Effects of carbonization duration on the characteristics of bio-coal briquettes (coal and cane waste)

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Abstract. One of the technologies used to utilize low quality coal is by making bio-coal briquettes. Bio-coal briquettes are briquettes made of a mixture of coal and biomass. In this study, bagasse biomass is used as a mixture material of the briquettes. The objective of this study is to disclose the effects of the duration of carbonization on the characteristics of the briquettes. The process of carbonization is conducted to reduce water content and the level of volatile substances and increase the calorific value of the raw materials, so that the resulting briquettes will be of higher quality. This study uses the variations of carbonization duration of 30, 60, 90, 120, and 150 minutes. The result of the study reveals that the best duration of carbonization of raw materials in making bio-coal briquettes is 150 minutes. The bio-coal briquettes made with the duration of carbonization of 150 minutes has moisture content of 10.25%, ash content of 12.91%, volatile substance content of 31.88%, fixed carbon content of 44.96%, calorific value of 5,897 cal / gram, initial ignition time of 6.85 minutes, duration of combustion of 20.26 minutes, CO gas emission of 395 mg / Nm$^3$, and NO gas emission of 5.6 mg / Nm$^3$.

1. Introduction

The data obtained from the Directorate of Energy and Mineral Resources of the Year 2016 revealed that Indonesia had a low quality coal reserve of 50% of the total coal reserves. However, if the low-quality coal is directly used as a fuel, it will produce considerable emissions. Therefore, it is necessary to have a technology to utilize low quality coal as an environmentally friendly alternative energy. One of the technologies for utilizing low quality coal is the manufacture of bio-coal briquettes. Bio-coal briquette is a type of briquette product that uses raw materials of coal particles and biomass, both with or without binder or other added ingredients [1].

One of the biomass that can be used as a mixture in making bio-coal briquettes is bagasse. Bagasse is a by product of the process of extracting (milking) sugar cane in the manufacture of sugar and Sugar Cane Ice. Bagasse is usually used as fuel, material for paper pulp, organic fertilizer, and animal feed [2]. However, in reality, the traders of Sugar Cane Ice simply discard the bagasse, so that it can be classified as a waste product. This will certainly add to the environmental problem, whereas bagasse can be recycled.

Several studies have been conducted to utilize bagasse as an energy source in the form of briquettes. However, in general the briquettes only consist of bagasse or added with other biomass (Bio-briquettes). Many factors influence the quality of bio-coal briquettes, one of which is the duration of carbonization factor of raw materials that can affect the physical and chemical properties of briquettes produced.

High level of water content and volatile substances both in low quality coal and bagasse will result in a low calorific value of the bio-coal briquettes produced. To reduce the moisture content and the content of volatile substances in bio-coal briquettes, carbonization process can be carried out on coal and bagasse before being made into briquettes. In making bio-coal briquettes, the longer the duration
of carbonization, the lower the content of water and volatile substances and the higher the calorific value in the briquettes will become [3].

One of the criteria of good briquettes is that the exhaust emissions produced from the combustion process do not contain toxins. The emissions produced from burning coal such as NO and CO will increase if more coal is used [4]. Biomass has low emissions so that if added to coal it will reduce emissions produced in the combustion process. Briquettes made by mixing coal and biomass produce better fuel properties and lower emissions. In addition, the addition of biomass can accelerate the ignition time in the briquetting process [5].

The aforementioned problem is the background for conducting this study on the effects of the duration of carbonization in the manufacture of bio-coal briquettes of coal and bagasse on the characteristics of the briquettes. The objective of this study is to obtain an optimal duration of carbonization that can produce the best quality bio-coal briquettes based on the quality standards of coal briquettes.

2. Research method

This study is a laboratory-scale study. This study uses low quality coal and bagasse as the raw material for making briquettes. The adhesive material used is tapioca flour. The variations of duration of carbonization used are 30, 60, 90, 120, 150 minutes.

The process of making bio-coal briquettes begins with the preparation of the raw materials. Large sized coal is crushed first using a jaw crusher and ball mill to reduce the size of the coal. After being ground, then the sieving process is carried out on the coal. The sieve used measures 30 mesh and 50 mesh. Ground coal sieving aims to obtain coal size of -50 mesh. The flowchart of the process of bio-coal briquette manufacturing with overall variations of duration of carbonization can be seen in Figure 1.

