A study of coal upgrading in briquette making based on briquette characteristics using heated mechanical methods

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Abstract. Indonesia has low quality coal reserves which are quite abundant. The low quality of coal is due to the inherent water content that is still quite high. Therefore, an upgrading process is needed. The upgrading process is intended to increase the calorific value of coal. The upgrading process can be applied to the process of coal briquettemaking. Generally, the manufacturing of low quality coal briquettes uses mechanical and heating methods in two different processes. In this study, the manufacturing of the briquettes uses the tools in a series of processes. The working principle of this tool is based on the strength of pressure and heating temperature. The maximum pressure is 900 psi, and the maximum heating temperature is 150°C. One of the important factors that determines the success of the upgrading process is the magnitude of heating temperature. The variations of heating temperature used are 50°C, 75°C, 100°C, 125°C, 150°C. The heating temperature affects the characteristics of coal briquettes produced. The heating temperature that produces the best quality coal briquettes is 150°C. The results of analysis of the coal briquette's composition are as follows: the inherent water content is 11.00%, the volatile substance level is 46.48%, the ash content is 6.13%, the fixed carbon value is 36.39, and the calorific value is 5.235 cal / gr.

1. Introduction

Indonesia is one of the largest coal producers in the world. Based on the performance report of the Directorate General of Mineral and Coal of the year 2016, coal reserves in Indonesia in 2016 totaled 28,457.29 million tons, and 14,229.74 million tons of which were low-calorie coal. This type of coal has a high moisture content, which is around 15 - 35% and a low heat value of less than 5000 kcal / kg. Low calorific value is due to the fact that this type of coal still has a high water content, so that it will affect the quality of coal itself, including having high self-fueling properties. The water contained in coal will cause problems in the process of its utilization, especially if used as direct fuel [1]. The inherent water in coal will reduce the calorific value of coal, so that the amount of coal needed in the combustion process will be greater. For this reason, it is necessary to upgrade the coal which has a low calorific value. This process is intended to eliminate the water content contained in the coal in order to increase the calorific value so that the coal can be further utilized.

One of the uses of coal is used as briquettes. Briquette is one type of alternative fuel whose raw material consists of compacted powder. The basic ingredients for making briquettes vary, one of
which is coal. Coal briquettes can be made from both low-calorie and high-calorie coals. The
manufacture of briquettes from high-calorie coal is carried out in the absence of a carbonization
process, whereas the making of briquette from low-calorie coal requires a carbonization process.

The making of briquettes from low-calorie coal requires two stages, namely molding and heating.
The purpose of heating is to reduce the water content contained in the coal, so that the calorific value
increases. The two stages of the process usually use different tools, namely heating devices and
molding devices. To simplify these two stages, briquette molding tools that use mechanical methods
and heating can be a solution. With regard to heating, the important thing is the temperature of the
device used. The temperature differences will affect the quality of the briquettes produced. Therefore,
in this study, besides observing the characteristics of the briquette molding equipment that uses
mechanical and heating methods simultaneously, the analysis of the effect of the temperature of the
tools on the characteristics of the briquettes produced is analyzed, so that the optimum temperature is
obtained for the coal upgrading process using a briquette mold and heater at the same time.

Based on the aforementioned background, the study on coal briquette upgrading was conducted.
The objective of this study is to disclose the characteristics of molding equipment as well as briquette
heaters, to reveal the effect of heating temperature on the characteristics of coal briquettes, and to
reveal the optimal temperature of the equipment to produce the best quality coal briquettes.

2. Research method
The material used in this study is low quality coal as the main raw material, and tapioca flour as an
adhesive. The coal used in this study originated from MusiBanyuasin Regency, South Sumatra. The
percentage of the adhesive used in making coal briquettes is as much as 20%. The variations of heating
temperature used in this study are 50°C, 75°C, 100°C, 125°C and 150°C. This coal briquette is made
by using briquette molding equipment that uses mechanical and heating methods.

The first step in making coal briquettes using molding equipment as well as briquette heaters is
material preparation. The bulk of low quality coal is crushed and mashed up using jaw crusher and ball
mill so that it becomes powder. The fine coal is then sieved using a sieving tool (Ro-Tap) with 30 and
50 mesh sieve sizes. In addition to the coal preparation process, both molding and heating devices need
to be observed. The observation of this tool is intended to understand the parts of the tool, the function
of the parts of the tool and also the working mechanism of the tool.

