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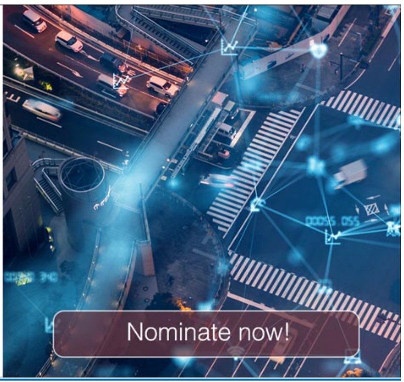

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The effect of various varieties of cassava stems waste and tapioca adhesive concentrations on the quality of bio-coal briquette

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Abstract. This study aims to utilize the combination of cassava and coal waste as raw materials for making briquettes using several different concentrations of tapioca adhesives. This study uses a completely randomized design (RDC) with 2 factorials. The first factor is material composition, assigned by the letter P, which has 3 different varieties of different cassava, which are (P1) Kasetsart cassava and coal waste, (P2) Thai cassava and coal waste, and (P3) butter cassava and coal waste. The second factor is tapioca adhesive concentration, which consists of two different treatments: (M1) 15% and (M2) 20%. The combination of these different treatments then repeated 4 times resulted in 24 experimental units. The briquettes produced then underwent several characteristics tests, including water content, calorific value, combustion rate, density, compressive strength, shatter resistance index, and changes in the temperature of the pan base when the briquettes were burned. The acquired data then processed using Microsoft Excel 2010 and SAS v9 software. The data obtained will then be compared to SNI (Indonesia National Standard) to find out whether the briquette is fulfilling the requirement for application. The results are as follows: treatment P1M1 and P1M2 have a water content ranging from 5.36-7.09% and a calorific value between 4.427 – 5.541 cal/g, and it also fulfills the SNI Standard. Another characteristic is shown by P1M1 and P1M2 such as combustion rate around 0.37-0.4 g/min, density between 0.37-0.39 g/cm^3, compressive strength between 48.67 N/cm^2, and shatter resistance index numbering around 99.90-99.92%, able to fulfill 95% of the SNI requirement for bio coal briquette, as well as changes in the bottom temperature of the pan which has reached the highest temperature of 303°C in the 26th minute of the P1M1 treatment combination and the lowest is 311°C at the 28th minute of the P1M2 treatment combination.

1. Introduction

Nowadays, energy is the primary need of humans. Increasing the human population promotes increasing energy demand. Currently, the energy was supplied from non-renewable energy sources (e.g., fossil fuels such as oil and coal), accounting for 81.1% of the world's primary energy [1]. Such sources are assigned as responsible for the increase of CO2 concentration in the atmosphere and the consequent negative impacts caused by climate changes and global warming [2]. To minimize the impact of climate changes due to the overuse of fossil fuel energy, renewable energy is one way and needs to be considered. The use of biomass As renewable energy is an attractive option and has attracted considerable interest since the '90s to mitigate global climate change [3]. One of the potential biomass sources in a tropical country is cassava waste, especially the stem of cassava [4]. Cassava (Manihot esculenta Crantz.) stem is currently wasted after harvesting the starchy roots. Moreover, cassava stem waste can be used as material to produce bio briquette

Briquetting is a densification process with the application of pressure to materials to obtain a compact, durable, and high quality fuel [5]. Briquetting processes involve drying, grinding, sieving, compacting, cooling, and packing as the need be. The drying reduces the moisture content of raw material; the dried material is grinded, passed through a screen, and then briquetted. The obtained briquettes are allowed to dry and stored. The briquetting process is a promising method for producing a uniform, stable, and durable fuel with the standard quality [6-7]. The briquetting process helps to decrease the costs of handling, transportation, and storage. Briquettes can be produced from biomass materials in three different ways by one kind of biomass or mixtures of various biomass materials can be used in the biomass–based briquette production and biocoal (a mixture of biomass and coal). Bio coal briquette represents a type of solid fuel produced from coal and biomass with pressure. During the briquetting process, biomass and coal particles adhere and interlace to each other. Therefore, these two materials do not separate from each other during storage, transportation, and utilization [8]. The purpose of this study is to investige the effect of various varieties of cassava stems waste and tapioca adhesive concentrations on the quality of bio-coal briquette.

