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Proximate Analysis and Calorific Value of Fuel Briquettes from Wood and Coffee Skins Biomass as a Renewable Energy Source

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ABSTRACT

One of the fuels made from biomass are Charcoal briquettes. The biomass used in this study was coffee husk and coffee wood. This study aims to find out the ratio of coffee husk and coffee wood that accordance the briquette standards of the Minister of Energy and Mineral Resources (ESDM) and (Indonesian Nasional Standard) SNI 01-6235-2000. In this research, a comparison was made between coffee fruit skin charcoal and coffee wood charcoal with a ratio of 100:0 (KK_1), 75:25 (KK_2), 50:50 (KK_3), 25:75 (KK_4), 0:100 (KK_5). The resulting briquettes were tested for their proximate value using a furnace, for the calorific value they were tested using a boom calorimeter. Apart from that, a combustion rate test was also carried out by burning briquettes in a combustion furnace. The results of the analysis of proximate obtained were water content of the briquettes ranging from 3.39–5.91%, all of which in accordance with SNI and also which in accordance with the regulation of ESDM, the ash content that which in accordance with SNI was KK_4 and KK_5, namely 6.71% respectively. and 6.47% and those that comply with the ESDM Ministerial Regulation are KK_3, KK_4 and KK_5 with ash content values of 9.62%, 6.71% and 6.47% respectively. Meanwhile, the volatile matter value ranges from 32.31–35.59%, not yet accordance with SNI. for fixed carbon values ranging from 50.1–54.55%, this also does not accordance with SNI. However, for the calorific value of 4536–6723 Cal/g, all of them meet the ESDM Ministerial Regulation, and those that accordance with SNI is KK_2, KK_3, KK_4 and KK_5 with calorific values of 5650, 5821, 5866 and 6723 Cal/g respectively. Meanwhile, the combustion rate ranges from 0.341 to 0.711 g/min. Coffee husk waste combined with coffee wood has the potential to be used as fuel briquettes where the KK_4 composition has water content, ash content and calorific value that meets SNI and ESDM regulations, even though the volatile matter and fixed carbon values do not yet meet.

Keywords: wood of coffee, husk of coffee, charcoal briquettes, calorific value.

INTRODUCTION

The higher use of fossil fuels results in their diminishing availability because fossil fuels are unsustainable and non-renewable. in addition, its emission in forms of CO_2, SO_2 and NO_x creates a dangerous environmental impact (Chandra, 2021). The way to overcome this problem is to look for alternative energy which is a renewable energy source. Apart from the increasing scarcity of fossil energy sources, the development of bioenergy as an alternative energy source needs to be continuously improved (Nurdin et al., 2022). One of the alternatives is the use of biomass (Sunardi et al., 2018). Biomass has the ability to be converted into alternative energy sources with relatively high energy content (Rahmawati et al., 2023). The third energy source after oil and coal is biomass, and it is estimated that it will become a very important contributor to renewable energy (Tumuluru et al., 2011; Zubairu and Gana, 2014). One of the main and valuable fuels used in daily life is biomass (Arachchige, 2021). Sukarta et al. (2018) reported that wood waste biomass mixed with biosolids can be used as fuel pellets. This biomass is renewable in nature. Additionally, the production of blended coal with a biomass content of no more than 20% (weight) has no significant impact on the emissions of pollutants in the combustion test. The obtained fuel has a rather high energy value (22–24 MJ·kg^{-1}). The value shows that the energy alternative can potentially be used as an alternative fuel for industrial and civil boiler combustion (Borowski and Hycnar, 2013). Currently, the fuel that is widely used in industry is mostly sourced from charcoal. (Syafrudin et al., 2015)

