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Improvement of Brown Coal Quality Through Variation of Acacia Wood Waste Biochar Composition in Producing Alternative Solid Fuel

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ABSTRACT

More than 41% of households and 2.8 billion people worldwide depend on solid fuels including coal. The available coal reserves in Indonesia are 31.7 billion tons and only enough for the next 65 years. This makes the government encourage the development of research on the utilization of biomass waste as alternative energy. Efforts are made to convert biomass waste in the form of rubber wood into alternative solid fuels through the pyrolysis process. Biochar is produced from biomass through pyrolysis, resulting in excellent combustion quality. Biochar from pyrolysis is combined with brown coal and molasses adhesive to create coal biobriquettes as an alternative solid fuel. The purpose of this study was to identify the optimal composition of brown coal and biochar in producing coal biobriquettes with the best quality. The pyrolysis process of rubber wood waste was carried out at a temperature of 350–400 °C for 2 hours. This study used variations in the composition of biochar (75%, 80%, 85%, 90%, and 95%) and brown coal (5%, 10%, 15%, 20%, and 25%) and 15 mL molasses adhesive. Testing the combustion quality of coal biobriquettes through proximate analysis and value. The results showed that the most optimal product was a sample with a composition of 85% biochar and 15% brown coal.

Keywords: acacia wood, pyrolysis, biochar, brown coal, coal bio-briquettes, SEM.

INTRODUCTION

Brown coal is a type of coal with a low calorific value (Rauf et al., 2018). The high inherent moisture of up to 19.58% makes this type of coal rarely used in the industrial and power generation sectors because it requires a dewatering process first. Besides being used directly as fuel, coal can also be utilized into briquettes through certain modifications. Coal briquettes are one of the solid fuels composed of fine coal particles that undergo a compression process with a certain compressive power with the aim of being easy to handle and increasing its use value. Another innovation from coal briquettes is coal biobriquettes. Coal biobriquettes are coal briquettes in which there is a mixture of biomass in a certain composition, either with or without binders or other additives. Biomass in coal briquettes is biomass that has been converted into biochar. One of the methods to convert biomass into biochar is through the pyrolysis process.

Biochar is defined as one of the products of pyrolysis, which is the thermal decomposition of organic materials without or limited oxygen supply, and at relatively low temperatures (< 700 °C) (Abdullah et al., 2023). The main components of biomass are lignin, hemicellulose, and cellulose. One characteristic of biomass suitable for conversion into biochar through the pyrolysis process is biomass containing a large amount of cellulose, typically found in biomass with wood structures. One of the biomass that is easily found around us is acacia wood. According to data from the Central Statistics Agency in 2021, acacia wood ranks first in round wood production with a value of 30,377.156 m^3. Acacia wood biomass can be considered as waste due to its nature as an invasive plant, often having negative effects on native plants and natural ecosystems due to its rapid growth (Baskin and Baskin, 2022). Its high lignin content poses challenges in pulp production processes if processed through delignification, thus requiring alternative methods to break down this lignin chain, such as through combustion. When converted into biochar, acacia wood can be utilized with lower energy and cost but can yield products with higher market value.

Biochar has good combustion quality so that it can be used to improve the quality of brown coal by forming it into coal biobriquettes. Owever, during the formation of bio-coal briquettes, powdered raw material particles tend to naturally separate (Setiawan and Syahrizal, 2018). Therefore, adhesives are needed that can unite these grains so that they can be fused and shaped as needed. Adhesives have the ability to bind charcoal particles that make water bound in the pores of charcoal so that a compact briquette structure is produced (Sugiharto and Firdaus, 2021). Based on previous research, among briquettes made with wheat flour, tapioca starch, and molasses adhesives, briquettes with molasses adhesive at 30% adhesive composition produced the highest calorific value of 112.86 cal/g. Molasses is a thick liquid residue from sugar extraction (Masthura et al., 2022).

This research provides a solution by improving the quality of brown coal through the combination of pyrolysis biochar from acacia wood waste into an alternative solid fuel. The combustion quality of biochar which is much better than brown coal is expected to improve the properties of brown coal. Furthermore, the combination of biochar raw material and brown coal requires optimal composition ratios to achieve the best product results. Therefore, the influence of the type and composition of raw materials on the quality of coal biobriquettes produced needs to be studied further.

MATERIALS AND METHODS

Procedure

The stages of research conducted in producing coal biobriquettes are presented in Figure 1 below.

