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Research Article

Effect of Activation Time on the Quality of Microwave-Activated Sago Trunk Charcoal Briquettes (Metroxylon Sagu Rottb)

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Abstract

Research has been conducted on the effect of activation time on the quality of sago stem charcoal briquettes (Metroxylon Sago Rottb) activated by microwave. This experimental study aimed to determine the impact of activation time on various parameters of sagu stem charcoal briquettes, including density, moisture content, ash content, volatile matter content, fixed carbon content, calorific value, and combustion characteristics such as ignition time and flame rate. The research involved several stages, including raw material collection, carbonization, grinding and sieving, adhesive mixing, printing and bulking, drying, and quality assessment of the briquettes. Sago stem charcoal briquettes were produced using sago as an adhesive at a ratio of 9:1. The charcoal powder was sieved using an 80-mesh sieve. The samples were printed and compacted at a pressure of 100 kg/cm^2 and activated using a 150-watt microwave for durations of 5, 6, and 7 minutes. The results demonstrated that the density ranged from 0.3601 to 0.4892 g/cm^3, moisture content ranged from 2.103% to 3.369%, ash content ranged from 4.6422% to 6.4706%, volatile matter content ranged from 80.306% to 84.740%, fixed carbon content ranged from 7.222% to 11.1205%, calorific value ranged from 5467.5 cal/g to 5805.5 cal/g. The briquettes activated by microwave, under a pressure of 100 kg/cm^2, exhibited the highest quality, with a combustion rate ranging from 0.0137 g/min to 0.0183 g/min, maximum temperature ranging from 519 ^{o}C to 538 ^{o}C, and a briquette flame duration ranging from 29 minutes to 35 minutes.

Keywords: Briquettes, sago stem, carbonization, microwave activation, activation time.

INTRODUCTION

Petroleum is a non-renewable energy source utilized in everyday life, resulting in the depletion of petroleum reserves. Petroleum products used as fuel include Liquefied Petroleum Gas (LPG), gasoline, kerosene, diesel, and others. The calorific value of petroleum is 45 kJ/g (Jindal, Negi, Palla, Krishna, & Thallada, 2024; Sharma & Shrestha, 2023). Alternative energy sources developed as substitutes for petroleum include natural gas, coal, charcoal, and biomass. Indonesia has a significant biomass energy potential, estimated at 146.7 million tons per year (Sharma & Shrestha, 2023)

Biomass, the primary source of energy for living things, is estimated to contribute 13% of the world's energy supply. Biomass briquettes are an alternative for utilizing waste to increase the added value of agricultural products. Various potential biomass waste materials, such as rice husks, bagasse, coconut shells, sawdust, and livestock manure, have been used for biomass briquettes (Ahmad, Nisar, Anwar, & Muhammad, 2023; Jindal et al., 2024; Sudiana et al., 2017). Biomass, typically considered waste and often burned, is a biological material. Plant biomass mainly consists of lignin cellulose biomass, composed of cellulose, hemicellulose, and lignin, with small amounts of pectin, protein, extractive substances, and ash. One example of lignocellulose biomass is sago waste (Alam, Greco, Rajabimashhadi, & Esposito Corcione, 2024; Zhou & Tian, 2022).

Sago trunks can be utilized as an environmentally friendly alternative fuel to replace fossil fuels. Utilizing sago trunk waste as briquettes can increase the economic value of starch processing industry waste. Various potential biomass waste materials, such as rice husk, bagasse, coconut shell, sawdust, and livestock manure, have been used for biomass briquettes. However, the calorific value produced is still low due to high water content, ash content, and volatile matter content. Unlike the aforementioned materials, sago stems contain 56.86% cellulose and 37.70% lignin, making them highly potential for biomass briquettes since lignocellulose is the main ingredient required in briquette raw material (Ngene, Bouesso, González Martínez, & Nzihou, 2024; Silva, Filleti, Musule, Matheus, & Freire, 2022).

Existing biomass briquettes have not achieved the desired properties, necessitating various treatments during the manufacturing process to obtain briquettes with improved characteristics. In addition to charcoal, the addition of adhesive enhances the properties of the briquettes. Applying a thin layer of adhesive on the surface of the briquettes improves consistency and density. The use of adhesive materials in briquette making produces better results, including increased burning value and improved strength against external pressure (less prone to breakage) (Yirijor & Bere, 2024; Zhang, Sun, & Xu, 2018).

