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Effect of Gondorukem (Arpus) Adhesive Composition on Organic Waste-Based Briquettes using Biodrying Technology

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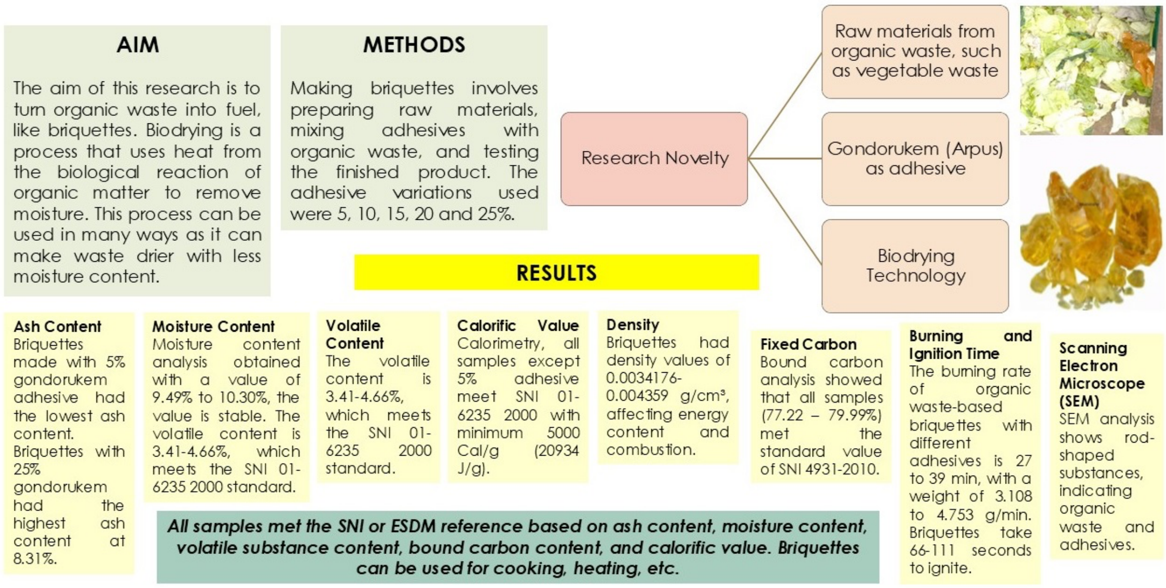
GRAPHICAL ABSTRACT



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ABSTRACT

This research aims to turn organic waste into fuel, like briquettes. Briquettes are one way to deal with organic waste. This research turns organic waste into briquettes using the biodrying technique. Briquettes made with 5% gondorukem adhesive had the lowest ash content. Briquettes with 25% gondorukem had the highest ash content at 8.31%. Moisture content analysis was obtained with a value of 9.49% to 10.30%; the value is stable. The volatile content is 3.41-4.66%, which meets the SNI 01-6235 2000 standard. Calorimetry: all samples except 5% adhesive meet SNI 01-6235 2000 with a minimum of 5000 Cal/g (20934 J/g). Briquettes had density values of 0.0034176-0.004359 g/cm³, affecting energy content and combustion. Bound carbon analysis showed that all samples met the standard value of SNI 4931-2010. The burning rate of organic waste-based briquettes with different adhesives is 27 to 39 min, weighing 3.108 to 4.753 g/min. Briquettes take 66-

111 seconds to ignite. SEM analysis shows rod-shaped substances, indicating organic waste and adhesives. All samples met the SNI or ESDM reference based on ash content, moisture content, volatile substance content, bound carbon content, and calorific value. Briquettes can be used for cooking, heating, etc.

1. INTRODUCTION

Energy demand continues to grow, driven primarily by population growth and significant increases in commercial and industrial activity worldwide. Fossil fuels, such as petroleum products, coal, natural gas, etc., are the most important energy source, meeting approximately 80% of the world's primary energy needs. Increased global demand for and use of fossil fuels has fueled economic growth, exacerbated the adverse climate impacts of greenhouse gas (GHG) emissions, and threatened public health [1]. According to data assembled by the Ministry of Environment and Forestry of Indonesia in 2022, this country's total waste is 68.7 million tons per year. This waste is composed primarily of organic matter, with food waste accounting for 41.27% of the total. Approximately 38.28% of the waste originates from residential sources. Certain organic materials, including vegetable scraps, food waste, and rotten fruit, can be utilized as a base material for briquette production. Using organic waste can minimize the waste currently being thrown into the environment. This resource must be utilized optimally to enhance its intrinsic value, fostering economic growth for diverse stakeholders, including traders, farmers, gardeners, and the broader community.

In most developing countries, the annual production of organic and agricultural biomass waste is limitless. The inefficient utilization and indiscriminate disposal of these wastes pose a significant environmental threat. Drying techniques make the conversion of these wastes into high-density, energy-efficient briquettes possible. The process of biodrying organic waste into briquettes offers a renewable energy alternative to fossil fuels. The lower sulfur and nitrogen content of organic biomass waste reduces NOx and SOx emissions when compared to coal [2].

Nabil et al. (2022) made briquettes from plastic waste. Different techniques and adhesives can be used to make briquettes from plastic. Briquettes made with starch adhesive had a calorific value of 6328 kcal/kg and a specific heat of 6366 kcal/kg. Arpus adhesives usually produce black smoke because they have a high heating value and are made from rubber tree sap [3]. Biodrying is one way to treat municipal solid waste, according to Jolanta Latosińska et al., 2022. Biodrying removes water from waste [4]. Khan et al. (2023) used biomass waste to make bio-coal briquettes. The study shows that bio-coal briquettes can help solve energy problems and provide good heat [5]. Miller and Takase (2023) produced composite biomass briquettes utilizing household waste and coconut fiber as the primary constituents, with coconut fiber as the binder. Cow dung was employed as an additional binding agent. The composite biomass briquettes had high heating values of 19.3 MJ/kg, 7.4% ash, and a 512.03 g/m³ density. The cow dung used as a binder had excellent lignin composition and adhesive properties. These properties conform to ASTM E791-08 standards [6].