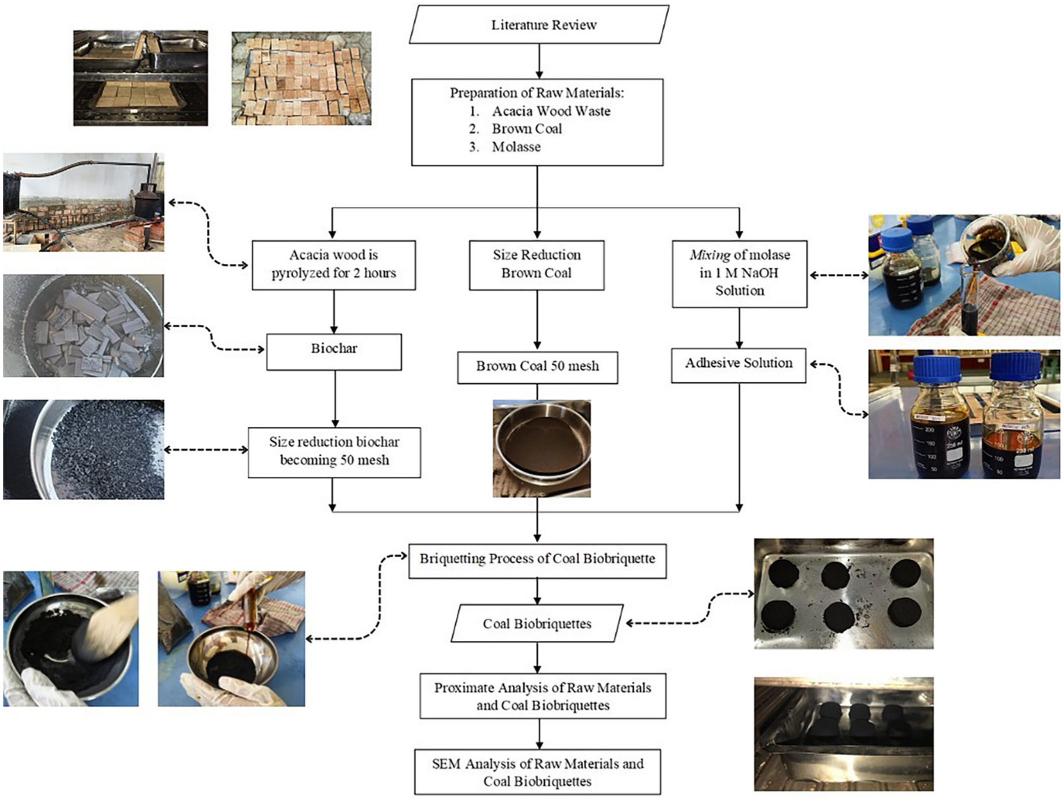

Figure 1. Flow chart of coal biobriquette production

Raw material preparation process

Raw materials consisting of biomass waste, brown coal, and molasses adhesive were prepared in advance. Acacia wood waste as much as 6.5 kg was cleaned from dirt and acacia wood that was still in the form of logs was size reduced to 4–6 cm. his is done to facilitate and expand the drying process of both wastes. The acacia wood waste is dried in an oven for 3 hours at 105 °C until its weight becomes constant, resulting in a total final mass of 5 kg. Pre-treatment such as drying is used to overcome the high inherent moisture, low bulk density, and irregular shape of the resulting biochar (Zeng et al., 2019). Furthermore, brown coal is cleaned from impurities and then mashed with a mortar until it is powdered and sieved using a 50 mesh sieve. This step aims to accelerate and broaden the combustion process of the solid fuel produced. Additionally, the particle size will affect each proximate analysis value in the bio-coal briquettes (Ifa et al., 2019). Lastly, preparation for the molasses adhesive involves dissolving it in a 1 M NaOH solution. The ratio is 7:3 in mL units, meaning 3 mL of molasses is dissolved in 7 mL of NaOH solution. The choice of NaOH as a solvent is based on its ability to slow down the combustion rate of a solid fuel (Azman and Pa, 2021).

Pyrolysis process of biomass waste

Each biomass waste in the form of rubber wood and acacia wood is weighed with a total mass of 5 kg and pyrolyzed in a pyrolysis reactor for 2 hours. The products obtained through pyrolysis are solid biochar, liquid bio-oil, and gas (Saputro et al., 2021). The resulting biochar and bio-oil from pyrolysis are measured and recorded. Then the resulting biochar is separated which burns completely or has not burned. Biochar that has burned completely is then sized reduction using a mortar until smooth. Biochar that has been in powder form is then sifted with a 50 mesh sieve.

Briquetting process of coal biobriquettes

Biochar, brown coal, and molasses adhesive solution are mixed evenly. The adhesive solution is used at 15 mL for a total sample mass of 10 grams of biocoal briquettes. Each variation of raw material composition with adhesive solution is mixed to form a dough. The dough is molded using a briquette molding tool until it becomes solid. The molded bio-coal briquettes are then dried at 105–110 °C for 1 hour and stored in an airtight condition.

Instrumentation

The production of biochar that will be formulated into coal biobriquette products is carried out in a series of pyrolysis equipment. This pyrolysis equipment consists of a furnace, pyrolysis reactor, and condenser. In this study, to minimize failure, the design of the tool, the previous design guidelines were used from research conducted by Afrah et al. (2020).

Coal Biobriquettes quality analysis

Inherent moisture determination

The inherent moisture calculation method uses the ASTM D3173/D3173M-2017 standard. The Equation used in calculating the percentage of inherent moisture is:

$$Inherent\ moisture = \frac{(W_2 - W_3)}{(W_2 - W_1)} \times 100\% \quad (1)$$

where: W_1 = weight of cup + lid (g); W_2 = weight of cup + lid + sample (g); W_3 = weight of cup + lid + sample after heating (g); $W_2 - W_1$ = weight of sample (g).

Ash content determination

The ash content calculation method uses the ASTM D3174-12 (2018)e1 standard. The equation used in calculating the percentage of ash content is:

$$Ash\ content = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100\% \quad (2)$$

Volatile matter determination

The volatile matter calculation method uses the ISO 562-2010 standard. The equation used in calculating the percentage of volatile matter is:

$$Volatile\ matter = \frac{(W_2 - W_3)}{(W_2 - W_1)} \times 100\% - \%\mathrm{IM} \quad (3)$$

Fixed carbon determination

The fixed carbon content calculation method uses the ASTM D3172-02 standard (11). Calculation of carbon content using the equation:

$$FC = 100 - IM - AC - VM \quad (4)$$

where: *FC* – fixed carbon, *IM* – inherent moisture, *AC* – ash content, *VM* – volatile matter.

Calorific values determination

The calorific value calculation method uses the ASTM D5865/D5865M-2019 standard. Calculation of calorific value using the equation:

$$Calorific\ value = \frac{(E \times T) - e1 - e2}{W}\ cal/g \quad (5)$$

where: W – weight of sample (g), E – energy equivalent value (cal/°C), T – temperature rise (°C), $e1$ – acid correction, $e2$ – wire correction, $e3$ – sulfur correction.

RESULTS AND DISCUSSION

Raw material characteristics

The main raw materials that are mixed in producing coal briquettes in this study are acacia wood biochar and brown coal. The pyrolysis of biomass is influenced by the lignocellulosic components it contains. The content of hemicellulose, cellulose, and lignin in acacia wood is 25.60%, 47.76%, and 23.67% respectively (Amini et al., 2017). In addition, each raw material used needs to be analyzed proximate to determine its initial condition before being made into coal biobriquettes so that it can be reviewed which raw materials most affect its value. The results of the proximate analysis of each raw material are presented in Table 1 below.

