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Production and Characteristics Test of Bio-Char Briquettes from Coconut Shells and Corncobs to Optimize Agricultural Waste in Indonesia

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Abstract

Biomass waste is one of the potentials that can be utilized to become alternative energy that can contribute to sustainable development. With briquetting, waste that previously had no benefit can be used as a renewable energy source. In this study aims to compare the characteristics (moisture content, ash content, volatile matter content, bound carbon content and calorific value) of raw materials (coconut shell, corn cob and tapioca flour) and then test characteristics after the raw materials are briquetted. The results of this study with briquetting of waste were able to produce 3.78% moisture content, 11.7% ash content, 0.869 volatile matter content, 5512 cal/g calorific value and 83.651% bound carbon content. So that briquetting can be one of the innovations to optimize the utilization of waste to be processed into renewable energy.

Keywords: *coconut shell, corn cobs, tapioca flour, briquetting.*

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INTRODUCTION

Energy is one of the important factors in achieving sustainable development [1]. The most exploited energy to support the development of human civilization is fossil energy, which contributed to global climate change from 1750-2005 [2]. In Indonesia, the use of fossil energy has increased on average per year by 36 million barrel oil equivalent (BOE) from 2000 to 2014 [3]. Therefore, the development of new renewable energy is being increased by the Indonesian government, as evidenced by government regulation no. 79 of 2014 and presidential regulation No. 22 of 2017 concerning the draft target for the use of new renewable energy in 2025 and 2030 of 23% and 31% respectively, and has been realized by 11.31% in 2020 [8].

One of the materials that can be utilized as alternative renewable energy is biomass waste [9]. Biomass is the residue of living things composed of cellulose and lignin [6]. The potential of biomass in Indonesia is 146.7 million tons per year 2020 which comes from the plantation, agriculture and forestry sectors [10] with an estimated energy generated of 49,810 MW [11]. Unfortunately, these potential wastes are disposed of or burned directly by community, causing pollution and degradation of the surrounding environment [12]. As an alternative energy source, biomass can be burned directly or changed its characterization through densification and charring [6]. Products from biomass can be solid (bio-char, briquettes), liquid (bioethanol, biodiesel, methanol), gas (syngas, bio gas) [13][15]. This research aims to process waste materials and perform a comparative analysis of the physicochemical characteristics of both raw materials (waste and adhesive) and the resulting briquettes, in accordance with the Indonesian briquette standard SNI 01-6235- 2000. Unlike many previous studies that overlooked detailed characterization of raw materials and their alignment with standard criteria, this study highlights the misconception that conventional combustion and briquetting yield similar properties, particularly in terms of calorific value

Briquettes

Biocharcoal briquettes are a product of processing biomass waste containing lignocellulose (hemicellulose, cellulose and lignin) into solid fuel through the briquetting stage [17] to improve characteristics and facilitate fuel storage [18]. The utilization of biomass into briquettes is one of the innovations in the use of alternative energy that is renewable and sustainable [5][6] because it comes from plants so that it can be renewed, can reduce the remaining agricultural waste and can be adopted in various energy sectors [18].

Materials

Coconut is a plant whose entire part can be utilized [19], [20] with the main product being the fruit which is composed of 25.1% coconut coir, 28.1% coconut meat, 32.7% coconut water and 14.1% coconut shell from a total weight of 1.64 kg [21]. The coconut shell is a hard part located in the center of the fruit with a thickness of 3-5 mm which serves as a protector of coconut meat and water. Coconut shell contains lignocellulose of 33.61% cellulose, 29.27% hemicellulose and 36.51% lignin [22] while the chemical compounds contained include 74.3% Carbon, 21.9% Oxygen, 0.2% Silicone, 1.4% Potassium, 0.5% Sulfur, 1.7% Phosphorus [23]. Based on figure 1, organic compounds of coconut shell will decompose into charcoal at temperature 200^{o}C - 500^{o}C, hemicellulose will decompose at temperatures <200^{o}C, cellulose in the temperature range 200^{o}C - 400^{o}C and lignin in the temperature range >400^{o}C [24].