Briquettes are an alternative fuel in solid form that can be obtained on a large scale in a relatively short time and inexpensive (Ibrahim et al., 2020). Briquettes are environmentally friendly as they are biodegradable. Materials for making briquettes can be obtained from biological sources or biomass. Currently, Indonesia is the fourth largest coffee exporting country in the world with a market share of around 11% in the world (Rahardjo, 2012). Even though it has a positive impact, it turns out that coffee also has a negative impact because it produces quite a large amount of processed food, between 50–60% of the harvest. The waste produced is coffee skin. Apart from that, quite a lot of coffee wood is also produced because when the coffee plants are no longer productive, the coffee plants will be rejuvenated so that a lot of coffee wood waste will be produced. The results of the analysis carried out by (Tarmiji, 2020) show that the potential amount of waste from Robusta coffee skins is 1,425,923 tons/year and Arabica is 533,225 tons/year in the next 5 years, namely 2021–2025. Most coffee skin waste is immediately thrown away and has not been optimized by farmers. Coffee skin waste that is not managed or simply thrown away can become a source of pollution in the surrounding area. Waste of wood stems and coffee bean rind also has the potential as an alternative energy, namely charcoal briquettes. Coffee cherries have a high calorific value, low water content, and relatively low sulfur content. So, it is important to use coffee rind waste to make briquettes (Dewi et al., 2021). Apart from that, coffee skin waste is produced in large quantities and in abundance every year, so that if it is not handled properly, it will become an environmental problem for the environment.

In this research, briquettes were made with a mixture of wood and coffee bean rind. More specifically, the characteristics of a mixture of wood and coffee pod briquettes based on standard charcoal briquettes were set (Table 1). Examination of the test parameters was carried out by emphasizing the main attributes of solid fuels such as proximate analysis data (water content, ash, volatile matter and fixed carbon), calorific value and combustion rate. It is expected that this research will enable the use of biomass waste to provide alternative fuels, which become useful fuel briquettes.

MATERIALS AND METHODS

The principal materials utilized in this study were coffee husks and coffee logs. Another material used is tapioca flour adhesive. The wood stems and coffee rinds were taken from one of the coffee-producing plantations in, Buleleng Regency.

Making briquettes

The charcoal was sieved on a 60-mesh sieve. The adhesive used is tapioca flour as much as 12%. The various combinations used were 100% coffee pod skin and 0% coffee wood (KK_1), 75% coffee pod skin and 25% coffee wood (KK_2), 50% coffee pod skin and 50% coffee wood (KK_3), 25% leather, coffee fruit and 75% coffee wood (KK_4), and 0% coffee fruit skin and 100% coffee wood (KK_5).

Table 1. Briquette quality standards according to the Indonesian National Standard (SNI) and the Minister of Energy and Mineral Resources (Fausta et al., 2021)

Charcoal briquettes parameters	SNI	Minister of Energy and Mineral Resources of the Republic of Indonesia
Water content, %	≤8	<15
Volatile matter, % on dry base	≤15	According to raw materials
Ash content, % on dry base	≤8	<10
Fixed carbon, % on dry base	≥77	According to raw materials
Calorific value, Cal/g	≥5000	> 4400

Proximate analysis

Moisture content (SNI-01-6235-2000)

A sample of 2 g and entered in porcelain cup. The example was warmed in the stove at 105 °C for 3 h. Then, at that point, the example was cooled in a desiccator for 15 minutes and afterward the example was gauged. The water content is calculated by the equation.

$$\%\, moisture\ content = \frac{(a-b)}{a} \times 100\% \quad (1)$$

where: % moisture content – percentage bound water content (%), a – initial sample mass (g), b – sample mass after heating (g).