2. Methods

This research was conducted from January - April 2019 at Agricultural Machine Tool Power Laboratory of Agricultural Engineering Department, Faculty of Agriculture, University of Lampung. The tools used to make the briquette included: cassava rod chopper type TEP-1, screw press briquette, hammer mill, drying oven, bomb calorimeter, bucket, digital calipers, aluminum dish, Tyler Meinzer II size 25 mesh, tray, measuring cup, analytical scale, digital scale, stopwatch, thermometer, thermocouple, mortar, pestle, clamp, desiccator, stove, pan, stirring container, stirring spoon, label paper, ruler, matchbox, tarpaulin, plastic bag, laptop camera, and stationery. While the materials used, include: cassava stem waste (Kasetsart, Thai, and Butter), tapioca flour adhesives, BA60 coal obtained from PT Bukit Asam Tbk (PTBA) Natar Briquette Factory Unit, diesel, wood, and water level.

This study uses a completely randomized design (RDC) with 2 factorials and uses a statistical method. The first factor is material composition has 3 different varieties of different cassava, which are (P1) 52.17% Kasesart cassava waste and 34.78% coal, (P2), 52.17% Thai cassava stem waste and 34.78% coal, and (P3) 52.17% of Butter cassava stem waste and 34.78% coal waste. The second factor is tapioca adhesive concentration which consists of two different treatments, (M1) 15% and (M2) 20%. The combination of these different treatments then repeated 4 times resulted in 24 experimental units. Formulation of briquette dough weights can be seen in Table 1.

Table 1. Weight Formulation for Briquette compositions

Cassava varieties (P)	Adhesive Concentration(M)	Weight of briquette dough (gram)			
		Cassava Stem	Coal	Adhesive	Total
Kasetsart	15% tapioca	360	240	90	690
		360	240	90	690
		360	240	90	690
		360	240	90	690
	20% tapioca	360	240	120	720
		360	240	120	720
		360	240	120	720
		360	240	120	720
Thailand	15% tapioca	360	240	90	690
		360	240	90	690
		360	240	90	690
		360	240	90	690
	20% tapioca	360	240	120	720

		360	240	120	720
		360	240	120	720
		360	240	120	720
Butter	15% tapioca	360	240	90	690
		360	240	90	690
		360	240	90	690
		360	240	90	690
	20% tapiocca	360	240	120	720
		360	240	120	720
		360	240	120	720
		360	240	120	720