Based on the results of proximate analysis of raw materials, the inherent moisture (IM) of acacia wood and brown coal biochar was 5.38% and 24.34%, respectively. Acacia wood is converted into biochar through pyrolysis process The inherent moisture of brown coal is naturally higher because it does not undergo pre-treatment such as drying after being extracted from open areas, leading to a greater potential for water vapor absorption into the pores of brown coal. The drying process significantly affects the inherent moisture of raw materials, including the weight of biochar produced from biomass waste. Acacia wood biochar has a relatively low inherent moisture and meets the standards. The inherent moisture of biochar itself affects its calorific value, with low moisture biochar being preferred for higher combustion quality (Kongprasert et al., 2019). The pyrolysis process itself can remove the hydroxyl functional group (O-H) on the biomass, so that when the biomass has formed into char it will be more difficult to absorb water.

The ash content for acacia wood biochar and brown coal are 1.31% and 2.45%, respectively. Ash content in a material indicates the presence of non-volatile and non-combustible components (Ali et al., 2022). The raw material that is expected to play a role in improving the quality of brown coal is acacia wood biochar obtained through pyrolysis. The low ash content in acacia wood biochar indicates that the pyrolysis process is carried out at the right temperature range because the lignocellulose component in acacia wood has been converted almost entirely into biochar. This study took place at a temperature of 350–400 °C, which when the temperature gets higher or tends to stabilize at high temperatures, the hemicellulose component tends to be easier to reduce in intensity. Meanwhile, cellulose and lignin components that have not been decomposed will leave minerals and inorganic compounds that form ash from the remaining combustion products called ash content. Lignin has a slower thermal decomposition rate than other components (López-Beceiro et al., 2021). Brown coal has a higher ash content compared to biochar due to the inorganic components in the form of minerals it contains. The smaller the ash content value of a material will contribute to a greater fixed carbon value and heating value when produced into a solid fuel.

Table 1 shows the volatile matter in each raw material, namely acacia wood biochar, and brown coal, which are 9.23% and 41.38%, respectively. These volatile matter generally consist of hydrocarbons, carbon monoxide (CO) gas, carbon dioxide (CO_2) gas, and hydrogen gas with tar (Reza et al., 2019). During the drying process the inherent moisture can be removed, then during pyrolysis there is devolatilization or release of volatile (flying substances) in the raw material (Borman and Ragland, 1998). The high content of brown coal volatile matter is related to the water content it contains. High inherent moisture can increase the level of volatile matter because most of the water will evaporate at low temperatures. In addition, hydrocarbons such as methane, ethane, and

Table 1. Raw material characteristics

Raw materials	Proximate analysis				
	IM (%)	AC (%)	VM (%)	FC (%)	CV (cal/g)
Acacia wood biochar	5.38	1.31	9.23	84.08	7370
Brown coal	24.34	2.45	41.38	31.83	5604

propane contained in brown coal tend to turn into gas at low temperatures. Meanwhile, the volatile matter of biochar from pyrolysis of a biomass is closely related to the cellulose and lignin content of the biomass. Wood with high lignin content and low cellulose content will produce low fly content. The incomplete combustion process during the pyrolysis process can also cause the volatile matter to increase because the raw material does not burn completely (Efiyanti et al., 2020).

The fixed carbon value of acacia wood biochar is much higher than that of brown coal, which is 84.04%. The fixed carbon value states the percentage of carbon remaining for fuel after substances classified as volatile have been lost (Azman and Pa, 2021). Brown coal has a relatively low fixed carbon value of only 31.83%, which shows that impurities in brown coal are still very high. In addition, in this study brown coal was not pre-treated such as pyrolysis or carbonization. The fixed carbon value of biochar indicates that the pyrolysis process carried out is optimal. Thermal decomposition that occurs in lignocellulosic biomass waste is influenced by temperature and pyrolysis time. The higher temperature and longer pyrolysis time will refer to full decomposition (Ali et al., 2022). Increasing the temperature of the pyrolysis process provides a higher degree of polymerization so that the carbon structure can be condensed into biochar. The higher value of fixed carbon will refer to the higher heating value and less impurities in the fuel.

The value that is the final determination of fuel quality is the calorific value produced during the combustion process. Table 1 shows that each feedstock has met the qualification standards. The calorific value depends on the chemical composition (Sitogasa et al., 2022). High moisture leads to lower thermal efficiency of the fuel. The very high inherent moisture and volatile matter values of brown coal cause the calorific value of brown coal to be lower than that of rubber wood biochar and acacia wood. The calorific value of a material is directly proportional to its fixed carbon value. Therefore, the level of fixed carbon value of the largest raw material will refer to an increase in calorific value successively, namely acacia wood biochar, rubber wood and brown coal. Acacia wood and rubber wood biochar have heating values of 7370 cal/g and 7159 cal/g, respectively. Therefore, in the briquetting process, it is expected to optimize the value of each proximate analysis result from the variation in coal biobriquette composition.

Characteristics of Coal Biobriquette

Table 2 shows the results of proximate analysis and calorific value of coal biobriquette products in each composition variation.

Effect of coal biobriquette raw material composition on inherent moisture

The inherent moisture in coal biobriquettes has a significant impact on the quality and performance of coal biobriquettes. When using briquettes as fuel, the inherent moisture biobriquettes can be a determining factor in combustion efficiency. This is because the higher the inherent moisture, the lower the calorific value (Rath et al., 2023). Coal biobriquettes with high inherent moisture tend to have low heating values because most of the heat energy is used to vaporize water during the combustion process. Figure 2 swows the graph of the effect of biochar composition percentage on the inherent moisture contained in coal biobriquette products.