Corn is the main carbohydrate producer in Indonesia besides rice. Every year, corn production in Indonesia increases, in 2016 corn production in Indonesia was 23.6 million tons, which increased in 2017 to 28.9 tons and 30 million tons in 2018 [25]. The increase has an impact on the increase in waste generated. Corn cob is wasted product that has potential to be utilized because it has a dry basis chemical composition of 38.8% cellulose, 44.4% hemicellulose and 11.9% lignin [27]. The proximate content of corn cobs before carbonization contains 11% moisture content, 9.8% ash content, 9.2% bound carbon content, 70% volatile matter content [28]. Corn cobs decompose into charcoal at 300^{o}C [30].

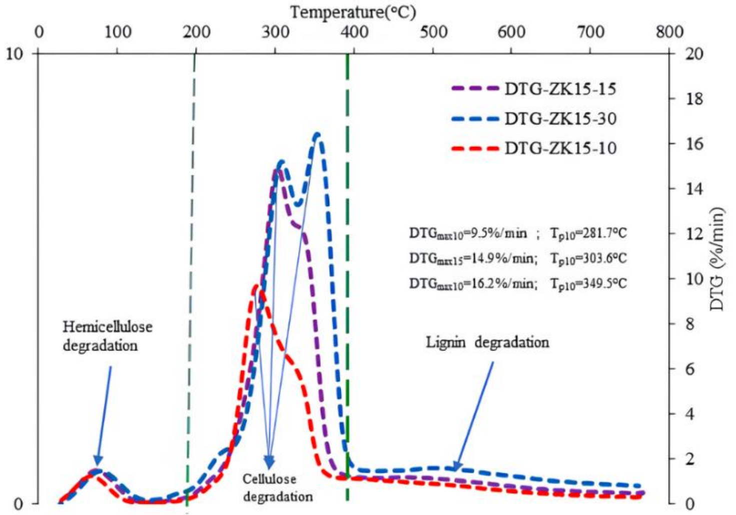

Figure 1. Decomposition Process (DTG) of Coconut Shell [24]

METHODS AND ANALYSIS

Briquette Making

The process of making briquettes is divided into 3 stages, the preparation stage (collection of raw materials and carbonization), the production stage (briquetting) and the experimental stage (characteristic test). Carbonization is a process of removing moisture content, volatile substances that aim to form carbon through the formation of carbon in raw materials through the decomposition of cellulose and lignin [6]. The purpose of carbonization in biomass waste is to increase the carbon content contained in the material which has an impact on increasing the calorific value. In the carbonization process, chemical decomposition occurs as shown in formulas (1-4) [30].

a. Cellulose Decomposition Reaction

$$(C_6H_{10}O_5) \xrightarrow{270\,℃-310\,℃} 6C + 5H_2O \quad (1)$$

b. Lignin Decomposition Reaction
Decomposition of p-coumaryl alcohol ($C_9H_{10}O_3$)

$$C_9H_{10}O_3 \xrightarrow{310\,℃-500\,℃} 6C + 5H_2 + 3CO \quad (2)$$

Decomposition of coniferyl alcohol ($C_{10}H_{12}O_3$)

$$C_{10}H_{12}O_3 \xrightarrow{310\,℃-500\,℃} 7C + 6H_2 + 3CO \quad (3)$$

c. Carbon Formation Reaction

$$\left(C_xH_yO_z\right) + O_2 \xrightarrow{500\,℃-1000℃} C_{(grafit)} + CO + H_2O \quad (4)$$

Briquetting is an attempt to change the characteristics of a material through several stages that serve to change the characterization and increase the calorific value that can be produced by biomass [5]. The stages of briquetting include crushing, sifting, mixing, molding and drying.