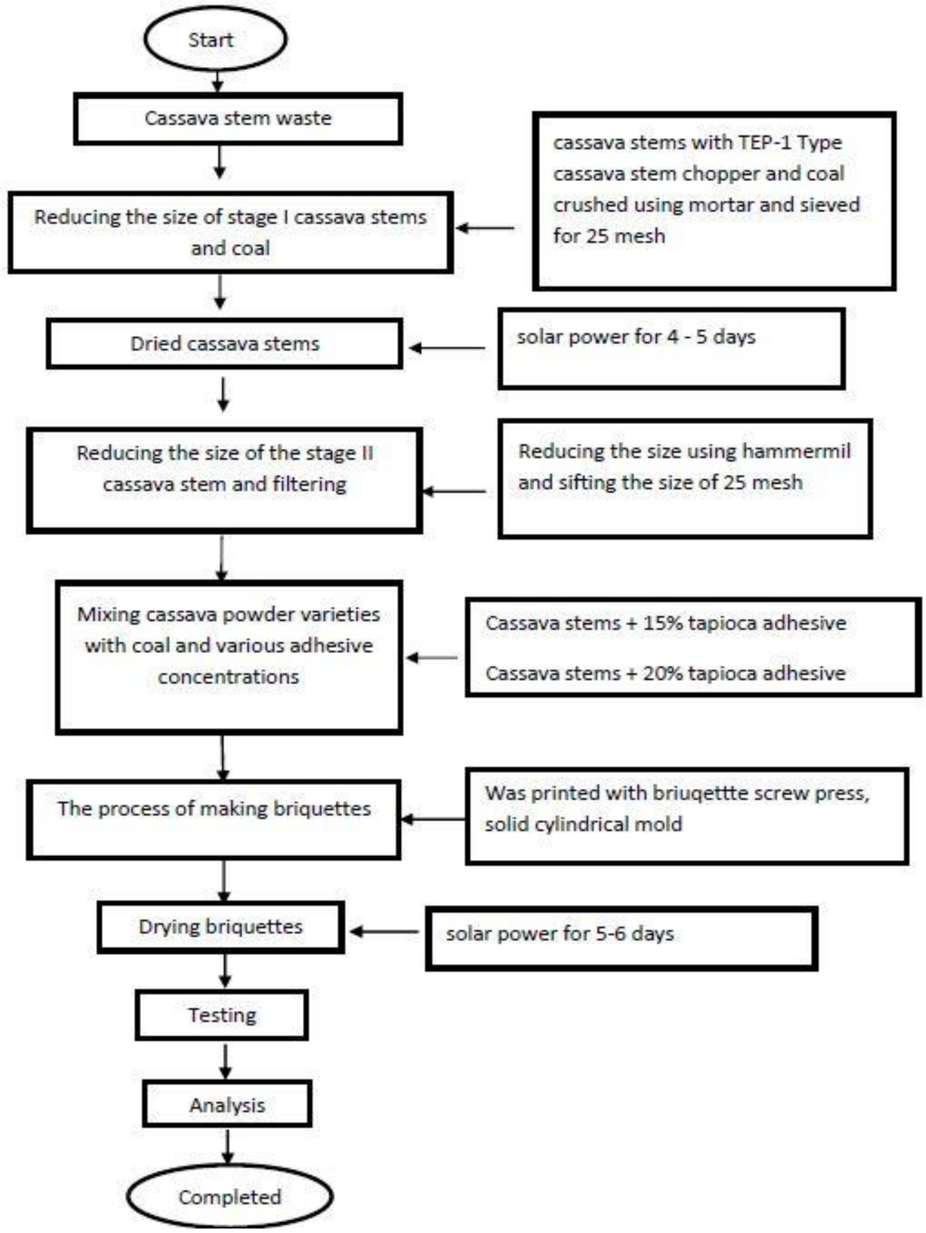

Figure 1. Research Procedure Step Diagram

There are two phases in reducing the cassava waste size, and phase 1 is by using chopper Type TEP-1 to reduce the size and using mortar to crush the coal, then sift both the cassava and coal using 25 mesh sieves. The cassava then dried under the sun for 4-5 days. The 2nd phase uses a hammer mill to reduce the cassava particle sizes further and then sift it again through 25 mesh sieves. From this, the materials are ready to be used by mixing the cassava waste, coal, and different concentration of tapioca adhesive into a dough and then mold it using briquette mold and drying it under the sun for 5-6 days; the briquettes are ready to be used and tested. The briquettes are then tested to determine their water content, heating value, combustion rate, density, compressive strength, shatter resistance index, and temperature changes. The diagram to show the procedure of this research can be seen in Figure 1.

3. Results and Discussions

Bio coal briquette produced in this study is a type of biomass briquette; in this case, the biomass used is agricultural waste in the form of cassava stem. Cassava stem waste is specifically chosen for this study because of the abundant amount available. This study uses three different cassava varieties: Kasesart, Thai, and Butter variances, and then mixed it with coal and 2 different concentrations (15 and 20%) of tapioca adhesives. An indicator of a good quality briquette is its low moisture and combustion rate but has a high density, heating value, and high live coals. To find out the characteristic of produced briquette, it undergoes several different parameter tests.

3.1. Water Content

Water content is the amount of water contained inside. A good quality briquette will have low water content. It will allow the briquette to combust easily and increase its heating value, while higher water content will make it harder for the briquette to combust, lowering its heating value; this is because the energy used to burn the briquette are used to evaporate the water instead. According to Riseanggara [9], the high-water content will lower its quality due to the influence of microbes; also, it will produce much smoke when combusted. The result of the briquette water content test is shown in Figure 2.