In Figure 2, it can be seen that the inherent moisture of coal biobriquettes is quite low and close to the standard, which is a maximum of 15% according to Energy and Mineral Ministry Regulation Number 47 of 2006. Based on the graph, as the composition of biochar in the coal biobriquette mixture increases, the inherent moisture will decrease. Samples with a higher proportion of

Table 2. Characteristics of coal biobriquette products

Sample	% Mass Composition		Proximate analysis				
	Biochar	Brown coal	IM (%)	AC (%)	VM (%)	FC (%)	CV (cal/g)
A_1	75	25	16.18	6.95	35.56	41.31	5161
A_2	80	20	15.65	7.26	32.37	44.72	5538
A_3	85	15	9.21	8.20	32.56	50.03	5939
A_4	90	10	8.77	7.82	32.13	51.28	5961
A_5	95	5	6.52	7.28	36.27	49.93	5696
A_6	100	0	7.52	7.57	32.41	52.50	5964

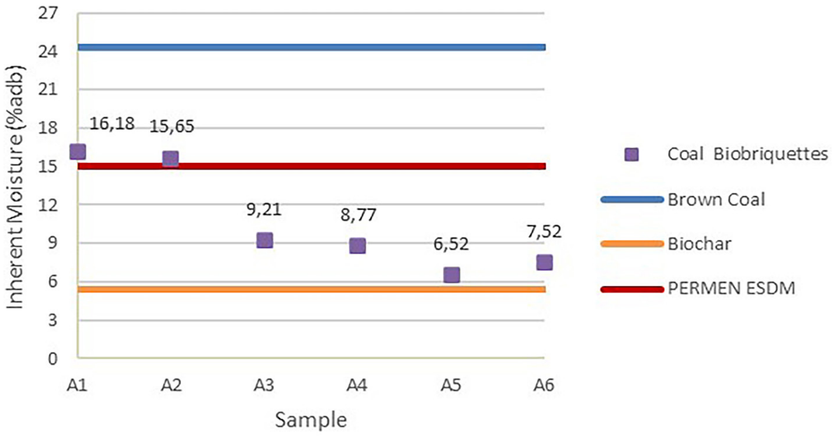

Figure 2. Inherent moisture of coal biobriquettes

brown coal result in higher inherent moisture due to the high moisture content of brown coal as a raw material compared to biochar. In all biobriquette samples with variations in composition, the sample with the lowest inherent moisture is found in the composition of 95% biochar and 5% brown coal. Samples that have not met the Inherent Moisture standard are samples A_1 and A_2. The higher inherent moisture in coal biobriquettes compared to the initial raw materials is due to the addition of molasses binder, as molasses contains a relatively high water content (Haliza & Saroso, 2023). The high inherent moisture of briquettes affects the quality of briquettes, especially the calorific value, where briquettes with high inherent moisture will cause low calorific value (Sihombing et al., 2020).

Effect of coal biobriquette raw material composition on ash content

Ash content in solid fuel can reduce its thermal efficiency or heat when the fuel is used. Ash formation indicates residual combustion products, meaning there is mineral content. This gives a decrease in calorific value so that the resulting fuel is difficult to operate in processes that require high heat levels and increased handling of combustion ash (Sitogasa et al., 2022). The graph in Figure 3 illustrates the effect of biochar composition percentage on ash content in coal biobriquette products.

The ash content standard contained in the Energy and Mineral Ministry Regulation Number 47 of 2006 regarding coal biobriquettes is a maximum of 10%. The ash content percentage of biobriquettes increases during the briquetting process. The briquetting process can contribute high ash content influenced by the addition of brown coal and molasses adhesive. According to research from Utchariyajit et al. (2019), it was found that along with the addition of molasses mass, the ash content increased. Molasses is a waste product of cane sugar manufacturing, meaning it has a mineral content of about 10.50%,

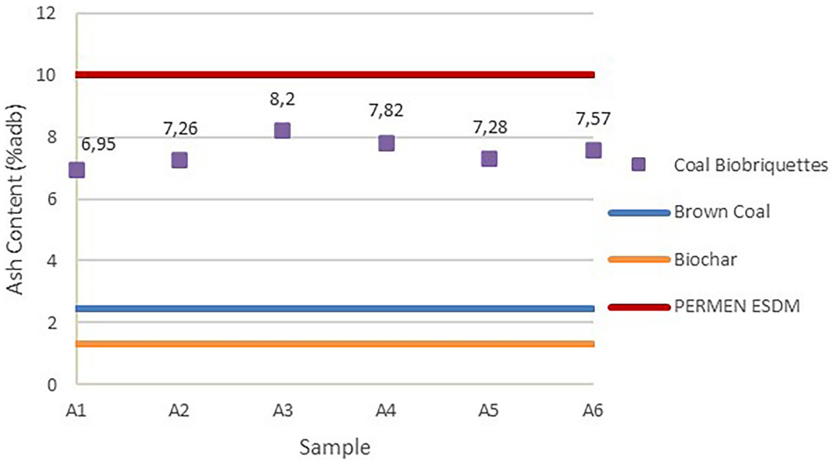

Figure 3. Ash content of coal biobriquettes

moreover, generally bagasse can produce as much as 70% silica from the ash obtained. Therefore, the use of molasses as an adhesive is not good in reducing the ash content of biobriquettes due to its high mineral content. In addition, it can be observed that the increase in biochar composition is directly proportional to the ash content of coal biobriquettes. Supposedly, the higher the mass of biochar will reduce the ash content of coal biobriquettes. However, in this study sample A_1 has the lowest ash content value of 6.95%. This can occur due to the lack of ability of brown coal to be bound by molasses adhesive compared to pyrolyzed biochar. The ability to absorb a raw material is influenced by open or closed and the size of the pore of a material, rubber wood biochar and acacia wood have large pores and are still open so that the ability to absorb is very good. Biochar plays a role in increasing the absorption of nutrients in the soil, such as nitrogen, phosphorus, potassium, calcium, magnesium, manganese and zinc (Hou et al., 2022). hus, it can be concluded that the increase in ash content is due to the properties of biochar, which tends to absorb minerals or inorganic compounds from molasses more easily than from brown coal.. The absence of a pretreatment stage on brown coal causes absorption and its ability to bond more difficult because the pores are smaller and tend to be closed. So that the minerals in the molasses are not completely absorbed in sample A_1. The briquette sample with an ash content value that meets the Energy and Mineral Ministry Regulation Number 47 of 2006 is sample A_1 with a value of 6.95% and then increases as the brown coal decreases.

