product weight before and after drying, and dry condition. The observation result of the physical test from bio-briquette samples is shown in Table 6.

Table 6. Physical test of bio-briquette from coconut shell charcoal and coal with various composition

Parameter	Composition of coconut shell: coal (%)				
	100:0	**25:75**	**50:50**	**75:25**	**0:100**
Shape	Cube	Cube	Cube	Cube	Cube
Hardness	Hard	Hard	Hard	Hard	Hard
Hardening time (days)	3	3	3	3	3
Printout condition	Wet	Wet	Wet	Wet	Wet
Product compactness	Nice and compact	Nice and compact	Nice and compact	Nice and compact	Nice and compact
Product weight before drying (grams)	31	38	38	36	39
Final product weight after drying (grams)	25	30	32	33	33
Dry condition	Hard	Hard	Hard	Hard	Hard

Overall, the physical properties of bio-briquettes manufactured in this study were almost the same. Table 6 shows similar results for some parameters of bio-briquettes samples. All samples produced a cube shape with a hard, nice, and compact form. However, the weights of the samples from various compositions before drying varied from 31–39 grams because it depended on the cutting process after the briquette dough was discharged from the printed tool. This causes the final product weight of bio-briquettes (after drying) to differ from each other, ranging from 25–33 grams.

3.6.2. Briquette Burning Test

After the examination of physical properties, bio-briquettes were tested by burning test. The burning test includes the investigation of fire ignition, burning time, the height of the fire, color of fire, result of smoke, dry weight, smoke smell, and the firelight during the combustion of bio-briquettes samples. The development of the burning test is shown in Table 7.

Table 7. Burning test of bio-briquette from coconut shell charcoal and coal with various composition

Parameter	Composition of coconut shell: coal (%)				
	100:0	**25:75**	**50:50**	**75:25**	**0:100**
Fire ignition	Easy	Easy	Easy	Easy	Quite easy
Firing up time (min)	2.18	1.53	2.43	3.37	5.31
Height of fire (cm)	2.6	2.1	2.4	2	2.7
Color of fire			Reddish orange		
Result of smoke	A lot	A lot	A little	A little	A little
Dry weight (gr)	25	30	32	33	33
Smoke smell			Strong		
Firelight			Distributed evenly		

The observation of the burning process during combustion is shown in Figure 7, while the burning time until bio-briquettes were burnt out can be seen in Figure 8.

Figure 7. Observation result during combustion of bio-briquettes

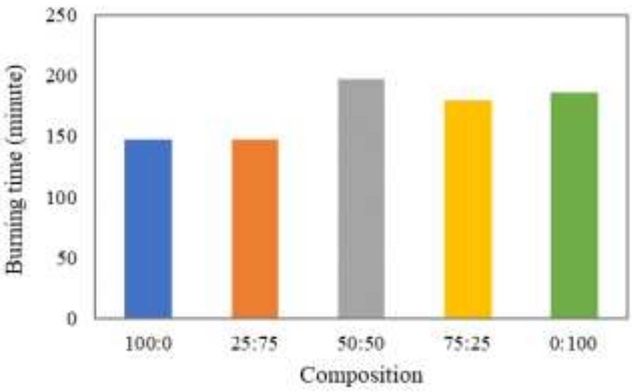


Figure 8. Burning time of bio-briquettes from various composition

Table 7 shows some properties of bio-briquettes in terms of the burning test were similar, such as the color of fire, height, and fire light. All bio-briquette samples produced the same reddish-orange flame color, with the height of the flame ranging from 2.1 to 2.7 cm. The fire lights during combustion were distributed evenly, as seen in Figure 7. Meanwhile, almost all variations have the same easy level of igniting the fire for the fire ignition, except for the interpretation of 0:100, which took longer to ignite the fire. However, this variation has the longest firing-up time (5.31 minutes) than others, which only lasted less than 4 minutes.

Based on Figure 8, it can be seen that each sample required a different time to completely burn bio-briquettes. The shortest time was obtained by composition of 100:0 and 25:75, which needed 147 minutes to burn out the bio-briquettes. It was followed by variations of 75:25 and 0:100, which required longer burning time, 180 minutes and 186 minutes, respectively. At the same time, the longest time was achieved by bio-briquettes with a composition of 50:50, which took 197.4 minutes to burn the sample completely.

To determine the optimum composition of bio-briquette, the value is taken by considering the moisture content, ash content, combustion rate, and calorific value results. However, the calorific value is the main factor in examining the quality of the briquette, so the optimum value is taken based on the highest calorific value. Thus, in this study, bio-briquette with a mixture of coconut shell charcoal and coal 75:25 is the best composition to produce good quality briquette. It has a moisture content of 7.6325%, ash content of 6.9697%, combustion rate of 0.1833 gr/min, and calorific value of 5833.78 cal/gr.

4. Conclusion

In this study, the manufacture of bio-briquette with various compositions of coconut shell charcoal and coal using tapioca flour adhesive was utilized using a screw press system. The highest calorific value of bio-briquette of 5,833.78 cal/gr was obtained for the composition of coconut shell charcoal and coal ratio of 75:25. In general, the calorific value of the majority of bio-briquette composition was higher than the standard calorific value ($\geq$ 5,000 cal/gr). For future work, it is recommended to characterize flue gas from the combustion of these bio-briquettes.

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