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Characteristics of Charcoal Briquettes from Agricultural Waste with Compaction Pressure and Particle Size Variation as Alternative Fuel

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Abstract – *Bio charcoal briquettes is one of the fuel that comes from biomass. Biomass is one of the sources of renewable energy. The biomass was used in this study is the maize cob agricultural waste which is currently not widely used by farmers. This study aims to know the characteristics of bio charcoal briquettes from maize cob with compaction pressured (22.426 kg/cm^2 and 44.80 kg/cm^2) and particle size variation (40, 50, and 60) mesh. Analysis the characteristics of briquettes includes: density, moisture content, ash content, volatile matter, fixed carbon, heating value, ignition time and flame rate. The process of making briquettes was making charcoal from maize cob waste, then it was crushed manually to produced charcoal particles. The composition of briquette mixture consisting of 60% charcoal particles, 10% sago flour and hot water as much as 30% of the total weight of charcoal briquettes. The compaction tools using hydraulic jack to pressure the briquette. The proximate analysis is a standardized analysis procedure that attempts to quantify some characteristics of biomass briquettes which affect its combustion characteristics. The analysis done with the help of a bomb calorimeter is explained and a brief description of what each of these components is, how each one is found in the biomass briquettes and their significance in the burning of the briquettes is given. The variation of pressured and particle size of briquettes give different effects on the characteristic of briquettes burning quality.*

Keywords – *agricultural waste, alternative fuel, bio charcoal briquettes, biomass, maize cob.*

1. INTRODUCTION

The energy problem for human survival became a complicated problem in many countries of the world today. The unavailability of amounts of oil reserves for a long period of time was forced the peoples to innovate in response. Energy is a major sector in the world economy today which will take a strategic role in the future to providing conservation of energy resources. Energy utilization was increased along with the human activities, especially fuel derived from plant and animal fossils. The availability of increasingly scarce fossil fuels has results in the high fuel prices; therefore an alternative fuel is needed to reduce use of fossil energy.

Residues vary widely in their form and characteristics, which determine how well they can be used as fuel. Other crop residues are considered to make poorer fuels. For example, low-density materials are considered to burn too rapidly, with fluctuating power output, in their unprocessed form. For these residues to become a more attractive alternative fuel, they have to be upgraded to improve their burning performance. This study is focused on upgrading waste crop residues. It could be particularly useful for the rural poor because they are often the people with the most direct access to many of the residues.

The current government policy that coupled with the large obstacles to the development of renewable energy, then emissions from the energy sector will tend to increase sharply threefold by 2030. Meanwhile, the environmental damage caused by burning fossil fuels in six cities in developing countries that were monitored was 68% impacting health, 21% impacting climate change and 11% impacting on other aspects [1].

Alternative energy sources that can be renewed are quite a lot, including biomass or organic waste materials. Some of the biomass that have considerable potential are wood waste, rice husks, straw, bagasse, coconut shells, palm shells, livestock manure, and municipal waste [2].

Biomasses, especially from wood and energy crops, are important energy carriers that contribute to the energy demand. A possible alternative to cover future energy demand is utilization of the above-mentioned residues, for example, for the production of solid fuel [3].

Biomass can be processed and used as an alternative fuel, for example by making briquettes. Briquettes have an economic advantage because they can be produced simply, high calorific values, and the availability of raw materials is quite large so they can compete with other fuels [4].

Biomass is an abundant source of energy and can be renewed. The general biomass comes from the results of agricultural processing waste. This biomass can be used as an alternative fuel to replace petroleum which is suitable to be developed in the rural community. Agricultural waste can be processed into an artificial solid fuel as an alternative fuel called briquette [5].

Biomass of maize cob waste is an abundant alternative energy source, with relatively large energy content. Biomass when treated with special treatment

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will become a solid fuel that is more widely used as alternative fuel. One effective method for converting solid raw materials into a compact form that is easier to use is the briquette method [6].

