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EFFECTS OF PARTICLE SIZE AND COMPOSITION OF SAWDUST/CARBON FROM RICE HUSK ON THE BRIQUETTE PERFORMANCE

SRI ANGGRAENI[1], GABRIELA CHELVINA SANTIULY GIRSANG[1], ASEP BAYU DANI NANDIYANTO[1,*], M. ROILD BILAD[2]

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

Abstract

This study investigated effects of particle size and composition of sawdust (SWs) and carbon from rice husk (CRHs) on briquette performance. In the experiments, briquettes with 10, 30, 50, 70, 90% of CRHs and a specific particle size (i.e., 250, 500, 1000, and 2000 μm) were prepared and starch paste was used as binder. To support the analysis, moisture content in wet basis and dry basis, bulk density, compressed density, relaxed density, compressed ratio, relaxation ratio, water resistance capacity, durability index, burning rate, and specific fuel consumption were determined. The experimental results showed that a low concentration of CRHs resulted in high bulk, compressed, relaxed density values, and increases in relaxation ratio of the briquettes. However, a high concentration of CRHs resulted in decreases in compaction ratio, water resistance, durability, and relatively not favourable for briquetting. Cooperative combustion was positively affecting the burning rate and specific fuel consumption in 10, 50, 90% of CRHs briquette under the influence of rapid burning. Finer particle size of briquette resulted in increases in moisture content on a wet basis and compaction ratio. On the other hand, large particle size led to increases in bulk, compressed, relaxed densities, relaxed ratio, moisture content on a dry basis, water resistance, durability, specific fuel consumption, and burning rate. This study demonstrated new information on utilization of agricultural wastes as a renewable energy fuel.

Keywords: Briquette, Carbon, Composition, Particle size, Sawdust.

1. Introduction

Sawdust is one of the most promising materials to be used as cooking fuels due to their abundant availability as a wood industrial waste [1]. However, raw sawdust is bulky and dirty as well as having uncontrollable burning, excess smoke production, and difficulties in handling and storing [2, 3]. To resolve such issues, raw sawdust must be densified into fuel briquettes, providing a relatively high-quality alternative source of fuel [2, 3].

Briquettes from agricultural waste have received considerable interest because of their potential to utilize low-grade combustible material. In addition to sawdust, many studies have reported the utilization of biomass as briquettes such as corn cobs [4], rice husk [5], wastepaper [6], tea waste [7], olive mill waste [8], and cotton stalk [9].

To improve the quality of briquettes, biomass is typically blended with other materials with high fixed carbon content such as coal and lignite. Recent studied has reported that combination of coal and biomass increased the burning properties. The existence of cooperative combustion between the coal and biomass is the main reason [10]. The coal-biomass briquettes also showed favourable ignitability, better thermal efficiency, and less dust. One of the types of coals is lignite. Lignite-biomass briquettes have good performances in shatter index, water resistance, compressive strength, and mechanical strength [11].

Although studies on combining coal and biomass have been well-documented, the coal itself is a non-renewable energy, creating issues when using for long and scaling up process. Thus, finding an alternative material to coal is inevitable.

Utilization of carbon from biomass waste in briquettes in order to increase the fixed carbon content is one of the excellent alternative materials. However, the study on this material has not been well-reported. In fact, biomass has been well-known as an abundant source for carbon. Carbonization of biomass has been reported as an effective way for increasing fixed carbon and heating value. Further, inexpensive and abundant biomass is largely available.

One of the preferred carbon materials is rice husk. Rice husk has excellent biochemical and physicochemical properties, making it suitable material for carbon source [12] and possessing it in wide range of applications, such as an activated carbon [13], an adsorbent [14], a supercapacitor [15], an electrode [16], and a gas storage component [17]. Indeed, additional rice husk in biomass briquette could increase the fixed carbon content. Therefore, the purpose of this study was to evaluate the effects of particle size and composition of sawdust (SWs)/carbon from rice husk (CRHs) on the briquette performance.