In modifying the aeration-supplied configuration in the biodrying process to produce refuse-derived fuel, Bhatsada et al. (2023) obtained a moisture content of 24.07% and a calorific value of 4787 kcal/kg. The aeration-supplied configuration can be utilized in the local cement industry in Thailand [7]. As He et al. (2013) indicated, the research findings suggest multiple methods for enhancing energy efficiency and improving drying. These methods include making organic material decompose faster, improving the material's structure, using heat from the exhaust to speed up drying, and using solar and waste heat to aid drying [8]. Pecorini et al. (2020) used a light biodrying technique with anaerobic pre-treatment of plantation waste. The results showed a high weight reduction (47-48%) was achieved due to moisture loss and improved stability. Biodrying light fraction can be used as fuel. It meets waste fuel standards [9].

Yerizam et al. (2020) produced briquette bio-pellets from coconut shell waste as an alternative energy source for households. The best quality of bio-pellets is seen in the temperature variation, namely 500 °C drying temperature and 1 hour cooking time with 10.58% moisture, 11.03% ash, and

30.01% fixed carbon. It has 30.01% substance content, 48.38% fixed carbon content, and a calorific value of 6564.88 cal/g. This meets the bio-pellet standard SNI 8021-2014 [10]. Harussani et al. (2021) used pyrolysis to make briquettes from PP waste from Coronavirus Disease 2019 (COVID-19) using palm starch. The material in question exhibits excellent compressive strength and a high heating value [11].

One potential solution to the issue of urban waste is the utilization of waste as fuel or refuse-derived fuel (RDF). A variety of processes may be employed to produce RDF, including biodrying. Biodrying represents a specific application of mechanical-biological treatment (MBT) technology. This process aims to reduce the moisture content of waste materials by harnessing the heat generated from the activities of microorganisms engaged in the degradation of organic matter. This approach is designed to enhance the calorific value of the waste stream [12]. This study aims to investigate the feasibility of converting organic waste into a fuel source, such as briquettes, as a potential solution for the management of organic waste disposal. Organic waste was made into briquettes using the biodrying technique. The briquettes were made using vegetable and fruit waste with gondorukem (arpus) adhesive at 5, 10, 15, 20, and 25%. The different adhesives are used to find the best chemical and physical properties, including ash content, moisture content, volatile content, calorific value, bound carbon, density, flash time, and morphology.

2. EXPERIMENTAL METHODS

The organic waste that will be used as the primary raw material for manufacturing briquettes is vegetable waste and odor fruits from the market of Lhokseumawe City, Aceh and gondorukem (arpus) from pine resin as an adhesive. The research procedure carried out consists of several stages, namely: the preparation stage of raw materials, the crushing and sieving stage, the stage of making adhesive materials, the stage of mixing adhesives with organic waste, the printing and drying stage, then the testing stage on the briquettes produced.

2.1. Drying with Biodrying Reactor

Organic waste was analyzed for moisture content before being put into the biodrying reactor. Organic waste weighing 5 kg was put into the reactor. The blower at the back is turned on with an airflow rate of 2.5 m^3/hour (0.04167 m^3/min). The reactor ran 18 hours daily for three days to see what would happen. Moisture content, temperature, waste mass and leachate volume were measured every three days until day 12.

2.2. Crushing and Sieving

Crushing organic waste is carried out with a crusher after the drying process using biodrying technology. After the destruction of organic waste, screening is carried out with a sieve measuring 40 mesh to obtain fine powder.

2.3. Preparation of Adhesive Materials

The process of making adhesive material is mixing gondorukem (arpus) as much as 5, 10, 15, 20, and 25% into 30 mL of water, then stirring until homogeneous. After that, the adhesive material that has been homogeneously mixed is heated to a temperature of 100°C until the adhesive material thickens.

2.4. Mixing of Adhesive with Organic Waste, Molding and Drying

After the organic waste is 40 mesh in size, it is mixed with adhesive material in a ratio of 1:1. After mixing perfectly, pressing is carried out with a pressure of 200 kg/cm^2. The molded briquettes are then dried in the sun for 7 days until they have the lowest moisture content. The briquette drying process aims to avoid disturbing the calorific value and combustion rate during testing.

2.5. Characterization and Testing

The ash content test on briquettes aims to determine the level of inorganic materials in the briquettes. Ash content is the residual material that remains after the material is burned, such as charcoal bio-briquettes. Samples in a cup are placed in an oven at 600°C for 1 hour. The material is cooled in a desiccator and then weighed, and the results of the scales are subtracted from the weight of the cup. Take a sample to be burned. After the combustion process, the ash waste produced is weighed using a scale to determine the ash content produced. Calculating ash content with Equation 1.

$$\text{Ash Content} = \frac{\text{weight of ash}}{\text{weight of the sample before ashing}} \times 100\% \quad (1)$$

The water content test determines the high and low water content produced by a combination of substances used in several comparisons. Briquettes' moisture content affects their calorific value and combustion rate. Elevated moisture content will reduce both the heating value and combustion rate, as the heat applied is initially employed to evaporate the water present within the briquette. To test the water content, weigh 5 grams of briquettes in a porcelain cup, heat it in an oven at 105°C for one hour, and then weigh it again. Weigh in a desiccator for 15 minutes. Heating and weighing were repeated until the weight was fixed. Moisture content is expressed as a percentage (w/w), calculated to two decimals using the formula in Equation 2.

$$\text{Moisture Content} = \frac{W_2 - W_1}{W} \times 100\% \quad (2)$$

Where, W_1= Final Weight; W_2 = Cup + Sample Weight and W = Sample Weight.

Briquette quality can be determined by testing for volatile content. This affects how well briquettes burn and the strength of the fire. Briquettes contain carbon, hydrogen, and oxygen from biomass. Volatile matter is material that evaporates at 600°C. Burning these volatiles produces heat. This heat is measured and called the briquette's calorific value. Equation 3 below to calculate the volatile content of briquettes.

$$\text{Volatile content} = \frac{(\text{Weight of cup+sample before heating}) - (\text{Weight of cup+sample after heating})}{(\text{Weight of cup+sample before heating}) - \text{Weight of empty cup}} \times 100\% \quad (3)$$

The heat test on briquettes shows how much heat each mass of briquettes produces. The calorific value is a crucial quality parameter for briquettes intended for use as fuel. The higher the heating value, the superior the quality of the briquettes. The heat test is carried out using a bomb calorimeter. The calorific value obtained through the bomb calorimeter is lower (lowest heating value, LHV).

The weight of the briquettes was determined by weighing them on a digital scale. Moreover, the dimensions of the briquettes (height and diameter) were measured to determine their volume. The determination of density was carried out at a specific moisture content (based on the results of the calculation of the moisture content of the ASTM D 3173-03 standard [13], following the ASTM D 2395-14 standard [14], and was calculated using the following Equation (4):

$$\text{Density} = \frac{m}{v} \quad (4)$$

In the formula, the value of "m" represents the mass of wood in briquettes (in grams) and "v" represents the volume (in cubic centimeters).