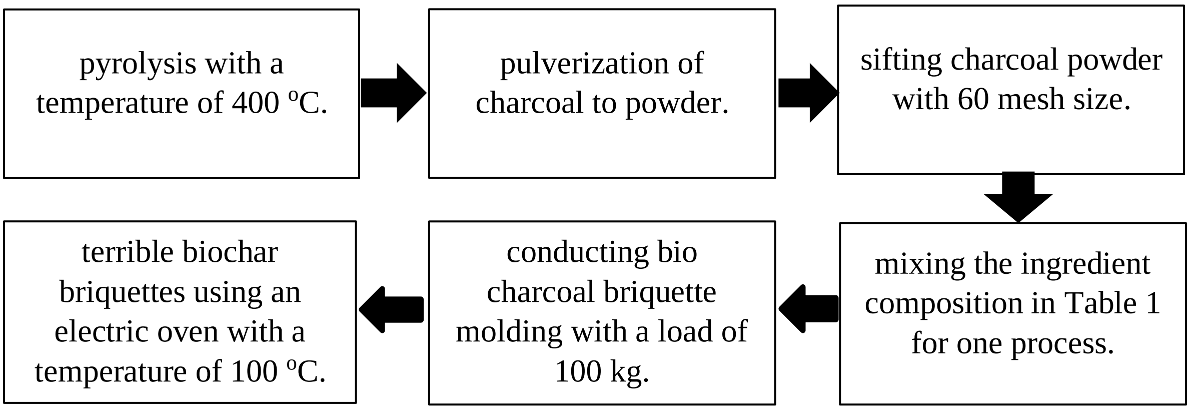

Figure 2. Process scheme for making biocharcoal briquettes.

Table 1. Composition of biochar briquette material

Sampel	Briquette Mix Composition (%)			Water (ml)
	Coconut Shell	Corn Cob	Tapioca Flour	
BB	56	16	8	80

Based on Figure 2, after becoming charcoal, the raw materials are pulverized to a size of 60 mesh. The smooth raw materials are mixed with the composition according to Table 1. Then molded with 2.5 cm hollow iron with a loading of 100kg.

The molded briquettes were then dried using an electric oven (in this study using Sharp EO-18L) at 100ºC for 6 hours, then the briquettes were ready for the experimental stage (characteristic test). Characteristic tests were carried out by analyzing moisture content, ash content, volatile matter content, bound carbon content and calorific value.

Quality Testing

In experimental stage, the data were analyzed by comparing characteristic tests result on raw materials (biomass waste charcoal) and briquettes (raw materials through briquetting) including moisture content, ash content, volatile matter content, bound carbon content and calorific value using SNI 01-6235-2000 standards and describing the results into a graph.

Moisture Content

Moisture content is the amount of water contained in the briquette. The quality of briquette quality is influenced by moisture content, the higher the moisture content, the lower the heating value produced because heat is used to evaporate the water content first [34]. Water content testing uses the SNI 01-6235-2000 method, with the following procedure: Weighing a 1 g sample of biocharcoal briquettes in a porcelain cup of known weight. Putting the sample into the oven with a temperature of (115 °C ± 5 °C) for 3 hours. Cooling the sample in a desiccator. Lastly, finding out the final weight of the measurement by weighing the sample. Moisture content was calculated using the equation (5)[35]:

$$Moisture\ Content\ (\%) = \frac{A - B}{B} \times 100\% \qquad (5)$$

A is material before drying (gram) and B is Material after drying (gram).

Ash Content

Ash is part of the residual material from the combustion process [34]. The main components contained in ash include calcium, potassium, magnesium and silica [36]. The increase in ash content is inversely proportional to the heating value produced, this is because the ash attached to the solid will cause obstruction of oxygen entering the pores of the briquette, resulting in a decrease in the heating value produced. Water content testing uses the SNI 01-6235-2000 method, with the following procedure: Weigh the empty cup to determine its mass. Weigh the empty cup and sample as much as 1 gram. Putting the cup and the sample into the furnace, raising the temperature to 450-500 °C for 1 hour, and continuing the temperature of 700-750 °C for 2 hours, and finally ashing with a temperature of 900-950 °C for 2 hours. Finally, weighing the cup and ash to determine the final weight. Ash content was calculated using the equation (6)[35]:

$$Ash\ Content\ (\%) = \frac{B-A}{C} \times 100\% \tag{6}$$

A is weight of empty cup (gram), B is weight of empty cup and ash content (gram), and C is initial weight of sample (gram).