In this study, SWs were blended with CRHs. The briquettes were mixed using a starch paste as the binder. The briquette parameters were determined such as the moisture content in wet basis and dry basis, the bulk density, the compressed density, the relaxed density, the compressed ratio, the relaxation ratio, the Water Resistance Capacity (WRC), and the durability index. Water boiling test was also conducted to determine burning rate and specific fuel consumption of prepared briquettes. Results from this study demonstrated new information on utilization of agricultural wastes as a renewable energy fuel.

2. Method

2.1. Material preparation, binder, and mixing

Figure 1 shows illustration of experimental methods conducted in this study. Sawdust (SWs) and carbon from rice husk (CRHs) were purchased from local markets in Bandung, Indonesia. To investigate the role of particle size, SWs and CRHs were saw-milled, sieved to get a specific particle size (i.e., 250, 500, 1000, and 2000 μm), and blended together.

In this study, two parameters were varied. The first variation is the particle size (using the ratio of SWs and CHRs of 50:50). The second variation is the composition (using a particle size of 1000 μm). The 1000 μm particles were selected since the size relatively was the highest fraction in the particle.

To make the SWs and CRHs binding together, adhesive material from a starch paste was used. The starch paste was prepared by mixing 10% of starch in boiling water. For getting the best briquettes, 39 g of starch paste was added for 20 g of SWs/CRHs mixtures.

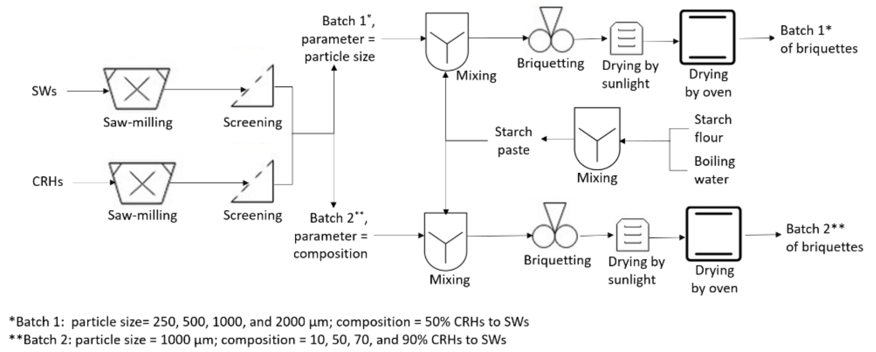

Fig. 1. Illustration of experimental method.

2.2. Briquetting and drying process

The briquetting process were carried out by mixing thoroughly and moulding (pressing for 60 seconds under 36 N/cm^2 pressure into cylinder mould). The dimension of the prepared briquette was 3 and 1 cm for diameter and height, respectively. The moulded briquettes were dried naturally (by sunlight) until it gets constant weight. Thereafter, prepared briquettes were placed in an electrical furnace at 150°C until constant weight was achieved.

2.3. Percentage moisture content on wet and dry basis

The briquettes percentage moisture content was determined on wet (PMC_W) and dry basis (PMC_D). To determine PMC_W (%), the weights of the initial (D) and sun-dried briquettes (E) [18]. The PMC_W (%) was measured using Eq. (1) [19]:

$$PMC_w = 100\frac{D-E}{D} \tag{1}$$

PMC_D (%) was determined by adding calculation of electrical heated briquettes (F), which was expressed in Eq. (2) [19].

$$PMC_D = 100\frac{E-F}{E} \tag{2}$$

2.4. Bulk, compressed, and relaxed density

The bulk density (*BD*) of the prepared blends was determined by filling an empty container (28.26 cm^3) with the sample. The material was tapped slightly to avoid large void spaces. The *BD* (kg/m^3) then calculated by Eq. (3) [20].

$$BD = \frac{W2 - W1}{V} \tag{3}$$

where *W1* is the empty container weight (kg), *W2* is the container and sample weight (kg), and *V* is the container volume (m^3). The compressed density (*CD*; kg/m^3) and relaxed density (*RD*; kg/m^3) were determined by Eqs. (4) and (5), respectively [20].

$$CD = \frac{m_w}{V_w} \tag{4}$$

where m_w and V_w represent the mass (kg) and the volume (m^3) of the as-prepared briquette, respectively.

$$RD = \frac{m_D}{V_D} \tag{5}$$

where m_D and V_D were the mass (kg) and volume (m^3) of the briquette after leaving it for 30 days.

