PRODUCTION OF DURIAN PEEL BRIQUETTES (Durio Zibethinus Murr) USING VARIATION IN CARBONIZATION TEMPERATURE AND MASS RATIO OF CLAY ADHESIVE TO USED COOKING OIL

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Abstract
Briquettes are an alternative to fossil fuel. The raw material for briquettes uses durian peel to reduce organic waste and increase economic value. The main adhesive uses clay, as it is plastic and forms strong bonds after drying. Additional adhesives in the form of used cooking oil can increase the binding power of particles and increase the calorific value. This study examined the characteristic of durian peel briquettes with a size of 60 mesh, a carbonization time of 90 minutes, variations in carbonization temperature (400°C, 450°C, and 500°C) and variations in the mass ratio of clay: used cooking oil in g/g (1:2; 1:2.5; 1:3; 1:3.5; 1:4). The results of the study show that each variation affects the characteristics of the briquettes. The highest caloric value was obtained at 400°C carbonized temperature briquettes with a 1:4 adhesive mass ratio of 6520,59 cal/gram. However, 500°C carbonized temperature briquettes with an adhesive mass ratio of 1:4 are optimum result, because they excel in four out of five parameters, namely moisture content of 1.667%, ash content of 7.848%, volatile matter 3.940%, fixed carbon content 86.545%, and calorific value of 6495.39 cal/gram which meets the parameters of SNI 01-6235-2000.
***Keywords**: Briquettes, Durian Peel, Clay, Used Cooking Oil.*

INTRODUCING

The increasing global energy needs as well as the negative impact of the use of fossil fuels on the environtment encourage the development of more sustainable renewable energy sources. An alternative solution to the use of fossil fuels is to convert biomass into briquettes as an energy source with low carbon emissions, while reducing organic waste. Durian peel is one of the abundant biomass waste in Indonesia, especially East Java [1]. Based on Central Statistic Agency in 2026, Malang Regency produces 780,455.15 quintals of durian fruits with a total of 4,427,190.91 quintals in East Java Province, which 60-75% of its total mass is durian peel [2].

Briquettes in general can be interpreted as solid charcoal obtained from the biomass carbonization process [3]. In the manufacture of briquettes, after the biomass becomes charcoal, adhesive are added where these two components are formulated to determine the quality of the briquettes [4]. Clay is one of the inorganic adhesives that can be used in the manufacture of briquettes to bond the particles that make it up [5]. Clay has the advantage of being relatively cheaper and more practical to use because it does not require mixing with hot water to become sticky and hard when dry [6]. Used cooking oil is leftover cooking oil from frying activities at various scale ranging from households to industries, its abundant availability if nor managed properly will become waste that has the potential to pollute the environment [7]. One method of processing used cooking oil is to use it as a supporting material used in conjunction with the primary adhesive, as it can be utilized as a secondary adhesive and increase the calorific value of the briquettes [8] [9]. Mechanically, the liquid phase of this oil coats the biomass particles and helps to improve the contact and adhesion between the particles, thus supporting the performance of key adhesives such as clay [10].

Although there has been a lot of research on the manufacture of durian peel briquettes, the literature on the use of adhesives such as clay in the manufacture of briquettes include moisture content, ash content, volatile matter, fixed carbon content, and calorific value, which can be affected by carbonization temperature and adhesive mass ratio, respectively [11] [12]. In previous research on durian peel based briquettes, the carbonization process was carried out at a temperature of 450°C, with a particle size of 60 mesh, a molasses adhesive concentration of 65%, and a used cooking oil content of 10%. As a result, the calorific value obtained reached 5989.485 cal/g and met the SNI 01-6235-2000 standard. However, other test parameters that are also included in the SNI were not carried out by the researcher [13]. Meanwhile, in the manufacture of briquettes from a composition of 60% wood powder, 10% clay as an adhesive, and 30%

waste oil, a calorific value of 11,064.26 BTU/lb, an ash content of 10.45%, and a moisture content of 6.18% [12].

Based on this research gap, the present study systematically evaluates the simultaneous effect of carbonization temperature of 400°C, 450°C, and 500°C and the clay: use cooking oil mass ratio in g/g (1:2; 1:2.5; 1:3; 1:3.5; 1:4) on the characteristics of durian peel briquettes, including moisture content, ash content, volatile matter, fixed carbon, and calorific value, as well as their compliance with the applicable SNI requirements. The researcher aims to investigate the optimum arrangement of briquettes so that it can meet the provisions of SNI 01-6235-2000, including moisture content, ash content, volatile matter, fixed carbon content, and calorific value. Furthermore, the findings of this research are expected to be able to present an overview of the characteristics of durian peel briquettes as well as become a reference for future research in efforts to develop durian peel briquettes as a source of renewable energy.

