JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(7), 25–34
https://doi.org/10.12911/22998993/163309
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.04.14
Accepted: 2023.05.14
Published: 2023.05.24

Influence of Sieve Size on Calorific Value and Proximate Properties of Bio-Briquette Composites

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ABSTRACT

This work aimed to observe the influence of calorific value and proximate properties in the fabrication of rice husk (RH) and coffee shell (CS) briquettes composite. Rice and coffee husks contain cellulose, hemicellulose, and lignin. These contents are necessary for the adhesive to bind the briquette (amylose and amylopectin). The raw materials were carbonized at 400 °C for 60 minutes. Variations of sieving size (60, 80, and 100 mesh) and the composition ratio of raw material CS:RH were reviewed to study their effect. Tests of density, moisture content, volatile matter content, ash content, fixed carbon content, shatter index, combustion rate, and calorific value were carried out to determine the optimum composition. The results were obtained with the best quality at a particle size of 60 mesh with the highest calorific value of 17.422 MJ/kg. It showed that the briquettes have good quality and are comparable with the standard briquette.

Keywords: bio-briquette, rice husk, coffee shell, calorific value, fixed carbon.

INTRODUCTION

Coal is one of the energy sources used as fuel and power plants (Li, 2021). Generally, coal was utilized as a fuel in the form of briquettes. This fuel has a dangerous side effect, namely sulphur and oxide of nitrogen from sufficient combustion. So it causes air pollution and pollutes the surrounding environment (Kumar et al., 2021; Afsal et al., 2020). It can be demonstrated that coal generated more than 40% of the overall increase in world CO2 emissions in 2021 by 15.3 billion tons (Agency, 2021). Therefore, researchers are trying to reduce the use of coal by making alternative energy that utilizes biomass with almost the same quality as coal briquettes (de Araújo Drago et al., 2023), such as research conducted by ref. (Espuelas et al., 2020) with coffee powder waste materials, ref. (Wang et al., 2020) with sawdust materials, China fir wood, and durian skin (Wirabuana & Alwi, 2021).

Coffee shell and rice husk waste are two of the biomass materials not yet to be used optimally. The waste generated from coffee production is only used as organic fertilizer without being processed optimally. The benefits of coffee rind include a high calorific value, a high moisture content of 75-80%, and a low sulphur level. The coffee rind contains 10.78% crude protein, 33.13% crude fibre, 24.67% lignin, and 20.22% cellulose (Harsono et al., 2022).

Rice husk is the hard layer that covers rice grain obtained after milling. Based on the Central Statistics Agency of West Java in 2020, the rice harvested area in West Java is 1,587 hectares, with rice production of 9,017 million tons of dry milled grain (Badan Pusat Statistik, 2021). The rice husk has advantages like good biochemical and physicochemical properties, which are suitable carbon sources. Some application of rice husk-base carbon is activated carbon (Nayak & Datta, 2023), adsorbents (Mortada et al., 2023), supercapacitors (Liu et al., 2023), and electrodes (Daulay & Gea, 2022). Rice husk has an ash content of 18–29%, moisture content of 6.0–10.0%, carbon content of 35.0–42.0%, lignocellulose and cellulose content of 40%, 5% hemicellulose as a sugar polymer material and a remaining five carbon content of silica, alkali minerals, etc. (Saeed et al., 2021). Therefore, it is necessary to use coffee husks and rice husks as alternative fuel sources. The excess coffee and rice husk waste contain cellulose and lignin, which are needed to manufacture briquettes (Sugebo, 2022; Lubwama & Yiga, 2018).

Briquette production necessitates the inclusion of a binder to keep the briquettes together during briquette creation and burning. They are strong bond, pollution free, do not affect heat release, flammable, minimal smoke, odourless, toxic and dangerous, environmentally friendly, and economically available (Zhang et al., 2018). Tapioca flour has good starch quality, around 70–75%. The nature of starch owned by starch is that it has high binding power at high temperatures and can be in the form of an amylopectin paste that looks clear.