The coal that has undergone the process of size reduction and subsequent sieving is carbonized using the Nabertherm Carbolite Furnace, 30-3000°C with a temperature of 500°C. The duration of carbonization varies, namely 30, 60, 90, 120, 150 minutes. After carbonization, the coal cannot be directly removed from the furnace until the temperature reaches a room temperature. This process takes 5-6 hours or is best left for 1 night. The same process is also carried out in bagasse preparation process. However, the bagasse is first carbonized with the same temperature and variations of duration of carbonization in the carbonization process of the coal before sieving. The size of the bagasse used in this study is the same as the size of the coal which is -50 mesh.

The raw materials that have been prepared are then mixed by adding adhesive material in the form of tapioca flour. This mixing process uses a composition percentage of 50: 50 between coal and bagasse. The adhesive material used is 3.75 grams of the weight of one briquette of 15 gram. The ingredients and adhesives that have been mixed are then made into bio-coal briquette mixture. The dough is then molded using a manual molding tool with a compressive strength of 470 kg / cm².

The molded briquettes are then dried to reduce the water content that is still contained in bio-coal briquettes. The drying process is carried out using an oven at 50°C for 1 hour. After being dried the briquettes cannot be removed directly from the oven until the temperature inside the ovens is the same as the room temperature. This process takes 5-6 hours and is best left for 1 night.

The dried briquettes are then analyzed to obtain the optimal duration of carbonization out of the existing variations of carbonization duration. The analysis conducted includes proximate tests (moisture content, ash content, volatile substance content, fixed carbon content, calorific value), initial ignition time, duration of combustion and CO and NO emissions produced from burning bio-coal briquettes.
3. Results and discussion

The raw materials for making briquettes in the form of low quality coal and bagasse were first tested to disclose the initial chemical characteristics of the raw materials. The initial chemical characteristics of the raw materials tested were the water content (Inherent Moisture) with the method of ASTM D. 3173-11, the ash content with the method of ASTM D. 3174-11, the volatile matter content with the method of ISO-562: 2010 (E), the content of the fixed carbon with the method of ASTM D. 3172-02 (11), and the calorific value with the method of ASTM D. 5865-11a. The test results of the initial chemical characteristics of the raw materials can be seen in Table 1. Then, the raw materials are carbonized with the variations of duration of carbonization of 30, 60, 90, 120, 150 minutes.
The results of proximate analysis and calorific value of bio-coal briquettes using variations of duration of carbonization can be seen in Table 2. The results of the analysis of ignition time and the duration of bio-coal briquette combustion using the variations of duration of carbonization can be seen in Table 3. In addition, the results of the analysis of CO and NO emissions of bio-coal briquettes using the variations of duration of carbonization can be seen in Table 4.

**Table 1. Proximate Test and Calorific Value of Raw Materials**

| No | Raw Materials | Inherent moisture Content (% adb) | Ash Content (% adb) | Volatile Matter (% adb) | Fixed Carbon Content (% adb) | Calorific Value (cal/gram) |
|----|---------------|----------------------------------|---------------------|-------------------------|----------------------------|--------------------------|
| 1  | Coal          | 28.84                            | 4.52                | 33.76                   | 32.88                      | 4348                     |
| 2  | Bagasse       | 21.00                            | 8.40                | 65.55                   | 5.05                       | 3255                     |

**Table 2. Proximate tests and calorific value of briquettes using variations of duration of carbonization**

| No | Duration of Carbonization (minute) | Inherent Moisture Content (% adb) | Ash Content (% adb) | Volatile Content (% adb) | Fixed Carbon Content (% adb) | Calorific Value (cal/gram) |
|----|------------------------------------|----------------------------------|---------------------|-------------------------|----------------------------|--------------------------|
| 1  | 30                                 | 14.68                            | 7.46                | 36.36                   | 41.50                      | 5508                     |
| 2  | 60                                 | 12.75                            | 9.91                | 33.97                   | 43.37                      | 5673                     |
| 3  | 90                                 | 12.36                            | 10.69               | 33.28                   | 43.67                      | 5698                     |
| 4  | 120                                | 10.72                            | 12.15               | 32.76                   | 44.37                      | 5734                     |
| 5  | 150                                | 10.25                            | 12.91               | 31.88                   | 44.96                      | 5897                     |