The percentage of the fixed carbon content of the briquettes was calculated by subtracting the amount of volatile matter, ash content, and moisture content from 100, and the percentage of the fixed carbon content of the briquettes was calculated.

$$\text{Fixed Carbon} = 100\% - (\text{Moisture Content} + \text{Volatile Matter} + \text{Ash Content}) \quad (5)$$

The flame test was conducted to determine how long it takes for the briquettes to ignite until they become ash. The test was carried out using 30 grams of each sample (not repeated), then heated on a gas stove with open surrounding conditions until the briquettes began to burn. Briquette ignition time is calculated using a stopwatch. Combustion rate testing is a process of burning briquettes to determine the flame duration of a fuel and then weighing the mass of briquettes that burn. The duration of ignition time is calculated using a stopwatch, and the mass of briquettes is weighed on a digital scale.

3. RESULTS AND DISCUSSIONS

3.1. Ash Content Analysis

Ash content research on briquettes is done to see how well they burn and how good they are. If there is too much ash, the briquettes will burn less well and be less valuable [15]. Figure 1 presents the ash content results of organic waste-based briquettes from vegetable and fruit wastes with variations of gondorukem (arpus) adhesive (5, 10, 15, 20 and 25%).

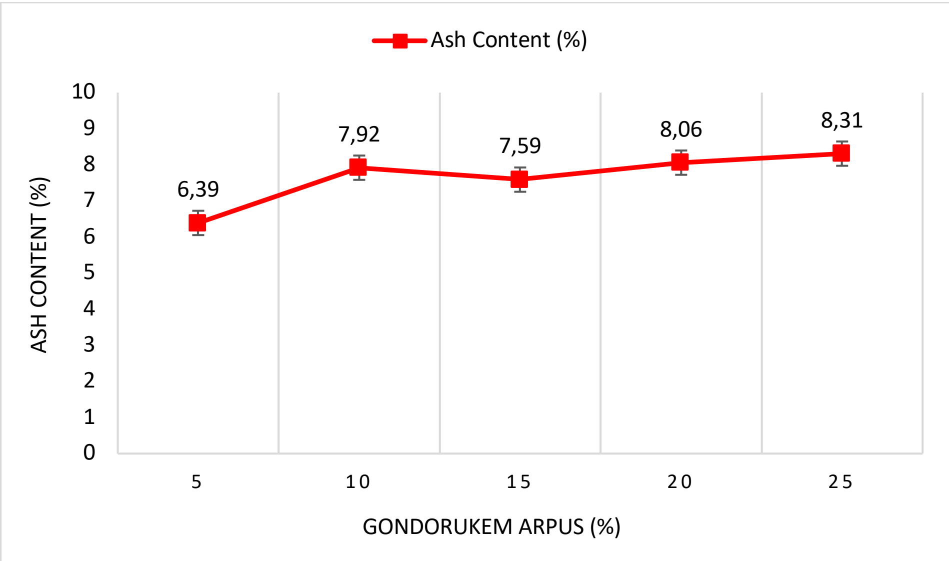

Figure 1. Ash content of briquettes made from organic waste with gondorukem (arpus) adhesive

The ash content of the organic waste briquettes exhibited a range of 6.39% to 8.31%, as illustrated in Figure 1. The lowest ash content was observed in briquettes produced with a 5% gondorukem (arpus) adhesive ratio, exhibiting a value of 6.39%. Conversely, the highest ash content was observed in briquettes manufactured with a 25% gondorukem (arpus) adhesive ratio, displaying a value of 8.31%. The data shows a clear correlation between using adhesives in briquettes and the resulting ash content. Specifically, an increase in the use of adhesive is related to the ash content. Higher adhesive proportions result in higher ash content, while lower adhesive proportions result in lower ash content.

Tambunan et al. (2023) found that wood briquettes made from mata buaya wood with potato starch had the lowest ash content, while those made from buta-buta wood with corn starch had the highest. Most wood briquettes met the ISO 17225-3:2-2020 class A_2 standard, requiring a maximum % ash content of 3%. Two exceptions were wood briquettes made from oil mangrove with potato starch adhesive and buta-buta with corn adhesive. Wood briquettes made from mata buaya wood with potato starch adhesive meet the minimum ash content for class A_2 (KFRI), which requires less than 1.50% [16]. Maulidna et al. (2023) produced charcoal briquettes from banana frond and palm trunk materials. Their results indicated an ash content ranging from 0.25% to 0.30%. Ash content is an important quality parameter for briquettes, as excessive ash can reduce their calorific value by forming crusts that impede ignition. Conversely, briquettes with low ash content exhibit superior quality [17].

Nikiforov et al. (2023) studied the ash content of bio-coal briquettes made from agricultural waste and coal. The ash content of the briquettes was between 8.33% and 14.42%. This is a little higher than the standard but much lower than the ash content of coal used in small boilers and households. Leaf briquettes burned longer than sunflower husk briquettes. Leaves have more lignin and are denser. A considerable ash content in coal markedly affects its operational efficiency in terms of calorific value, rendering it unsuitable for utilization [18]. The ash content of briquettes made from organic waste and gondorukem (arpus) adhesive (5, 10, 15 and 20%) is optimal. It meets the SNI 01-6235-2000 standard for wood charcoal briquettes, allowing up to 8% ash (Indonesia SNI, 2020) [19].

3.2. Moisture Content Analysis

The moisture content of briquettes is employed to ascertain their hygroscopic properties. Briquettes with elevated moisture levels may exhibit brittleness, which can be attributed to inadequate drying periods. As stated by Solano et al. (2016), before the briquetting process, biomass must undergo a drying procedure to attain a moisture content (MC) of 5-15% [20]. Figure 2 illustrates the ash content of organic waste-based briquettes with varying quantities of gondorukem (arpus) adhesive (5, 10, 15, 20, and 25%).