In addition to the raw material content, the briquette making process needs to consider the binding agent to produce compact briquettes. Organic adhesives generate minimal ash after burning and are generally effective, such as sago. Sago (Metroxylon Sp.) is a highly productive starch-producing plant and can be used as an adhesive. Southeast Sulawesi is an area with abundant sago potential. In addition to sago, clay can also be mixed with charcoal briquette materials. Based on the aforementioned background, this study focuses on manufacturing sago trunk charcoal briquettes activated by microwaves.

MATERIALS AND METHODS

Materials and instrumentations

The materials utilized consist of Sago trunk, Sago, distilled water, and Kerosene. The tools employed encompass a Mortar, Sieve, Microwave, Digital scales, Hot plate, Hollow cylinder briquette mold, Briquette compactor, Porcelain cup, Desiccator, Infrared thermometer, Vernier caliper Furnace, Aqua glass, Stirring rod, and Dropper pipette. Additionally, the DSC (Differential Scanning Calorimeter) is employed.

Preparation sample and adhesive stem sago

The stem sago is dried under sunlight to remove its water content. Subsequently, the refined sago is dried in the sun to eliminate any remaining moisture, ground using a mortar, and then sieved.

Carbonization process

The carbonation process begins with measuring the mass of the sample. Next, carbon material is placed into a previously prepared small drum, filling it to 75% of its volume. An igniter is then inserted into a larger drum and arranged so that the small drum can sit at a height of 10 cm inside the large drum. The igniter is ignited until lit. The small drum is then placed inside the large drum. The igniter material is replenished until it covers the small drum, reaching a height of 10 cm above the surface of the small drum lid. The temperature inside the large drum and the chimney are measured when the small drum is inside the large drum. This temperature measurement is conducted to control the temperature inside the large drum, ensuring it remains constant at the highest temperature reached. The air control hole on the chimney is observed to ensure that the sago stem has burned perfectly.

At a certain point in time, smoke starts to come out of the chimney. Once the smoke is no longer thick but appears clear, it indicates that the carbonization process is complete. The charcoal is then removed from the small drum and cooled by splashing it with water. Next, the sago stem charcoal is refined using a mortar and sifted through a 70-mesh sieve. The powder that passes through the sieve is collected. After that, the powder is sifted again using an 80-mesh sieve, and this time, the remaining powder is collected.

Activation charcoal stem sago using microwave

A total of 10 grams of charcoal stem sago were placed in a cup and then securely wrapped with aluminum foil. The activation process of the charcoal stem sago was conducted using a microwave, with activation parameters set at 10, 15, and 20 minutes.

Mixing process powder charcoal stem sago with adhesive sago

The process of mixing charcoal and adhesive is performed using a standardized method involving the precise measurement of the mass of the powder stem sago and the adhesive material in a ratio of 9:1. Specifically, 4.5 grams of powder charcoal stem sago is carefully weighed and combined with 0.5 grams of adhesive sago. The mixture of powder charcoal stem sago and adhesive sago is then thoroughly stirred until a uniform consistency is achieved. To facilitate this process, 2 mL of heated water, maintained at a temperature of 100°C, is gradually added to the mixture on a hot plate. The stirring process is continued until the components of powder charcoal stem sago and adhesive sago are completely integrated and a homogeneous mixture is obtained.

Compaction process briquette charcoal stem sago

A mixture of powdered charcoal, weighing more than 5 grams, was introduced into a mold to form cylindrical hollow briquettes with an inner diameter of 0.8cm and a height of 8cm. The powdered charcoal mixture was compacted using pressure levels of 34.66 kg/cm2, 69.32 kg/cm^2, 103.98 kg/cm^2, and 117.78 kg/cm^2.

Analysis process briquette charcoal stem sago

Density

This test aims to determine the mass of briquettes by comparing it to the volumetric dimensions of briquette charcoal stems made from sago. The test determined by Equation 1 and Equation 2.

$$Briquette\ Density\ (\rho) = \frac{m}{Vtot} \quad (1)$$

$$Briquette\ Volume\ (Vtot) = \pi r^2 t \quad (2)$$

Where ρ represents the density of the briquette (g/cm^3), m is the mass of the briquette (g), V_{tot} denotes the total volume (cm^3), r denotes the radius (cm), and t represents the height of the briquette (cm).