Other researchers improved the quality of briquettes by modifying specific parameters, as Setter et al. (2020) analysed the effect of particle size on coffee husk briquettes. The lack of technique from coffee husk briquettes with the pyrolysis method produces high levels of volatile matter. Lubwama & Yiga (2018) analysed the effect of adhesive variations on coffee husk briquettes and rice husk deficiencies with the addition of cassava flour adhesive caused a decrease in the quality of briquettes. Saeed et al. (2021) analysed the moisture content of rice husk-based briquettes. Therefore, in this work, we studied the effect of particle size on bio-briquette composite based on rice husk and coffee shell. Characterizations such as moisture content, volatile matter, ash content, fixed carbon, combustion rate, density, and calorific value were conducted and discussed. The results give new information regarding the briquette parameter based on the rice husk-coffee shell composite.

MATERIALS AND METHOD

Briquetting

Bio-briquette was made from a mixture of rice husk (RH) and coffee shell (CS) from a region in Indonesia. The starch was used as a binder to bind powder purchased from the market. RH and CS raw materials were dried in an oven at 100 °C for 60 minutes. The dried materials were then carbonized in the furnace at 400 °C for 60 minutes. This means making the activated carbon will reduce the CO_2 emission contained in the bio-briquette. Afterward, the activated carbon was ground until smooth, then sieved with various mesh sizes, 100 mesh (149 µm), 80 mesh (177 µm), and 60 mesh (250 µm). RH and CS carbon were mixed with different ratios of 0:100, 75:25, 50:50, and 100:0. The carbon mixture was then mixed with a binder until homogeneous. The wet mixtures were compacted under a pressure of 4.4 tons. Then we have the bio-briquette after drying them at 100 °C for 60 minutes. An illustration of experimental procedures is shown in Figure 1.

Proximate analysis

Measurement of density was conducted by measuring the mass and volume of the bio-briquette based on the ASTM D 2395 standard. The moisture content was measured with the ASTM–1959 standard by comparing water content with the dry weight of the bio-briquette. The volatile matter was measured with the ASTM-D3195 standard, which fired the briquette at the temperature of 900 °C for six minutes. The ash content test was performed by heating the sample to 600 °C for 2 hours (ASTMN D – 1762-84). The fixed carbon is the briquettes' carbon fraction, excluding moisture, volatile matter, and ash content. The shatter index test is carried out with the ASTM D-440 standard, where the sample is dropped from a height of 1.8 meters after the initial mass of the briquettes is recorded.

Combustion rate

Testing the combustion rate is conducted by observing changes in the mass of the briquettes while burning them. The briquette mass before being burned becomes the initial mass m_i. The briquettes are given a breeze using a portable fan with a distance of ~15–20 cm. Observations were