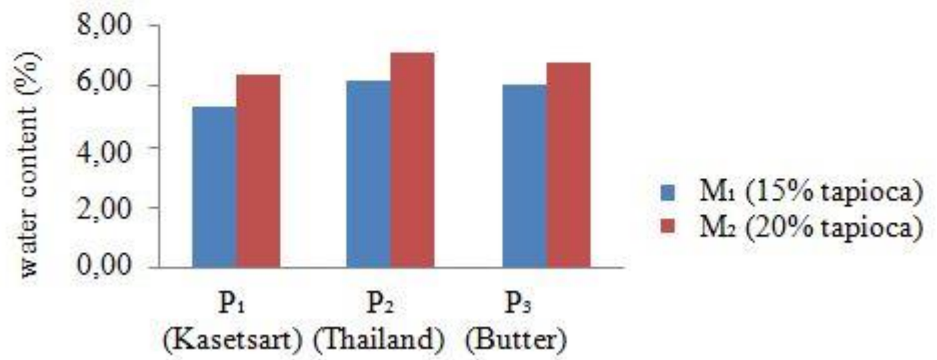

Figure 2. Test results of briquette water content.

From figure 2, it can be seen that the concentration of adhesive affects the amount of water contained inside the briquette. The higher the adhesive concentration used, the higher the water content due to water addition from the adhesive itself. The highest amount of water content can be found in P2M2 (20% adhesive) with 7.09% of water, while the lowest can be found in P2M1 (15% adhesive) with 5.36% of water. A briquette with lower moisture content is preferable due to a higher heating value when compared to a briquette with high moisture content. According to Hendra [10], a high level of water content can decrease the briquette heating value; this is due to the heat when burning the briquette is first used to evaporate the water contained inside the briquette. Also, the high-water content will cause much smoke when the briquette is combusted. This can be prevented by lowering the water content beforehand by drying it before use, either by sun-dried or by putting it in the oven. The length of time spent drying the briquette also affects the water content. The longer time is taken drying the briquette, the lower the water content, increasing the heating value of bio-coal briquette [11]. The type of adhesive used also affects the quality of the briquette. Riseanggara [9], states that generally increasing the amount of adhesive increase the heating value of briquette due to the addition of carbon elements presents in the adhesive. This statement contradicts the fact that the increase in water content is due to the addition from the adhesive itself, therefore, lowering the heating value. However, this can be explained by the adhesive type, either plant-based adhesive or hydrocarbon adhesive. Moreover, Boedjang [12], state that plant-based adhesive such as starch is needed less when compared to hydrocarbon adhesive, but plant-based adhesive are higher in water content due to their water-absorbing nature.

3.2. Heat Value

Fuel value or heat value is a value that shows the energy content in the fuel [13]. The higher the value, the better the briquette quality. Low water content resulted in high heating value and makes it easier to be united. This makes heat value become an important quality parameter for briquettes as fuel. Because of this, it is crucial to know the heat value when making a briquette because it shows whether the briquette produced is suitable for use or not. The test result of the briquette heat value is presented in Figure 3.

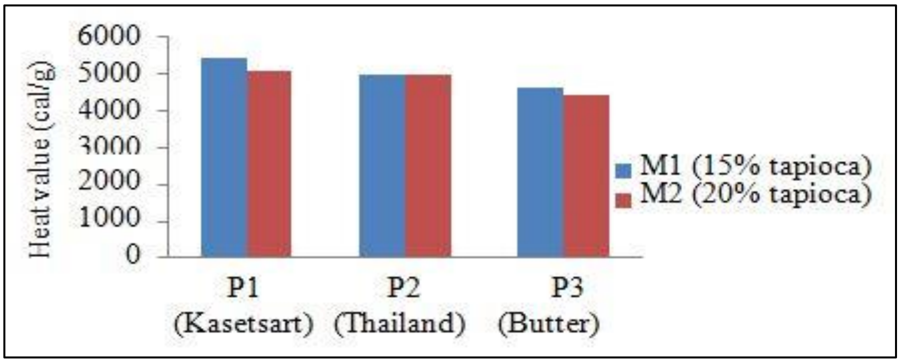

Figure 3. Test results for the heating value of briquettes measured using bomb calorimeter