Water content (ASTM D.3137-11)

The process begins by weighing a sample of briquette stem sago. This weighed sample is then placed into a cup that has already been measured for its empty mass. To determine the empty mass, the cup is heated to a temperature of 105°C for several hours and then allowed to cool before being weighed. This heating and weighing process is repeated until a constant mass is achieved. Once the cup containing the sample is prepared, it is placed into an oven and heated at a temperature of 105°C for a duration of 3 hours. After the heating process, the cup is lifted and transferred into a desiccator to cool down and prevent any external contamination. Once cooled, the cup, now containing the briquette stem sago, is weighed again inside the desiccator. To determine the water content in the sample, Equation 3 is used.

$$M\ (\%) = \left(\frac{m_2 - m_3}{m_2 - m_1}\right) \times 100\% \quad (3)$$

Where M (%) represents the moisture content in percentage, m1 represents the mass of the empty cup in grams, m2 represents the mass of the cup with the sample in grams, and m3 represents the mass of the cup with the sample after heating in grams (Ulfi, et al., 2016).

Ash content (ASTM D.3174-12)

Sample briquette stem sago entered to in cup porcelain that has been counted heavy empty . Sample heated on temperature 700 °C to become ash for 3 hours. The sample was cooled in desiccator . sample weighed And determined level the ashes with Equation 4.

$$AC\ (\%) = \left(\frac{m_3 - m_1}{m_2 - m_1}\right) \times 100\% \quad (4)$$

Where AC represents the ash content (%), m1 signifies the mass of the cup when empty (in grams), m2 represents the mass of the cup when empty plus the mass of the sample (in grams), and m3 signifies the mass of the cup plus the sample after being subjected to a temperature of 700 °C (Ulfi, 2016).

Volatile matter (ASTM D.3175-10)

A sample of charcoal briquette, with a known water content, is placed into a porcelain cup and covered with a porcelain lid. The sample is then carefully introduced into a furnace and heated to a temperature of 750 °C for a duration of 15 minutes. Afterward, the sample is allowed to cool inside a desiccator. The content of volatile matter present in the sample is determined using Equation 5.

$$VM\ (\%) = \left(\frac{m_2 - m_3}{m_2 - m_1} \times 100\%\right) - M\ (\%) \quad (5)$$

Where m_1 represents the mass of the empty cup (in grams), m_2 represents the mass of the cup plus the sample (in grams), and m_3 represents the mass of the cup plus the sample after being heated to a temperature of 750 degrees Celsius (Ulfi, 2016).

Fixed *carbon* (ASTM D.2172-12)

The bound carbon content refers to the fraction of carbon in charcoal that excludes the ash, volatile matter, and water fractions (Earl, 1997 in Husada, 2008). The fixed carbon content is determined by reducing the total carbon content by 100% against the percentage of water content, volatile matter content, and ash content.

Mark heat

The sample was weighed and then placed in a cup. The cup containing the sample was pressed using a press tool. The cup was then inserted into the DSC (Differential Scanning Calorimeter) 4000 calorimeter slowly and closed securely. The reactor was filled with nitrogen gas, and the computer device connected to the DSC 4000 calorimeter was operated. Furthermore, the system DSC 4000 calorimeter, which was connected to the computer, will read the calorimetry results.

Test on briquette stem sago

The briquettes are to be tested by burning them in North Sulawesi. A stopwatch will be used to time the burning process, starting from the moment the briquette is ignited until it turns into coal. The duration of burning the briquette from the moment it forms coal until all briquettes turn into ash will be calculated. Additionally, the maximum temperature will be measured using an infrared thermometer.

RESULTS AND DISCUSSION

Quality analysis of sago trunk charcoal briquettes (Metroxylon Sagu Rottb)

Density

Density refers to the ratio between the mass and volume of a compound (Putrid, 2017). Briquettes with high density exhibit higher compressive strength, ash content, bound carbon, and calorific value compared to briquettes with low density (Figure 1).