Charcoal briquettes are solid fuels that contain carbon, have a high calorific value, and can ignite for a long time. Briquettes that are currently mass produced are coal briquettes, whose raw materials are natural resources that cannot be renewed. While bio briquettes derived from crop residues or waste residues have not been developed.

Briquettes are potential and reliable fuel for households. Briquettes are able to supply energy in the long time. Briquettes are defined as fuels that are solid forms that come from the remains of organic matter, which has undergone a process of utilization with a certain compressive power. [7]

Bio briquette is charcoal bar made from organic waste that has been mold with a certain pressured. The utility of bio briquette as a fuel is one of the alternative solutions to save the use of fuel oil, especially kerosene, which is now decreasing. Biomass energy is an alternative energy that needs priority in its development. Because many agricultural product that produces a lot of untapped agricultural waste.

Bio briquettes can replace the use of firewood that begins increase in the consumption. In addition, bio briquettes prices are relatively cheap and affordable by the public. Bio Briquettes is charcoal made from various kinds of biological or biomass materials, such as wood, twigs, leaves, hay grass, or other agricultural waste. Usually, these materials are considered waste that is useless so it is often destroyed by burning. However, these materials can actually be processed into bio charcoal. This bio charcoal can be used as a fuel that is not inferior to other fuels. However, to maximize its utilization, this bio briquette still has to go through a bit of processing so that it becomes fuel.

The factors that influence the nature of bio briquette are the specific gravity of the charcoal particles, fineness of the particles, carbonization temperature, and compacting pressured. Briquettes mixing formula also affect the briquette properties. A good bio briquette requirement smooth surface and does not leave black marks on the hand. In addition, as fuel, briquettes must also meet the following criteria: (a) easy to ignite, (b) do not emit smoke, (c) gas emissions from combustion products are non-toxic, (d) the water and the result of burning is not moldy if stored for a long time, (e) shows a good combustion rate (time, combustion rate, and combustion temperature) [8], [9], [10].

Several types or forms of briquettes are commonly known, including: pillows (oval), honeycomb nests, cylinders, eggs, and others [11]. The advantages of the form of briquettes are as follows: (a) the size can be adjusted as needed, (b) porosity can be adjusted to facilitate combustion, (c) easy to use as fuel. In general, some specifications of briquettes needed by consumers are: (a) durability of briquettes, (b) size and shape suitable for their use, (c) clean (not smoky), especially for the household sector, (d) free dangerous gases, (e) the nature of combustion that is in accordance with needs (ease of burning, energy efficiency, stable combustion) [12],[13].

The purpose of this study was to determine the effect of compaction pressure and roughness of bio charcoal particles on bio charcoal briquette characteristics such as density, moisture content, ash content, volatile matter, fix carbon, calorific value, ignition time, and flame rate.

The method of making briquettes used in this study is a medium pressure compaction method with the addition of briquette binder using local sago flour. The method of making briquettes in this way is very simple and easy to apply to the rural community.

This research is expected to be an alternative solution for the utilization of waste that is not useful into a product that useful and valuable to increase the economic value of a society.

2. METHODS

2.1 Tools and Material

The tools used in this research were bomb calorimeter, charcoal furnace (carbonization drum), sieve size 40 to 60 mesh, The mold and press employed to produce briquettes in this study are of cylindrical type (inner diameter 24 mm and height 60 mm), manual hydraulic which has a capacity of 20 tons (compacting tools), oven and digital scales (moisture content testing), ash content testing using ovens and digital scales, fixed carbon testing using digital scales, volatile matter testing using stoves and digital scales. The materials used in this research were aluminium foil, sodium carbonate (Na_2CO_3), MO indicator, water (H_2O), sago flour, and maize cob.

