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EFFECTS OF PARTICLE SIZE AND COMPOSITION OF CASSAVA PEELS AND RICE HUSK ON THE BRIQUETTE PERFORMANCE

SRI ANGGRAENI[1], SITI NUR HOFIFAH[2],
ASEP BAYU DANI NANDIYANTO[1,*], MUHAMMAD ROIL BILAD[2]

[1]Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No 299, Bandung, 40154, Indonesia
[2]Universiti Teknologi Petronas, Malaysia
*Corresponding Author: nandiyanto@upi.edu

Abstract

This study investigated the effects of particle size and composition of cassava peels (CPs) and rice husks (RHs) on the briquette performance. The experiments were done by combining CPs and RHs with a ratio of carbon CPs:RHs of 90:10; 70:30; 50:50; 30:70; and 10:90. In the experiments, CPs and RHs were dried naturally for 3 days, carbonized, and saw-milled. 10 g of carbon particles mixed with 4 g binder and moulded. The result showed the optimum compressed and relaxed density was obtained for briquette with small particles and a CPs:RHs ratio of 70:30 and 50:50. The relaxed density ranged between 1.70 and 2.26 g/cm3. The lower moisture content was obtained from the small particle size at the ratio of 50:50. The water boiling test, the burning rate, and the specific fuel consumption indicated that the briquette with small particles and the ratio of 90:10 have an excellent calorific value. The good water-resistant index was obtained for briquette with medium particles and the ratio of 50:50. The average durability index values for all briquettes were about 98%. The steam engine run time ranged from 4.18 to 6.42 minutes. The additional RHs are effective for increasing the density, the moisture content, and the heating value of briquettes. The smaller particle size of RHs and CPs gave impacts on the enhancement of the density, the heating value, the ignition time, and the water resistance index. These briquettes are potentially used as one of the renewable energy sources.

Keywords: Briquette, Cassava peels (CPs), Particle size, Rice husks (RHs).

1. Introduction

Briquettes have been used as an effective method to harness the energy potential of biomass to become renewable energy [1]. Briquettes are created by pressing biomass materials into compacted solid composites [2]. Briquettes can increase the heating value per unit volume of biomass [3].

Many studies have reported manufacturing briquettes using biomass, such as using rice husks [4], corn cobs [5], coconut shells [6], cocoa pod husks [7], peanut shells [8], and cotton stalk [9]. There has been no research on mixing rice husks (RHs) and cassava peels (CPs) in making briquettes. Research on the effect of particle size in the making of briquettes are also still rare. In fact, RHs are widely used as raw material for making briquettes because they show good performance in briquettes combustion (good heating value), while CPs can become natural binders when mixed in briquette dough because they have starch content. CPs themselves can be used as a single binder in briquette manufacturing. Therefore, the mixture of RHs and CPs has great potential for briquette. Further, RHs and CPs are available abundantly in Indonesia.

CPs are mostly found as the waste in the production of tapioca starch, cassava chips, cassava tape, or other cassava-based Indonesian foods. RHs are found in the rice milling process, in which rice is the main food in Indonesia. These types of wastes are typically directly disposed to the environment or burned in the open field. In fact, RHs and CPs have great potential energies, reaching values of 19.41 and 2.30 GW, respectively [10]. Indeed, strategies for developing this type of waste into renewable energy are required, giving two advantages: (i) creating an alternative energy source, and (ii) adding product value from the waste.

Here, the purposes of this study were to evaluate the effects of particle size and composition of CPs and RHs on the briquette performance. The experiments were done by combining CPs and RHs with tapioca starch as the binder. Tapioca starch was used since this type of material has been well-known as the binder for briquettes formation [11]. Experimental data were completed with the compressed density, the relaxed density, the relaxed ratio, the moisture content, the water-resistant index, the durability index, the burning rate, the specific fuel consumption, and the effectiveness of the briquette as the alternative energy (as the energy for a steam engine). The results showed that the particle size and the combination of CPs and RHs can affect the performance of the briquettes. The smaller particle size makes no pores in the briquettes, and the characteristics of RHs and CPs can affect the calorific value on briquettes combustion. This study demonstrates new information for the utilization of agricultural wastes, which can be used for further development of renewable energy.