**Table 3. Initial ignition time and duration of briquette combustion**

| No | Duration Carbonization (minute) | of Inherent Moisture Content (% adb) | Initial Ignition Time (minute) | Duration of Combustion (minute) |
|----|---------------------------------|-------------------------------------|-------------------------------|---------------------------------|
| 1  | 30                              | 10.2292                             | 14.4500                       |
| 2  | 60                              | 9.7875                              | 16.0167                       |
| 3  | 90                              | 9.3625                              | 17.1583                       |
| 4  | 120                             | 8.6292                              | 18.2833                       |
| 5  | 150                             | 6.8458                              | 20.2584                       |

**Table 4. Results of analysis of emission test using variations of duration of carbonization**

| No | Duration of Carbonization (minute) | NO(mg/Nm$^3$) | CO(mg/Nm$^3$) |
|----|-----------------------------------|---------------|---------------|
| 1  | 30                                | 9.4           | 3155          |
| 2  | 60                                | 7             | 1478.75       |
| 3  | 90                                | 6.15          | 1280          |
| 4  | 120                               | 6             | 1043.75       |
| 5  | 150                               | 5.6           | 395           |
The relationship between the duration of carbonization and the water content, the ash content, the volatile substance content, the fixed carbon content, the calorific value, the initial ignition time, the duration of combustion and the combustion emissions can be seen in Figure 2-10.

The moisture content indicates the amount of water contained in the structure of a solid fuel [6]. The higher the moisture content, the smaller the calorific value of the briquettes will be [7]. The effects of the duration of carbonization on the moisture content of the bio-coal briquettes generated in this study are shown in Figure 2.

Ash is the amount of residue after the organic matter is burned [6]. The effects of the duration of carbonization on the ash content of the bio-coal briquettes produced in this study are shown in Figure 3. Volatile matter is one of the chemical characteristics of a briquette. High content of volatile matter in bio-coal briquettes will make the briquettes easy to ignite and burn, so that the initial ignition rate in the briquetting process is faster [6]. The effects of the duration of carbonization on the volatile substance content of the bio-coal briquettes produced in this study are shown in Figure 4.

Fixed carbon content or can also be called bonded carbon content is a component found in solid fuels in the form of char [8]. The bonded carbon content shows the number of tethered carbon elements contained in the briquettes. The effects of the duration of carbonization on the level of bonded carbon of the bio-coal briquettes produced in this study are shown in Figure 5.

Calorific value shows the energy content contained in a fuel. High calorific value will produce good quality briquettes [9]. The effects of the duration of carbonization on the calorific value of the bio-coal briquettes produced in this study are shown in Figure 6.

![Figure 2](image-url)  
**Figure 2.** The graph of the effects of the duration of carbonization of the raw materials on the inherent moisture of the briquettes

Figure 2 shows that the duration of carbonization affects the moisture content of the briquettes. The longer the duration of carbonization of raw materials for the briquettes, the lower the moisture content in the briquettes will become. The results of the analysis showed that the duration of carbonization of 150 minutes had the lowest moisture content of 10.25%. This is consistent with the theory that states that the longer the duration of carbonization the less the moisture content of the briquette will become [10]. The long duration of carbonization makes the pores of the charcoal more open resulting in the release of moisture content contained in the materials [10]. The longer the duration of carbonization, the more pores that will open and more moisture content is released. The results of the study showed that the highest moisture content produced was 14.68%. Based on the standards, the maximum moisture content in the bio-coal briquettes is 15% [1]. The results of the analysis show that the moisture content of the all samples produced still meet the standards.
Figure 3. The graph of the effects of the duration of carbonization of the raw materials on the ash content of the briquettes

Figure 3 showed that the duration of carbonization affects the ash content of the briquettes. The longer the duration of carbonization of the briquette raw materials the more ash content of the briquettes will become. The results of the analysis showed that the duration of carbonization of 150 minutes produced the highest ash content of 12.91%. The duration of carbonization of 30 minutes produced the lowest ash content of 7.46%. The duration of carbonization affects the ash content contained in the briquettes. The longer the duration of carbonization the more the ash content of briquettes will be. [11]. It is because the carbon will burn out and leave the ash which is the result of the combustion. The ash content can affect the calorific value of the briquettes. High level of ash content can reduce the calorific value of the briquettes so that the quality of the briquettes will decrease. The ash content contained in the briquettes must be as low as possible so that the quality of the briquettes is maintained [12]. The results of the study showed that the highest ash content produced was 12.91%. Based on the standard, the maximum ash content in bio-coal briquettes is 10% [1]. It shows that the ash content of the samples with the variations of duration of carbonization of 90, 120, and 150 minutes have not met the standards yet.