Ash content (SNI 01-6235-2000)

Twi grams of a sample is put into a porcelain cup whose weight is known. The sample was heated in the furnace at 750 °C for 5 h. Samples were cooled in a desiccator for 15 min. The ash remaining in the container is weighed and calculated using the equation.

$$\%ash\ content = \frac{(w_3 - w_1)}{(w_2 - w_1)} \times 100\% \quad (2)$$

where: % ash content – percentage of ash in the sample (%), W_1 – weight of empty cup (g), W_2 – weight of cup + sample (g), W_3 – weight of cup + residue (g)

Volatile matter (SNI 01-6235-2000)

The sample is weighed as much as 2 grams and put into a cup that has been weighed. The sample was heated in the furnace at 900 °C to 7 minutes. The sample is cooled in a desiccator for ½ hour and then weighed. Volatile matter levels are calculated by the equation.

$$\%VM = \left(\frac{C-A}{B} \times 100\%\right) \quad (3)$$

where: VM – volatile matter analyzed (%), A – mass of empty cup (g), B – mass of sample analyzed (g), C – mass of cup + sample after heating (g).

Fixed carbon (SNI 01-6235-2000)

Fixed carbon is calculated from 100% minus the water content, ash content, volatile matter content. Fixed carbon calculated by the equation

$$FC\ (\%) = 100\% - (\%moisture\ content + \%ash\ content + \%VM) \quad (4)$$

Calorific value of testing

Using a bomb calorimeter, one can determine a fuel's calorific value – also known as its heating value. The bomb calorimeter determines the upper calorific value, also known as the highest and lowest heating values (HHV and LHV). The gross calorific value is determined using the ASTM D240 standard. Energy equivalent with a bomb calorimeter equivalent to HHV and LHV can be calculated by using a bomb calorimeter to measure heat absorbed water. The bomb calorimeter's formula is used to calculate the heat absorbed by water.

$$Q = m \cdot Cp \cdot \Delta T \quad (5)$$

where: Q – absorbed of heat (kJ), m – water mass in a bomb calorimeter (g), Cp – 4,186 kJ/kg °C (specific heat), ΔT – difference of temperature (°C) LHV and the HHV is determined by the accompanying condition:

$$LHV = \frac{(m \times Cp \times \Delta T)}{m_{\text{briquettes}}} \quad (6)$$

The equation used to calculate HHV:

$$HHV = (T2 - T1 - TKP) \times Cv\ \ (kJ/kg)$$
$$LHV = HHV - 3240\ (kJ/kg)$$
$$HHV = LHV + 3240\ (kJ/kg) \quad (7)$$

where: $T1$ – the cooling water temperature at bomb calorimeter before combustion (°C), $T2$ – the cooling water temperature at bomb calorimeter after burnng (°C), TKP – temperature rise caused by combustion wire, HHV – highest heating value ($kJ \cdot kg^{-1}$), LHV – lowest heating value ($kJ \cdot kg^{-1}$).

Burning rate

The briquettes whose combustion rate would be tested were burned over a flame, the burning time is calculated from the start of the briquettes starting to burn until the coals of the briquettes die off. The remaining combustion of the briquettes was weighed on an analytical balance (Ningsih & Hajar, 2019). Calculation of the combustion rate was calculated with equation (8).

$$\text{Burning rate (g/min)} = (W_1 - W_2)/t \quad (8)$$

where: W_1 – mass before combustion (g), W_2 – mass of ash remaining from combustion (g), t – burning time (minutes).

RESULTS AND DISCUSSION

Proximate analysis

Moisture content

The quality of the resulting briquettes is affected by the moisture content, the higher the moisture content, the lower the combustion power and calorific value; vice versa, the lower the water content, the higher the combustion power and calorific value. (Sitogasa et al., 2022). The decrease in moisture content observed after the carbonation process can be seen in Figure 1. It can also be seen that the moisture content of the raw materials and charcoal from coffee pod shells is higher than that of coffee wood. This is because the wood used is old coffee wood so the moisture content is low.