2.2 The Process of Making Bio Charcoal Briquettes

a) Corn cob charcoal obtained from the results of the charcoal was mashed up manually to produce charcoal powder. The selected maize cob are inserted into charcoal maker container arranged in such a way that it is almost full, the drum was tightly closed then the fire is turned on through the ventilation hole at the base of tube until it reaches a temperature of 250°C, the combustion process continues until all materials are burned. After being cooled, the charcoal produced was separated from the remaining ash for further processing. The crushed charcoal is sieved with a sieve size of 40 to 60 mesh.
b) Making briquettes, consisting of: charcoal amounting to 60%, sago flour 10% and hot water (98.6°C) as much as 30% of the total bio briquette weight of maize cob.
c) The adhesive from sago flour (10%) and hot water at 98.6°C, mixed with the charcoal particle manually.
d) After that the charcoal was pressured at various 22.426 kg /cm^2 and 44.80 kg/cm^2 in the form of a hollow cylinder.

2.3 Briquette Quality Test

Analysis of the quality of corn cob charcoal briquettes includes density, moisture content, ash content, volatile matter, fixed carbon, calorific value, ignition time and flame rate.

The density test is carried out by weighing the desired briquette weight, then measuring the height and diameter of the briquette, then multiplying the results expressed in volumes as follows:

$$\rho = \frac{m}{v} \quad (1)$$

Where :

P = Density (gram/cm^3)
M = Briquette mass (gram)
Y = Volume (cm^3)

One of the most common ways to determine the moisture content is to place the test object in a cup, then weigh and record the weight. Then dry it using an oven or using a stove at a temperature of 103 ± 2°C. Moisture content is calculated using equation:

$$MC = \frac{X1 - X2}{X1} 100\% \quad (2)$$

Where:

MC = Moisture content
X1 = Weight of initial sample (gram)
X2 = Weight of the sample after drying (gram)

Ash content is a measure of material and various content inorganic material in the test specimen. This test method includes the determination of ash which is expressed by the percentage of residual dry oxidation results of the test object at a temperature range of ± 580-600°C, after testing the moisture content. Ash content is calculated based on the equation:

$$AC = \frac{F - G}{W} 100\% \quad (3)$$

Where:

AC = Ash content
F = Weight of crucible and ash (gram)
G = Empty crucible weight (gram)
W = Initial weight of specimen (gram).

Volatile matter (VM) or often called a flying substance, affect the combustion of briquettes. VM content affects perfection of combustion and intensity of fire. The assessment is based at the ratio or comparison between the carbon content (fixed carbon) with flying substances, which is called the fuel ratio. The higher value of the fuel ratio will reduce the amount of carbon burned in briquettes. If the fuel ratio is more than 1.2, combustion will result in poor combustion and reduced combustion speed. Volatile matter (VM) is calculated using the equation:

$$VM = \frac{B - C}{W} 100\% \quad (4)$$

Where:

VM = Volatile matter
B = Weight of the sample after drying at temperatures of 105-110 ºC
C = Specimen weight after heating

The value of carbon content is obtained by reducing the number 100 by the amount of water content (moisture), ash content, and number of flying substances. To determine the fix carbon calculated using equations:

$$FC = 100 – (MC + VM + AC) \% \quad (5)$$

Where:

FC = Fix carbon (%)
MC = Moisture content (%)
VM = Volatile matter (%)
AC = Ash content (%)

Testing of calorific values is done using bomb calorimeter. It is a device used for determine the heat released by a fuel and oxygen at a fixed volume.

Fig. 1. Maize cob waste.

Fig. 2. Briquette presses and products.

Fig. 3. Bomb calorimeter.

3. RESULTS AND DISCUSSION

The proximate analysis is a standard analysis procedure that attempts to quantify some key physical characteristics of biomass briquettes which affect its combustion characteristics. This analysis consists of five main components, *i.e.* estimating the density, fixed carbon, volatile matter, moisture and ash content, followed by determining the relative proportions of these by various procedures. In the following sections, the analysis done with the help of a bomb calorimeter is explained and a brief description of what each of these components is, how each one is found in the biomass briquettes and their significance in the burning of the briquettes is given.

3.1 Density

The results of measuring the density of maize cob briquettes with the influence of pressure and particle size are shown in Table 1 below.