2.5. Compressed ratio and relaxation ratio

Compaction ratio (*CR*) and relaxation ratio (*RR*) were measured using Eqs. (6) and (7) [20]:

$$CR = \frac{CD}{BD} \tag{6}$$

$$RR = \frac{CD}{RD} \tag{7}$$

where *CD* is the compressed density (kg/m^3).

2.6. Durability index

The durability index test was done by putting the briquette in polythene bag and dropping them from 1.50 m for 50 times onto concrete floor and the weight loss was documented. The durability index (*DI*) of the briquette was expressed as Eq. (8) [21].

$$DI = 100\frac{m_i}{m_f} \tag{8}$$

where m_i is the briquette mass before the test (g) and m_f is the briquette mass after the test (g).

2.7. Water resistance capacity

To determine water resistance capacity (WRC), the briquette was immersed in water for 2 minutes and the changes in the briquette weight was recorded. WRC was calculated using Eq. (9) [22]:

$$WRC = 100 - 100\frac{m_{iw} - m_{fw}}{m_{iw}} \tag{9}$$

where m_{iw} is the briquette mass before immersed (g), and m_{fw} is the briquette mass after immersed in water (g).

2.8. Water boiling test

Water boiling test was conducted to compare the cooking efficiency of the briquettes by heating water [10]. The prepared briquette was used to heat 50 mL of water (29.5˚C) in beaker glass that was heated on ceramic cantered wire gauze with domestic briquette stove. A thermometer was used to measure the water temperature. During this test, burning rate (*BR*; g/min) and specific fuel consumption (*SFC*; g/mL) of the briquette were determined. *BR* is the ratio of the consumed fuel mass to total time taken whereas *SFC* is the ratio of consumed fuel mass to total volume of boiling water, in which the calculations use Eqs. (10) and (11):

$$BR = \frac{m_{final} - m_{initial}}{t} \tag{10}$$

$$SFC = \frac{m_{final} - m_{initial}}{V_w} \tag{11}$$

where m_{final} is the final briquette mass, $m_{initial}$ is the initial briquette mass (g), t is the total time taken (min), and V_w is the volume of the boiling water (mL). In addition, we monitored and recorded the changes in water temperature every minute for 20 minutes.

3. Results and Discussion

3.1. Effects of particle size in SWs-CRHs briquettes

The photograph image of the prepared briquettes as a function of particle size is shown in Fig. 2. The PMC_W of the prepared briquettes was relatively high due to using starch paste as the binder (Fig. 3). Briquette with finer particles has the highest PMC_W, informing the finer particles absorbed moisture well. The highest PMC_W and the lowest PMC_D were achieved when using briquette with 2000 μm particles, confirming that although finer particles absorbed moisture well, it was easier to remove the moisture by the drying process.

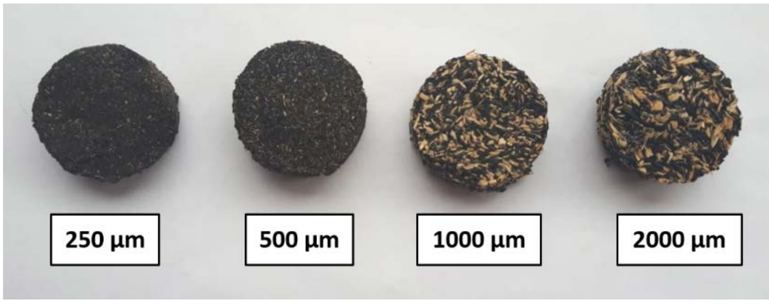

Fig. 2. Sample of prepared briquette.

Figure 4 presents the densities of briquette in all three states (i.e., bulk (*BD*), compressed (*CD*), and relaxed (*RD*)). 250 μm particle briquette has the highest density value. The compressed density was higher than the bulk density for all particle sizes, confirming that SWs and CRHs blends with various particle sizes were favourable for briquetting. Compared to fine particles, there is relatively more differences between *CD* and *BD* for large-particle briquette. This shows that large particles are more favourable for briquetting. Low *RD* of fine-particle briquettes correlated with the PMC_D. The fine-particle briquette experienced a large loss of mass due to the drying process (low PMC_D), therefore making them to have low *RD*.