Volatile Matter Content

Volatile matter content is the decomposition of compounds contained in briquettes other than water [6]. Volatile matter content is dominated by active compounds including hydrogen (H), hydrocarbons (CH), methane and carbon monoxide (CO). High levels of volatile substances will cause smoke when the combustion process increases, if carbon monoxide is high it will adversely affect the environment. Testing of volatile substance content using the SNI 01-6235-2000 method, with the test procedure: Weighing a 2-gram sample into a porcelain or platinum cup. Heating the sample to a temperature of 950 °C for 7 minutes. Cooling the sample in a desiccator. Lastly, weighing the sample to determine the weight that has been lost. Volatile substance content is calculated using equation (7)[15]:

$$Volatille\ matter\ (\%) = \frac{W_1-W_2}{W_1} \times 100\ \% \tag{7}$$

W_1 is material that has been dried (gram), W_2 is material that has been heated to 950 °C.

Calorific Value

Calorific value is the main indicator of fuel. The higher the calorific value produced, the better the quality of the briquettes produced [14][37]. According to SNI 01-6235-2000 calorific value is very important to determine the quality of briquettes. The higher the calorific value of a briquette, the better the quality produced. Calculation of calorific value of briquettes using a bomb calorimeter in the laboratory. Calorific value is the effort of a material to increase 1 temperature at a weight per unit gram [4],[14],[15],[41].

The calorific value testing procedure is as follows: turn on the power heater and pump button. Set the temperature to be used (15 - 20 ℃). Install the bomb head, gas hose and flush tank. Then press START PRETEST, and press START. Flow oxygen into the calorimeter bomb at a pressure of 30 bar. Prepare and weigh ingredients weighing 0.8 - 1.2 grams (accuracy 0.0001 gram). Install the air bomb on the calorimeter then add 1250 ml of cooling water. Close the calorimeter cover, then turn on the water stirrer and observe the temperature changes. Finally, turn off the bomb calorimeter when finished. The calorific value and energi equivalen (gross calori value) are calculated using equation (8-9) [38],[39]:

$$CV_{db} = \frac{CV_{adb}}{\frac{(1-RM)}{100}} \tag{8}$$

$$\frac{(Ee \times \Delta T) - e1 - e2 - e3}{A} \quad (9)$$

CVdb is Calorific Value on dry basis (cal/gram), CVadb is Calorific Value in air dried basis (cal/gram), RM is Residual Moisture (water content) (%), Ee is Equivalent Energy (cal/°C), ΔT is Initial and final temperature difference (°C), e1 is Acid Correction (cal), e2 is Fuse Correction (cal), and e3 is Sulfur Correction (cal).

Bound Carbon Content

Bound carbon content is the content of carbon compounds in briquettes. An increase in bound carbon content is directly proportional to the increase in heating value produced, considering that carbon compounds (C) are the main compounds that are an indicator of the quality of the briquettes produced.

The testing procedure is as follows: after testing the water content, ash content and volatile substance content. Calculate the formula for the bound carbon. Bound carbon content is calculated using equation (10)[6]:

$$FC\ (\%) = 100\% - (KZM \mp KAB + KA)\% \quad (10)$$

KZM is volatile matter content (%), KAB is ash content (%), KA is moisture content (%), and FC is bound carbon content (%).

RESULTS AND DISCUSSIONS

Test Results of Biocharcoal Briquette Characteristics

This research tests characteristics including moisture content, ash content, volatile matter content, calorific value and bound carbon content of raw materials before and after going through the briquetting stage. Testing these characteristics aims to determine and analyze changes in characteristics that occur in raw materials before and after the briquetting stage. Testing the characteristics of biochar briquettes consisting of water content, ash content, volatile content, calorific value, and bound carbon can be seen in Table 2. From the results of Table 2, the characteristics of biocharcoal briquettes and raw materials there are differences in the raw materials, especially in the calorific value. Characteristic testing is expected to have a calorific value according to the SNI 01-6235-2000 standard [22] so that biomass waste can utilized optimally. The calorific value is very important to determine the quality of the briquettes. The higher the calorific value of a briquette, the better the quality produced.

Table 2. Characteristics of raw material and biocharcoal briquettes.