Table 1. Density

Pressure (kg/cm^2)	Density (gr/cm^3)		
	40 (Mesh)	50 (Mesh)	60 (Mesh)
22.42	0.64	0.65	0.68
44.80	0.65	0.68	0.71

Based on Table 1, it was found that maize cob briquettes had a density ranging from 0.64 gr/cm^3 - 0.71 gr/cm^3. The lowest density of 0.64 g/cm^3 was produced by briquettes with a pressure of 22.42 kg/cm^2 of 40 mesh and the highest density was 0.71 g/cm^3 produced by briquettes with a pressure of 44.80 kg/cm^2 of 60 mesh. Based on these results, it appears that the increase value of pressure can increase the density, this is because the pressure will cause the bond between the charcoal molecules to be stronger and give the tendency of the adhesive to flow throughout the charcoal surface so that it will reduce the cavity or gap that can be filled by water [14].

The size of the density is influenced by the particle size and homogeneity of the ingredients of the briquette itself. Density can also affect the firmness of the press, the duration of combustion, and whether or not it is easy when the briquette will be turned on. The high the density can cause charcoal briquettes to be difficult to burn, while briquettes that have not too high density will facilitate combustion because the larger the air cavity or gap that can be passed by oxygen in the combustion process. Briquettes with too low density can cause briquettes to run out quickly in combustion because the weight of the briquettes is lower [12].

The value of the density of maize cob charcoal briquettes is strongly influenced by the size of the particles used. According to [15], the density of maize cob briquette is influenced by the quality of the material used. For wood with high density tends to produce charcoal or high quality charcoal briquettes. It was further stated that the charcoal particle size used also affected density, the smaller the charcoal particle size, the higher the charcoal briquette density produced. This may be due to the smaller pores between the charcoal particles so that the greater the weight of the unity of the volume [16].

The density of a charcoal briquette is very useful in transportation and packing, so that briquettes are not easily destroyed and packing is easier. When compared with the Indonesian national standard (SNI) [18] which is > 0.7 gr/cm^2, the maize cob briquettes that meet SNI are charcoal briquettes with a pressure of 44.80 kg/cm^2 and particle size of 60 mesh that is 0.71 gr/cm^3.

3.2 Moisture Content

The moisture content is a measure of the amount of water in the fuel. The moisture content can be measured by taking a small pre-weighed sample and oven drying it at 105^{o}C until the required consistency in the sample's mass is obtained. The change in weight can then be used to determine the sample's percentage moisture content. The burning characteristics of the biomass can be greatly affected by the moisture content. During combustion, the moisture in the biomass will absorb heat from the burning fuel to form vapor due to heat of vaporization thereby appreciably reducing the heating value of a used fuel. This can result in incomplete combustion of the volatile matter and the deposition of un burnt carbon (smoke) around the stoves, vessels and pans, making it difficult to clean them. High moisture content can cause difficulty in ignition. Practically, burning a fuel with such high moisture content will result in significant products of incomplete combustion [6].

The results of measurements of maize cob briquette moisture content with the influence of pressure and particle size are shown in Table 2.

The moisture content produced in this study ranged from 6.91% - 8.95%. The lowest moisture content of 6.18% was produced by briquettes with a pressured of 44.80 kg/cm² at 40 mesh and the highest moisture content of 8.95% was produced by briquettes with a pressure of 22.42 kg/cm² at 60 mesh. Moisture content affects the quality of the briquettes produced. The moisture content in briquettes is expected to be as low as possible so that it can produce high heat values and will produce briquettes that are easy to ignite or initially burn. The lower the water content, the higher the heating value and combustion power. Conversely, briquettes with high moisture content will cause the calorific value produced by the briquette to decrease. This is because the energy produced will be absorbed a lot to evaporate water. This research is in accordance with research conducted by [19] and [20].

When compared with the water content of the Indonesian National Standard (SNI), which is ≤ 8%, the moisture content of maize cob for most of all particle sizes and pressures in this study meets the quality requirements except at the pressure of 22.4 kg/cm^2 and 60 mesh with a value of water content reaching 8.95% beyond the SNI standard. From this study it can be seen that the particle size can also affect the water content, the coarse particle size absorbs less water than the finer particle size, besides it may be due to the incomplete drying process with drying time still needs to be extended. Likewise, sago adhesive has the high moisture content. The size of the particle is directly proportional to the moisture content produced [21].