Through variations in composition carried out in the formation of coal biobriquettes in terms of ash content values, it shows that biochar will tend to absorb mineral content more easily in the adhesive so that it contributes a greater ash content when used as solid fuel. Meanwhile, brown coal with closed and small pores tends to be difficult to absorb and be bound by molasses adhesive and reduce the ash content value. Therefore, the selection of adhesive should pay attention to the mineral content so that the ash content in biochar can be minimized. It is intended that biochar can optimize its role in improving the quality of brown coal without the binding of inorganic compounds that cause ash.

Effect of coal biobriquette raw material composition on volatile matter

The decomposition results of compounds from coal biobriquette raw materials that can evaporate are called volatile matter. The volatile matter content in fuel can affect combustion efficiency and the amount of smoke produced during combustion. A high volatile matter content in coal biobriquettes indicates that the carbon content in this fuel is low, as well as its calorific value (Brayen et al., 2022). The graph in Figure 4 illustrates the effect of biochar composition percentage on the volatile matter contained in coal biobriquette products.

The volatile matter standard of coal biobriquettes contained in the Energy and Mineral Ministry Regulation Number 47 of 2006 depends on the raw material. Based on the volatile matter testing results of coal biobriquette samples shown in Figure 4, the volatile matter content of the researched coal biobriquette samples ranges from 32.13% to 36.37%, which is relatively low as it

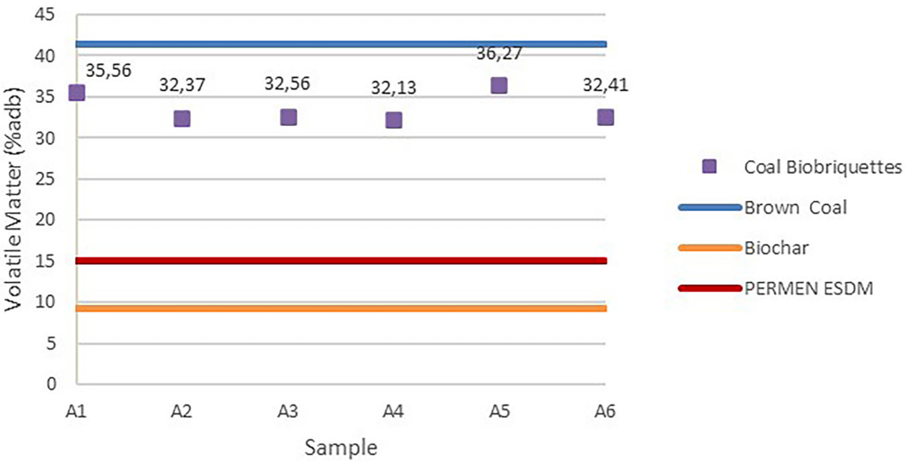

Figure 4. Volatile matter of coal biobriquettes

falls below the initial volatile matter content of brown coal at 41.38%. The higher volatile matter content in coal biobriquettes compared to the initial biochar is due to the addition of brown coal and molasses binder. The change in volatile matter content of coal biobriquettes tends to decrease with the increasing composition of biochar in the coal biobriquette samples. This is in accordance with research from Partiwi and Prabowoi (2021), which states that briquettes with a higher coal composition tend to have higher volatile matter content compared to briquettes with a lower coal composition. In this case, the characteristics of rubber wood and acacia wood biochar raw materials also affect the volatile matter of coal briquettes. The volatile matter of rubber wood biochar is much higher than that of acacia wood biochar, so that when it becomes coal briquettes, samples with rubber wood biochar raw materials tend to have higher volatile matter.

Effect of coal biobriquette raw material composition on fixed carbon content

The fixed carbon is the main content of solid fuel constituents produced and remaining after the pyrolysis process, which is obtained from the subtraction of each value of other proximate test results. The constituent material of fixed carbon in briquettes is dominated by the element carbon which is then followed by hydrogen, oxygen, sulfur, and nitrogen (Iskandar and Rofiatin, 2017). Increasing the fixed carbon value improves the quality of solid fuel and is correlated with higher calorific value. The influence of biochar composition percentage on the fixed carbon content in coal biobriquette products can be seen in Figure 5 below. Based on the results of proximate analysis for the fixed carbon content of coal briquettes contained in Figure 5, it states that there is an increase in carbon content along with the addition of biochar composition. The smallest fixed carbon value is owned by sample A_1 which has the most brown coal composition, which is 25% of the total mass of briquettes. This is due to the low fixed carbon value possessed by brown coal at the beginning which still contains many impurities. So that when the briquetting process is carried out, increasing the composition of brown coal plays a role in decreasing the fixed carbon content in coal biobriquettes. The decrease in the percentage of fixed carbon is caused by a decrease in the composition of biochar (Wahyuni et al., 2022). The variation of raw material composition in the sample with the highest fixed carbon value is sample A_4 (90:10) of 51.28%. The fixed carbon content obtained is the influence of other proximate analysis values. In addition, acacia wood biochar with higher fixed carbon also produces coal biobriquettes with the highest fixed carbon content. The high value of fixed carbon in fuel will increase the length of the combustion process.

Effect of coal biobriquette raw material composition on calorific value

Calorific value is the most important indicator in determining the quality of solid fuel or biobriquettes in this study. Calorific value indicates the amount of heat generated during the combustion process of biobriquettes. The larger the calorific value of biobriquettes, the higher the quality of solid fuel produced (Hakika et al., 2023). The effect of the percent composition of biochar on the calorific value of coal biobriquette products can be seen in Figure 6 below.