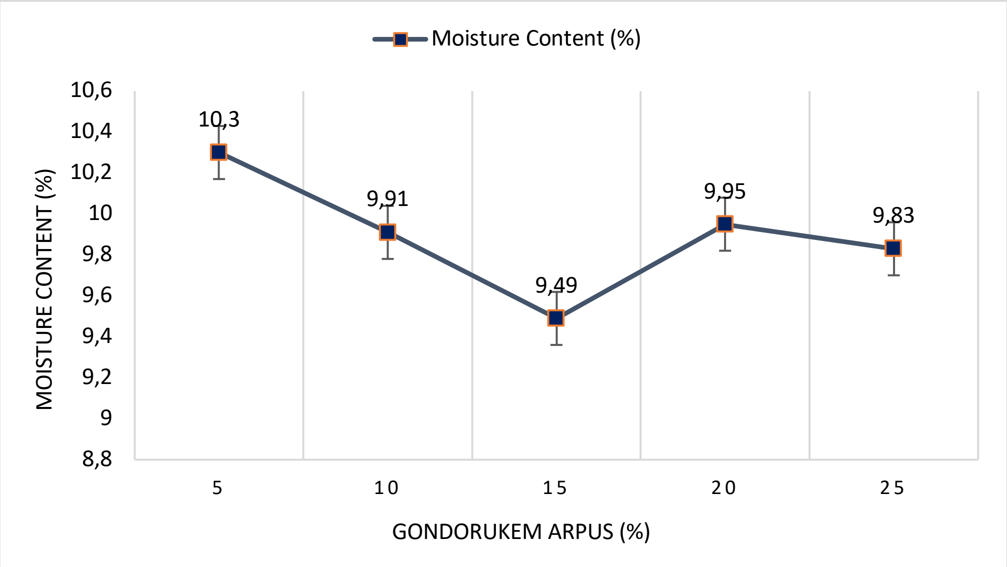

Figure 2. Moisture content of briquettes made from organic waste with gondorukem (arpus) adhesive

The moisture content is a significant factor in assessing potential alterations in the physical state of briquettes during storage and transportation [1]. Figure 2. shows the value of moisture content obtained in this study, ranging from 9.49% to 10.30% for briquettes from organic waste with variations of gondorukem (arpus) adhesive. The less adhesive content used in the briquette, the greater the water content value obtained; otherwise, the less adhesive content used, the less water content obtained or tends to stabilize. It is necessary to subject biodrying products to additional drying processes, as their final moisture content (MC) is typically too high to be burned directly. Notably, biodrying products containing coffee grounds exhibit a high drying rate even when the residual water content in the mixture is relatively low [21]. Table 1 presents a series of characteristic parameters about bio briquettes following the standards outlined in SNI 01-6235 2000 by the National Standardization Agency and the Minister of Energy and Mineral Resources (ESDM).

TABLE I. Bio Briquette Quality (SNI 01-6235 2000) [19] and the Minister of Energy and Mineral Resources (ESDM) [22]

No	Parameters (Units)	SNI 01-6235 2000	ESDM
1.	Inherent Moisture (%)	Max. 8	Min. 15
2.	Ash Content (%)	Max. 8	According to raw materials
3.	Volatile Matter (%)	Max. 15	Min. 10
4.	Fixed Carbon (%)	Min. 77	According to raw materials
5.	Calorific Value (Cal/g)	Min. 5000	Max. 4400

A review of the samples revealed that none met the national briquette standards set forth by the National Standards Agency (BSN), as outlined in Table 1. As stated by Aal et al. (2023) briquettes produced with an 8% moisture content exhibit enhanced density, stability, and durability. Furthermore, briquettes with a moisture content of approximately 17% tend to exhibit a proclivity for developing substantial fissures. The moisture content briquetting process is unstable because the briquettes are retained in the press mold. The moisture causes cracks in the product, making it unstable or too soft to store or transport. Furthermore, a considerable quantity of moisture ascends and accumulates within the mold. This exerts a force on the briquette, causing it to dislodge from the adhesive bond between the briquette and the mold wall [23]. In a three-way interaction experiment conducted by Thoreson et al. (2014), the effects of 8.3 and 54.5% of moisture contents were investigated. The highest moisture content in the briquettes harmed their density and elasticity [24].

In a recent investigation, Font et al. (2023) demonstrated that briquettes derived from biomass with 1% moisture content exhibited enhanced durability compared to briquettes produced from biomass with elevated moisture levels (6.8% and 8.4%). The presence of water is essential for the densification of biomass, as it serves as a binder and lubricant. However, the mechanical durability of briquettes with high water content is inferior, potentially due to the re-expansion of water after compaction. As indicated in the data mentioned above, most authors have experience in manufacturing briquettes with moisture contents ranging from 9 to 18% [25]. This study's results indicate that the base material's moisture content can be reduced by approximately ±1% without adversely affecting the quality of the ash content or the briquettes' ability to withstand shocks during transportation and storage. However, a significant reduction in moisture content may result in a decline in the mechanical properties of the briquettes [26].

3.3. Volatile Content Analysis

The volatile matter content of briquettes significantly impacts their combustibility. The briquettes become more flammable and ignitable as the volatile matter content increases. Figure 3 shows the volatile content of briquettes made from organic waste with different amounts of gondorukem (arpus) adhesive (5, 10, 15, 20, and 25%). Based on the illustration of Figure 3, the volatile content obtained in briquettes from organic waste with various variations of gondorukem (arpus) adhesive is 3.41 - 4.66%. The more adhesive used, the higher the volatile value. Bio briquettes based on SNI 01-6235 2000 have a maximum volatile content of 15%. Briquettes made with gondorukem (arpus) adhesive meet this value. A high volatile content means the briquettes will burn easily, but it also indicates that the briquettes will have a faster burning time [27]. Nikiforov et al. (2023) analyzed briquettes from sunflower husk and Karazhyra coal dust. The samples had less than 7.5% moisture, 5.04-12.63% ash, 20464.0-24413.3 kJ/kg calorific value, and 38.07-42.18% volatile matter. The combustion duration is adversely affected by high volatile matter yields, which depend on the plant material specifications [18].

The composition of the base material affects the volatile content of the briquettes. In the study by Pereira et al. (2024), the authors produced briquettes through a mixture of sewage sludge and sawdust of Pinus sp. The proximate analysis revealed that the sludge exhibited a diminished volatile matter content (35.51%), fixed carbon content (3.75%), and an augmented ash content (60.74%), culminating in a heating value of 14.8 MJ/g. This value is inferior to that of pine wood, which has a heating value of 20.3 MJ/g [28]. An essential factor in the combustion of briquettes is the volatile matter content, which is directly proportional to the energy released during combustion. The higher the volatility of a substance, the longer the ignition time, as more time is required for the combustion of the volatile substance [29].