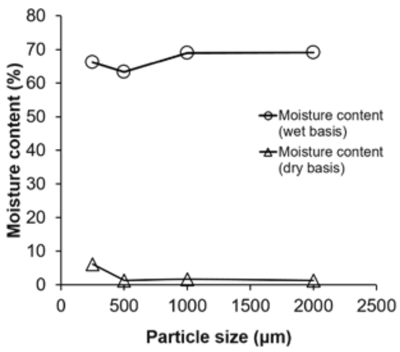

Fig. 3. Moisture content of briquette as a function of particle size.

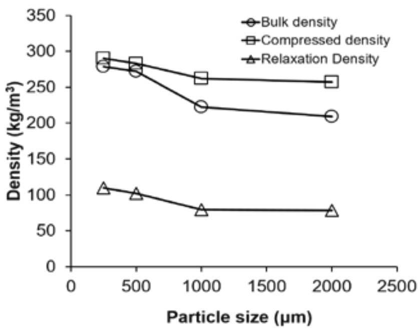

Fig. 4. Bulk, compressed, and relaxation density of briquette as a function of particle size.

As the particle size increased, the *CR* value increased whereas the *RR* value decreased (Figs. 5 and 6). *CR* increased along with the particle size, confirming that large particles were more favourable for briquetting. On the other hand, *RR* decreased along with particle size due to removal of the moisture during the drying process.

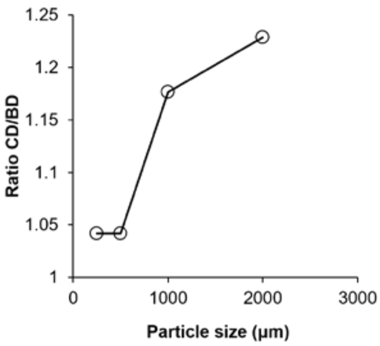

Fig. 5. Compaction ratio vs. particle size.

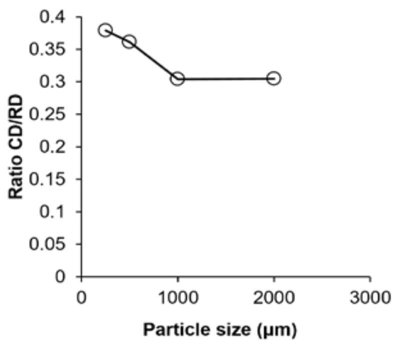

Fig. 6. Relaxation ratio vs. particle size.

As shown in Fig. 7, DI of the briquette decreased along with the particle size, which was because of the mass loss during the test. According to the observation during the test, the edge of fine-particle briquette was more vulnerable to shatter than large-particle briquette. In addition, briquette with finer particles produced more dust and therefore more mass loss compared to that with large particles. Briquette with large particles has poor resistance. The poor water resistance correlated to the porous nature of the large particle briquette (confirmed with the low *CD* value). Therefore, water can penetrate easier. Briquette with 250 μm particle was the most durable and water resistant, whereas briquette with 2000 μm was relatively less durable and not water resistant.

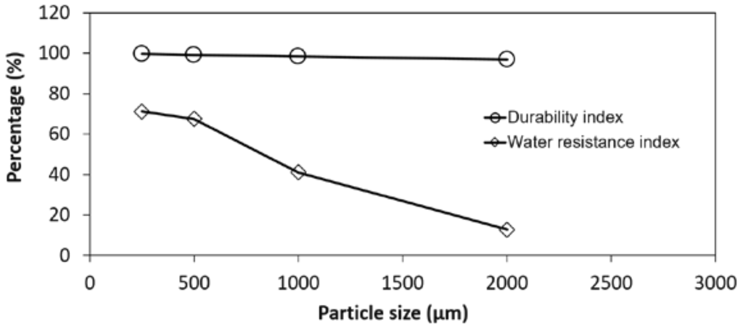

Fig. 7. Durability and water resistance of briquette as a function of particle size.