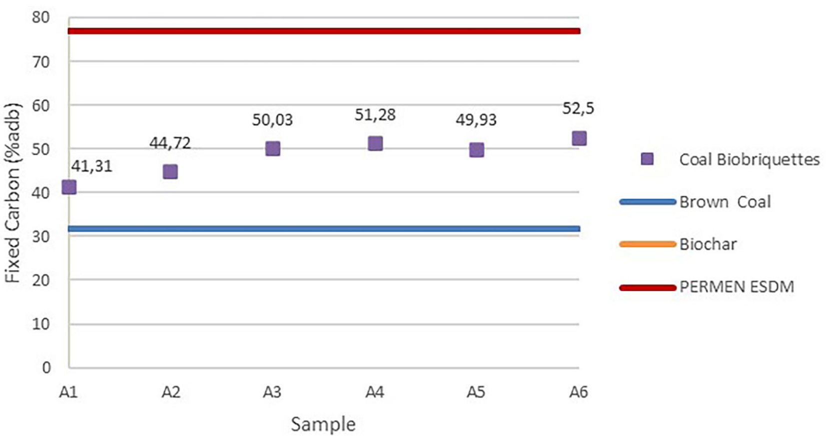

Figure 5. Fixed carbon of coal biobriquettes

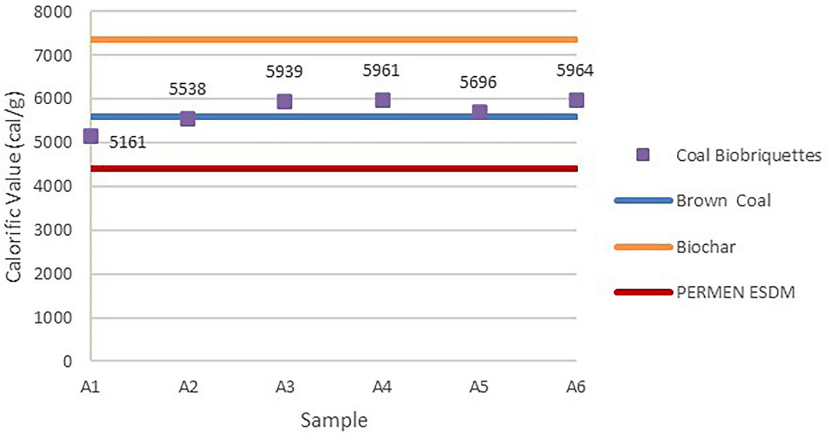

Figure 6. Calorific value of coal biobriquettes

The increasing composition of biochar can in fact increase the calorific value of coal biobriquette products as shown in Figure 6. Based on the composition variations carried out, each sample has met the standards of the Energy and Mineral Ministry Regulation Number 47 of 2006 which is above 4,400 cal/g. The lowest calorific value is owned by sample A_1 (75:25) at 5161 cal/g. This is because the inherent moisture and ash content of this sample is relatively high, thus affecting the calorific value of coal biobriquettes. The coal biobriquette sample with composition variation that gives the highest calorific value is A_4 (90:10) at 5961 cal/g. However, for biobriquettes without coal mixture that has the highest overall value is sample A_6 (100:0) which is 5964 cal/g. The high calorific value of the two samples is due to the high and low values of fixed carbon and volatile matter in coal biobriquettes (Sunaryo et al., 2023). Therefore, the composition variation with the best quality in coal biobriquettes is sample A_4. Sample A_4 (90:10) has the second highest percentage of fixed carbon after sample A_6 and the lowest volatile matter compared to other samples. This results in an increased calorific value compared to the initial brown coal value. Initially, the calorific value of brown coal was only 5250 cal/g, but it increased to 5961 cal/g after adding 90% biochar. Therefore, it can be concluded that increasing the biochar composition will improve the quality of coal biobriquettes as an alternative solid fuel.

Surface morphology and surface area

The surface morphology analysis of coal biobriquettes was conducted using a scanning electron microscope (SEM). This morphological analysis serves to see the appearance of cavities or pores between the constituent materials of coal biobriquettes. According to Adhani et al. (2019), f the cavities between the briquette materials are denser, then the calorific value produced tends to be higher as well. The product sample analyzed was the sample with the best quality, especially in terms of its calorific value, namely sample A_4. The composition of this sample consists of 90% acacia wood biochar and 10% brown coal with a calorific value of 5961 cal/gam. In addition to analyzing the surface morphology of coal briquette products, raw materials in the form of acacia wood biochar and brown coal were also analyzed to determine the initial morphology of raw materials before becoming coal briquettes. The results of SEM analysis of brown coal, acacia wood biochar, and sample A_4 of coal biobriquette products can be seen in Figure 7.

Based on the results of SEM analysis of brown coal in Figure 7a, the surface morphology of brown coal is rough with an irregular (amorphous) shape. In addition, the pore size of brown coal tends to be tight and the distribution is less visible. The average pore diameter of brown coal samples based on SEM analysis conducted with 2500 times magnification is 1.80 µm. The raw material of brown coal did not undergo pre-treatment such as heating, so the pores of brown coal are still filled with water and volatile matter it carries. In accordance with the statement from Li et al. (2020), that the release of gases consisting of water and flying substances during heating helps enlarge the pores and create a large number of coal macropores. Therefore, it is the absence of pre-treatment that causes the low combustion quality of brown coal.

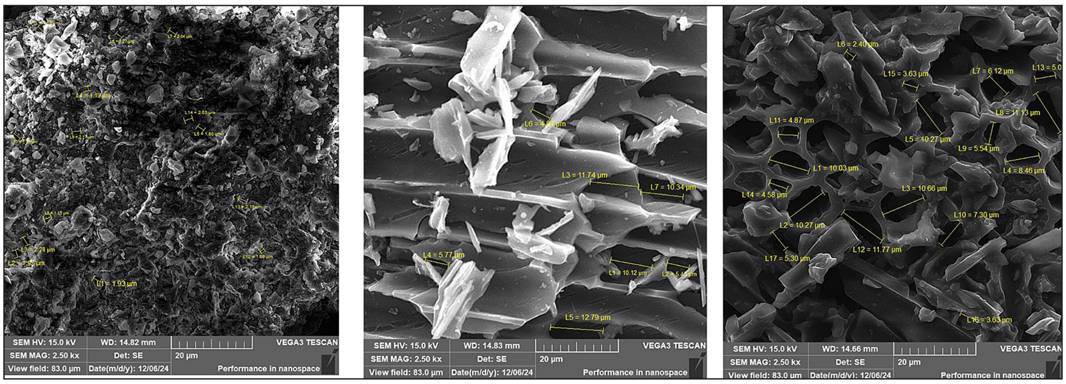

Figure 7. Scanning electron microscope characterization

Figure 7b shows the SEM analysis of the acacia wood biochar sample at 2500 times magnification. It can be seen that the biochar morphology has a pore surface that is evenly distributed but with non-uniform pore size. Pores on the biochar surface are clearly visible with an average pore diameter of 8.72 µm. The image shows wood fibers that are still clearly visible with some irregular channels and in some parts there are organized cellulose crystal microfibrils, which indicate the fibrous nature of lignocellulosic materials, even after the pyrolysis process (Beltrame et al., 2018). Pyrolysis causes biochar to develop porosity, resulting in large pore sizes. After pyrolysis, the existing pores will expand, and new pores will form due to the evaporation of decomposed cellulose components and the release of volatile matter from biochar. Additionally, the reduction of hydrocarbon compounds during pyrolysis also makes the biochar surface morphology clearer (Nurrahman et al., 2021). Meanwhile, the results of SEM analysis of coal biobriquette products with the best quality can be seen in Figure 7c.