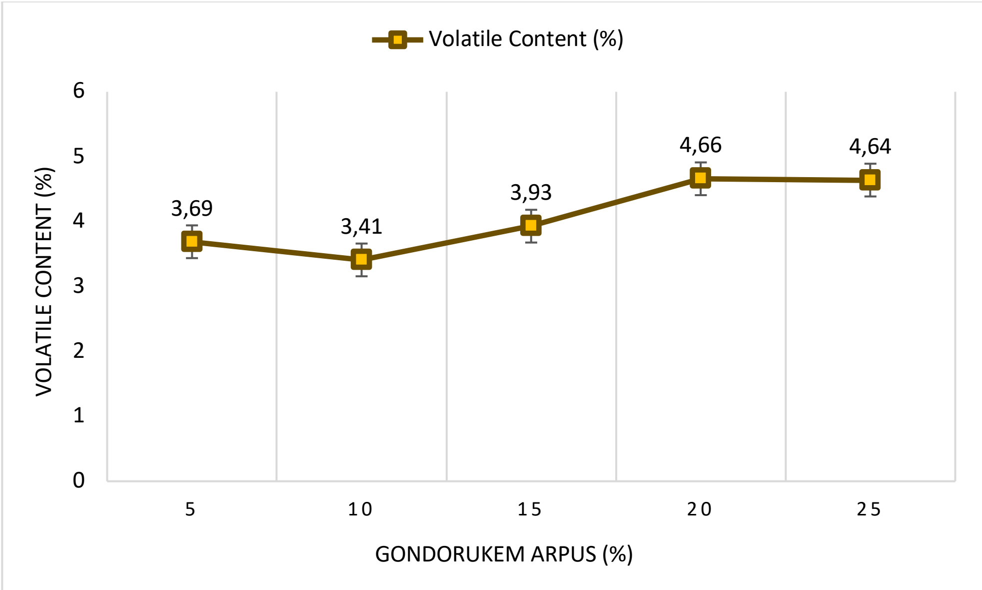

Figure 3. Volatile content of briquettes made from organic waste with gondorukem (arpus) adhesive

3.4. Calorific Value Analysis

The calorific value of a briquette is defined as the amount of energy contained in the briquette per unit mass. It is crucial to be aware of the calorific value of briquettes, as it can inform the quantity of fuel required for combustion. Figure 4 illustrates the heating value of organic waste-based briquettes with varying quantities of gondorukem (arpus) adhesive (5, 10, 15, 20, and 25%).

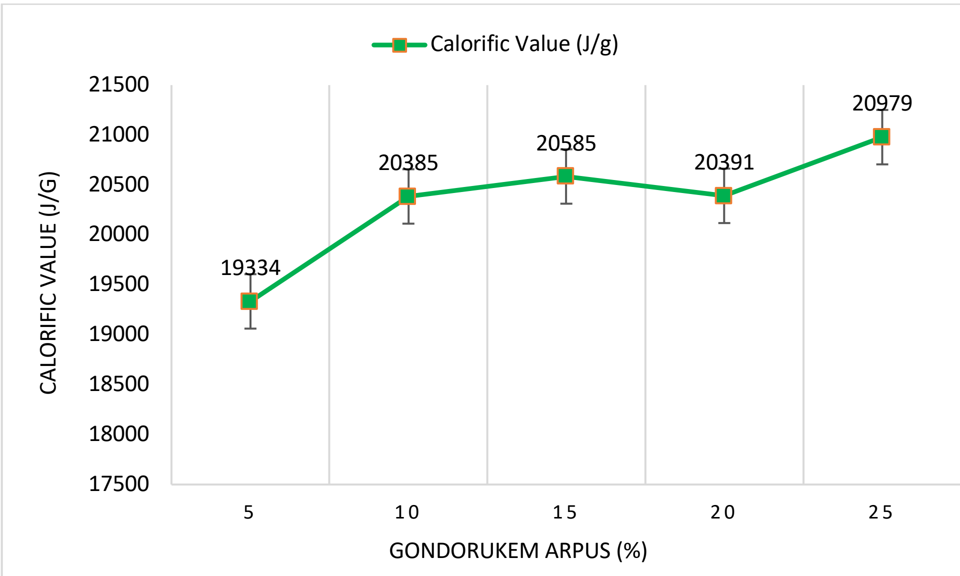

Figure 4. Calorific value of briquettes made from organic waste with gondorukem (arpus) adhesive

Figure 4 shows that the more adhesive used, the greater the heating value of the organic waste briquettes. The heating value obtained in organic waste-based briquettes with gondorukem (arpus) adhesive is 19334 - 20979 J/g - Low Heating Value (LHV) with a moisture content of 9.49% to 10.30%. The average upper heating value (HCV) of 17260 kJ/kg and the average lower heating value (LCV) of 17010 kJ/kg were obtained from data by Dragusanu et al. (2022) for 4% moisture content. As the moisture content of the briquettes increased, the heating values HCV and LCV exhibited a corresponding decline. A notable reduction in yield was observed below 42% when the moisture content reached 60%. Therefore, the maximum moisture content of layered briquettes should not exceed 10% when the calorific efficiency is in excess of 94% [30]. The briquettes developed by Onukak et al. (2017) have calorific values ranging from 18632 to 24101 megajoules per kilogram. The elevated calorific value may be attributed to the high carbon content and the incorporation of high-fleshing and chrome shavings in the formulation [31].

As Zaman et al. (2021) indicated, the fabricated briquettes possess a calorific value of 17.63 MJ/kg, making them a viable alternative to brown coal. Their suitability extends to applications in hard coal, brown coal, and fluidized bed combustion [32]. All samples except the 5% adhesive variation met the national briquette standard by the National Standards Agency (BSN) based on (SNI 01-6235 2000) with a minimum value of 5000 Cal/g (20934 J/g). However, the calorific value obtained with 5% adhesive has met the Minister of Energy and Mineral Resources Regulation, as stated in Table 1, is > 4400 Cal/g (18409 J/g) [19, 22]. Sukarta et al. (2023) produced briquettes with calorific values of 4536-6723 Cal/g, which meet the Minister of Energy and Mineral Resources Regulation. Some are also SNI compliant with 5650, 5821, 5866 and 6723 Cal/g calorific values. Coffee husk waste and coffee wood can be used as fuel if it is 3.53% moisture, 6.71% ash, and 5855 Cal/g. However, the volatile matter and fixed carbon values do not meet the requirements [33].