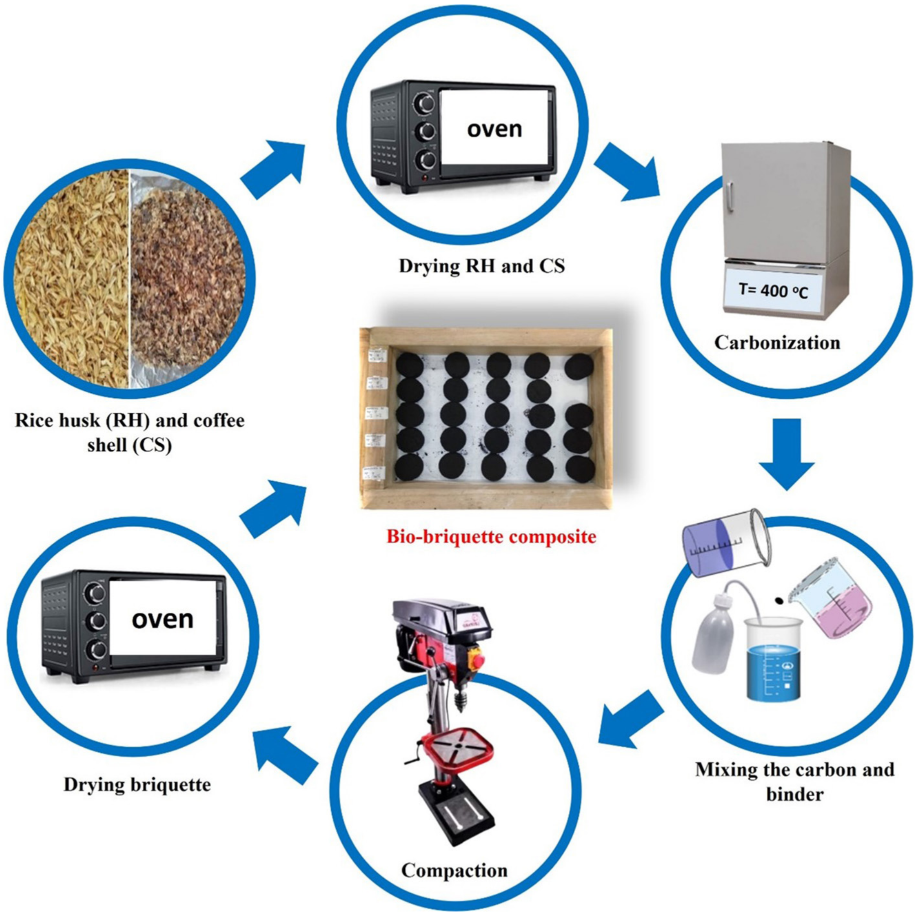

Figure 1. Briquetting procedure

made for 5 minutes. The mass after burning is the final mass m_f, and t is the time needed to burn the sample from the beginning to the end of measurement. To get the value of the rate of burning briquettes can be calculated using Eq. 1.

$$combustion\,rate = \frac{m_i - m_f}{t} \quad (1)$$

RESULTS AND DISCUSSION

Density is a physical property that is the ratio between the mass of the briquette and its volume. The density size is influenced by the particle size and the homogeneity of the charcoal making up the briquettes. For briquettes with a significant density value, the combustion rate produced from charcoal briquettes will be greater and vice versa (Aliah et al., 2023). The bulk density of lignocellulosic in coffee husks may be improved by lowering particle size, which improves material durability owing to increased particle contact area (Setter et al., 2021). Figure 2 shows the resulting density of various compositions between CS and RH. The use of different particle sizes of 250 μm, 177 μm, and 149 μm showed that the variation in particle size affected the density of the briquettes. The highest density occurred at 149 μm particle size, 662.81 kg/m^3, and the lowest density at a particle size of 177 μm of 570.44 kg/m^3.

The density of briquettes increased as the particle size got smaller. The smaller particle size caused the briquettes to be more compact, and the cavities contained in the briquettes will be smaller so that the oxygen entering the briquettes will be difficult to diffuse. Then it will lead to longer burning times (Setter et al., 2021).

Variations in composition with a mixture of more coffee husks will get a high-density value compared to a mix of rice husks for all variations in particle size. This is because rice husks' density is lower than coffee husks. Another factor that causes density values between different compositions is the volume between briquettes is different because of the pressure applied during the briquette moulding process (Lubwama et al., 2020). These results are supported by research (Aliah et al., 2023).

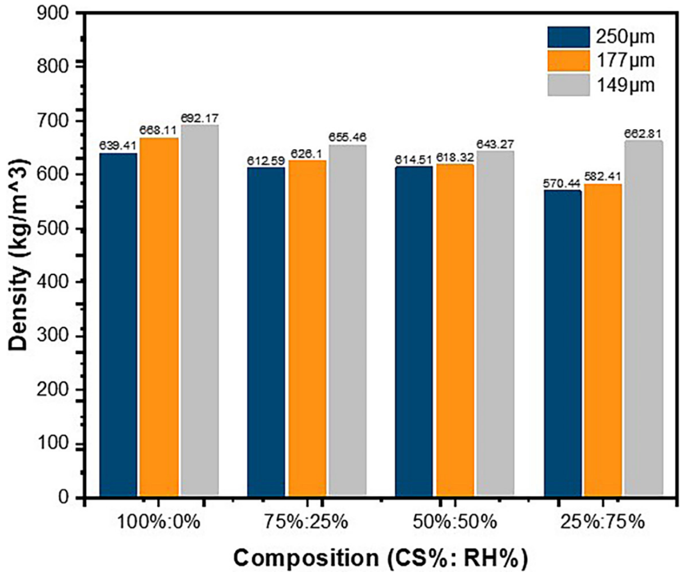

Figure 2. Density versus composition with different particle sizes

The moisture content of the briquette mixture of coffee and rice husk is by the quality standard of briquettes according to SNI 01-6235-2000. Low moisture content will reduce energy consumption because the excessive moisture content would lower the briquettes' calorific value. The water content of briquettes tends to increase when the particle size gets smaller (see Fig. 3). This is because when the particle size is larger, the water absorption process will be less than the small particle size. The decrease in moisture content in briquettes is caused by the level of water released in the furnace during testing, which is then to make direct contact with hygroscopic elements with the air. So that it will absorb much water vapor. When the material used for briquettes has a higher moisture content, it will cause the briquettes expansion due to higher residual stress causing elasticity (Saeed et al., 2021).