The high moisture content is caused by the nature of the charcoal particles which are hygroscopic to water from the surrounding air (Hazra and Sari, 2011). The water content of briquettes is also influenced by the adhesive used in making the briquettes (Kurniawan et al., 2019). Besides that, the raw materials for briquettes of charcoal which have a low density and have a low specific gravity such as coffee skin charcoal can more easily absorb moist air from the surroundings so that it can cause high moisture content of the resulting charcoal (Figure 2). The moisture content of these composite briquettes is consistent with the moisture content of the raw materials and charcoal obtained. This means that the more coffee berry husk charcoal composition added to the briquette composition, the higher the moisture content of the composite briquettes. The moisture content of the briquettes in this experiment ranged from 3.39–5.91%. The result shows that the experiment meets the standard requirements of SNI briquettes (≤8%) and Regulation of the Minister of Energy and Mineral Resources (<15%). The briquettes that are made are expected to have the lowest possible moisture content. This aims to obtain a high calorific value and to facilitate the initial ignition or combustion.

Ash content

In Figure 3, there is an increase in the ash content after the carbonation process. This happens because conventional carbonization produces a high ash content compared to carbonization at

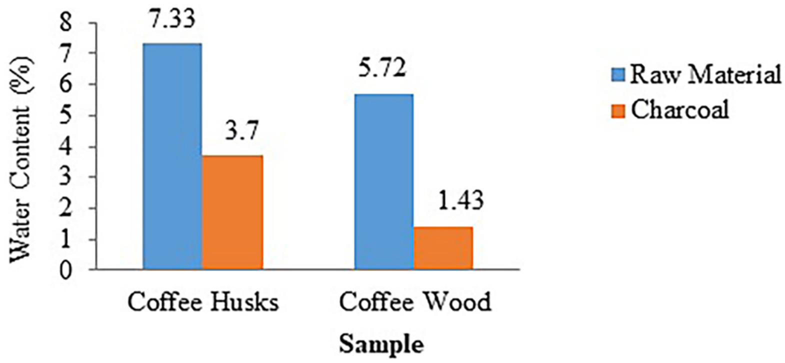

Figure 1. Moisture content of raw materials of charcoal

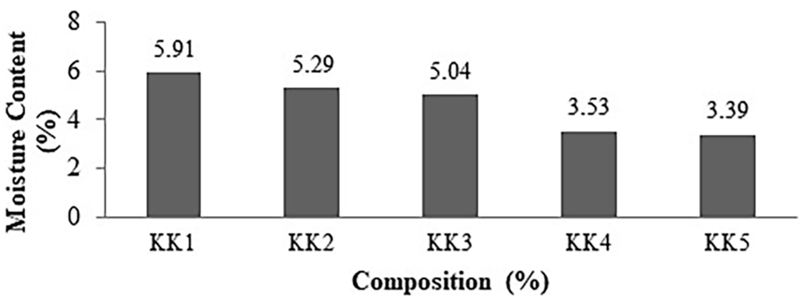

Figure 2. Moisture content of charcoal briquettes

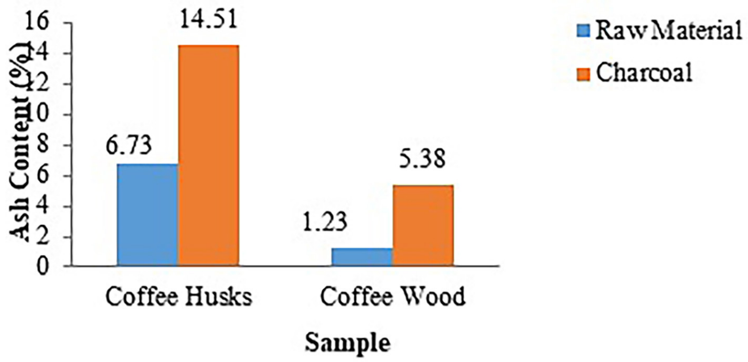

Figure 3. Ash content of raw materials and charcoal

500 °C. This happens because the material that is burned in conventional cooking has a propensity to interact with air in the surroundings so that the biomass decomposes into ashes (Rahmadani et al., 2017). In Figure 4, the ash content of the composite briquettes decreased as a coffee pod decreased. an ash content of the composite briquettes ranges from 6.47–11.68%. The results of this study indicate that based on the ash content, the composition of KK_4 (6.71%) and KK_5 (6.47%) meets the briquette standard and the composition of KK_1 (11.68%), KK_2 (10.66%) and KK_3 (9.6%), didn't meet the requirement quality SNI briquettes standards (≤ 8%) and Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia (<10). The silica content of coffee pod shells is high compared to wood. So, the amount of ash produced from charcoal briquettes will be directly proportional to the mixture of coffee pod shell charcoal used (Fitri, 2017).