3.5. Density Analysis

The term "briquette density" describes the ratio between the weight and volume of a briquette. The potential exists to increase the density of briquettes obtained from various materials by improving the available information on biomass properties, conditioning requirements, and operational adjustments to equipment for process optimization [34]. Table 2 and Figure 5 show the density values of briquettes made from organic waste with different amounts of gondorukem (arpus) adhesive (5, 10, 15, 20 and 25%).

TABLE II. Density of briquettes made from organic waste with gondorukem (arpus) adhesive

Sample (%)	Height (mm)	Length (mm)	Wide (mm)	Mass (g)	Volume (cm^3)	Density (g/cm^3)
5	25.52	28.34	27.43	6.78	1983.83	0.0034176
10	25.31	27.79	27.04	7.05	1901.89	0.0037068
15	25.14	28.29	27.62	7.8	1964.36	0.0039707
20	25.02	27.51	26.74	7.95	1840.51	0.0043194
25	27.47	29.04	27.32	9.5	2179.39	0.0043590

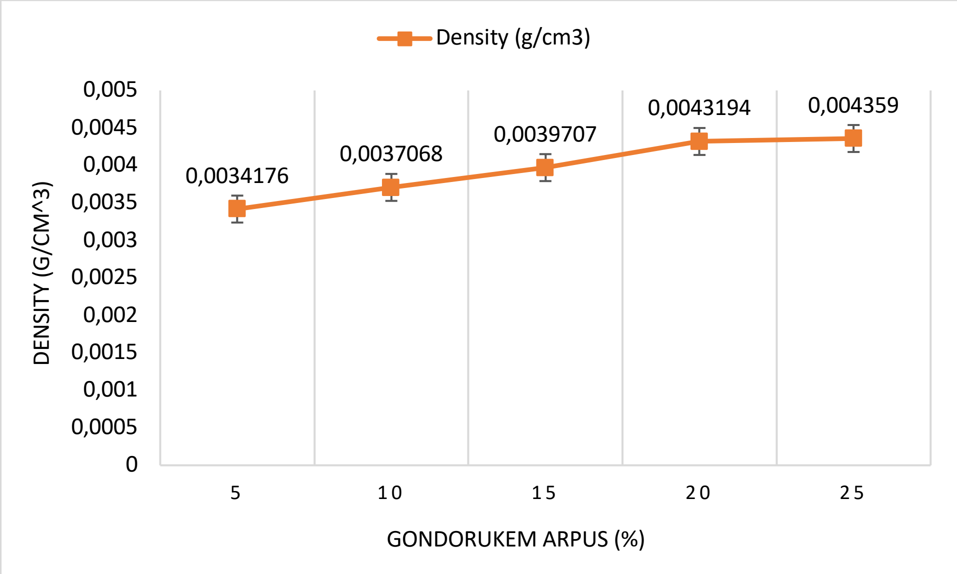

Figure 5. Density of briquettes made from organic waste with gondorukem (arpus) adhesive

Figure 5 shows that the more adhesive used, the tighter and better the density value of the briquettes produced. Density values obtained in organic waste-based briquettes with adhesive gondorukem (arpus) is 0.0034176 – 0.004359 g/cm^3; briquette height 25.02-27.54 mm with the obtained values tend to rise from the variety of adhesives used. The density of briquettes varies; cotton stalk briquettes have the highest density, while Pigeon Pea Stalk briquettes have the lowest density, with diameters of 40, 50, and 60 mm with values obtained 1406.90, 1288.30, and 1204.68 kg/m^3 [35]. The density of briquettes produced from Bambara peanut shells and their combinations ranges from 0.55 g/cm^3 to 1.0 g/cm^3, impacting their energy content and combustion properties [36]. The density of briquettes produced from a combination of peanut shells, rice husks, sawdust, and waste paper ranges from 800 to 900 kg/m^3, which indicates a high degree of compactness and a solid structure [37].

The density of briquettes ranges from 0.44 to 0.53 g/cm^3, with the highest density observed in briquettes produced from peanut shells (0.53 g/cm^3), as reported in research on agricultural waste and wood residues [38]. The density of briquettes made from wheat straw was 1237 kg/m^3 for briquettes without basins and 1178 kg/m^3 for briquettes with basins, comparable to wood waste commonly used as briquettes [30]. The standard range of bulk density for briquettes is 490-820 kg/m^3 or, if converted to 0.49-0.82 g/cm^3, as shown in the study on the physico-mechanical characteristics of high-density briquettes produced from composite sawdust [39]. The moisture content of the particles has a pronounced effect on the density of the compressed briquette, reducing it and consequently impairing the quality of the product. Conversely, the relaxation density of briquettes increases with increasing particle size. The impact resistance index (IRI) of briquettes is significantly affected by moisture and particle size [39]. From various studies that have been carried out on organic waste-based briquettes and gondorukem adhesives (arpus), the density value obtained still needs to be improved by trying various other adhesives to get optimal values.

3.6. Fixed Carbon Analysis

The carbon bound to the briquette is the fraction of carbon bound in the briquette, in addition to the fraction of evaporating substances, water, and ash. Bound carbon is defined as the amount of pure carbon bound in charcoal. Pure-bound carbon analysis determines the amount of carbon remaining after the carbonization process and during activation. Figure 6 shows the carbon content of bonded briquettes made from organic waste with different amounts of adhesive (gondorukem arpus) (5, 10, 15, 20 and 25%).

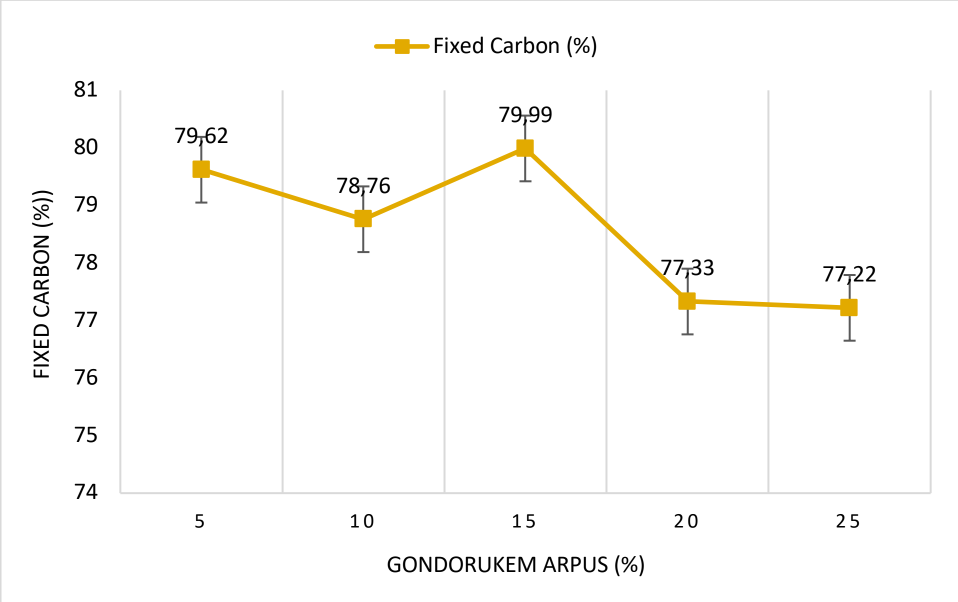

Figure 6. Fixed carbon of briquettes made from organic waste with gondorukem (arpus) adhesive