From figure 3, it can be seen that the lowest heat value is produced by P3M2 briquette numbering in 4.427 cal/g, while the highest is produced by P1M1 with a heat value of 5.141 cal/g. However, it should be noted that measuring calorific value using bomb calorimeter is very susceptible to errors. Based on the data obtained, on P1 and P3, the briquette with lower adhesive concentration has a higher compare to briquette with higher adhesive, this shows that lower adhesive means lower water content resulted in higher heat value and true according to the theory stated before, however on P2, it shows that lower concentration of adhesive produced low heat value at 4.967 cal/g compared to a high adhesive concentration with a heat value of 4.983 cal/g. This could happen due to an error while measurement or because the number of samples used in measurement is very small, so it's not enough to represent the data [14].

3.3. Burning Rate

The burning rate or combustion rate shows the amount of material burned per minute. A high combustion rate means that briquette will burn for a shorter period than briquette with a low combustion period. In application, this number will show how long a single briquette can be used for fuel before needing another briquette. The results of the combustion rate test can be seen in Figure 4.

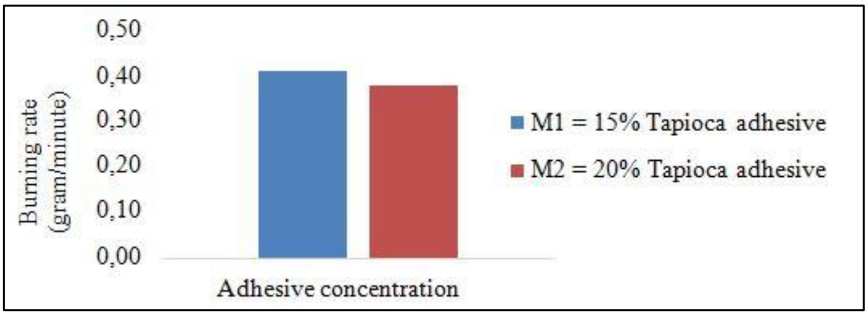

Figure 4. Test results of combustion rate.

From figure 4, it can be seen the rates of combustion of the briquettes are lower when the adhesive concentrations used are higher. The burning rates are ranging from 0.37 to 0.4 gram/minute. The lowest combustion rate can be found in M2 (20% adhesive concentration) with the rate of 0.37 gram/minute, while the highest can be found in M1 (15% adhesive concentration) with the rate of 0.4 gram/minute. The higher the adhesive concentration added, the lower the combustion rate. This is because the organic matter contained inside the adhesive causes the briquette to tighter and become denser [9]. The denser the briquette, the lower the air cavity; this, in turn, will make the rate of combustion go lower. Based on analysis of variance, at the 5% level, the cassava varieties did not significantly affect the combustion rate. At the same time, the adhesive concentration has a significant effect, but the interaction between the varieties and adhesive concentration does not affect the burning rate. The average value of briquette burning rate due to the influence of different adhesive concentrations can be seen in Table 2.

Table 2. Average values of combustion rate (g / min) of briquettes due to the influence of different adhesive concentrations.

Treatment	Mean (hg/minute)	t Grouping
M1	0.404292	A
M2	0.374992	B

In t group if there are the same letters, the treatment is not significantly different, but if there are different letters, the treatment is significantly different. Based on the results presented in Table 2, it can be seen that the effect of tapioca adhesive concentration is significantly affects the rate of combustion.

3.4. Density

Density is the ratio between the weight and volume of the briquette. It affects the combustion rate. A low-density briquette will have a lot of air cavity, which allows for air circulation allowing oxygen to enter and increasing combustion rate [15]. Density can also affect the briquette's firmness and whether the briquette is easy to ignite or not. The density of the briquette is affected by the size and the homogeneity of the briquette dough. Briquette density test results are presented in Figure 5.