Efforts to improve the quality of brown coal into coal biobriquettes with the addition of biochar from pyrolysis can also be seen from the surface morphology shown in Figure 7c, which is sample A_4 with a composition of 90:10. Figure 7c shows the SEM results of coal biobriquette samples with an average pore diameter of 7.12 µm. This indicates an enlargement of pore size from brown coal and a reduction in pore size from biochar after the briquetting process. When comparing the SEM results between biochar and coal biobriquettes, the fragmentation in the biobriquettes tends to be smaller, and the surface is smoother. This can occur because each component, both biochar and brown coal, has become a cohesive unit due to binding by molasses. From the SEM analysis results, the average pore sizes of biochar and brown coal are 8.72 µm and 1.80 µm. The briquetting process of both materials will experience compaction and consolidation with the help of the adhesive (Bembenek et al., 2021).

The pore size of coal biobriquettes indicates the consolidation of brown coal and minerals contained in molasses accumulated on biochar, forming a cohesive solid fuel. When related to proximate analysis results, the increase in calorific value of brown coal when turned into coal biobriquettes indicates a densification process has occurred. However, it is essential to note that the accumulation of inorganic/mineral compounds in biobriquettes will lower their quality. Additionally, the small pores of brown coal caused by the presence of impurities also contribute to the same negative impact. These coal biobriquettes have adequate quality to be used as alternative solid fuels to address the limited utilization of brown coal, but their fragmentation level should be reduced to increase densification.

CONCLUSION

The pyrolysis process conducted on acacia wood waste has produced high-quality biochar with the following properties: inherent moisture content 5.38%; ash content 1.31%; volatile matter 9.23%; fixed carbon 84.04%; and calorific value 7370 cal/g Increasing the proportion of biochar in briquetting will result in better quality biobriquette products. This indicates that biochar can enhance the quality of brown coal, which has limited utilization as an alternative fuel. The coal biobriquette with the best quality is sample A_4 (90% biochar:10% brown coal), which has inherent moisture content of 8.77%; ash content 7.82%;

volatile matter 32.13%; fixed carbon 51.28%; and calorific value 5961 cal/g. The surface morphology of coal biobriquette A_4 shows reduced fragmentation due to the addition of brown coal and molasses adhesive to biochar, leading to consolidation among each component, as seen from the pore size of the biobriquette at 7.12 µm compared to the original biochar pore size of 8.72 µm and brown coal pore size of 1.80 µm.

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REFERENCES

1. Abdullah, N., Mohd Taib, R., Mohamad Aziz, N.S., Omar, M.R., Md Disa, N. 2023. Banana pseudo-stem biochar derived from slow and fast pyrolysis process. Heliyon, 9(1).
2. Adhani, L., Asrya, M.A.M., Octavia, S.I., Sindiany, I.I. 2019. Analysis of alternative fuel composite bio-briquettes from water hyacinth with cow manure adhesive. Al-Kimiya, 6(2), 81–86. (In Indonesian)
3. Afrah, B.D., Riady, M.I., Cundari, L., Rizan, M.A., Aryansyah, A.D. 2020. Design of liquid smoke production equipment with pyrolysis method using fusion 360 software. Journal of Chemical Engineering, 26(3), 113–121. (In Indonesian)
4. Ali, L., Palamanit, A., Techato, K., Ullah, A., Chowdhury, S., Phoungthong, K. 2022. Characteristics of biochars derived from the pyrolysis and co-pyrolysis of rubberwood sawdust and sewage sludge for further applications. Sustainability, 14(1), 21.
5. Amini, M.H.M., Rasat, M.S.M., Ahmad, M.I., Wahab, R., Elham, P., Wan, W.M.N.A.R., Ramle, N.H. 2017. Chemical composition of small diameter wild leucaena leucocephala species. ARPN Journal of Engineering and Applied Sciences, 12(10), 3169–3173.
6. Azman, N.A.M., Pa, N.F.C. 2021. Production of smokeless biofuel briquettes from palm kernel shell assisted with slow pyrolysis treatment. Progress in Engineering Application and Technology, 2(1), 38–49.
7. Baskin, C.C., Baskin, J.M. 2022. Plant regeneration from seeds: a global warming perspective (1st ed.). Academic Press.
8. Beltrame, K.K., Cazetta, A.L., de Souza, P.S.C., Spessato, L., Silva, T.L., Almeida, V.C. 2018. Adsorption of caffeine on mesoporous activated carbon fibers prepared from pineapple plant leaves. Ecotoxicology and Environmental Safety, 147(1), 64–71.
9. Bembenek, M., Krawczyk, J., Frocisz, Ł., Śleboda, T. 2021. The analysis of the morphology of the saddle-shaped bronze chips briquettes produced in the roller press. Materials, 14(6), 1–18.
10. Borman, G.L., Ragland, K.W. 1998. Combustion Engineering. Mc Graw-Hill.
11. Brayen, D., Windiarti, R.Y.P., Erlinawati, Zikri, A. 2022. Effect of process variables and palm shell addition on sawdust biopelet characteristics. Distillation Journal, 7(1), 41–51. (In Indonesian)
12. Efiyanti, L., Wati, S.A., Setiawan, D., Pari, G. 2020. Chemical properties and charcoal quality of five wood species from west kalimantan. Journal of Forest Products Research, 38(1), 55–68. (In Indonesian)
13. Hakika, D.C., Jamilatun, S., Zahira, S., Setyarini, R., Rahayu, A., Ardiansyah, R.S. 2023. Combustion quality analysis of bio-briquettes from mixture of coconut shell waste and coal with tapioca flour adhesive. Indonesian Journal of Chemical Engineering, 1(1), 1–10.
14. Haliza, H.N., Saroso, H. 2023. Production of bio-briquettes from coconut coir and teak wood powder using tapioca starch adhesive. DISTILAT, 8(1), 238–244. (In Indonesian)
15. Hou, J., Pugazhendhi, A., Sindhu, R., Vinayak, V., Thanh, N.C., Brindhadevi, K., Lan Chi, N. T., Yuan, D. 2022. An assessment of biochar as a potential amendment to enhance plant nutrient uptake. Environmental Research, 214(2), 1–8.
16. Ifa, L., Yani, S., Nurjannah, N., Sabara, Z., Yuliana, Y., Kusuma, H.S., Mahfud, M. 2019. Production of bio-briquette from biochar derived from pyrolysis of cashew nut waste. Ecology, Environment and Conservation, 25(1), S125–S131.
17. Iskandar, T., Rofiatin, U. 2017. Biochar characteristics based on biomass types and pyrolysis process parameters. Journal of Chemical Engineering, 12(1), 28–34. (In Indonesian)
18. Kongprasert, N., Wangphanich, P., Jutilarptavorn, A. 2019. Charcoal briquettes from madan wood waste as an alternative energy in Thailand. Procedia Manufacturing, 30, 128–135.
19. Li, Z., Liu, D., Cai, Y., Si, G., Wang, Y. 2020. Pore structure and compressibility characteristics of heat-treated coals by N2 adsorption/desorption and mercury intrusion porosimetry. Energy and Fuels, 34(3), 3173–3187.
20. López-Beceiro, J., Díaz-Díaz, A.M., Álvarez-García,