The volatile matter content indicated the quantity of mass loss. Because briquettes containing highly volatile matter tend to emit a lot of smoke, the lower the briquettes' volatile matter concentration, the higher their quality (Kaliyan & Morey, 2009; Karunanithy et al., 2012). Figure 4 shows the quantity between the volatile matter content against a ratio of CS: RH for all variations. The level of volatile matter produced tends to rise and fall. It can be seen from the results obtained that the smaller the particle size will

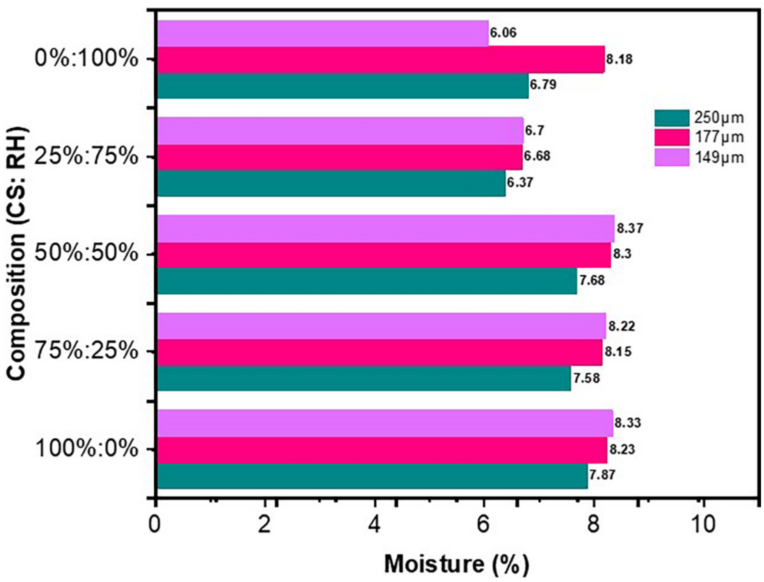

Figure 3. Moisture content against different compositions and particle sizes

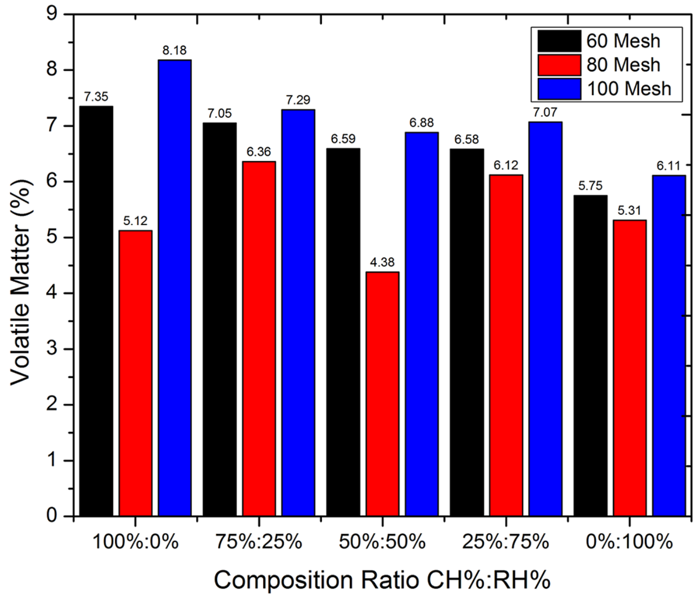

Figure 4. Volatile matter versus composition under different particle sizes

increase the volatile matter content created. Still, the results obtained are a decrease in the volatile matter content at the particle size of 177 μm composition CS: RH 50%:50% at 4.38%. The high volatile matter content is caused by the imperfection of the carbonization process, temperature, and cooking time. The higher the temperature and the longer the carbonization time, the more volatile matter is wasted, so the volatile matter content produced is low.

The ash is a mineral that, after combustion, cannot be burnt (Mitan & Sa'adon, 2019). Ash is part of the rest of the combustion and consists of calcium, magnesium, phosphorus, and silica. The main element that can affect combustion performance is silica. This silica has a negative impact on briquettes' calorific value, which might lower their quality (Deglas & Fransiska, 2020). The quantity of the ash content of briquettes is shown in Figure 5.