Characteristic test	Sample				SNI 01-6235-2000
	Coconut Shells	Corn Cobs	Tapioca Flour	Biochar Briquette	
Moisture Content (%)	7,5	7,2	12,2	3,78	<8
Ash Content (%)	4,2	6,6	2	11,7	<8
Volatile Matter Content (%)	0,878	0,959	0,995	0,869	<15
Calorific Value (cal/g)	3652	3569,32	3460,05	5512,37	>5000
Fixed Carbon (%)	87,422	85,241	84,805	83,651	>77

Moisture Content

Water content testing aims to determine the moisture content contained in the raw materials of corn cobs, coconut shells, tapioca flour and a mixture of these raw materials (briquettes). The high moisture content contained in the material affects the heating value produced, this is because the heat contained is used to evaporate the water content contained before experiencing the combustion process [34],[31].

Based on Tabel 2 and Figure 3, the results of testing the moisture content of each coconut shell, corn cob, tapioca flour and charcoal briquettes are 7.5%, 7.2%, 12.2% and 3.78%. The maximum moisture content in SNI 01-6235-2000 is 8%, the highest moisture content of the raw materials that not accordance with SNI 01-6235-2000 is tapioca flour, because that composed by starch which is composed of hydroxyl groups that bind and retain water [5]. While the lowest moisture content in briquettes is (3.78%) this is influenced by particle size, density and the mixture of using tapioca as an adhesive. So that briquetting can reduce the water content of raw materials so that the quality of biomass waste increases.

Ash Content

Ash is a residue that does not burn, composed of combustible materials such as silica, calcium, magnesium [36]. Ash content can affect the calorific value, this is because ash that accumulates on the surface of the material will block the incoming oxygen, thus affecting the combustion process [6]. The purpose of testing ash content is to determine particles that do not burn during the combustion process of a material.

Based on Table 2 and Figure 4, The ash content of coconut shell, corn cob, tapioca

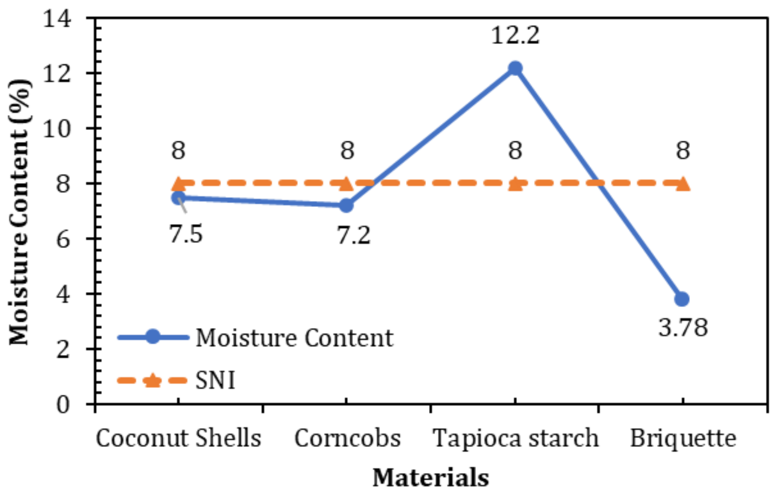

Figure 3. Graph of Moisture Content Raw Materials and Briquettes

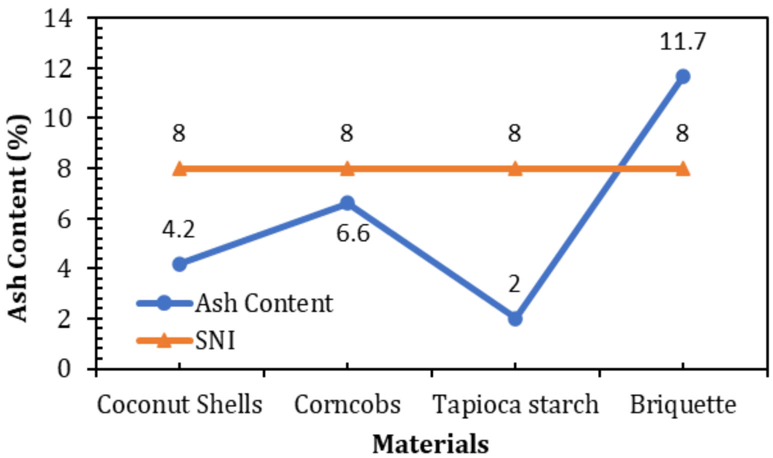

Figure 4. Graph of Ash Content Raw Materials and Briquettes

starch and charcoal briquettes was 4.2%, 6.6%, 2%, 11.7%, respectively. According the SNI 01-6235-2000 standard, the highest ash content in the briquettes was 11.7 % and the lowest ash content in the tapioca starch composition was 2 %.