Theory

Durian peel is one of lignocellulosic biomass which is formed from 3 types of polymers [14], that contains about 50%-60% cellulose, 13.90% hemicellulose, lignin about 5% [15], also starch about 5% with long and thick fiber structure dimensions so that it is able to form good bonds when adhesive materials are added. The relatively high contents of cellulose, hemicellulose, and lignin in durian peel make it a promising raw material for briquette production [11]. The production of briquettes involves a carbonization process, which can be conducted using pyrolysis as one of the applicable methods, where cellulose will be thermally decomposed without free air oxidation [16]. The thermal decomposition process causes cellulose depolymerization resulting in a solid residue in the form of charcoal [17].

Clay, also known as alumina hydrosilicate, is a mineral particle composed of a silica base framework with a diameter of less than 4 μm [18]. The mineral content of clay imparts plasticity, enabling it to become cohesive when mixed with water and harden upon drying. This characteristic provides an advantage over conventional starcth based binders, as clay does not require hot water for activation, thereby reducing operational costs and simplifying the briquette production process [6]. Clay that has high plasticity will be easier to mold compared to one with low plasticity [19]. In general, plastic clay contains a moisture content of around 25% [20].

Used cooking oil is residual oil produced through from frying activities across various scales, from households to industrial operations. Due to its abundant availability, improper management of used cooking oil can result in waste that poses a potential threat to environmental quality [7]. One approach to utilizing used cooking oil is to incorporate it as a supporting material alongside the primary adhesive, as it can function as a secondary adhesive while contributing to an increase in the calorific value of briquettes [8] [9]. Mechanically, the liquid phase of used cooking oil can coat the biomass particles and enhance particle contact and adhesion, thereby supporting the binding performance of primary adhesives such as clay [10]. Used cooking oil has a calorific value of 9,197.29 cal/gram and a flash point ranging from 240-330°C. Its relatively low flash point contributes to the flammability of solid fuels. Furthermore, the incorporation of used cooking oil can reduce the moisture content of biomass briquettes, making it an effective additive [13].

Experimental Section

The implementation of the research took place at the Chemical Engineering Bioenergy Laboratory, Faculty of Industrial Technology, National Institute of Technology Malang. This study uses a quantitative method that aims to determine the effect of carbonization temperature variations and adhesive mass ratio variations. This study uses two types of variables, namely control variables and independent variables. Control variables: the type of butter durian peel comes from the waste of the “Happy Durian” restaurant on Cerme street No. 1, Kendalpayak, Pakisaji District, Malang Regency, clay comes from brick craftsmen on Jabal Nur Street No. 55, Tlogowaru, Kedungkandang, Malang City, used cooking oil comes from “lalapan” street vendors in Arjowinangun, Kedungkandang, Malang City, charcoal composition of 100 grams, clay composition 10 grams, water composition 25 mL, carbonization times 90 minutes, sieve size 60 mesh, hydraulic press pressure 100 bar, drying temperature 105°C, drying time 60 minutes. Independent variable: carbonization temperature 400°C, 450°C, and 500°C, slay adhesive mass ratio used cooking oil (gr/gr) which is 1:2; 1:2.5; 1:3; 1:3.5; 1:4.

Research procedure

The material preparation stage began by cleaning the durian peel waste from impurities, such as residual fruit fresh and seeds. The durian peel was then dried under the sun for 2 days until its moisture content reaches less than or equal to 10%. The dried durian peel was into several pieces. The clay was

cleaned of impurities such as leaves, grass, roots, and animals. Used cooking oil was filtered using filter paper from impurities such as bones, spices, other fryer residues. The used cooking oil was subsequently analyzed for moisture content, peroxide number levels, and free fatty acid levels [21].

The briquette manufacturing stage began by carbonizing durian peel using a furnace for 90 minutes at a carbonization temperature of 400°C, 450°C, and 500°C according to the treatment. The resulting charcoal was crushed using mortar and pestle until it becomes powder and then sieved using a 60 mesh sieve [13]. The powdered charcoal was weighed using a digital balance of 100 grams. Subsequently, 10 g of clay was weighed using a digital balanced and mixed 25 mL of water [12]. Used cooking oil was then added with an according to mass ratio of clay to used cooking oil g/g (1:2; 1:2.5; 1:3; 1:3.5; 1:4). The charcoal powder, clay, and used cooking oil were mixed until homogeneous using a stirring rod. The resulting mixture was molded using a hydraulic press to form briquettes with a diameter of 2.5 cm and a height of 3.5 cm. The briquettes were then dried in an oven at 105°C for 1 hour to reduce the remaining moisture content [22]. Each of 15 samples was tested three times in the form of moisture content, ash content, volatile matter, fixed carbon content, and calorific value.