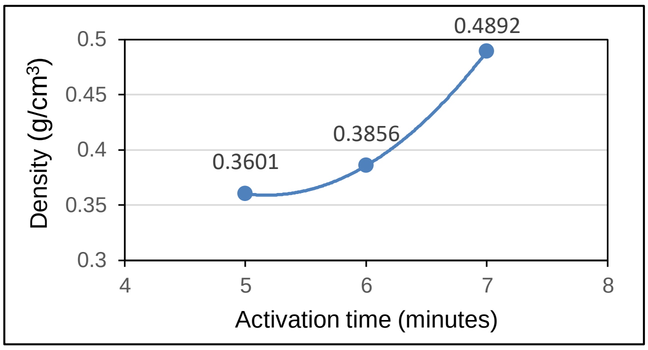

Figure 1. illustrates the relationship between activation time and the density of charcoal briquettes made from sago trunk.

Based on the conducted research (Figure 1), the density obtained at 5 minutes of activation time was 0.3601 g/cm^3. At 6 and 7 minutes of activation time, the densities obtained were 0.3856 g/cm^3 and 0.4892 g/cm^3, respectively. The results of this study also indicate that longer activation times result in higher briquette density. This is because longer activation times lead to smaller briquette particle sizes. Smaller particle sizes result in better quality of bonding due to increased contact surface area between particles. Thus, the 7-minute activation time leads to even denser briquettes.

Water content

The moisture content of briquettes refers to the ratio of the weight of water contained in the briquette to the dry weight of the briquette. Water content in solid fuel includes internal water, hygroscopic water, external water, and mechanical water. High water content negatively impacts the calorific value and combustion characteristics of solid fuel (Amalinda & Rismawati, 2019). The results of the research reveal that the water content in these briquettes changes over time. At an activation time of 5 minutes, the water content is 3.396%. For activation times of 6 minutes and 7 minutes, the water content decreases to 2.825% and 2.103% respectively.

The microstructural changes in the briquettes, such as smaller grain size and larger pores, facilitate the evaporation of water during the drying process. Consequently, the water content in the briquettes decreases, while the heat content increases. This is due to the fact that high water content reduces the calorific value, as the heat of the briquette is initially utilized to evaporate the water instead of emitting radiation for combustion heat (Sudiana et al., 2017).

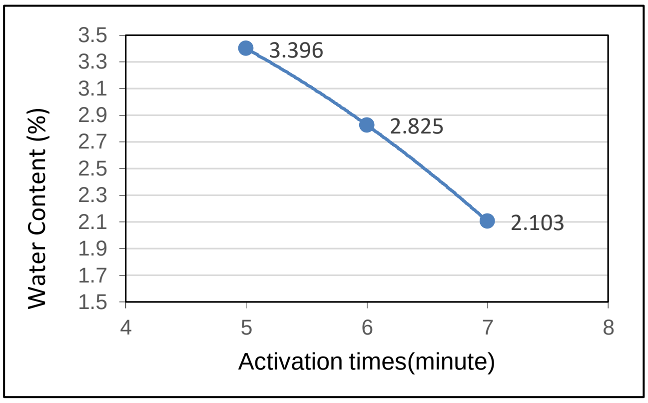

Figure 2. illustrates the relationship between activation time and water content in charcoal briquettes made from sago trunk.

As depicted in Figure 2, the water content in sago stem charcoal briquettes decreases with longer activation times. This is attributed to increased exposure of the briquettes to radiation energy from the microwave as activation time is extended. This energy induces changes in the microstructure of the briquette pores and grain size.

Additionally, ash content is an important factor to consider. Ash represents the inorganic material remaining after wood is heated to a constant weight. Silica is the main component of ash. The higher the ash content, the lower the calorific value and overall quality of the briquettes. Further note that ash is the residual part of the combustion process devoid of carbon elements (Amalinda & Rismawati, 2019).

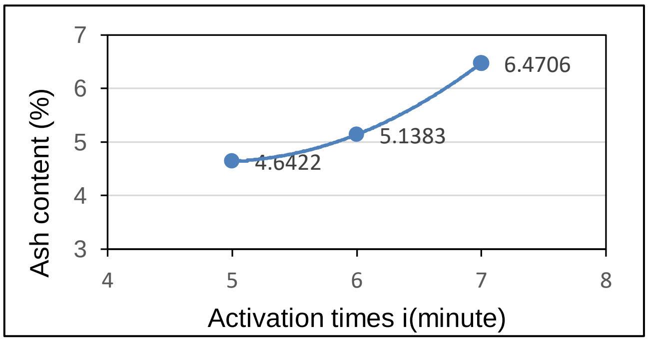

Figure 3. Graph illustrating the relationship between activation time and ash content reduction in sago trunk charcoal briquettes.