The coal that has been sieved is then mixed with adhesive material with 80% coal and 20% adhesive. The adhesive used is tapioca flour which was previously heated first by adding twice as much
water as the amount of tapioca flour. The process of mixing coal with adhesive is done in a plastic
container with a mixture weight of 70 grams for one coal briquette mixture. Weighing of coal and
adhesives is done by using an analytical balance. Coal and adhesive are stirred manually until they are
evenly distributed.

The coal dough and adhesive that is evenly stirred are then put into the mold which function as
amold and briquette heater at the same time. The briquette mold has a cylindrical shape with a diameter
of 4 cm and a height of 12 cm. The dough in the mold is then pressed with a compressive strength of
800 psi, and heated with temperature variations of 50°C, 75°C, 100°C, 125°C, and 150°C for 60
minutes. The molded briquettes are then removed from the mold after the mold temperature drops to
40°C. Then the molded briquettes made by using molding equipment and briquette heater at the same
time are cooled to a room temperature and then they are ready to be tested.

The coal briquettes resulting from molding equipment as well as heaters with the temperature
variations of 50°C, 75°C, 100°C, 125°C, and 150°C are then analyzed for the water content, the ash
content, and the volatile substances by using a thermogravimetric analysis (TGA). The analysis of
calorie values is done by using a calorimeter. The coal briquettes that have been tested will get the
optimal temperature heating tool that produces the best quality through analysis and discussion.
The flowchart of the study method includes various stages, starting from obtaining references through
literature studies, observing molding devices as well as heaters, preparing raw materials, making
briquettes, testing quality to knowing the effect of heating temperature on the
characteristics of the briquettes. The overall flow chart of the study can be seen in Figure 1.

3. Result and discussion
In this study, the observation of the characteristics of molding equipment and briquette heater was conducted. Besides observing the tool, the test of the chemical characteristics of raw materials in the form of low quality coal and the characteristics of coal briquettes as the result of upgrading with the variations of heating temperature was also conducted. The chemical characteristics of the coal briquettes that are tested are the inherent moisture content, the ash content, the levels of volatile substances, and the calorie values.

In this study, a mold as well as briquette heater (Figure 2) which is useful for molding as well as improving the quality of coal briquettes. This tool serves to simplify the process of molding and heating briquettes which are generally carried out in two stages. With this tool, the coal with low quality value can be made into briquettes with better quality than the original coal. This briquette mold and heater has parts that have different functions that form a single unit to support the performance of the tool to function properly. These parts include a briquette heating molding device which has some parts, namely the frame tool, hydraulic lever, hydraulic jack, pressure gauge, electric motor, pump, fluid tube, control valve, mold, hose, heating element, shaft lever, lever shaft and digital thermostat.
The briquette mold and heater has a working principle in which the pressure is obtained from the hydraulic press which is controlled by the hydraulic lever, while the heat on the mold is obtained from the heating element which is controlled by a digital thermostat. In a series of molding and heating process, at first the mold is heated by charging electric current to the heating element. The heating element attached to the mold will heat the mold. The mold heating can be controlled by a digital thermostat. The function of this digital thermostat is to disconnect and connect the electric current so that the heating carried out by the heating element can be controlled. The temperature reading on the mold is read by the temperature sensor attached to the mold. This temperature sensor will send a signal to the thermostat so that the thermostat can display the temperature contained in the mold and cut off the electricity when the desired heat has been reached and reconnect the electric current if the temperature is below the predetermined temperature. With this digital thermostat, the heat can be controlled as desired. After the mold reaches the desired temperature, then the sample is inserted into the mold, then the hydraulic jack will press the sample down to the required pressure.