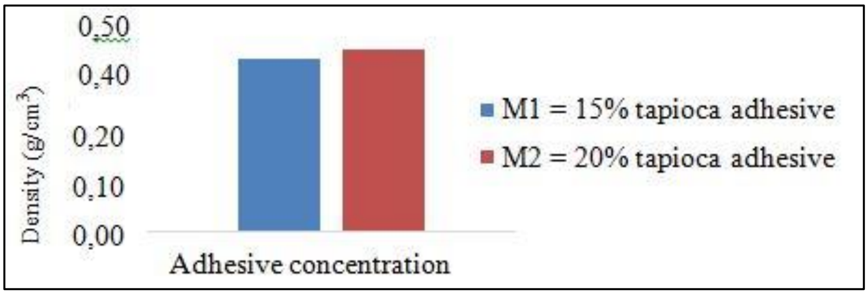

Figure 5. Test results for briquette density.

Figure 5 shows that the increase in adhesive concentration is followed by an increase in briquette density. The lowest average briquette density can be found in M1 (15% concentration), which around 0.37 g / cm^3. In contrast, the highest average was found in the M2 (20% concentration), which around 0.39 g / cm^3. Based on analysis of variance at the 5% level, the cassava varieties did not significantly affect the density. At the same time, the adhesive concentration has a significant effect, but the interaction between the varieties and adhesive concentration does not affect the briquette density. The average value of briquette density due to the influence of different adhesive concentrations can be seen in Table 3.

Table 3. Average values of density (g/cm^3) of briquettes due to the influence of different adhesive concentrations.

Treatment	Mean (g/cm^3)	t-Grouping
M2	0.416225	A
M1	0.407592	B

Note: In t group if there are the same letters, the treatment is not significantly different, but if there are different letters, the treatment is significantly different.

Based on the result it can be seen that the effect of tapioca adhesive concentration significantly affects the briquette density. One of the factors that can determine the density is the amount of pressure applied when printing the briquette. Taulbee et al. [16] stated that the increase in briquette will also increase other physical characteristics, such as compressive strength, shatter resistance, water resistance, and durability of briquette.

3.5. Compressive Strength

Firmness shows the integrity of the briquette structure, it determines how resistant the briquette to break. The compressive test consists of giving the briquette pressure until it breaks. The greater the compressive strength, the higher the durability of the briquette. High compressive strength will be beneficial in packaging and distribution [10]. The results of compressive strength testing of briquettes can be seen in Figure 6.

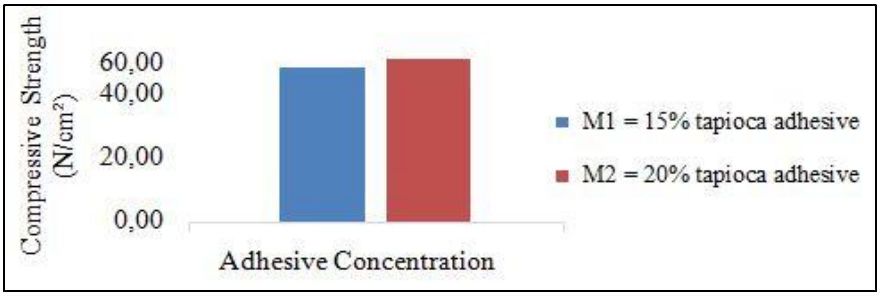

Figure 6. Results of compressive strength testing of briquettes.

From figure 6, it can be seen that the compressive strength increases along with the increase in adhesive concentration. The lowest average compressive strength can be found in M1 treatment, around 48.67 N/cm^2. The highest average compressive strength of 51.35 N/cm^2 found in M2 treatment. In the compressive strength test, the briquettes are put under several different load weights, from 50, 60, 70, 80, and 90. The briquettes only experience a structural failure when under the pressure of 90 kg load weight and above. Briquettes with higher adhesive concentration have higher compressive strength compared to briquettes with lower adhesive concentration.