Burning rate and specific fuel consumption are presented in Figs. 8 and 9. The *BR* and *SFC* values increased along with the particle size, which were due to the porous nature of the large-particle briquette, making it easier for air to circulate (confirmed by low *CD* value). The highest burning rate and specific fuel consumption were achieved by the 1000 μm particle briquette. The results showed that briquette with particle sizes of larger than 1000 μm replied to have high BR and SFC, which also positively affected the heating process.

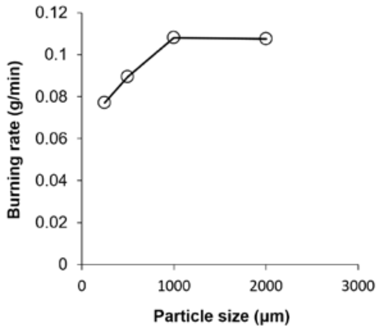

Fig. 8. Burning rate vs particle size.

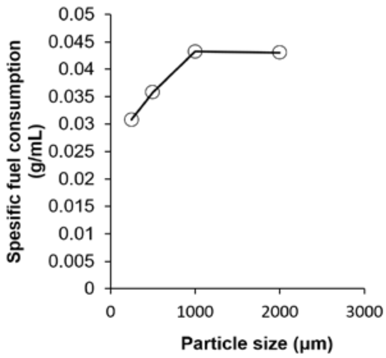

Fig. 9. Specific fuel consumption vs. particle size.

The briquette was used for heating water, and the changes in the temperature of the water were plotted for 20 minutes (Fig. 10). The highest changes in water temperature were achieved by briquette with 2000 μm particles, which were due to rapid combustion. Rapid burning of large-particle briquette could occur due to porosity. Large particle briquettes were not as compacted as fine-particle briquettes (confirmed by low *CD* value), making them more porous. Pores contributed to the obtainment of better air flow inside briquette, resulting in a high rate of combustion.

After ignition, the orange flame was produced by large-particle briquette, whereas the small blue flame was produced by fine-particle briquette. This result corresponds to the changes in water temperature. There are large differences in water temperature during 3-10 min for briquettes with 2000 and 1000 μm particles, which were due to rapid combustion, making it unstable for heating. Briquette with 250 μm particles was more stable for heating in the range of 0-20 minutes compared to that with 1000 and 2000 μm particles (although the final temperature was lower). For heating and cooking purposes, briquette with 250 μm particle was preferable.

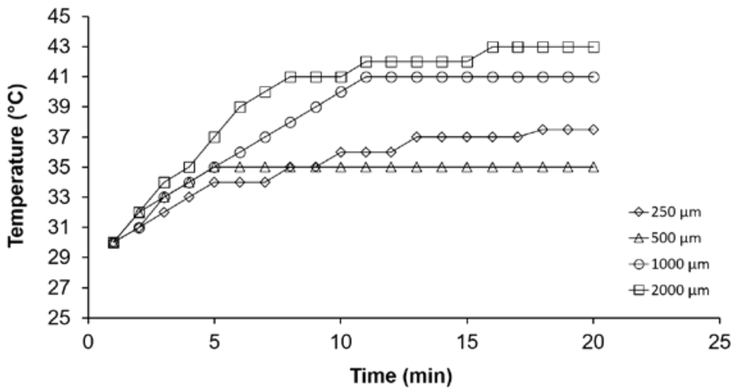

Fig. 10. The changes in water temperature during water boiling test for briquettes as a function of particle size.

3.2. Effects of particle size in SWs-CRHs briquettes

The photograph images of prepared briquettes as a function of SWs and CRHs composition are shown in Fig. 11. The PMC_W of the prepared briquettes was relatively high due to using starch paste as the binder (Fig. 12). As explained in Section 3.1, the sun-drying process was inefficient to remove moisture in the core of the briquettes, therefore drying in an electrical furnace is a mandatory. Low moisture content means more favourable combustion and ignitability. However, there was no significant effects of composition in moisture content. Briquettes with 50% of CRHs have the highest PMC_W and the lowest PMC_D compared to other ratios. The briquette with CRHs-SWs blends had different properties compared to that with CRHs and SWs only. CRHs tend to absorb water in comparison to SWs (confirmed by water resistance value). This is in line with the hypothesis, in which the trend should bright positively impacts for PMC_w and negative for PMC_D. However, since there are exceptions in the results, CRHs-SWs blends gave different moisture content properties compared to its originated material.