According to Figure 3, the ash content of sago stem charcoal briquettes is influenced by activation time. The ash content at 5 minutes of activation was 6.4706%. Subsequently, at 6 minutes and 7 minutes of activation, the ash content increased to 5.1383% and 4.6422% respectively. The ash content occurs when activation is conducted with a microwave, as the heat from microwave radiation causes organic compounds and hydrocarbons in the briquettes to evaporate. This, in turn, leads to a higher amount of residual combustion substances and subsequently a higher ash content value. The findings of the study indicate that the ash content increases as the activation time increases. This is due to prolonged exposure of sago stem charcoal briquettes to microwave radiation heat during activation. As a result, a significant amount of compounds in the briquettes, particularly hydrocarbons, evaporate, leading to a higher ash content (Arifin & Noor, 2016; Ngene et al., 2024; Sudiana et al., 2015).

Furthermore, the level of volatile matter in charcoal briquettes affects their combustion. Volatile compounds refer to substances that can evaporate when charcoal compounds decompose, excluding water. A higher concentration of volatile substances in charcoal briquettes results in increased smoke production when the briquettes are ignited. This is attributed to the reaction between carbon monoxide. The decomposition of volatile compounds in fuel helps stabilize the flame and accelerate the combustion of charcoal (Anggoro, Wibawa, & Fathoni, 2017).

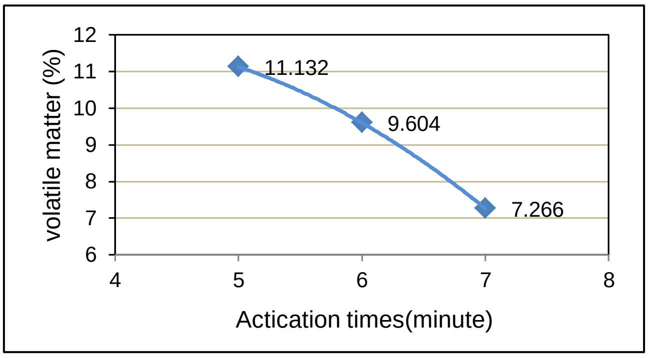

Figure 4. Graph of the Relationship between Activation Time and Levels of Volatile Matter in Sago Trunk Charcoal Briquettes.

According to Figure 4, the volatile matter level at 5 minutes of activation time was 11.132%. In contrast to the ash content, the volatile matter content decreased at 6 minutes and 7 minutes of activation time. The decrease in volatile matter content is influenced by activation time. The use of rapid heating with microwaves can reduce the ash and volatile matter content of briquettes. As the briquettes are activated for a longer time, the ash and volatile matter content decrease even further. This explains why the volatile matter levels decrease with increasing activation time. The decrease in volatile matter content is also influenced by the moment charcoal is activated with a microwave. The rapid heating with a microwave not only removes the remaining water content, but also reduces the ash and volatile matter content (Asomaning, Haupt, Chae, & Bressler, 2018; Hasan, Abdul Rahman, Nyakuma, & Muhamad Said, 2024; Mohamad Aziz et al., 2024; Sudiana et al., 2017).

Fixed Carbon Content

The fixed carbon content refers to the carbon fraction in charcoal that is apart from the ash fraction, volatile matter, and water. It is calculated as the FC (Fixed Carbon) content, which represents the fixed carbon content found in solid fuels in the form of charcoal (Figure 5).