A., Tarrío-Saavedra, J., Naya, S., Artiaga, R. 2021. The complexity of lignin thermal degradation in the isothermal context. Processes, 9(7).

21. Masthura, M., Daulay, A.H., Desgira, H.W. 2022. Effect of adhesive variation on the calorific value of briquettes from tea leaf powder. JISTech (Journal of Islamic Science and Technology), 7(1), 15–23. (In Indonesian)
22. Nurrahman, A., Permana, E., Gusti, D.R., Lestari, I. 2021. Effect of activator concentration on the quality of activated carbon from lignite coal. Journal of Daur Lingkungan, 4(2), 44–53. (In Indonesian)
23. Partiwi, W., Prabowoi, H. 2021. Proximate analysis of biocoal briquettes blend of CV. Bara Mitra Kencana Seam 1 Coal with Coconut Shell Charcoal. Journal of Bina Tambang, 6(5), 267–273. (In Indonesian)
24. Rath, D.P., Mahapatro, A., Pattanayak, B. 2023. Briquette production and performance evaluation from coal and agricultural waste. Materials Today: Proceedings, December 2023, 1–5.
25. Rauf, A.S., Widodo, S., Nawir, A. 2018. Improving calorific value of lignite coal with water and palm oil agglomeration method at PT. Indonesia Power UJP PLTU Barru. Jurnal Geomine, 6(3), 124. (In Indonesian)
26. Reza, M.S., Ahmed, A., Caesarendra, W., Abu Bakar, M.S., Shams, S., Saidur, R., Aslfattahi, N., Azad, A.K. 2019. Acacia holosericea: An invasive species for bio-char, bio-oil, and biogas production. Bioengineering, 6(2), 1–16.
27. Saputro, H., Yosin, K.A., Wijayanto, D.S., Muslim, R., Fitriana, L., Munir, F.A. 2021. A preliminary study of biomass briquettes based on biochar from pyrolysis of durian shell. Annual Engineering and Vocational Education Conference (AEVEC) 2020, 1808(18-19 September 2020).
28. Setiawan, B., Syahrizal, I. 2018. Performance of a mixture of sugarcane bagasse charcoal and coconut shell briquettes. Turbo: Journal of Mechanical Engineering Department, 7(1), 57–64. (In Indonesian)
29. Sihombing, L., Alpian, A., Mayawati, S., Jumri, J., Supriyati, W., Kehutanan, J., Pertanian, F. 2020. Characterization of charcoal briquettes from acacia wood (Acacia Mangium Willd) as renewable energy. Sustainable Technology Journal, 9(1), 31–38. (In Indonesian)
30. Sitogasa, P. S. A., Mohamad Mirwan, Firra Rosariawari, & Azizah M. Rizki. (2022). Analysis of Water and Ash Content in Biomass Briquettes from Durian Fruit Peel Waste and Sawdust. Journal of Research and Technology, 8(2), 279–288.
31. Sugiharto, A., & Firdaus, Z. ‘Ilma. (2021). Briquetting of Sugarcane Bagasse and Rice Husk Using Pyrolysis Method as Alternative Energy. Journal of Chemical Engineering Innovation, 6(1), 17–22. (In Indonesian)
32. Sunaryo, S., Sutoyo, S., Suyitno, S., Arifin, Z., Kivevele, T., Petrov, A.I. 2023. Characteristics of briquettes from plastic pyrolysis by-products. Mechanical Engineering for Society and Industry, 3(2), 57–65.
33. Utchariyajit, K., Panprasert, V., Chayawat, L., Jungthanasombat, W., Janprom, P., Choatchuang, M. 2019. Physical properties and calorific value of briquettes produced from Palmyra palm waste with molasses binder. IOP Conference Series: Materials Science and Engineering, 639(1).
34. Wahyuni, H., Aladin, A., Kalla, R., Nouman, M., Ardimas, A., Chowdhury, M.S. 2022. Utilization of industrial flour waste as biobriquette adhesive: Application on pyrolysis biobriquette sawdust red teak wood. International Journal of Hydrological and Environmental for Sustainability, 1(2), 54–69.
35. Zeng, K., He, X., Yang, H., Wang, X., Chen, H. 2019. The effect of combined pretreatments on the pyrolysis of corn stalk. Bioresource Technology, 281(1), 309–317.