Figure 6. illustrates briquettes from organic waste with adhesive variation gondorukem (arpus) obtained a fixed carbon value range of 77.22 – 79.99%. Carbon bonded with the largest value found in adhesives at 15% with a value of 79.99%. The bound carbon content of a substance is affected by the number of volatile substances and ash present. Lu et al. (2022) used the recarburization (RE) method in the manufacture of briquettes during the initial stage of carburization specified at a temperature of 1200°C. The RE of charcoal briquettes (70-72%) was observed to exceed the RE of hydrocarbons (43-58%) due to the higher fixed carbon content in charcoal briquettes [40]. Mardiyati et al. (2021) found lignin isolated using citric acid in briquettes maintained at pH 3 produced briquettes with a fixed carbon content of 72%. The results showed that the lignin produced for all samples had a fixed carbon content above the standard SNI 4931-2010 [41]. Portilho et al. (2020) used the torrefaction method in making biomass-based briquettes. The research evaluated the physical and chemical properties of four types of wastes (eucalyptus and pine sawn, coffee trimming, and bagasse) that were burned at a temperature of 300°C and compacted at pressures of 6.21, 8.27, and 10.34 MPa. Torrefaction increased the fixed carbon content of bagasse, coffee-trimming waste, eucalyptus and pine, which were torrefied by 102, 60, 81, and 86%, respectively. Torrefaction increases the calorific value and content of fixed carbon, and ash reduces the volatility of biomass, improving the quality of raw materials for energy generators. This process reduces hygroscopicity and increases the calorific value of all biomass. Therefore, torrefaction has the potential as a pre-treatment for biomass fuel enhancement [42].

The highest fixed carbon content (49.2 wt%) was observed in the pure charcoal particles. The fixed carbon contents of the briquettes were superior to that of pure pine sawdust but inferior to that of pure charcoal. A high percentage of fixed carbon indicates a high heating value of the briquette [43]. On briquettes from organic waste with adhesive gondorukem (arpus), all samples met the standard value of SNI 4931-2010. The carbon content bound to the briquette can indicate its quality because the higher the carbon content, the higher the calorific value.

3.7. Burning and Ignition Time Analysis

Briquette ignition time is used to determine how long it takes for the briquette to burn to ash. The burning rate is the mass rate of briquettes burning in the air at a given time [44]. Figure 7 shows the ignition time of briquettes made from organic waste with different amounts of adhesive gondorukem (arpus) (5, 10, 15, 20, and 25%).

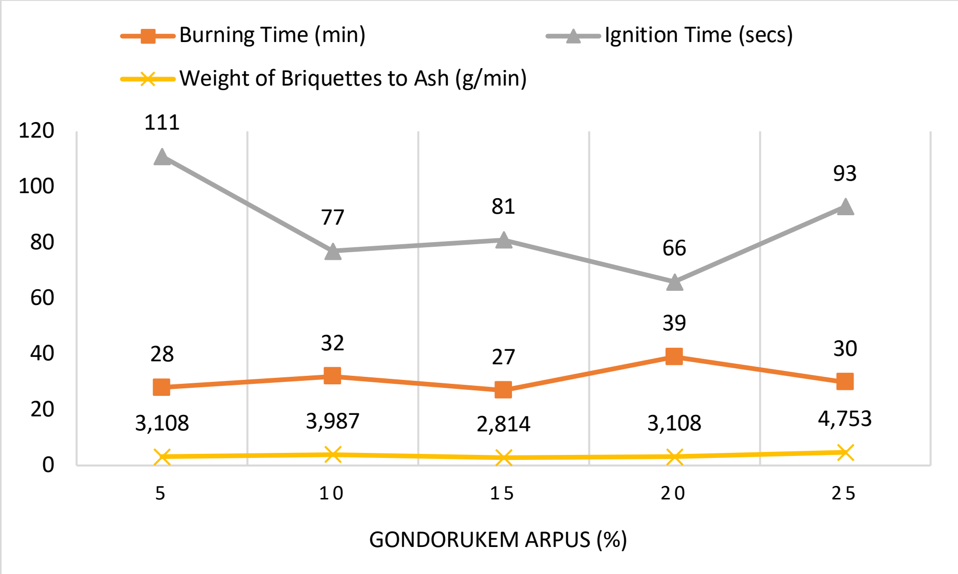

Figure 7. Burning time, ignition time and wieght of briquettes to ash made from organic waste with gondorukem (arpus) adhesive

Figure 7 illustrates the burning rate of organic waste-based briquettes with varying adhesive types, exhibiting a range of 27 to 39 minutes with a weight of briquettes to ash at the combustion time (3.108 to 4.753 g/min). The mean ignition time for the briquettes is 66 to 111 secs. Estiaty et al. (2017), the proximate analysis shows that the briquettes have a reasonable calorific value but that 60% coal is the best composition. The 40% corn cob briquettes have the following values: ash 20.17%, fixed carbon 44.83%, moisture 2.50%, density 0.414 g/cm³, volatiles 32.50%, porosity 48.12%. This mix has a caloric value of 124.45 KJ/kg, boils in 2.10 minutes, ignites in 29.56 seconds, and burns for 19.76 minutes. Its sulfur content is 7.56%. It is the best combustible mixture produced [45]. Wood charcoal briquettes have a burning rate of 3.53 ± 0.05 g/min and ignition time of 0.91 ± 0.07 mm/s [46].