Volatile matter

There is an increase in VM levels after carbonation. The low or high levels of VM is influenced by temperature and the length of the coagulation process. The VM level is affected by temperature and baking time. In other words, the greater the temperature and time of curing, the more the volatile matters are wasted (Figure 5 and 6).

Fixed Carbon

Based on Figure 7, it can be seen that there is a decrease in the content of fixed carbon (FC), after carbonation. Bonded carbon is the carbon content resulting from the reaction of cellulose and hemicellulose during combustion. From the study, results show that coffee wood has a higher FC value than coffee fruit skin because the amount of cellulose and hemicellulose in coffee wood is greater than coffee fruit skin. Additonally, coffee wood has 40.39% cellulose and 34.01% hemicellulose,

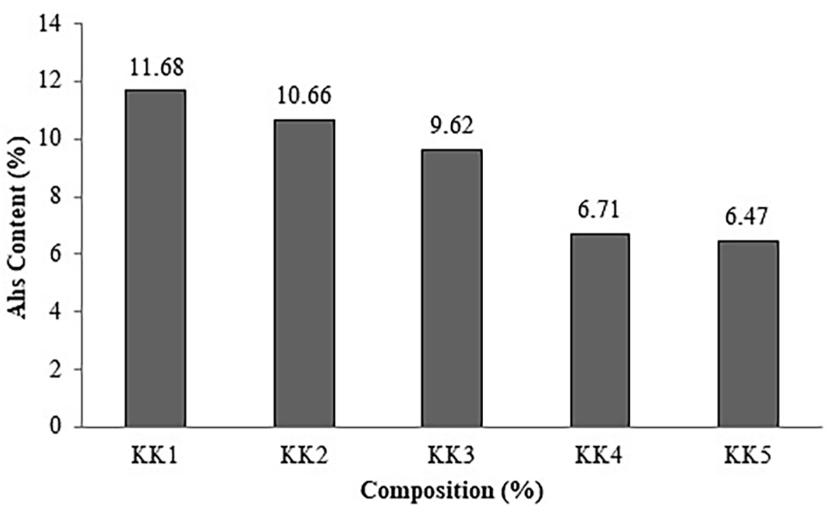

Figure 4. Ash content of charcoal briquettes

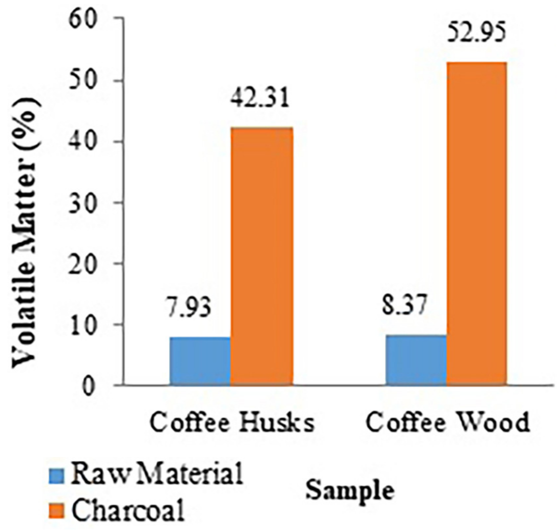

Figure 5. Volatile matter from raw materials and charcoal

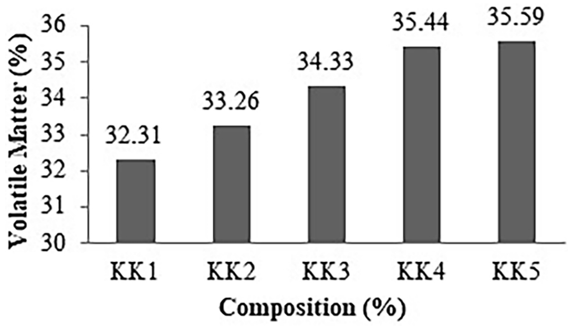

Figure 6. Volatile matter from charcoal briquettes

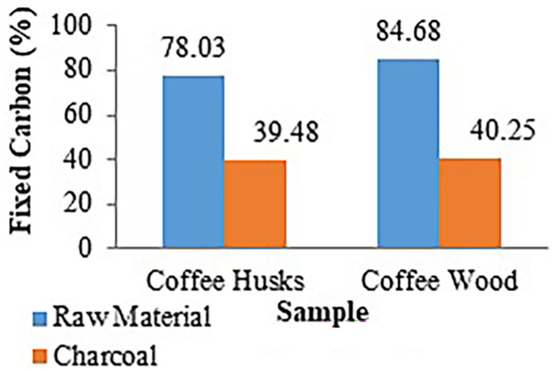

Figure 7. Fixed carbon from raw materials and charcoal

while coffee fruit skin has 23.33% cellulose and 2.85% hemicellulose (Restana et al., 2020).

In Figure 8, the FC value increases with the addition of coffee wood. Based on the research results, the % fixed carbon value does not meet the SNI standard (≥ 77%) because all the briquettes in this study shows a %FC value less than the standard. The FC value relates to the ash content, moisture content and content of volatile matter. Interpretatively, this means that the lower the ash content, the moisture content and the volatile matter content, the higher the bound carbon content. The FC content affects the calorific value of the charcoal briquettes meaning that