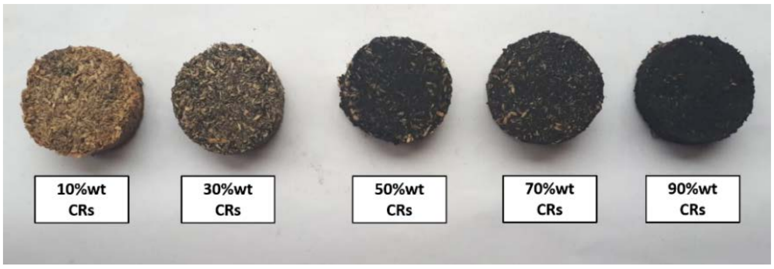

Fig. 11. Sample of prepared briquettes.

The concentration of *CR* in briquettes affected the density of the briquette (Fig. 13). The *BD*, *CD*, and *RD* values increased with increasing concentration of CRHs in briquette. Briquette with 90% of CRHs has the highest density in bulk, compressed, and relaxed state, whereas briquette with 10% of CRHs was the lowest. The *CD* was higher than the *BD* in all compositions, meaning that the mixtures of SWs and CRHs were favourable for briquetting. The differences between *BD* and *CD* values were found when the concentration of CRHs was high. This shows that CRHs were denser than SWs. Therefore, there were fewer changes between loose and compact states. Similar results were obtained in reference [23] that biomass such as CRHs was much less dense compared to high fixed carbon material such as coal. However, there were relatively high-density difference between compressed and relaxed state due to moisture removal during the drying process.

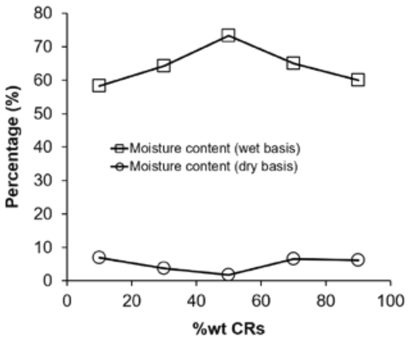

Fig. 12. Moisture content of briquette as a function of CRHs/SWs composition.

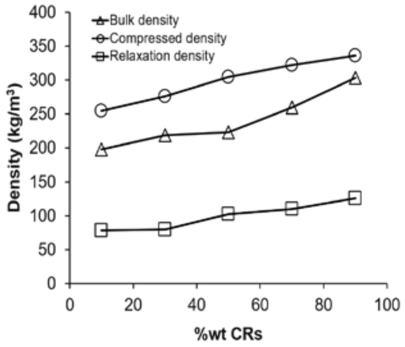

Fig. 13. Bulk, compressed, and relaxation density of briquette as a function of CRHs/SWs composition.

The *CR* decreased and the *RR* increased along with CRHs concentration (Figs. 14 and 15). The dense nature of CRHs is the main reason. Briquette with 50% of CRHs has the highest *CR* whereas briquette with 90% of CRHs was the lowest. On the other hand, briquette with 90% of CRHs has the highest *RR* whereas briquette with 10% of CRHs was the lowest.

The concentration of CRHs also affected the DI value as shown in Fig. 16. The increases in the concentration of CRHs affected decreases in the DI, as confirmed by the evaluation of briquette with 50, 70, and 90% of CRHs. However, high concentration of SWs (10 and 30% of CRHs) made the briquette less durable. Briquette with 30% of CRHs was the least durability value whereas 50% of CRHs briquette was the most durable. As a result, the blending of SWs and CRHs with a specific composition (30% of CRHs) improved the durability of the briquette, making it great for handling and storage. The briquette with high CRHs concentration was not water resistant. This has shown that CRHs tend to absorb water in comparison to SWs. Briquette with 90% of CRHs was not water resistant whereas briquette with 30% CRHs was the most resistant.