The results showed that the value of the ash content decreased when the particle size got smaller. According to the theory, the ash content is influenced by particle size, where a smaller particle size will produce a high ash content and vice versa. This is because briquettes with smaller particle sizes are smoother and denser, so the combustion process is imperfect.

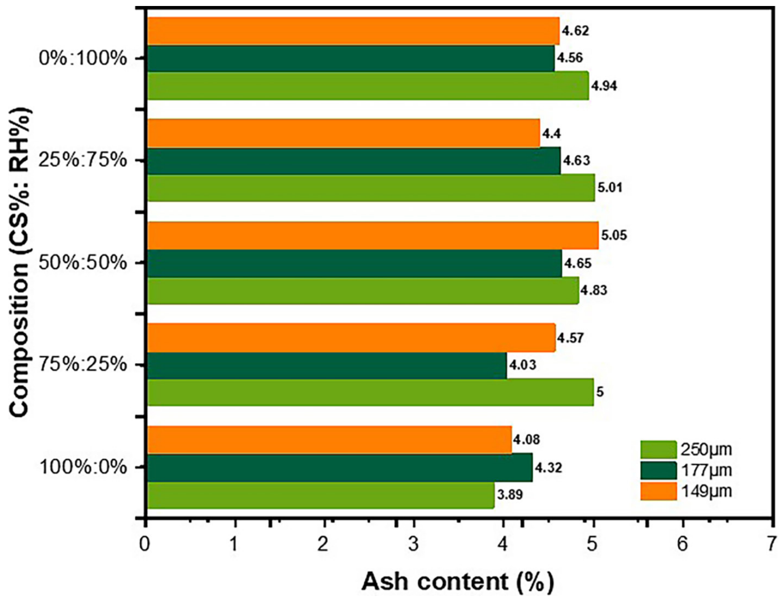

Figure 5. Ash content versus composition

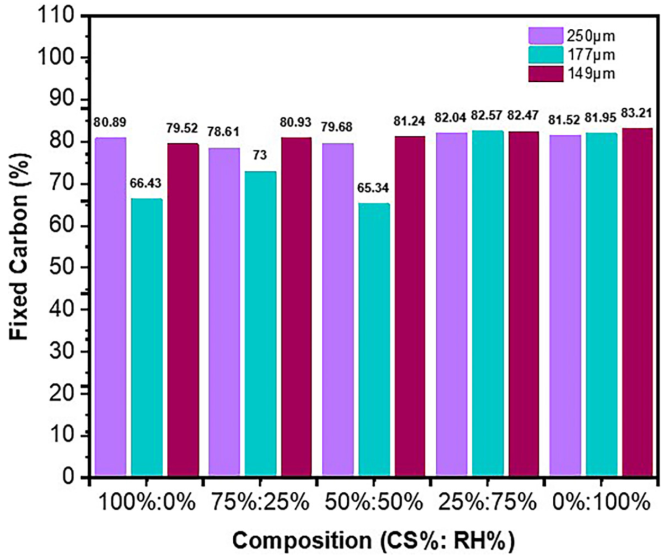

Figure 6. Fixed carbon versus composition under different particle sizes

Meanwhile, briquettes with a larger particle size have a looser particle density. Therefore, the ash content is low. This argument is supported by research conducted by reference (Bhattarai et al., 2016; Lukas et al., 2018). High ash content makes it difficult to utilize since the silica content impacts it. In addition, the inclusion of binder adhesive can also affect the level of ash content because the bond has inorganic components. Zubairu et al. investigated that the ash content depends on the binder concentration. As increasing the binder concentration, the ash content will reduce (Zubairu & Gana, 2014). According to the literature, excellent-grade briquettes should have an ash level of 3–4% (Quartey, 2011). In this work, the ash content is in the range of 3.89–5.05%. Some compositions are slightly higher than the literature even though these mixed briquettes give a promising composition to produce good quality.