3.3 Ash Content

Ash is the non-combustible component of a biomass, and the higher the fuel's ash content, the lower its calorific value. It is formed from both the mineral matter bound in the carbon structure of the biomass during its combustion (the inbuilt ash) and is present in the form of particles from dirt and clay introduced during processing (the entrained ash). Ash is known to cause problems in combustion systems, notably because of formation of slag and deposition over the surface of the metals and its tendency to increase the rate of corrosion of the metal in the system. These are mainly for fuels such as coal and have proved to be of limited value for biomass [6].

The results of the measurement of the ash content of the maize cob briquette test results with the influence of pressure and particle size are shown in Table 3 below. Ash content varied between 16.11% - 17.39%. The lowest ash content of 16.11% was obtained from 40 mesh particle size at pressure of 44.80 kg/cm² and the highest was 17.39% obtained from 60 mesh particle size at a pressure of 22.42 kg/cm².

Ash content was influenced by the quality of the raw material used. Giving pressure creates a bond between the surface of the adhesive material and the glued material so that the adhesive can spread perfectly into the crevices and the entire charcoal surface. So that the cavity that can be filled with water is getting smaller. The amount of pressure is inversely proportional to the level of ash produced. Ash content also depends on the type of wood. Raw materials with high density will produce charcoal with high bonded carbon values and low ash content and moisture content [22].

Ash content can affect the calorific value of a charcoal briquette. Corn briquette ash content when compared with SNI ash content (≤ 8%), then none of the briquette samples meet the quality standards. High ash content causes the bound carbon content to be low or vice versa [23]. It can be seen that the ash content ranges from 16.11% - 17.39%, this shows that the pressure and particle size do not significantly affect the ash content.

Lower ash content is valuable, while excess ash causes trouble during burning; the ash is capable of blocking air from penetrating into the stove, thereby retarding the burning rate of such briquette unless the stove is often shaken to clear the ash during cooking.

Table 2. Moisture content.

Pressure (kg/cm^2)	Moisture (%)		
	40 (Mesh)	50 (Mesh)	60 (Mesh)
22.42	6.91	7.82	8.95
44.80	6.18	7.22	8.12

Table 3. Ash content.

Pressure (kg/cm^2)	Moisture (%)		
	40 (Mesh)	50 (Mesh)	60 (Mesh)
22.42	16.79	17.31	17.39
44.80	16.11	16.21	16.28

Table 4. Volatile matter.

Pressure (kg/cm^2)	Volatile matter (%)		
	40 (Mesh)	50 (Mesh)	60 (Mesh)
22.42	21.28	21.30	21.32
44.80	21.30	21.33	21.35

3.4 Volatile Matter

Volatile matter represents the components of carbon, hydrogen and oxygen present in the biomass, which when heated is converted to vapor, usually a mixture of long-and short-chain hydrocarbons. In almost all biomasses, the amount of volatile matter is higher than in bituminous coal. Biomass generally has a volatile content of around 70-86% of the weight of the dry biomass, compared with coal, which contains only about 35% volatile matter. Consequently, the fractional heat contribution of the volatile matter is more for biomass. This makes biomass a more reactive fuel than coal, giving a much faster combustion rate during the volatilization phase. Generally, higher percentage of volatile matter is an indication that the ignition rate will be high. The volatile matter of the briquettes is somewhat more than conventional coals, so it enhances the burning characteristics of the fuel [6].

The results of measurement of volatile matter with the influence of pressure and particle size are shown in Table 4.