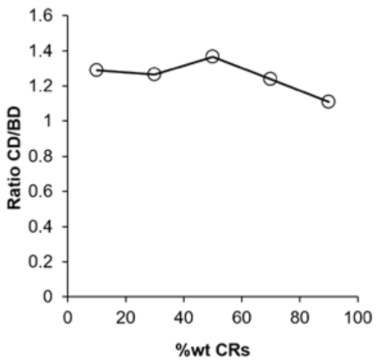

Fig. 14. Compaction ratio as a function of CRHs/SWs composition.

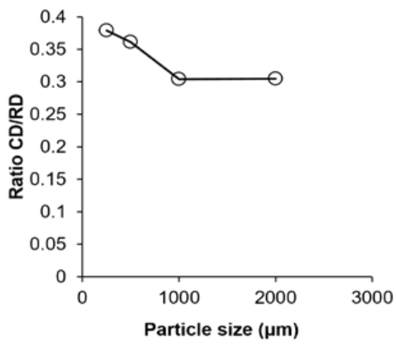

Fig. 15. Relaxation ratio as a function of CRHs/SWs composition.

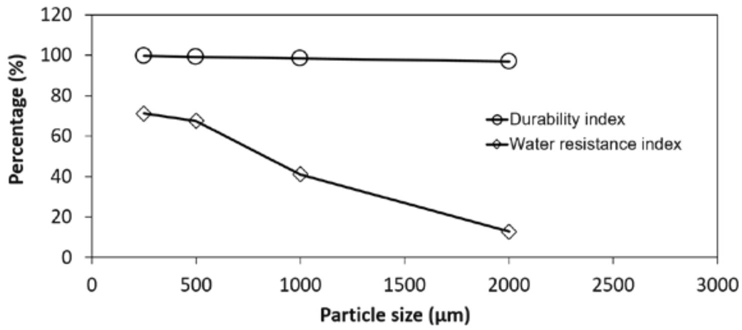

Fig. 16. Durability and water resistance of briquette as a function of CRHs/SWs composition.

The concentration of CRHs in briquette also affected the *BR* and the *SFC* values (Figs. 17 and 18). With increasing concentration of CRHs, the *BR* and the *SFC* value relatively decreased. However, there are exceptions in the result when using 30 and 70% of CRHs, in which this is due to cooperative combustion trends.

Cooperative combustion usually happened in briquette with heterogeneous materials. The same phenomenon also occurred in coal-biomass briquette [24]. Cooperative combustion in the prepared briquette occurred because of the combustion between two materials: SWs and CRHs. The combustion properties between SWs and CRHs were vastly different. Biomass combustion has undergone two processes: (i) volatile combustion and release; and (ii) carbon combustion. Carbon combustion has taken up only one process [25]. The SWs-CRHs briquette has undergone three combustion processes or tends to undergo a biomass or carbon combustion process, depending on the composition of the SWs-CRHs.

Briquette with 30 and 70% of CRHs have low *BR* and *SFC* values, meaning that they were not favourable for co-combustion. On the other hand, briquette with 10, 50, and 90% of CRHs have better results, thus confirming them favourable as co-combustion process.

Among briquettes with 10, 50, and 90% of CRHs, the highest *BR* and *SFC* values was achieved when using 10% of CRHs. The lowest was for 90% of CRHs.

The high *BR* and *SFC* values have responded to high voidage and rapid combustion trends of low CRHs briquette. High voidage (confirmed by low *BD* value) in low CRHs briquette resulted in better air flow, thus encouraging rapid combustion. Rapid combustion occurred due to high concentration of SWs and a major mass loss during combustion. As a result, the burning rate increased. On the other hand, the low *BR* and the *SFC* values were due to the high concentration of CRHs, which was more stable in combustion. Overall, 90% of CRHs briquette allowed combustion properties of carbon whereas 10% of CRHs briquette responded to biomass combustion properties.

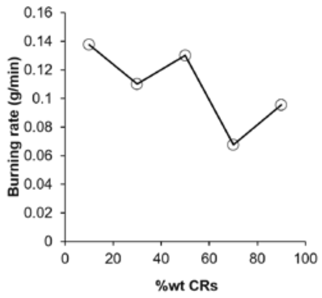

Fig. 17. Burning rate as a function of CRHs/SWs composition.