the higher the carbon content in the resulting charcoal briquettes, the higher a calorific value of a charcoal briquettes. A carbon content is also affected by the carbonization temperature and the duration of the carbonization process. This means the higher the carbonization temperature, the lower the volatile matter content and will increase the carbon bound to the briquettes (Reza et al., 2018).

Calorific value

Based on Figure 9, the calorific value increases with increasing coffee wood charcoal. The calorific value of KK5 has the highest value. This happens because this charcoal briquette has the lowest moisture content, ash content and higher FC content, namely, 3.39%, 6.47% and 54.55%, respectively. The difference in calorific value is not only influenced by the moisture content and ash content, but it is also influenced by the raw materials. Coffee pod rind has a lower calorific value than coffee wood so that when the rind is made into charcoal briquettes, briquettes with a high concentration of coffee wood will also produce a high calorific value.

The calorific value of briquettes depends on the composition of the ingredients. The high or low heating value is influenced by several factors. The main factor is the raw material. Each raw material will have a different calorific value according to the characteristics of the material used. Another factor that affects the calorific value is the carbonization temperature, the lower the carbonization temperature the lower the calorific value, because the content of water, ash, and volatile matter will be high but the fixed carbon content will be low, causing a decrease in the calorific value (Faizal et al., 2014).

Burning rate

Burning rate is useful to determine whether or not these briquettes are suitable for use as fuel. Several factors can affect the combustion properties of a material, namely the particle size, air