Cory [17] stated that a low adhesive concentration inside a briquette would make it easy to break, while a high adhesive concentration makes it harder to break. This is due to increased adhesive concentration strengthening the bond between the cassava and charcoal particle in the briquette. Based on analysis of variance at the 5% level, the cassava varieties did not significantly affect the compressive strength. At the same time, the adhesive concentration has a significant effect, but the interaction between the varieties and adhesive concentration shows no effect on the briquette compressive strength. The average compressive strength of briquettes due to different adhesive concentrations can be seen in Table 4.

Table 4. Average compressive strength (N/cm^2) value of briquettes due to the effect of different adhesive concentrations.

Treatment	Mean (N/cm^2)	t-Grouping
M2	51.3454	A
M1	49.6547	B

Note: In t group if there are the same letters, the treatment is not significantly different but if there are different letters, the treatment is significantly different.

Based on the result presented in table 4 it can be seen that the concentration of tapioca adhesive has a significant effect on the compressive strength of the briquette. The pressure applied when printing the briquette also affect the compressive strength, the higher the pressure the greater the compressive strength.

3.6. *Shatter Resistance Index*

Shatter resistance index is used to show the hardness of the briquette. The test was carried out by dropping the briquette from the height of 2 meters and calculate the weight percentage of the shattered briquette part. The test result can be seen in Figure 7.

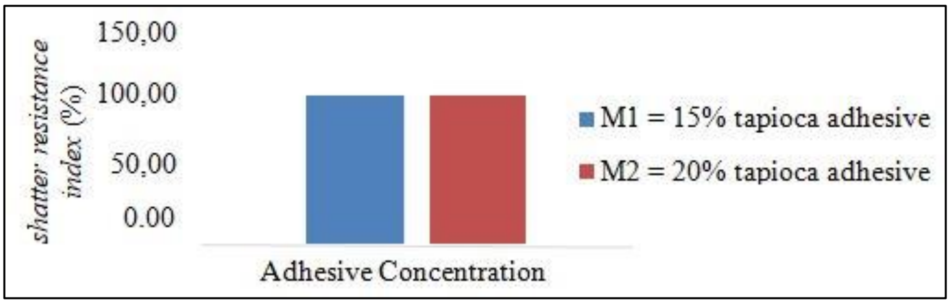

Figure 7. Shatter resistance index test results.

From Figure 7, it can be seen that the shatter resistance experiences an increase with the increase in adhesive concentration. The lowest average shatter resistance can be found in the M1 treatment with a value of 99.90%. At the same time, the highest average shatter resistance of 99.92% was found in M2 treatment. This is because the higher the adhesive concentration, the water content inside the briquette also increases, which makes it softer and more resistant to shatter, so when the briquettes are dropped from 2 meters height, the soft briquette tends to deform rather than shatters. Based on analysis of variance at the 5% level, the cassava varieties did not affect the shatter resistance. At the same time, the adhesive concentration has a significant effect, but the interaction between the varieties and adhesive concentration shows no effect on the briquette shatter resistance. The average value of the briquette resistance index affected by different adhesive concentrations can be seen in Table 5.

Table 5. The average value of shatter resistance index (%) of briquettes due to the different adhesive concentrations.

Treatment	**Mean (%)**	**t-Grouping**
M2	99.920858	A
M1	99.896133	B

Note: In t group if there are the same letters, the treatment is not significantly different, but if there are different letters, the treatment is significantly different.

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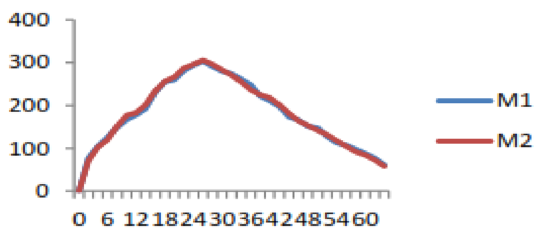
From the results presented in Table 5, it can be seen that the effect of tapioca adhesive concentration has a significant effect on the strength of the briquettes. Also, the briquette resistance index has similarities to the compressive strength of briquettes in which the two parameters are determined the density of the briquettes produced.