The lowest result of tapioca starch (2%) is influenced by the inorganic mineral content is quite low (potassium 0.2%, phosphorus 0.2%, calcium 2%, magnesium 0.5%) so as to produce a small ash content [42].

Volatile Matter

Volatile substance content testing is a test that aims to determine the content of substances that can evaporate other than water [6] including hydrogen (H), Hydrocarbons (CH), methane and carbon monoxide (CO) [15]. The test results of volatile substance content are presented in the following figure. The test results of volatile substance content are presented in the Figure 5. Based on Figure 5, it is known that briquetting can reduce the volatile content of the material. The test results of volatile meters in coconut shell, corn cob, tapioca flour and briquettes are 0.878%, 0.959%, 0.995%, 0.869% respectively. These results meet the SNI 01-6235-2000 standard with a maximum of 15%.

The lowest volatile matter content in briquettes (0.869%) while the highest in tapioca flour (0.995%). Vaporized substances dominated by CO produce materials that are not good for health and the environment, while if the vaporized substances are dominated by hydrocarbon (CH) content, it will facilitate the ignition of briquettes.

Calorific Value

Calorific value is the amount of heat produced by each raw material (corn cob, coconut shell, tapioca and briquettes) in the combustion process. Calorific value is one of the main parameters of briquette quality. The calorific value is influenced by the raw material, moisture content, ash content and particle density of the material. The higher the heating value produced is directly proportional to the temperature produced. The test results are presented in Figure 6.

The results of high calorific value can produce high heat energy, high heat energy can cause combustion to be almost perfect. The calorific value indicates the heat energy produced per 1 gram of biochar briquette mass. According SNI 01-6235-2000 standard, minimum amount of calorific value is 5000 cal/g. Based on figure 6, the test results of the calorific value of each coconut shell, corn cob, tapioca flour and briquettes were 3625 cal/g, 3569.32 cal/g, 3460.05 cal/g and 5512.37 cal/g. The high calorific value of the briquettes is influenced by the decrease in moisture content during the drying process and the particle density. The highest results on briquettes show that briquetting can improve the quality of the material, to optimally utilize biomass waste.

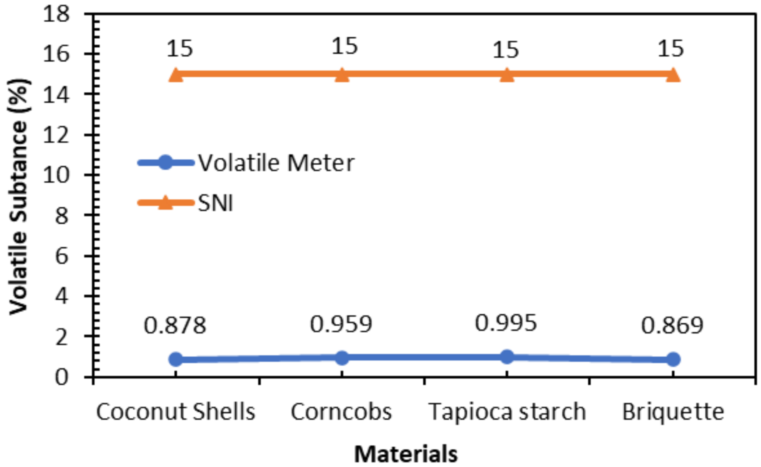

Figure 5. Graph of Volatile Subtance Content Raw Materials and Briquettes.