Figure 4. The graph of the effects of the duration of carbonization of the raw materials on the content of volatile matter of the briquettes

Figure 4 showed that the duration of carbonization affects the content of the volatile matter of the briquettes. The longer the duration of carbonization of the raw materials for the briquettes is the lower the content of volatile substances in the briquettes. The content of volatile substance tends to decrease as the duration of carbonization increases. So that the longer the duration of carbonization the lower the content of the volatile matter of the briquettes will become. The results of the analysis showed that the duration of carbonization of 150 minutes produced the lowest content of volatile substance of 31.88%, while the duration of carbonization of 30 minutes produced the highest content of volatile
substance of 36.36%. Based on the standards, the maximum content of volatile substance in the bio-coal briquettes depends on the raw materials used [1]. The maximum volatile substance level is 65.55%. This shows that the content of volatile substance of the all samples produced still meet the standards.

![Graph of fixed carbon content vs. duration of carbonization](image1)

**Figure 5.** The graph of the effects of the duration of carbonization of the raw materials on the content of the fixed carbon of the briquettes

Figure 5 showed that the duration of carbonization affects the content of the fixed carbon in the briquettes. The longer the duration of carbonization of the briquette’s raw materials, the higher the content of the fixed carbon in the briquettes produced. The results of the analysis showed that the duration of carbonization of 150 minutes produced the highest content of fixed carbon of 44.96%, while the duration of carbonization of 30 minutes produced the lowest content of the fixed carbon of 41.5%. The longer the duration of carbonization the more fixed carbon in the briquettes produced will become. The longer the duration of carbonization, the more perfect the carbon formation will be and will produce high fixed carbon content in the briquettes produced. In addition, the content of the fixed carbon is also influenced by the content of volatile substances in the briquettes. The lower the content of the volatile substances is the higher the content of the fixed carbon in the briquettes and vice versa [6].

![Graph of calorific value vs. duration of carbonization](image2)

**Figure 6.** The graph of the effects of the duration of carbonization of the raw materials on the calorific value of the briquettes

Figure 6 showed that the duration of carbonization affects the calorific value of the briquettes. The longer the duration of carbonization of the raw materials for the briquettes, the more calorific value of the briquettes will be obtained. The calorific value is affected by the water content of the briquettes.
The higher the water content, the smaller the calorific value of the briquettes will be [7]. In addition, the calorific value of briquettes is also influenced by the content of volatile substances. The high content of volatile matter will reduce the calorific value of the briquettes and will reduce the quality of the briquettes [13]. The results of the analysis showed that the duration of carbonization of 150 minutes produced the highest calorific value of 5897 cal / gram. This is because the duration of carbonization of 150 minutes produced the lowest water content and also the lowest volatile substance content. The duration of carbonization of 30 minutes produced the lowest calorific value of 5508 cal / gram. This is because the duration of carbonization of 30 minutes produced the highest water content and also the highest volatile substance content. The results of the study showed that the lowest calorific value produced was 5508 cal / gram. Based on the standard, the minimum calorific value in the bio-coal briquettes is 4400 cal / gram [1]. This shows that the calorific value of all briquettes produced still meets the standards.

The content of water and volatile substances contained in the briquettes will affect the length of time of the initial ignition of the briquettes. The lower the water content, the faster the briquettes will light up during the combustion process. In addition, the higher the content of the volatile substance is the faster the process of ignition of the briquettes [14]. The duration of combustion is affected by the calorific value contained in the briquettes. High calorific values will make burning longer and can save the briquettes [14]. The effects of the duration of carbonization on the time of the initial ignition and the duration of the combustion of bio-coal briquettes in this study are shown in Figures 7 and 8.