Volatile matter obtained ranged between 21.28% - 21.35%. At a particle size of 40 mesh for a pressure of 22.42 kg / cm² the volatile matter obtained was lower at 21.28% and the volatile matter obtained was higher at a particle size of 60 mesh for 44.80 kg / cm² (21.35%). This shows that the increase in compaction pressure and the amount of briquette particles also increases volatile matter. Volatile matter produced in this study does not meet the Indonesian national standard (SNI) which is 16.14%. But when compared with the quality standards of charcoal made in Japan (15-30%) and America (19-28%), the maize cob for all pressure and particle size still meet the quality standards of Japanese and American charcoal briquettes.

The value of volatile matter is much influenced by chemical components of charcoal such as the presence of extractive substances from charcoal raw materials. This is also due to the non-optimal carbonation process. Just as we know the purpose of carbonation is to break down hydrocarbons such as cellulose and hemi cellulose to become pure carbon. This happens because during the carbonation process, the amount of oxygen is still high so that it affects the hydrocarbon cutting process [24].

3.5 Fixed Carbon

The percentage of fixed carbon is normally determined by the difference in the other quantities, such as moisture, volatile matter and ash content, of the total biomass in percentage. Essentially, the fixed carbon of a fuel is the percentage of carbon available for char combustion after all the volatile matter is removed from the biomass. This is not equal to the total amount of carbon in the fuel (the ultimate carbon) because there is also a significant amount released as hydrocarbons in the volatile matter. Fixed carbon gives significant indication of the fraction of char that remains after the volatilization phase. These carbons will react with the oxygen to release heat [6].

The results of measurements of fix carbon of maize cob briquettes with a compressive effect and particle size are shown in Table 5.

The fixed carbon content produced ranges from 30.42% - 33.25%. The highest fixed carbon content was 33.25% at the pressure of 44.80 kg/cm² with the lowest particle size of 40 mesh and fixed carbon 30.42% at a pressure of 22.42 kg / cm² with a particle size of 60 mesh. This is influenced by changes in ash content, moisture content, and volatile matter of corn cob briquettes due to changes in pressure.

With the addition of particle size, the fixed carbon content is lower. This is influenced by changes in ash content, moisture content, and volatile matter of maize cob briquettes. The higher the value of the volatile matter, then the fixed carbon value will be lower, and vice versa. Similarly, if the value of the ash content gets higher, then the fixed carbon value will be lower [24]. The fixed carbon produced in this study did not meet the Indonesian national standard of 77%.

A high percentage of fixed carbon will enhance the heat value, but the fixed carbon content and the calorific value of above-mentioned briquettes are lower than coal. So, the heating value is low when compared with conventional fuels and fire wood; however, on the other side, the cost of briquettes is low compared with conventional coals [6].

3.6 Calorific Value

The calorific value (or heating value) is the standard measure of the energy content of a fuel. It is defined as the amount of heat released when a unit weight of fuel is completely burnt and the combustion products are cooled to 298K. When the latent heat of condensation of water is included in the calorific value, it is referred to as the gross calorific value or the higher heating value. However, in stoves, any moisture that is contained in the fuel and which is formed during the combustion process is carried away as water vapor, and so its heat is not available. It is useful, therefore, to subtract the heat of condensation of this water from the gross calorific value. The characteristics of the calorific value of maize cob charcoal briquettes can be seen in Table 6 below.

Table 5. Fixed carbon (%).

Pressure (kg/cm^2)	Fixed carbon (%)		
	40 (Mesh)	50 (Mesh)	60 (Mesh)
22.42	33.14	32.11	30.42
44.80	33.25	32.33	30.64

Table 6. Calorific value.

Pressure (kg/cm^2)	Calorific value (calorie/gram)		
	40 (Mesh)	50 (Mesh)	60 (Mesh)
22.42	5,571.22	5,426.40	5,091.72
44.80	5,691.15	5,570.41	5,553.20

From Table 6 above, it can be seen that the highest calorific value of corn cob briquette is 5,691.15 calories/gram obtained at a pressure of 44.80 kg/cm^2 and a particle size of 40 mesh, this is due to the low moisture content in these conditions where the value of water content is inversely proportional to the heat value of bio-charcoal briquettes. Moisture content greatly affects the quality of charcoal briquettes produced. The lower the water content, the higher the combustion power and vice versa, the higher the water content, the lower the combustion power. The test results of the calorific value of maize cob briquettes are in accordance with the SNI standard which is greater or equal to 5,000 calories/gram.