Experimental results from Oyelaran et al. (2017) showed that the burning rate ranged between 0.171 and 0.217 g/min, boiling time ranged between 27.78 to 34.11 minutes, and ignition time was between 14.2 to 17.4 minutes. Combustion characteristics are indicated by temperature changes from when it starts to burn until it becomes ash [29]. Lestari et al., 2019 found the burning time, burning rate, and maximum temperature of briquettes by burning them in the open air at 25°C and 0.25 m/s wind speed. They used an infrared thermometer to measure the burning temperature. The combustion rate shows how well briquettes burn. It is the amount of material that burns over time [47]. Briquettes have different compositions and combustion rates. The combustion rate affects how you use briquettes. A briquette with a high combustion rate means you need more of them to burn. Meanwhile, ignition time depends on volatile matter and particle size. The higher the volatile matter, the longer the ignition time. Larger particles take longer to ignite [29]. In the study of briquettes from organic waste with arpus adhesive, the flame time, mass, and combustion rate obtained differed significantly from the previous research.

3.8. Scanning Electron Microscope (SEM) Analysis

A scanning electron microscope (SEM) analysis of the briquettes may reinforce the conclusion regarding their surface area. It is proposed that a larger surface area of briquettes may result in an enhanced burning rate [48]. Figure 8 shows the SEM results taken from the 25% adhesive variation at magnifications of 40×, 1000×, 3000×, 5000×, 8000×, and 10000×.

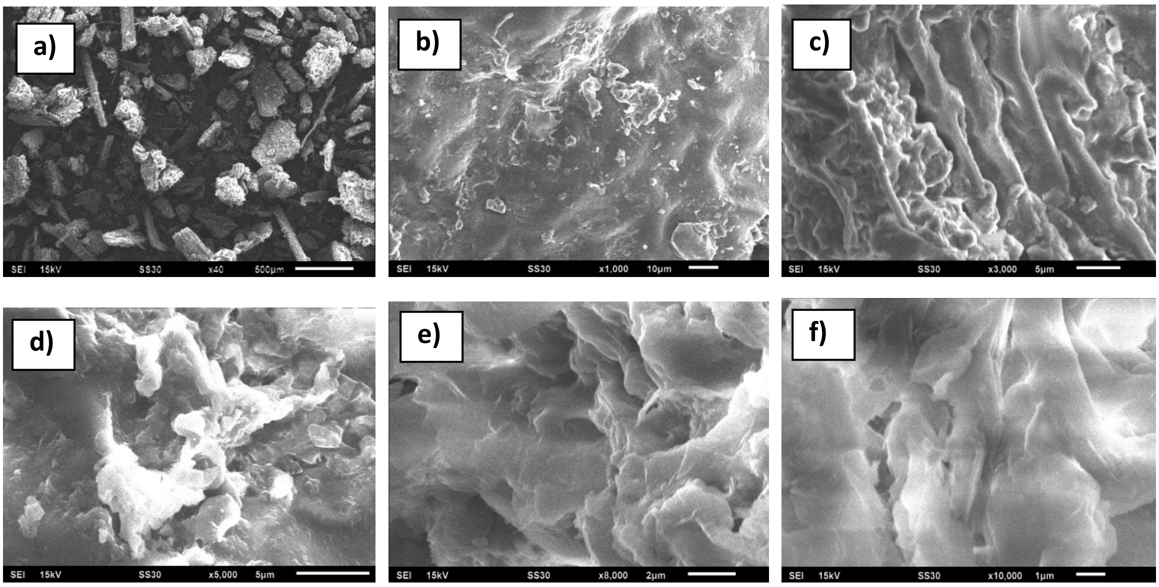

Figure 8. SEM of organic waste-based briquettes and gondorukem (arpus) adhesive 25% variation, magnification used: a) 40×; b) 1000×; c) 3000×; d) 5000×; 8000× and e) 10000×.

It can be seen from Figure 8 that there are lumps of rod-shaped, fiber-like substances and bubbles captured in the micrograph. Figure 8 a-c) significantly shows the content of organic waste and adhesive sticking together, which forms stems and fibers. The fibers visible on the surface in the micrograph are likely from cellulose in the organic waste. Cellulose, hemicellulose and lignin are known to act as natural binders to bind biomass pellets. The visible rods on the surface of the briquette serve a vital structural purpose, providing a framework that significantly enhances the strength of the biomass briquette [49].

When viewed in Figure b) at a magnification of 1000×, the surface of the briquette already looks smooth and has a few uneven particles. The morphology of the external surfaces of the briquette can be a valuable source of information for the accurate modelling or correction of forming tools' cavities. The extant literature contains numerous studies that describe the compressive strength of briquettes in relation to their density [50]. The research conducted by Bembenek et al. (2021) demonstrated that the physical and mechanical properties of briquettes exhibit variation depending on the surface area under examination. An analysis of the changes in porosity of the briquettes in cross-section revealed the presence of zones with varying densities [51].

4. CONCLUSIONS

The briquettes in this study are based on organic materials made from various vegetable waste materials. The adhesive used in this briquette is gondorukem (arpus) with 5, 10, 15, 20 and 25% variations to see the most optimal characteristics in the SNI reference. The ash content of the organic waste briquettes ranged from 6.39 to 8.31%. The data shows that using more adhesive in briquettes makes the resulting ash more solid. The volatile content of briquettes made from organic waste with different amounts of gondorukem adhesive is 3.41–4.66%. High volatile content means the briquettes burn easily and quickly. The heating value of organic waste-based briquettes with gondorukem adhesive is 19.334 to 20.979 J/g LHV. The more adhesive used, the hotter the organic waste briquettes. The more adhesive used, the better the density of the briquettes. Density values for organic waste-based briquettes with adhesive are 0.0034176–0.004359 g/cm^3. Briquette height is 25.02–27.54 mm. Briquettes made from organic waste with adhesive had a fixed carbon value range of 77.22–79.99%. The number of volatile substances and ash present affects the bound carbon content of a substance. The burning rate of organic waste-based briquettes with different adhesives is 27 to 39 minutes, weighing 3.108 to 4.753 g/min. The briquettes take 66 to 111 seconds to ignite. A high-rate briquette takes longer to burn. Ignition time depends on volatile matter and particle size. The more volatile the matter, the longer it takes to ignite. Larger particles take longer to ignite. The SEM analysis shows clumps of rod-shaped substances, such as fibers and bubbles, indicating organic waste and adhesives. The fibers on the surface are likely from organic waste. All samples meet the SNI or ESDM reference based on ash, moisture, volatile, bound carbon, and calorific value. Briquettes can be used for cooking, heating and so on.

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