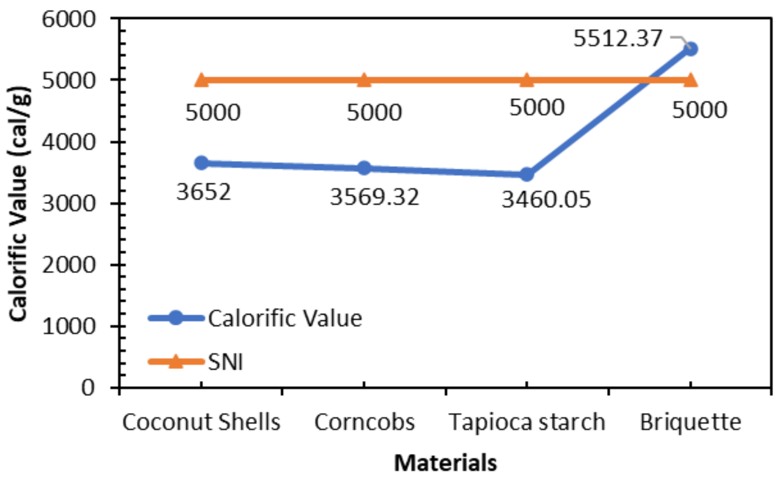

Figure 6. Graph of Calorific Value Raw Materials and Briquettes.

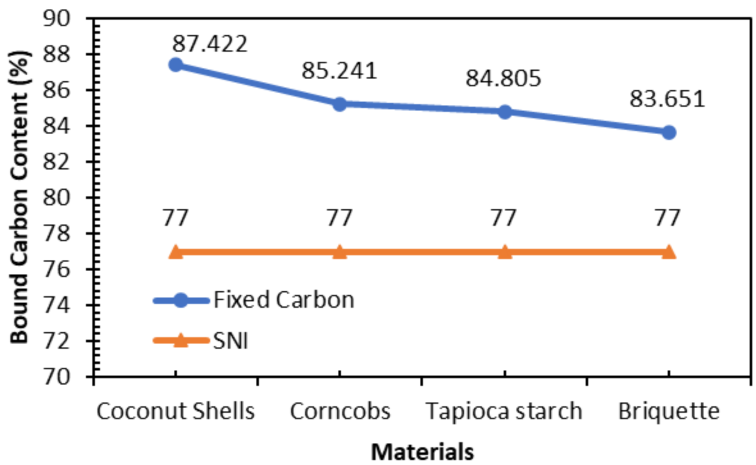

Figure 7. Graph of Bound Carbon Content Raw Materials and Briquettes.

Bound Carbon Content

In solid fuels, carbon is the main component burned in briquettes, so the higher the bound carbon content results can increase briquette calorific value. The test of bound carbon content aims to determine the content of carbon compounds (C) The bound carbon content is directly proportional to the calorific value of the biocharcoal briquettes, the higher the bound carbon content, the higher the calorific value of the biocharcoal briquettes produced. The test results of bound carbon content are presented in Figure 7.

Based on Figure 7, the bound carbon content of the raw materials shows the potential of the waste to be used as solid fuel. The characteristic test results of bound carbon content with coconut shell, corn cob, tapioca starch and briquette samples were 87.422%, 85.421%, 84.805% and 83.651%, respectively. These results meet the SNI 01-6235-2000 standard with a minimum value of 77%. The highest fixed carbon content result is found in coconut shell at 87.422%, and the lowest fixed carbon content result is found in briquettes at 83.651%.

The results of the bound carbon content are directly proportional to the resulting calorific value. The high levels of bound carbon indicate that the heat energy produced by the biochar briquettes is high, so the calorific value is also high [15],[34].

CONCLUSIONS

The results of research on the characterization of raw materials and biochar briquettes can be concluded as follows:

1. Biomass waste potentially utilized be a solid fuel by briquetting stage.
2. According the raw materials characteristic result, briquetting can increase the waste biomass characteristics reviewed from calorific value improvement when compared to direct combustion of raw materials(waste).

Suggestions and Input

The limitations and decreasing number of energy sources, especially fossil energy in Indonesia, are the main factors as reasons for seeking New Renewable and Sustainable Energy sources. Energy derived from biomass has great potential in Indonesia and has not been utilized optimally. Therefore

1. Research on biomass needs to be increased by using the other materials.
2. Need research to examine the physical strength, the emissions produced from briquettes and then make comparisons with existing briquettes for commercial use on the market.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare that they have no potential conflicts of interest regarding the research, authorship, and/or publication of this article.

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