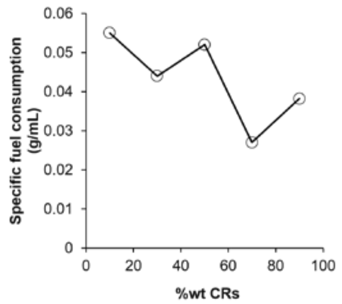

Fig. 18. Specific fuel consumption as a function of CRHs/SWs composition.

The briquette was used for heating water and the changes in water temperature for 20 minutes were plotted (Fig. 19). The highest water temperature was achieved by briquette with 10% of CRHs. Briquette with 10% of CRHs had the relatively high changes in temperature (3-8 min) due to the rapid combustion. Biomass, such as SWs, tends to burn in rapidly burning regions [26]. Orange flame was produced, making a burn or black mark under the wire gauze. On the other hand, the lowest water temperature was achieved by briquette with 90% of CRHs. The changes in water temperature are more stable than the briquette with less CRHs concentration. Orange flame was produced at the beginning, but then it turned into a small blue flame before the briquette began to burn without flame. Thus, briquettes with a low concentration of CRHs could raise a higher water temperature than briquettes with a high concentration of CRHs. However, briquette with high CRHs concentration was more stable for heating and emitted less smoke.

In terms of densities, water resistance, durability index, burning rate and specific fuel consumption values, CRHs-SWs briquette was not suitable for industrial uses. Nevertheless, CRHs-SWs briquette could be used for cooking and domestic heating purposes. Briquette with 50 and 70% of CRHs would be preferable for such purposes because of their high burning rate, stable heating, less emission of smoke, and less possibility of leaving black marks on utensils. Although the change in water temperature when using briquettes with CRHs between 50 and 70% were relatively similar, *SFC* for briquette with 70% of CRHs was the lowest. As a result, briquette with 70% of CRHs were more efficient in heating and less consuming fuel.

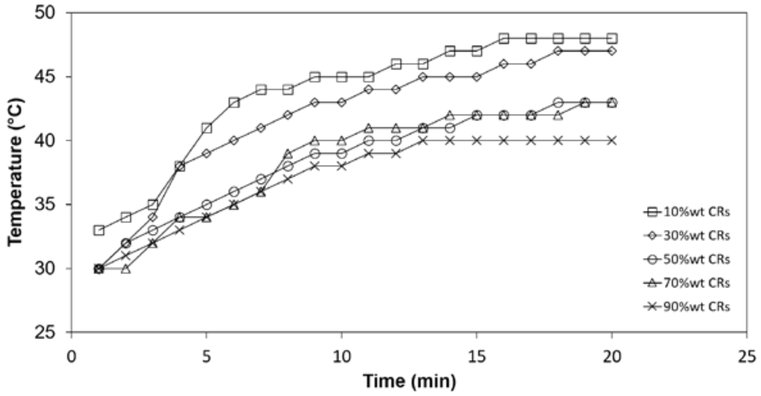

Fig. 19. The changes in water temperature during water boiling test for briquettes as a function of CRHs/SWs composition.

4. Conclusions

In this study, the effects of particle size and composition of SWs and CRHs on briquette performance have been studied. High concentration of CRHs in briquettes resulted in high density (bulk, compressed, and relaxed) and gave impacts on increases in RD. However, a high concentration of CRHs resulted in a decrease in the compaction ratio, water resistance, durability, and relatively unfavourable for briquetting. Cooperative combustion occurred in SWs-CRHs blend briquette. The burning rate and the specific fuel consumption of 10, 50, and 90% of CRHs briquette increased due to co-combustion. On the other hand, the increases in particle size have correlations to the increases in the moisture content on wet basis and the compaction ratio of briquette. However, the increases in particle size have impacts on decreases in density (bulk, compressed, relaxed), relaxation ratio, moisture content on dry basis, water resistance, durability, specific fuel consumption, and burning rate. Briquette of CRHs-SWs blends were not suitable for industrial use, but it is preferable for cooking and residential heating purposes.

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