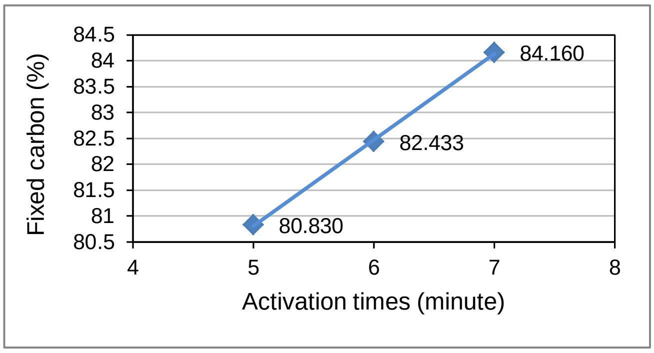

Figure 5. Graph illustrating the relationship between activation time and fixed carbon concentration in sago trunk charcoal briquettes.

Based on the research findings (Figure 5), the fixed carbon content decreased with each activation time. The minimum fixed carbon content was observed at 5 minutes of activation time, measuring 80.830%. Conversely, the maximum fixed carbon content was recorded at 7 minutes of activation time, measuring 84.160%. This increase in fixed carbon content can be attributed to the decreasing levels of volatile matter in the sago stem charcoal briquettes, resulting in an increase in fixed carbon content. Additionally, the activation time plays a role in determining the fixed carbon levels. Longer activation times lead to smaller briquette microstructures, including reduced grain size and increased pore size. This results in the loss of volatile matter content and subsequently higher fixed carbon content. The higher bound carbon content is influenced by factors such as water content, ash content, and volatile matter. Briquettes with higher water content, ash content, and volatile matter tend to have lower bound carbon content (Zhang et al., 2018).

Calorific value

Heat is defined as the energy transferred between a system and its surroundings due to a temperature difference. Calorific value, measured as gross calorific value, is a metric used to quantify the heat or energy produced. It is expressed in units of Btu/lb or kJ/kg. Calorific value is an important parameter as it directly impacts fuel efficiency. A higher calorific value indicates a greater potential for biomass to be used as a source of energy. The heat value, which is higher, contributes to more efficient burning and reduces biomass requirements. Higher heat values also lead to slower burning rates (Zhang et al., 2018; Zhou & Tian, 2022)

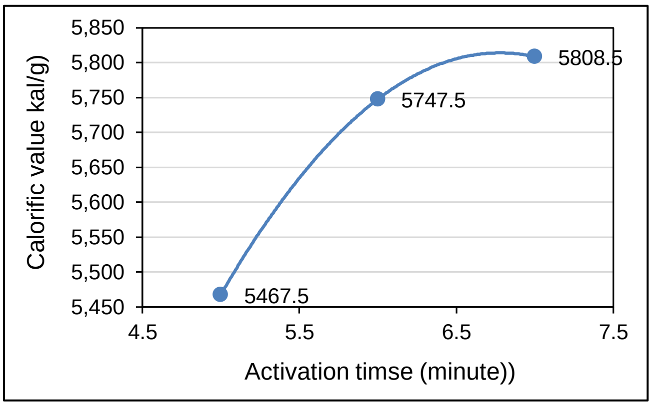

Figure 6. Graph illustrating the relationship between activation time and calorific value for sago trunk charcoal briquettes.

Based on the findings of the conducted research (Figure 6), the calorific value obtained was 5,467.5 cal/gram at an activation time of 5 minutes. At an activation time of 6 minutes, the calorific value increased to 5,747.5 cal/gram, and further increased to 5,808.5 cal/gram at an activation time of 7 minutes. The study revealed a significant and statistically significant increase in calorific value with the increase in activation time. This can be attributed to the larger pores that open up in the briquette with longer activation times, facilitating the evaporation of water content and volatile matter, resulting in a higher calorific value.

Sago trunk charcoal briquette quality

The ignition time is the duration it takes for the briquettes to ignite and produce embers when burned. A shorter ignition time indicates good briquette quality. This time is measured from the moment the briquettes are ignited until they begin to burn.

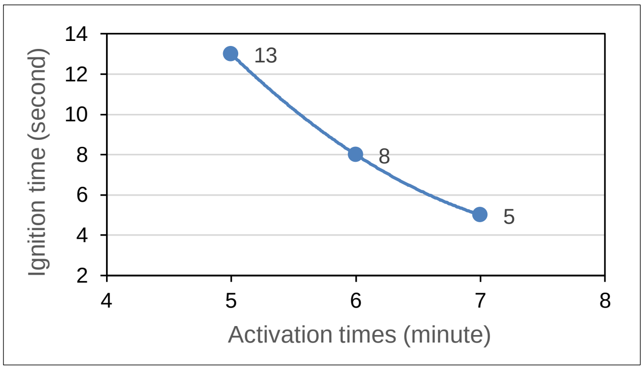

Figure 7 illustrates the relationship between activation time and ignition time for sago trunk charcoal briquettes.