Figure 6 revealed the carbon content of bonded briquettes. The highest bonded carbon content was found at 177 μm particle size of 82.57%. The carbon content bonded to the briquettes can be impacted by volatile matter, ash level, and moisture content. If the volatile matter, ash, and moisture contents are low, the carbon content attached to the briquettes will be higher (Felfli et al., 2011). Variations in composition affect the

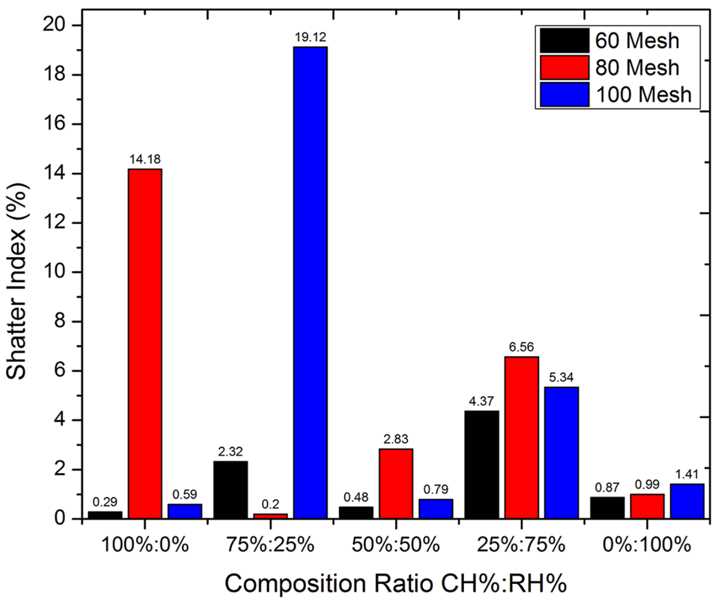

Figure 7. Shatter index versus composition under different particle sizes

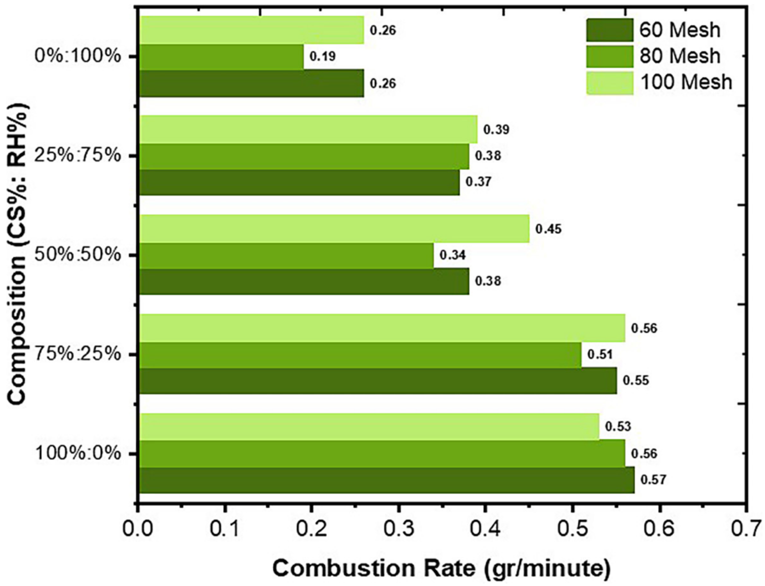

Figure 8. Combustion rate versus composition under different particle sizes

bound carbon content. The greater the rice husk mixture, the higher the bound carbon content compared to the ratio of the coffee husk mixture. This is because the chemical compounds present in rice husks, such as cellulose 48%, hemicellulose 31.6%, and lignin 24.6% are more significant than the coffee husk compounds between cellulose 19–26%, hemicellulose 24–45% and lignin 18–30% (Lubwama & Yiga, 2018).

The shatter index is a physical test on briquettes that measures their durability and may be used to assess their quality. The discharged particle from the briquettes can be measured by dropping a sample from a height of 1.8 meters. Figure 7 shows the results of the shatter index of briquettes. The smaller the particle size of the material with the same percentage of adhesive and the printing treatment results in stronger impact resistance because the smaller particle size will produce smaller cavities. So that the density of the briquettes will be greater. Therefore, they are not easily crushed (Haidar et al., 2022). However, the results obtained were the lowest lost particles at 250 μm particle size. This is caused when the mixing process between charcoal and adhesive is not homogeneous. The higher the quality of the briquettes, the lesser the lost particles.