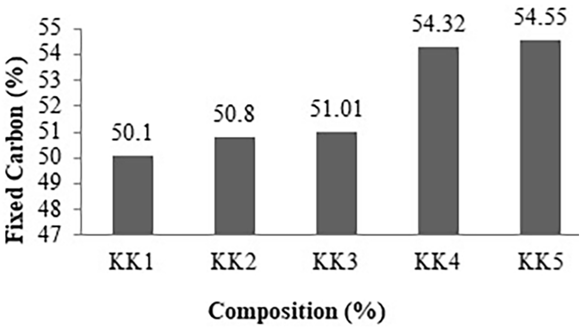

Figure 8. Fixed carbon from briquettes

Figure 9. Charcoal briquettes calorific value

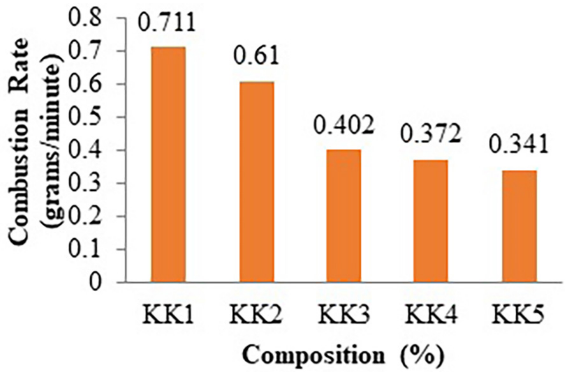

Figure 10. Burning rate of charcoal briquettes

flow velocity, fuel type and combustion air temperature. Based on Figure 10, there is a decrease in the burning rate of composite briquettes. The high burning rate value for KK_1 is 0.711 gram/minute, and the low burning rate is for KK_5 which is 0.341 gram/minute. From the combustion rate (CR) in this study it can be related to the calorific value (CV) obtained. The relationship between the two is to find out the heat per minute, which is obtained by multiplying the calorific value by the burning rate, so that the heat per minute is obtained from the composite briquettes. Based on Table 2, the heat generated in composite

Table 2. Calorific value/minute of mixed wood and coffee pod briquettes

Sampel	CV (cal/g)	CR (g/minute)	cal/minute
KK1	4536	0.711	3225.096
KK2	5650	0.61	3446.5
KK3	5821	0.402	2340.042
KK4	5866	0.372	2182.152
KK5	6723	0.341	2292.543

briquettes containing more coffee rinds shows higher heat per minute. Composite briquettes in this study in their application can be selected according to needs, which if the desired burning is fast in a short time, then the briquettes chosen are briquettes with more coffee husk composition, namely KK_2. This is because KK_2 has greater energy at a faster rate, fast burning. If you want to burn for a long time, you can use briquettes with a coffee wood composition, namely KK_5. This is because the resulting burning rate is slow.

CONCLUSIONS

Based on the results of the research that has been done, the following conclusions can be obtained. The results of the proximate analysis obtained were water content ranging from 3.39–5.91%, all of which in accordance with SNI the Indonesian National Standard (SNI) and also which in accordance with the Minister of Energy and Mineral Resources (ESDM) regulation, the ash content that which in accordance with SNI was KK_4 and KK_5, are 6.71% and 6.47%, respectively, those that comply with the ESDM Ministerial Regulation are KK_3, KK_4 and KK_5 with ash content values of 9.62%, 6.71% and 6.47% respectively.

Meanwhile, the volatile matter value ranges from 32.31–35.59%, not yet accordance with SNI. for fixed carbon values ranging from 50.1–54.55%, this also does not accordance with SNI. However, for the calorific value of 4536–6723 Cal/g, all of them meet the ESDM Ministerial Regulation, and those that accordance with SNI is KK_2, KK_3, KK_4 and KK_5 with calorific values of 5650, 5821, 5866 and 6723 Cal/gram respectively. Meanwhile, the combustion rate ranges from 0.341 to 0.711 grams/minute. Coffee skin waste combined with coffee wood has the potential to be used as fuel briquettes where the KK_4

composition has water content, ash content and calorific value that meets SNI and ESDM regulations, even though the volatile matter and fixed carbon values do not yet meet.

For researchers who are interested in research on coffee wood waste briquettes, they can add other biomass that has a high carbon value like coconut shell charcoal to increase fixed carbon and reduce volatile matter levels. so that it meets SNI and ESDM regulations.

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