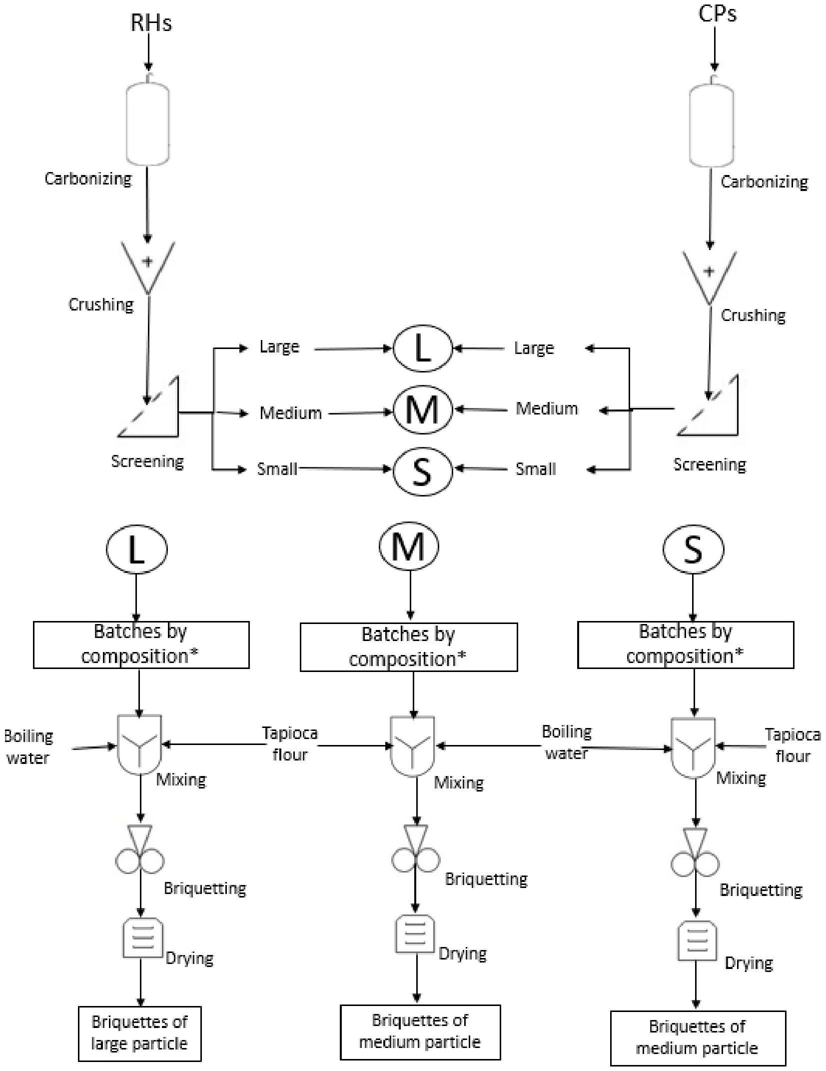
2. Material and Method

2.1. Raw material preparation

Several materials were used: RHs (obtained from a rice mill in West Bandung, Indonesia), CPs (obtained from freshly harvested cassava farm in West Bandung, Indonesia), and tapioca starch (obtained from the tapioca starch factory in West Bandung, Indonesia). Before using, the obtained materials were cleaned from impurities such as soil, rocks, and grass, dried naturally for 3 days.

Figure 1 shows illustration of experimental methods conducted in this study. The dried biomass was carbonized using an electrical furnace without grinding it first (Sharp; model EO-28LP(K), China) at 250˚C for 1 hour. After raw CPs and RHs turning into carbon, the carbon was ground by special treatment and filtered to obtain the required size. The particle sizes were divided into large (2000-500 μm), medium (501-100 μm), and small (smaller than 100 μm).

In this study, tapioca starch was used as an adhesive material to make the CPs and RHs binding together. The starch binder for each briquette is fixed at 40% of briquettes mass.



*CPs:RHs = 90:10; 70:30; 50:50; 30:70; and 10:90

Fig. 1. Illustration of experimental methods.

2.2. Briquette making process

The briquettes of each particle size variation were prepared with ratio of carbon CPs:RHs = 90:10; 70:30; 50:50; 30:70; and 10:90. The experiment was conducted once by making 3 briquettes for each ratio of carbon CPs: RHs, so that the total briquettes we made were 45 briquettes.

Figure 1 shows the illustration of experimental method. To get a clear ratio of the mass carbon, binder, and water, briquette in this study was made differently. 10 g of carbon RHs and CPs was weighed in a predetermined ratio and then mixed into a bowl. 4 g of tapioca starch was added to the bowl. 15 mL of boiling water was then poured into the bowl. The mixture was then stirred until the dough formed. The briquette dough was then put into the mold (round, D= 2.7 cm) and pressed with an average pressure of 25.43 N/cm.

2.3. Determination of briquettes properties

We desired briquettes that were dense, strong, waterproof, low moisture, long burning times, and high heating value. We did some briquette property tests to check the briquette quality of the CPs and RHs we made. The properties that are checked include Density, Percentage Moisture Content, Water Boiling Test, Water Resistance Index, Durability Index, and Steam Engine Alternative Energy.