![Figure 7](image1.png)

**Figure 7.** The graph of the effects of the duration of carbonization of raw materials on the initial ignition time of the briquettes

![Figure 8](image2.png)

**Figure 8.** The graph of the effects of the duration of carbonization of raw materials on the duration of the combustion of the briquettes
Figure 7 shows that the duration of carbonization of the raw material influences the initial ignition time produced by the briquettes. The longer the duration of carbonization is the faster the initial ignition of the briquettes. This is because the longer the duration of carbonization of the briquettes, the lower the content of water in the in the briquettes, so that the initial ignition time of briquettes becomes faster [14]. In addition, the content of the volatile substance of the briquettes also affects the initial ignition time. The high content of volatile substances in the briquettes will make the initial ignition time of the briquettes become faster. The results of the study showed that the duration of carbonization of 30 minutes produced the longest initial ignition time, namely 10.2292 minutes. It is because the briquettes with that duration of carbonization has a high water content. The high water content will prolong the initial ignition of the briquettes because it takes time to drain the water content before the volatile substance can burn. The duration of carbonization of 150 has the fastest initial ignition time of 6.8458 minutes. It is because the briquettes with that composition has a low water content and high content of volatile substances. The low water content will accelerate the initial ignition of the briquettes because it does not require a long time to drain the existing water content before the volatile substance burns.

Figure 8 shows that the duration of carbonization of raw materials affects the length of combustion produced by the briquettes. The longer the duration of carbonization, the longer the combustion of the briquettes will be. The length of time of the combustion of the briquettes is also influenced by the content of the fixed carbon in the briquettes. The high content of the fixed carbon will make the combustion become longer and can save the use of the briquettes [14]. The results of the study showed that the duration of carbonization of 150 minutes has the highest combustion time of 20.2584 minutes. It is because the briquettes with that duration of carbonization has a high content of fixed carbon so the combustion time is long enough. The duration of carbonization of 30 minutes has the shortest combustion time of 14.45 minutes. It is because the briquettes with that duration of carbonization has a low content of fixed carbon resulting in shorter combustion time of the briquettes.

Emissions are residual gases of the combustion of a fuel. The test of briquette’s gas emissions is needed to disclose the types of gases produced by the combustion, so as to prevent air pollution as a result of burning briquettes. Theoretically, burning fuel consisting of hydrocarbon elements will only produce H_2O and CO_2. However, in reality, there are other substances produced by the combustion process. These substances can be CO (Carbon Monoxide), NO (Nitrogen Monoxide) and other harmful substances [15]. The effects of the duration of carbonization on the emissions of bio-coal briquettes in this study are shown in Figure 9 for CO gas emissions and Figure 10 for NO gas emissions.
Figures 9 and 10 show that the duration of carbonization affects the emissions produced by the briquettes. The longer the duration of carbonization of the briquette’s raw materials is the lower the emissions of CO and NO gas of the briquettes. The high content of volatile matter in the briquettes will produce more smoke when the briquettes are burned [15]. A lot of smoke will produce high CO and NO emissions so this will have a negative impact on the health and the surrounding environment. The duration of carbonization will affect the content of the volatile substances of the briquettes. The long duration of carbonization will reduce the content of volatile substances [10]. The results of the study revealed that the briquettes with the duration of carbonization of 150 minutes have the lowest level of CO and NO gas emissions. This is because the briquettes with that duration of carbonization have low level of volatile substances. The results of the study showed that the lowest CO gas emissions produced were 395 mg / Nm$^3$, while the highest NO gas emission was 9.4 mg / Nm$^3$. Based on the standard, the maximum CO gas emission is 726 mg / Nm$^3$, whereas NO gas emission is 140 mg / Nm$^3$ [1]. This indicates that only the briquettes with the duration of carbonization of 150 minutes have met CO gas emission standards. In addition, NO gas emission of all the produced briquettes has met the standards.

4. Conclusions
Based on the results of the testing and the data analysis conducted in this study, the following conclusions are drawn:
1. The duration of carbonization in the process of making bio-coal briquettes has an effect on the characteristics of the bio-coal briquettes produced. The results of the study disclosed that the longer carbonization duration will reduce the moisture content, volatile matter, initial ignition, CO and NO gas emissions. On the other hand, the longer carbonization duration will increase ash content, fixed carbon, calorific value, and burning time of the briquettes.
2. The best duration of carbonization of the raw materials for bio-coal briquette manufacturing is 150 minutes. The bio-coal briquettes produced with the duration of carbonization of 150 minutes has a moisture content of 10.25%, ash content of 12.91%, volatile substance content of 31.88%, fixed carbon content of 44.96%, calorific value of 5897 cal / gram, initial ignition time of 6.8458 minutes, duration of combustion of 20.2584 minutes, CO gas emission of 395 mg / Nm$^3$, and NO gas emission of 5.6 mg / Nm$^3$.

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