3.7. The temperature of pan

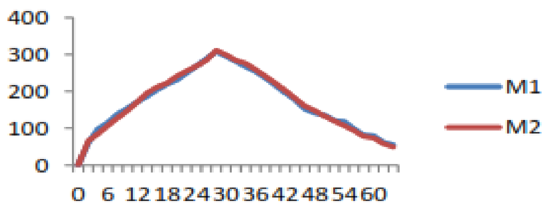
The usage of bio-coal for daily needs means that it should produce a low amount of pollution while achieving a high temperature; also, it needs to be easily ignited, increasing the efficiency and effectiveness of the briquette [17-18]. The briquette produced in this study produced a relatively small amount of smoke. The amount produced is also determined by the adhesive concentration. Based on the test results, briquette with 15% of adhesive, thus the water content is lower, produced the least amount of smoke. This is consistent with Riseanggara [9] statement that the high-water content in a briquette will affect the amount of smoke generated during the combustion process.

The boiling point of water at room temperature is 100°C, while the boiling point of palm oil used for frying is around 160-190°C [20]. Meaning the requirement for briquette as fuel for cooking is that it can reach a temperature around 160-190 °C. Temperature was measured on the base of an empty aluminum pan with a diameter of 15 cm. Changes in the temperatures are shown in Figure 8 (a), (b), and (c).

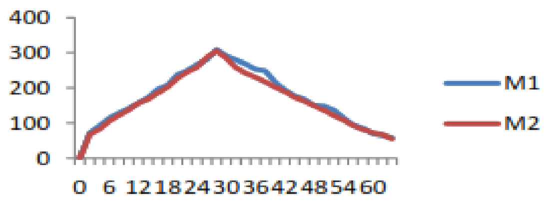
In Figure 8(a), in 26 minutes, P1M1 reaches a maximum temperature of 303 °C while P1M2 treatment reaches 306 °C. Figure 8(b) shows that P2M1 treatment reaches 311 °C and P2M2 reaches 307 °C; both require around 28 minutes to reach max temperature. Finally, in Figure 8(c), in 28 minutes of treatment P3M1 reaches a max temperature of 309 °C while P3M2 reaches 305 °C.



(a) Combination of P1M1 and P_1M_2 treatments



(b) Combination of P_2M_1 dan P_2M_2 treatments



(c) Combination of P_3M_1 dan P_3M_2 treatment

Figure 8. Changes in the temperature of the pan bottom

The change in temperature at the bottom of the pan is greatly influenced by the amount of energy expended by the briquettes. After ignition, the briquette will continue to burn until it reaches its maximum temperature. The combustion rate is determined by briquette density, and low density briquette has more air cavity, which allows for oxygen flow increasing the rate. After the briquette reaches its maximum temperature, it will continue burning until there is no material left inside the briquette to be burn then; the temperature will slowly decrease, and eventually, the briquette extinguished. A high combustion rate will shorten the ignition of briquettes, and the resulting briquette temperatures will be higher (Tamrin, 2011)

4. Conclusion

The conclusion of this study is different cassava varieties (Kasertsart, Thailand, and Butter) can be used for making briquettes with a mixture of coal and tapioca adhesive. Tapioca adhesive concentration significantly affected various briquette test parameters, namely the rate of combustion, compressive strength, density, and shatter resistance index. Cassava stem is suitable as bio-coal briquette raw material because it has several characteristics: water content ranges from 5.36 - 7.09% lower than the required SNI standard of 8%, a calorific value between 4.427 – 5.451 cal/g higher than required SNI standard of 4.4 00 cal/g. In P1M1 and P1 M2 treatments, the combustion rate between 0.37 - 0.40 gram/minute, density between 0.37 - 0.39 g/cm^3, compressive strength between 48.67 - 51.35 N/cm^2, shatter resistance index between 99.90 -99.92%, which fulfills SNI bio-coal briquettes by 95%, the briquettes also have 2 different max temperatures, treatment P2M2 reached 311°C in 28 minutes while P1M1 have a lower max temperature at 303°C in 26 minutes.

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