2.3.1. Density

The compressed density (*CD*), relaxed density (*RD*) and relaxation ratio (*RR*) were determined by Eq. (1), (2), and (3) respectively [12].

$$CD = \frac{W_c}{V_c} \tag{1}$$

where W_c is the weight of wet briquette (g) and V_c is the volume of the wet briquette (cm^3).

$$RD = \frac{W_d}{V_d} \tag{2}$$

where W_d is the weight of dry briquette (g) and V_d is the volume of dry briquette (cm^3).

$$RR = \frac{CD}{RD} \tag{3}$$

2.3.2. Percentage moisture content

To determine PMC, the initial mass of briquettes (D) and the sun-dried briquettes (E) was measured [13]. The PMC was determined by Eq. (4)

$$PMC = \frac{D-E}{D} \times 100 \tag{4}$$

2.3.3. Water boiling test

The water boiling test is done by burning the briquettes on the stove. The burning briquettes used to heat 100 mL of distilled water. The increases in water temperature were recorded by thermometer. The burning rate and specific fuel consumption were also determined during this water boiling test.

The burning rate (BR; g/min) is the ratio of the mass lost when briquettes combusted in air to the total time used. The specific fuel consumption (SFC; g/mL) is the ratio of the briquette mass burned with the amount of water to boil [14]. The BR and SFC were calculated use Eq. (5) and (6)

$$BR = \frac{Q_1 - Q_2}{T} \tag{5}$$

$$SFC = \frac{Q_1 - Q_2}{QW} \tag{6}$$

where Q1 is the initial briquette weight (g), Q2 is the final, briquette weight after burning (g), T is the total burning time (min). and QW is the quantity of boiling water (mL).

2.3.4. Water-resistance index

To conduct the water-resistance index (WRI), the briquette sample was immersed in water at 25°C for the 30s. Changes in briquette mass were then noted [12]. The percentage of WRI can be calculated using Eq. (7) and (8)

$$PWA = \frac{M_2 - M_1}{M_1} \times 100 \tag{7}$$

$$WRI = 100\% - PWA \tag{8}$$

where PWA is the percentage water adsorbed (%), WRI is the water-resistant index (%), M2 is the final mass of briquettes (g), and M1 is the initial mass of briquette (g).

2.3.5. Durability index

To conduct the DI test, the briquette was weighed and then put into a polyethylene bag. The polyethylene bag filled with briquettes then dropped from 2 meters of height onto the solid surface and repeated three times. The weight of the briquettes that are not crushed then recorded [15]. The PDI can be calculated using the Eq. (9):

$$PDI = \frac{W_2}{W_1} \times 100 \tag{9}$$

where W_1 is the weight of briquette before dropping, and W_2 is the weight of briquette after dropping.

2.3.6. Steam engine alternative energy

To perform this analysis, the steam engine was filled with water through one of the exhaust pipes. The briquettes were stored in a specially made kiln (a bowl with a diameter of 4.80 cm and a height of 0.90 cm). Then the briquettes were flooded with 5 mL of methanol. The briquettes that have been flooded with methanol were then placed under the steam engine and then burned. The steam engine run around the basin after the water in the engine was boiled. The steam engine run time was then recorded.

3. Results and Discussion

In the material preparation, we dried the biomass material for three days. Drying the biomass material reduced the moisture content by up to 10-15% [16]. The raw materials were then carbonized. Carbonization of raw biomass increased fix carbon and heating value of biomass briquettes [17].

Figure 2 shows the briquettes we have made. Actually, CPs and RHs can be activated to become natural binders when prevailing the pressure [18], but the higher binder concentration results in the higher quality of the briquettes [19]. So, we added tapioca starch as a binder. The briquettes were prepared by three sizes of carbon particles, and five kinds of combinations of CPs:RHs. For each combination, we made 3 briquettes so that we made a total of 45 briquettes. During the briquette-making process, it was observed that the mixed blend of small CPs and RHs carbon particles becomes very dull. In contrast, when mixing large CPs and RHs carbon particles, the dough formed is very porous. This is because the small carbon particles allow a larger surface area so that more extensive carbon particles bond with the binder.

Fig. 2. The prepared of CPs:RHs briquette.

3.1. Density

The briquettes produced using large (2000-500 μm), medium (501-100 μm), and small (smaller than 100 μm) particle sizes. Figure 3 shows the CD of the briquettes respectively ranged between 0.79 and 1.71; 1.07 and 1.29; and 1.22 and 1.39 g/cm3. The highest CD value (1.39 g/cm3) was found when the small carbon particle size with the ratio of CPs:RHs = 30:70. The lowest CD (0.79 g/cm3) was found when the large carbon particle size with the ratio of CPs:RHs = 10:90. When the ratio of CPs:RHs = 90:10; 70:30; 50:50, and 30:70 the CD increased with the increases of rice husks. But, when the ratio of CPs:RHs = 10:90, CD decreased. It means that carbon from RHs in all sizes are effective for increasing CD, but the optimum CPs and RHs mixture is at a ratio of 70:30. Appropriate with the literature [20], the density of RHs and coir dusk briquettes had higher density values when using higher RHs mixing ratio.