![Diagram of briquette mold and heater](image)

**Figure 2.** Molding tool as well as briquette heater

The hydraulic jack will push when the hydraulic lever is pushed, so that the fluid will flow and push the hydraulic press. The process of flowing the fluid into the hydraulic jack is assisted by a hydraulic pump. The fluid flow that presses the hydraulic jack is connected to the pressure gauge, so that the pressure exerted by the hydraulic jack can be read through a pressure gauge. The hydraulic jack will lift when the hydraulic lever is pulled. When the sample is sufficient to be warmed up and then pressed the sample can be removed by pulling the lever so that the sample will be pushed out and already in the form of briquettes. Hydraulic pressure and heating elements require
electric power in their operation. This tool can mold coal briquettes with a maximum pressure of 900 psi, and heat briquettes with a maximum temperature of 160°C.

The results of the analysis of the characteristics of the raw material of coal briquettes are shown in Table 1 and the results of the testing analysis of the inherent moisture content, the levels of volatile matter, the fixed carbon, and the calorific value of coal briquettes molded by using molding as well as heating equipment with the variations of tool heating temperature are shown in Table 2. The relationship between the level of inherent moisture content, the ash content, the level of volatile matter, the fixed carbon, and the calorific value and the heating temperature used are shown in Figure 3-7.

| Table 1. The characteristics of coal raw materials |
|-----------------------------------------------|
| No    | Parameter              | Value   |
|-------|------------------------|---------|
| 1     | Inherent Moisture (%)  | 30.36   |
| 2     | Volatile Matter (%)    | 33.96   |
| 3     | Ash Content (%)        | 4.68    |
| 4     | Fixed Carbon           | 31.00   |
| 5     | Calorific Value (kal/gr) | 3447    |

Table 2. The results of analysis of inherent moisture content, volatile matter, ash content, fixed carbon content, and calorific value of coal briquette with variations of heating temperature

| No | Temperature (°C) | Characteristics (%  adb) | Calorific Value (cal/gr) |
|----|------------------|--------------------------|--------------------------|
|    |                  | Inherent Moisture | Volatile Matter | Ash Content | Fixed Carbon |                |
| 1  | 50               | 24.14              | 40.49           | 5.13        | 30.24        | 3.570         |
| 2  | 75               | 17.94              | 44.35           | 5.42        | 32.29        | 3.843         |
| 3  | 100              | 13.70              | 45.96           | 5.65        | 34.69        | 4.371         |
| 4  | 125              | 11.06              | 46.90           | 5.84        | 36.20        | 5.173         |
| 5  | 150              | 11.00              | 46.48           | 6.13        | 36.39        | 5.406         |

The inherent moisture is the water that is trapped naturally or stuck in the pores of coal [2]. The inherent moisture content is an important factor in the characteristics of good briquettes. The less the inherent moisture content in coal briquettes, the better the quality of the coal briquettes. The temperature of coal heating in the coal briquettes making can affect the inherent moisture content. The relationship between the inherent moisture content and the variations of heating temperature can be seen in Figure 3. Based on the information in Figure 3, it can be concluded that the higher the heating temperature of coal, the lower the moisture content tends to be. The heating process of the coal causes the breakdown of the coal structure which causes the inherent moisture to come out [3]. The higher the temperature, the more fractures of the structure of the coal will form and the more inherent water content will come out. This is what causes the higher the heating temperature, the less inherent moisture content will become. The higher the carbonization temperature of coal, the less the inherent moisture content will become [4-5]. In this study, the highest inherent moisture content was found in the heating temperature variation of 50°C, namely 24.14%. While the lowest water content was found in 150°C coal heating temperature variation, namely 11.0%. The inherent moisture tends to decrease as the heating temperature increases.
The volatile matter are the result of the decomposition of the chemical compounds and the mixtures of coal-forming complexes [6]. The volatile Matters are the substances that evaporate when coal is heated [7]. The data presented in Figure 4 show that the heating temperature affects the content of the coal volatile Matters. This study revealed that at a heating temperature below 125°C there was an increase in the volatile Matter content.

Coal heating will change the material composition of the coal [8]. The volatile Matters are produced by the decomposition of a material or chemical compound during the heating process. During the heating process the breaking of chemical bonds occurs, and the broken bond is associated with other elements so as to form a volatile substance. The formation of volatile substances makes the content of the volatile substances in coal increase. In addition, under certain conditions, heating with a temperature below 200°C will result in a change in composition which results in a product in the form of residues containing carbon and minerals matter [3]. The mineral matter consists of
Volatile and non-volatile substances. This easy to evaporate substance will become the coal volatile substance content. Therefore, this easy to evaporate substances from mineral matter will increase coal volatile substances in the heating process. At temperature above 1250°C there is a decrease in the content of the volatile substance. The heating process will cause the volatile substance to decrease even more [9]. This is what makes coal volatile Matter in this study experience a decrease in the heating temperature of 1500°C.