The combustion rate test is carried out to determine fuel effectiveness. The combustion rate is done by dividing the mass briquettes by the length

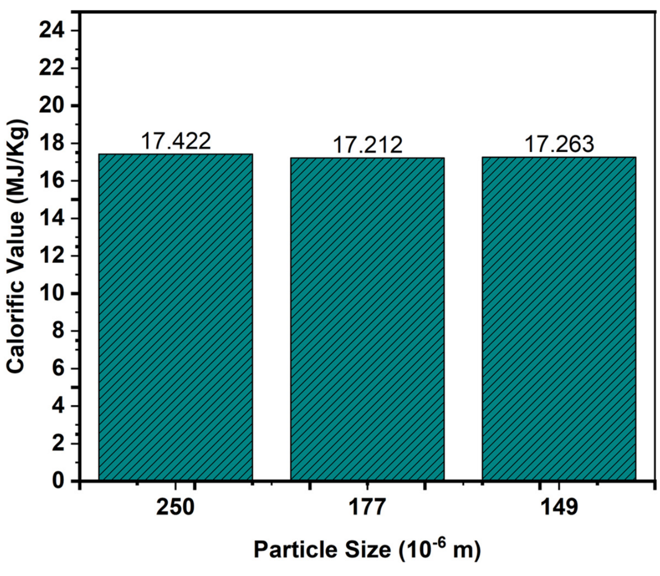

Figure 9. Calorific value against different particle sizes with the composition of 25%:75% (CS: RH)

of time the briquettes are burned (see Fig. 8). In the composition of CS: RH 25%: 75%, the longer combustion rate belongs to 250 µm particle size, only consuming 0.37 grams in one minute. The combustion rate gets faster (consuming more mass) as decreasing the particle. According to earlier research, the compacted product's density affects the combustion period. Therefore, denser briquettes have longer burn times (Rhén et al., 2007). However, as discussed in this work, they did not consider the contribution of other parameters, such as moisture and shatter index, that also affected the combustion rate performance.

Calorific value is the energy that is resulted from a briquette per the burned mass. The energy against particle size or density was shown in Figure 9 for a composition of 25%:75% (CS: RH) with different particle sizes. According to a recent study, the energy of briquettes increases as briquette particle size reduces (increasing density) because denser products have more energy concentrated per unit volume, underscoring the economic advantages of the biomass densification process (Sette Jr. et al., 2018). In contrast, this work showed that the energy of a briquette with 250 µm (17.422 MJ/kg) is a little bit larger compared with two energies with smaller particle size, 177 µm (17.21 MJ/kg) and 149 µm (17.263 MJ/kg). It is due to the 250 µm having a smaller moisture content and shatter index than the others. It indicates that the calorific value increase as moisture content decrease. The moisture content must be small to get an excellent combustion ability (McKendry, 2002). The moisture's highness affected the bond between the carbon and the binder, which led to loosing bonded carbon. As a result, the combustion process is ineffective, and energy decreases (Greinert et al., 2020). Other factors can affect the calorific value, such as the type of biomass, binder, and pressure (Bhattarai et al., 2016; Thabuot et al., 2015; Wu et al., 2018). This work is comparable with the results of Nazari et al., that obtained 16.396 MJ/kg (300 µm particle size) (Nazari et al., 2019) using banana residue and rice husk waste, Corn cob 16.06 MJ/kg and Eucalyptus sawdust of 17.01 MJ/kg (de Araújo Drago et al., 2023).

CONCLUSIONS

It is considering the findings of the studies on the impact of particle size and content on briquette quality. It can be concluded that the particle size affected the proximate characteristics and its calorific value. The bound carbon content of briquettes increases with decreasing particle size. The moisture and shatter index play the most crucial role in different particle sizes affecting the combustion rate performance, influencing the calorific value up to 17.422 MJ/kg. On the other hand, the comparison of material composition can affect the results obtained, where the most optimum results are found in the composition 25%:75% (CS:RH) with relatively high levels of bound carbon with water content and relatively low ash content. Therefore, the study of composite briquettes of coffee and rice husk waste in different particle sizes has an attraction to explore and could be used as an environmentally friendly alternative fuel and low cost.

Acknowledgments

This work was funded by the Ministry of Religion of the Republic of Indonesia through Universitas Islam Negeri Sunan Gunung Djati Bandung with grant No: 117/Un.05/V.2/KP.01.1/01/2022.

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