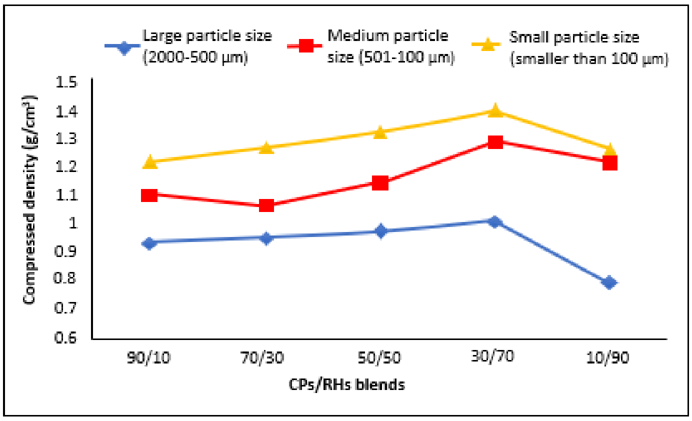


Fig. 3. Compressed density.

Figure 4 shows for all particle sizes, the RD value decreased slightly in the ratio of 70:30. All particle sizes show the optimum RD value at a ratio of 50:50. Then, it followed by the ratios of 30:70 and 10:90. The highest RD value of small particles reaches to 0.75 g/cm3, the medium particle size has optimum RD value at 0.59 g/cm3, whereas the large particle size just has an optimum RD at 0.52 g/cm3. It can be said that the smaller particle size increases the density. In line with the literature [21], the smaller particles for carbon from RHs caused increases in density of briquettes. Smaller particles allow a wider bond between the carbon particles and the binder, and this causes the briquettes to be denser. Meanwhile, larger particles reduce the bonds between particles with binders and other particles, thus making briquettes with large particles very porous.

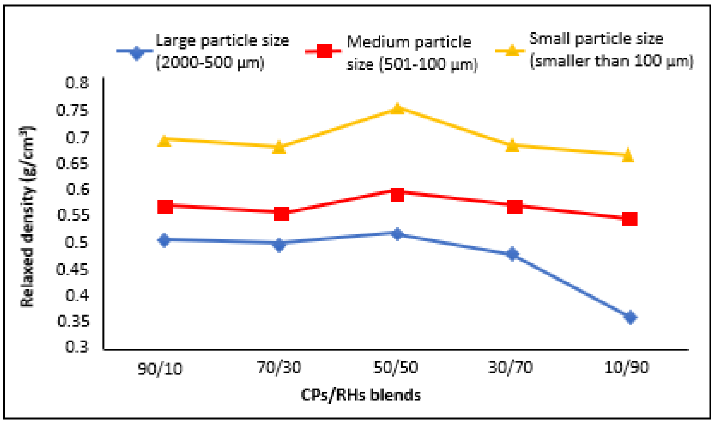


Fig. 4. Relaxed density.

As shown in Fig. 5, the RR of small carbon particles increases with the increases in rice husks of up to an optimum ratio of 30:70. The RR of small particles decreased in the ratio of 10:90. The RR of large particles in the ratio 90:10, 70:30, and 50:50 was about 1.87. Then, it jumped up to 2.11 at the ratio of 30:70. The RR of large particles reaches the highest value at the ratio of 10:90. The medium carbon particles showed the RR in the range of 1.93 for the ratio 90:10, 70:30, and 50:50. Then, it jumped up to 2.26 at the ratio of 30:70. The RR is high at the CPs:RHs ratio of 30:70 for all particle sizes. This means there is less stability of briquettes after ejection from the mold, while small size carbon particles showed a relatively lower RR even lower with the high content of CPs. It is suggested that small particles increased stability of the briquettes after moulding. The trend of decreasing RR in briquettes has been observed by literature [12] who produced briquettes from the blend of saw dusts and CPs. The RR decreased with the increases in CPs content in the briquette. Some studies [22] on briquettes production briquettes from the blend of RHs and palm oil mill sludge show that the RR decrease with the increases in blending ratio of RHs and palm oil mill sludge.