Based on the research conducted (Figure 7), an ignition time of 13 seconds was obtained. Activation times of 6 minutes and 7 minutes resulted in ignition times of 8 seconds and 5 seconds, respectively. Activation time directly affects the ignition time, with longer activation times resulting in faster ignition. This is due to the higher levels of calorific value and fixed carbon present in the briquettes activated for 7 minutes, which contribute to a shorter ignition time.

Burning rate

The burning rate refers to the time it takes for one gram of briquette to transform into ash, starting from the formation of coals. Briquettes are considered to be of good quality if they have a low flame rate. Based on this graph (Figure 8), the burning rate at 5 minutes of activation time was measured at 0.0183 g/minute. The study also revealed that the burning rate increases as the activation time lengthens.

Additionally, the burning rate of the briquettes is affected by the fixed carbon content and calorific value, whereby higher fixed carbon content and calorific value result in faster burnout of the briquettes.

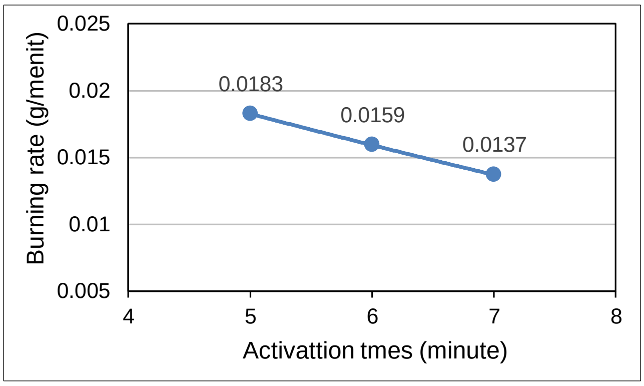

Figure 8. illustrates the relationship between activation time and burning rate for sago trunk charcoal briquettes.

Burning rate and burning time

The measurement of burning rate is conducted using an infrared thermometer to monitor the temperature of the briquette during the burning process. Combustion can be defined as a rapid process of oxidation reaction between fuel and oxidizer, producing flame and heat.

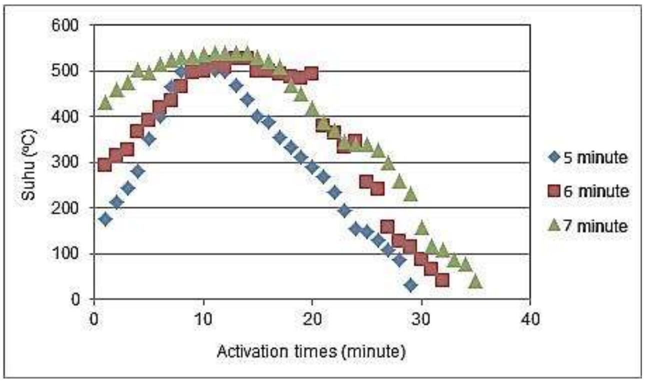

Figure 4.9 The relationship between activation time and burning rate, as well as burning time for sago trunk charcoal briquettes.

The measurement of temperature during the burning time of the briquettes indicates that increasing the activation time prolongs the combustion time, resulting in higher temperatures. Additionally, this study recorded a maximum temperature of 538°C after 7 minutes of activation time.

CONCLUSION

The impact of variation in activation time on the optimal quality of sago stem charcoal briquettes was observed at an activation time of 7 minutes. The resulting briquettes exhibited a density of 0.489 g/cm3, a water content of 2.103%, an ash content of 6.4706%, a volatile matter content of 80.306%, a fixed carbon content of 11.120%, and a calorific value of 5,805.5 cal/g. Furthermore, the effect of activation time on the combustion of sago stem charcoal briquettes was generally observed to be most favorable at an activation time of 7 minutes. These briquettes demonstrated an igniting time of 5 seconds, a combustion rate of 0.0137 g/minute, a combustion time of 35 minutes, and a maximum briquette temperature of 538°C.

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