The coal ash is a residue produced when an amount of coal is burned. The relationship between the levels of volatile substances and the variations in heating temperature used in making coal briquettes is shown in Figure 5. The data in Figure 5 show that changes in the ash content relate to the temperature changes. The coal ash comes from the mineral matter. The mineral matter which evaporates when heated is called a volatile substance, while substances that do not evaporate and do not burn out in the event of heating will be leftover as the ash. The ash content will increase due to a mass reduction in the form of a decrease in the coal water content [10]. This study reveals that the inherent water content tends to decrease with increasing heating temperature. Because there is a reduction due to decreasing water content, the percentage of ash content increases with increasing heating temperature. The increase that occurs is not due to the increasing ash content, but the percentage is increasing. This is due to a decrease in the percentage of the inherent water content. In this study the inherent water content was inversely proportional to the ash content. The lower the inherent water content, the greater the percentage of coal ash value becomes.

The fixed carbon content is a carbon fraction in briquettes in addition to the fraction of ash, volatile matter and water. The FC (Fixed Carbon) is a fixed carbon content found in solid fuels in the form of charcoal. The fixed carbon is obtained by reducing the number of 100 with the amount of the inherent water content, the ash content and the volatile Matter content [11]. The relationship of the fixed carbon values with the variations of heating temperature used in making coal briquettes is shown in Figure 6. The data in Figure 6 show that the higher the heating temperature used, the more fixed carbon value becomes. The results of the analysis showed that the heating temperature of 150°C produces the highest fixed carbon content of 36.39%, while the heating temperature of 50°C produces the lowest fixed carbon content of 31.0%. This study shows that high heating temperatures can increase the fixed carbon value of briquettes. So that, the higher the heating temperature used, the greater the value of the fixed carbon of the briquettes becomes.
Figure 6. The graph of the effect of heating temperature on the fixed carbon values

The calorific value shows the amount of energy produced when a certain amount of coal is burned [6]. The relationship between the calorific values and the variations of the heating temperature used in making coal briquettes is shown in Figure 7. The data in Figure 7 show that the higher the heating temperature used, the higher the calorific value becomes. The higher the moisture content, the lower the calorific value of coal [7]. In this study, we can see the relationship between the calorific value and the inherent water content of the coal briquettes. The inherent moisture content is inversely proportional with the calorie value of the briquettes. The inherent moisture content tends to decrease as the heating temperature increases, while the calorific value tends to increase as the heating temperature increases. The calorific value at heating temperature of 50°C is 4351 cal / gram, while heating temperature at 150°C produces a calorific value of 5235 cal / gram. This proves that there is an increase in calorific value as the heating temperature rises.

Figure 7. The graph the effect of heating temperature on calorific value
4. Conclusions
Based on the results of the study, the following conclusions are drawn that The heated briquette molding device has some parts, namely the tool frame, hydraulic lever, hydraulic jack, pressure gauge, electric motor, pump, fluid tube, control valve, mold, hose, heating element, shaft lever, lever shaft and digital thermostat. The working principle of this tool is based on strong pressure and heating temperature. This tool can mold coal briquettes with a maximum pressure of 900 psi, and heat the briquettes with a maximum temperature of 150°C.

The heating temperature has a very strong effects on the characteristics of coal briquettes produced. In which, the higher the heating temperature, the lower the inherent moisture content becomes, while the fixed carbon, the ash content and the calorific values tend to increase. At a heating temperature of 50°C to 125°C the levels of volatile matters increase, while at a temperature of 150°C the content of volatile matters decreases.

The optimal temperature of heating that produces the coal briquettes with the best characteristics is 150°C. The results of analysis of are as follows: the inherent moisture content is 11.00%, the content of volatile matters is 46.48%, the ash content is 6.13%, the fixed carbon is 36.39 and the calorific value is 5,235 cal/gr.

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