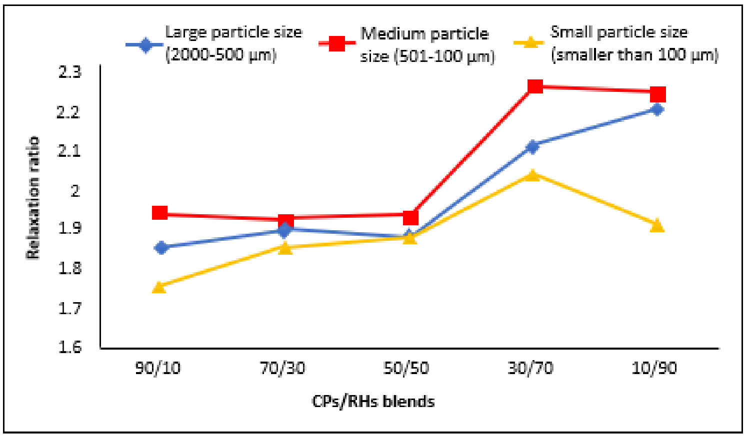


Fig. 5. Relaxation ratio.

3.2. Moisture content

The result of the moisture content (*MC*) shown in Fig. 6. The small carbon particles have lower moisture content. For small size carbon particles, the *MC* decreased with increasing ratio of rice husks of up to optimum at the ratio of 50:50, then *MC* increased at the ratio of 30:70 and 10:90. The lowest MC of the small carbon particles is obtained at the ratio of CPs:RHs 50:50. For the large-sized carbon particles, the *MC* values remained at 50% for the CPs:RHs ratio of 90:10, 70:30 and 50:50. Then at the ratio of 30:70 and 10:90, the *MC* increased to 55%. Medium size carbon in the ratio of 90:10 showed low *MC* value (42%) and it was even less the small- and large-sized carbon particles. But, at ratio of 70:30, the *MC* value for medium carbon particles increased to 57%, and then it fell back to the range of 54% in the ratio of 50:50, 30:70, and 10:90. Moreover, the medium particle has the highest *MC*.

The good briquettes have a low *MC* value. Generally, high levels of RHs or CPs increase the humidity of briquettes. However, if the ratio of CPs:RHs were made to be balance (50:50), the humidity of the briquettes decreased. Especially, for large carbon particles, the additional RHs increased the moisture of the briquettes. It could be caused by large carbon particles from RHs have the characteristics in absorbing high moisture. However, medium carbon particles have the highest *MC* value. The high of *MC* value followed high *RR* of the briquettes. As reported in literature [22], the increase of moisture content from rice husk and palm oil mill sludge briquettes due to increased density of the briquettes.

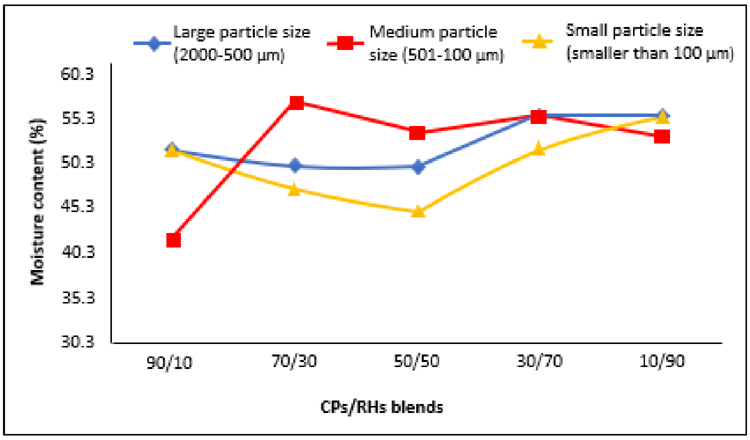


Fig. 6. Moisture content

3.3. Water boiling test

The water boiling test could be used to compare the efficiency of briquettes combustion. Figure 7(a) shows during the combustion, all samples briquettes in this study showed blue fire. Figure 7(b) shows the water boiling test increased the temperature of water from 26 to 70˚C. In this water boiling test, we used methanol to aid ignition to see the effect of methanol on the ignition briquettes. We compared the burning process of briquettes with the burning of methanol alone. The results showed that the burning time of methanol was just only 1.19 min and the water temperature increased to 49˚C.

a. **Burning briquettes on the stove** b. **Boiling water by briquettes**

Fig. 7. Water boiling test process.

Table 1 shows the results of the boiling water test. The longest ignition time for large particle carbon was obtained at the ratio of 50:50. The highest water temperature of large carbon particles increased along with increasing the ratio. The highest water temperature (69˚C) was obtained at the highest content of rice husks (10:90). The medium particles had the longest ignition time at the ratio of 50:50. The highest water temperature was obtained at the ratio of 70:30. The small particles with the ratio of 90:10 and 50:50 was able to raise the water temperature of up to 70˚C in about 4 min. The longest ignition time (4.56 min) was indicated by small carbon particles with the ratio of 10:90.