3.7 Burning Time

The maize cob briquettes that have been produced are then burned to find out the ignition time and duration of combustion. Knot time is the time needed for briquettes to emerge. Good briquette quality is shown by a short turn over time. Before burning the briquette is soaked into kerosene for about 1 minute. Kerosene functions as an igniter to facilitate combustion in briquettes. The time of ignition is observed from the ignition of briquettes to the briquette starts burning.

Based on Table 7 the elongation time ranged from 5.10 minutes to 7.85 minutes. The shortest turnover time is pressurized briquette 44.80 kg/cm^2 in 60 mesh particle size with a duration of 5.10 minutes which has a density of 0.71 g/cm^3, the percentage of water content is 8.12%, the percentage of ash content is 16.28%, the percentage of volatile matter is 21.35% and the percentage of fixed carbon is 30.64%. While the longest turnover time was on pressurized briquettes 22.42 kg/cm^2 at a particle size of 40 mesh with a duration of 7.85 minutes which had a density of 0.64 g/cm^3, the percentage of water content was 6.91%, the percentage of ash content was 16.79%, the percentage of volatile matter is 21.28%, and the percentage of fixed carbon is 33.14%. It appears that the addition of pressure on briquettes tends to change when the tendon decreases. The difference in particle size gives a different supply of oxygen which affects combustion. Factors that influence the burning of solid fuels include particle size, velocity of air flow, type of fuel, and combustion air temperature [25], [28].

3.8 Flame Rate

The flame rate is the mass of briquettes that burn to ash every time unit. From the results of the flame rate testing that has been done and presented in Table 8.

The test results show that the 40 mesh particle size briquette has the lowest flame rate of 0.10 gr/min at a pressure of 22.42 kg/cm^2. The flame rate decreases in the given pressure increase. The influence of the particle size to the flame rate value is presented in Table 7. The value of the flame rate shows the same pattern, *i.e.* the value of the flame rate tends to increase for each increase in particle size. According to Sulistyaningkarti [18], the rate of burning of briquettes is affected by the density of briquettes [26], [27]. Overcrowded briquettes will be difficult to burn, while less dense briquettes can result in the breakdown of briquettes during combustion so that the impression is not clean even though the combustion rate is fast. The fuel particles undergo a stage of charcoal oxidation which requires 70-80% of the total combustion time. Adding pressure will strengthen the bonds between the molecules that make up the briquette, thereby reducing the porosity of briquettes. The more pores in the briquette give more space for the entry of oxygen, so that the combustion is getting better and provides a large burning rate. Conversely, the stronger molecular bonds with increasing pressure reduce the porosity of briquettes and reduce the rate of combustion [26]

Table 7. Burning time.

Pressure (kg/cm^2)	Burning time (minutes)		
	40 (Mesh)	50 (Mesh)	60 (Mesh)
22.42	7.85	7.12	6.0
44.80	7.22	6.13	5.10

Table 8. Flame rate

Pressure (kg/cm^2)	Flame rate (gr/minute)		
	40 (Mesh)	50 (Mesh)	60 (Mesh)
22.42	0.10	0.11	0.12
44.80	0.11	0.12	0.13

4. CONCLUSION

This experimental work focuses on developing a method to manufacture briquettes of consistent quality at medium pressures by employing a wet technique. These techniques were used to carry out a study on cylindrical-shaped briquettes, observing the result of variables (density, moisture content, ash content, volatile matter, and fix carbon) on briquette burn quality (calorific value, burning time, and flame rate) with different compaction pressured and particle roughness. Therefore, the products of briquetting can be compared with other materials from agricultural waste and also the results can formulated. The method to manufacture briquettes can offers employment for the rural communities. It also overcomes the demand of firewood and other fuels for various burning processes.

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