Table 1. Water boiling test properties.

	Highest water temperature (˚C)	Time to reach the highest temp. (min)	Duration of the temperature stays in highest (min)	Ignition time (min)
Large particle size (2000-500 µm)				
90:10	64	4.00	0.20	3.25
70:30	65	4.25	0.21	3.59
50:50	67	4.16	0.34	4.14
30:70	67	4.06	0.35	4.10
10:90	69	4.15	0.10	3.31
Medium particle size (501-100 µm)				
90:10	66	4.10	0.29	3.47
70:30	67	4.37	0.45	4.09
50:50	66	4.54	0.30	4.48
30:70	63.5	3.50	0.13	3.25
10:90	62	4.51	0.20	3.43
Small particle size (smaller than 100 µm) sizes				
90:10	70	4.37	0.20	3.48
70:30	69	4.48	0.21	3.59
50:50	70	4.28	0.41	4.14
30:70	66	3.58	0.31	3.29
10:90	69	5.09	0.20	4.56

The good briquettes have a long ignition time. They can heat water quickly, and they have high heating values. Generally, for the briquettes with large particles, increasing rice husk resulted in an increase in the heating value. Different from medium particles, the water temperature decreased with the increasing ratio. It could be caused by various factors, such as the combustion conditions during the study, the pressure exerted in making the briquettes, and the condition of the water boiled process. The highest temperature change was 70˚C. The longest ignition time was obtained for small carbon particles, showing that the smaller carbon particles resulted in the increases in the heating value and ignition time. In line with the literature [21], the RHs briquettes from larger particles just burned for 19.25 min while the smallest particles burn until 28 min. Another literature [13] reported the RHs briquette with 1% cassava starch as a binder showed the longest heating time, and the temperature reached 78˚C. That report supported this study that the smaller particles generally showed better properties in burning briquettes. The reports also confirmed that the RHs could increase the heating value of briquettes.

During the water boiling test, we have determined several properties, including the BR and the SFC. The burning rate analysis is shown in Fig. 8. The highest burning rate (0.81 g/min) was obtained by small carbon particles with the ratio of 90/10. The BR of small particles was relatively decreased along with the higher ratio. The medium particle in the ratio of 90:10, 70:30, and 50:50 showed decreases in BR value but then the BR value increased again at the ratio of 30:70 and 10:90. The highest BR value in the medium particle size was obtained in the ratio of 10:90. The lowest burning rate (0.22 g/min) was indicated by the use of large particles with the ratio of 90:10. The highest BR value of large particle size was obtained at the highest ratio of 10:90. The good briquettes have high BR values. The small particles had again shown good performance. The burning rate on small particles decreased along with the decreases in content of CPs, indicating that small carbon of cassava peels could increase the burning rate. The smaller particle size makes the lower porosity. Indeed, the lower porosity inhibits mass transfer because there is less free space for mass diffusion. As a result, the combustion times were longer. As reported by literature [21], the combustion time of briquette increased when using smaller particles. Another literature [5] also reported that briquette from RHs have a higher heating value than that from corn cobs.

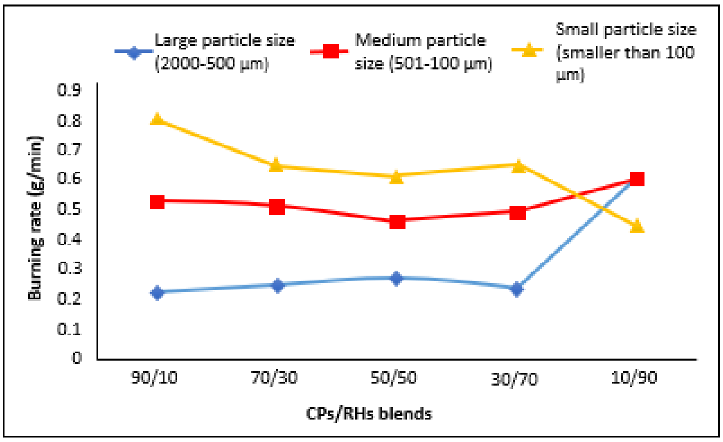


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Fig. 8. Burning rate.

The SFC is presented in Fig. 9. The best characteristics in this parameter was obtained on the small particles in the range of 0.41-0.56 g/mL. The highest SFC was obtained at the ratio of 90:10. For the medium particle, the highest SFC was obtained at the ratio of 10:90. The highest SFC of large particle was obtained at the ratio of 10:90. Thus, a lot of CPs content shows a high SFC value, while for medium and large particles, a lot of RHs showed a high SFC. However, all briquettes in this study show good combustion results.

3.4. Water-resistance index

Figure 10 shows the WRI, the percentage of water content absorbed by the briquettes. The analysis of WRI can be used to determine the response of briquettes when in direct contact with water during the rainy season or high humidity. The WRI ranged from 0 to 52.4%. The highest WRI was observed at medium particles with the ratio of 50:50. It is indicated that the medium size of RHs is highly resistant to water. The WRI of medium particle decreased at the ratio of 30:70 and 10:90. For the small particles, the highest WRI was obtained at the ratio of 90:10. Then, at the ratio of 70:30, 50:50, 30:70, and 10:90, the WRI of small particles fluctuated in the range of 25%.

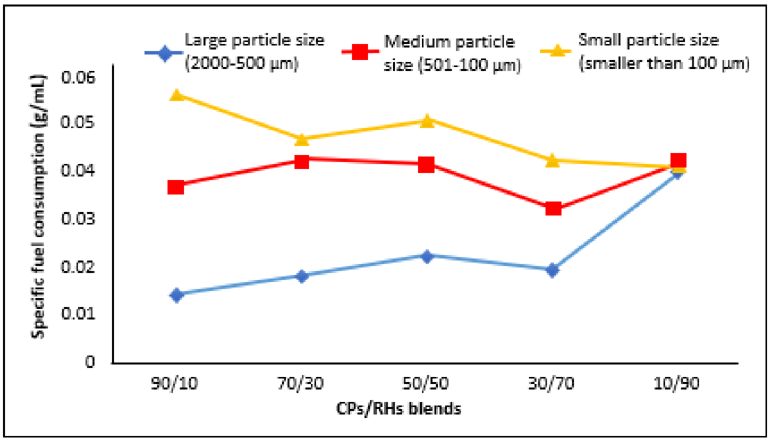

Fig. 9. Specific fuel consumption.

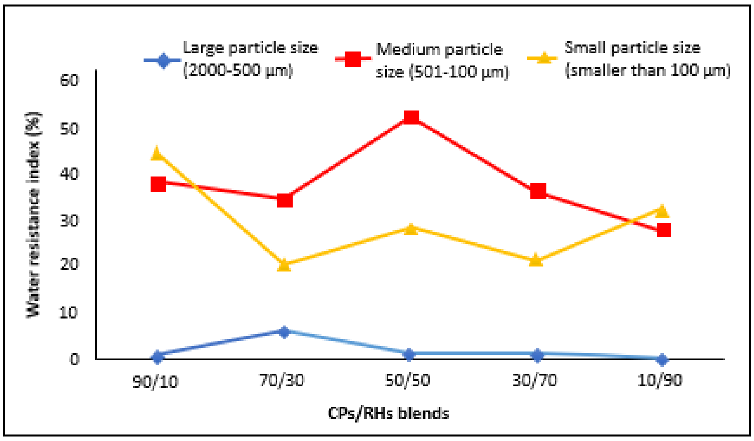

Fig. 10. Water resistant index.

The good briquettes have a high WRI value. While the large particles showed a very low WRI value (below 10%), the lowest WRI was observed at large particle size with the ratio of 10:90. The large particles almost showed no resistance to water penetration because the mass of adsorbed water is near 100%. It could be caused large carbon particles briquettes have many pores. Many pores make water easy to penetrate the briquette. Appropriate with the finding of other reports [23], plantain peels briquettes were also offered no resistance to water because plantain peels are hygroscopic materials. They also noted that the increases in the value of WRI was caused by the low porosity of the briquettes.

3.5. Durability index

Analysis Percentage of Durability index (DI) is useful for determining the strength level of briquettes. DI analysis is important to evaluate the ability of briquettes to remain undamaged when handling during transportation and storage. As shown in Fig. 11, the DI ranged from 82.30 to 99.7%. The large particles had almost the same DI value for all ratios, which was around 98%. But, in the ratio of 10:90, DI less decreased. The highest DI was obtained for small carbon particles with the ratio of 10:90. The medium particles with the ratio of 90:10 showed a low DI value (94.97%). At the ratio of 70:30, medium and small carbon particles showed low DI values (82.30 and 94.31%, respectively) and that are different from the others. At the ratio of 50:50, 30:70 and 10:90, DI of medium particle increased to around 99%.

All briquettes showed the good results for DI values (above 80%), indicating the developed cassava starch as a binder for briquettes allowed better compaction. As reported by literature [24], RHs and coffee husk briquettes using cassava starch as binder had higher drop strength. The medium and small carbon particles showed different DI values at the ratio 70:30. That is extremely low DI value, which could be caused by the lack of pressure during briquette moulding. As reported by literature [24], the strength of the agricultural waste briquettes increased with increasing pressure. The less pressure exerted during briquette moulding could make briquettes less dense. Thus, it created more brittle when dropped. In addition, extremely low DI value could also be caused by the less temperature of the water used when making briquette dough. Less temperature of water used to make the dough is caused by the fact that binder is not active optimally, making the briquettes more brittle.

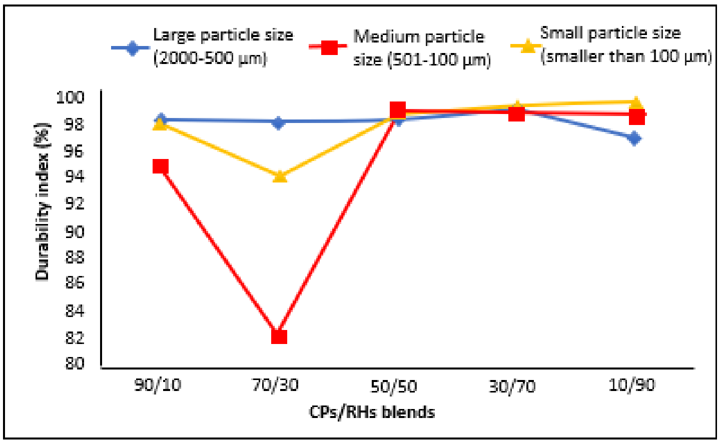

Fig. 11. Durability index.

3.6. Steam engine alternative energy

To analysis the application of briquettes as an alternative energy, we applicated the briquettes as the energy sources for the steam engine in the pop-pop boat as shown in Fig. 12. The working principle of the steam engine in the pop-pop boat is by utilizing a heating source (which can be wax, oil cotton, coal, and briquettes) to boil water in the engine. The boiling water turns into gas, and the gas comes out from one of the exhaust pipes. Thus, it pushes the pop-pop boat forward, while the other exhaust pipe suck water into the engine, and it boiled again by the heating source [25].

Figure 13 shows the steam engine run time ranged from 4.18 to 6.42 min. The higher steam engine run time was obtained at small particles with the ratio of 10:90. For the small particles, the steam engine run time began to rise at the ratio of 30:70 and 10:90. The lowest steam engine run time was obtained at large particles with the ratio of 10:90. Good briquettes can run a steam engine for a long time. However, increases in the RHs resulted increases in the running time of the steam engine. The small particles had the longest time of running the steam engine, indicating smaller particles caused the briquette system to have higher the calorific value. Thus, the steam engine got the good heating process for boiling water in the engine system.

Fig. 12. Steam engine on the pop-pop boat.

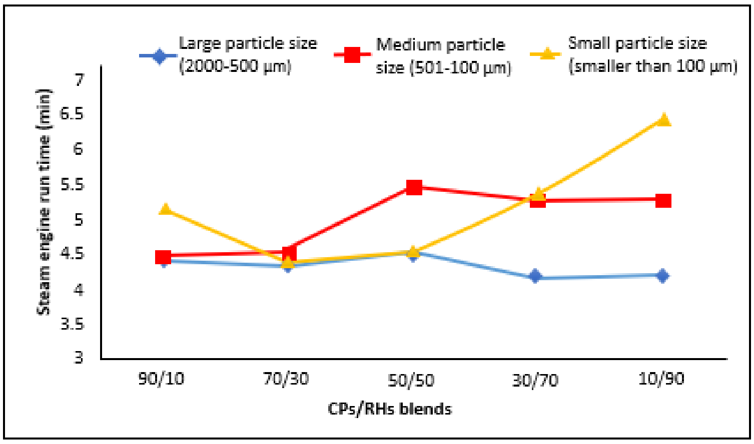

Fig. 13. Steam engine alternative energy.

4. Conclusions

This study investigates the effects of combinations of CPs and RHs on the performance of briquettes. CPs and RHs particle sizes used in this study divided into small, medium, and large particles. The tapioca starch was used as a binder. Based on the analysis using various parameters, overall small carbon particles showed good results. The water boiling test, the burning rate, and the specific fuel consumption indicated that the small particle carbon with a CPs:RHs ratio of 90:10 have a good calorific value. Small carbon particles with the ratio of 90:10 also good for the parameters of relaxation ratio. Small carbon particles with the ratio of 50:50 showed good results on the parameters relaxed density and the moisture content. Small carbon particles with the ratio of 10:90 showed good results on the parameter durability index, and the steam engine alternative energy. Meanwhile, small carbon particles with the ratio of 30:70 showed good results on compressed density. However, the properties of briquettes made with small particles in all ratios gave a better performance and potential to be used as one of the renewable energy sources.

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