Data analysis

Peroxide value

Put 5 grams of used cooking oil and 30 mL of acetic acid solution: chloroform (3:2) into the erlenmeyer and then close it. Then the solution is shaken in a circular shape like the number 8 until homogeneous. Add a 0.5 mL saturated iodide solution, and shake for 1 minute. Once homogeneous, 30 mL of aquadest is added. The solution is titrated with 0.1 N $Na_2S_2O_3$ until pale yellow. Add a 0.5 mL starch indicator and titrate again until the blue colour turns clear. Determination of blanks, and testing samples with 3 repetitions [21]. The peroxide value is expressed as milliequivalent O_2/kg fat calculated using the formula:

$$\text{Peroxides value (meq/kg)} = \frac{1000 \times \text{N } Na_2S_2O_3 \times (\text{Sample titration volume} - \text{Blank titration volume})}{\text{Sample weight}} \quad \ldots\ldots\ldots\ldots (1)$$

Free fatty acids

Put 5 grams of used cooking oil and 50 mL of 95% alcohol into the erlenmeyer. Heat the solution for 10 minutes and stir. Add 3-5 drops of 1% PP indicator after the solution cools, then titrate until red with a standardized 0.1 N NaOH solution. Repeat 3 times [21]. The calculation of free fatty acids %FFA calculated by the formula:

$$\%\text{FFA} = \frac{\text{mL NaOH} \times \text{N NaOH} \times \text{Fatty acid molecular weight (lauric acid)}}{\text{Sample weight (gr)} \times 1000} \times 100\% \quad \ldots\ldots\ldots\ldots (2)$$

Moisture content

Based on the National Standardization Agency, the analysis is carried out by weighing a sample of briquettes as much as 1 gram, then putting the sample into the oven at a temperature of 115°C for 3 hours, then weighing the sample of the oven results. Finally, calculate the moisture content with the formula:

$$\text{Moisture content} = \frac{\text{initial sample weight} - \text{dry sample weight}}{\text{initial sample weight}} \times 100\% \quad \ldots\ldots\ldots\ldots (3)$$

Ash content

Based on the National Standardization Agency, the analysis was carried out by weighing porcelain crosses without lids, weighing 2 grams of briquette samples, heating the sample at 450-500°C for 1 hour, heating the sample at 700-750°C for 2 hours, heating the sample at 800-900°C for 2 hours, cooling the sample in a decifier, weighing the cooled sample. Next calculate the ash content with the formula:

$$\text{Ash content} = \frac{\text{crucible and ash weight} - \text{empty crucible weight}}{\text{sample weight}} \times 100\% \quad \ldots\ldots\ldots\ldots (4)$$

Volatile matter content

Based on the National Standardization Agency, the analysis is carried out by heating the sample that has been tested for moisture content in the oven at a temperature of 950°C for 7 minutes, cooling the sample in a decifier, weighing the cooled sample. Next calculate the level of volatile matter with the formula:

$$\text{Volatile matter content} = \frac{\text{initial sample weight} - \text{sample weight after}}{\text{initial sample weight at water content}} \times 100\% \quad \ldots\ldots\ldots\ldots (5)$$

Fixed carbon content

Based on the National Standardization Agency, the analysis is carried out by calculating the level of fixed carbon based on the results of the test of moisture content, ash content and volatile matter with the formula:

$$\text{Fixed carbon content (\%)} = 100\% - (\text{water content} + \text{ash content} + \text{volatile matter content}) \ldots. (6)$$

Calorific value

Based on the National Standardization Agency, the analysis was carried out by measuring the amount of heat released using a bomb calorimeter to obtain the calorific value.

Result and discussion

The used cooking oil analyzed in this study had a moisture content of 0.276%, a free fatty acid (FFA) content of 7.208%, and a peroxide value of 13.33% meq O_2/kg. These parameters indicate the equality and degree of deterioration of the used cooking oil and can be used as indicators of its suitability for use [21]. Higher moisture content, free fatty acid content, and peroxide value in used cooking oil may affect the ease of ignition, reduce combustion efficiency, and decrease the calorific value of the resulting briquettes [23]. Durian peel with a moisture content of 9.88% was carbonized for 90 minutes at carbonization temperature of 400°C, 450°C, and 500°C. At 400°C, the mass decreased from 750 g of durian peel to 529 g of charcoal, corresponding to a mass loss of 29.47%. At 450°C, the mass decreased from 1000 g of durian peel to 578 g of charcoal, corresponding to a mass loss of 42.20%. Meanwhile at 500°C the mass decreased from 1200 g of durian peel to 508 g of charcoal, corresponding to a mass loss of 59.36%. The resulting charcoal was then mixed with clay and use cooking oil at clay to used cooking oil mass ratio of 1:2; 1:2.5; 1:3; 1:3.5; 1:4 and stirred until homogeneous. The homogeneous mixture was subsequently molded using a cylindrical mold and a hydraulic press at a pressure of 100 bar. The molded briquettes were then dried in an oven at 105°C for 60 minutes, producing cylindrical briquettes with a diameter of 2.5 cm and a height of 3.5 cm. The resulting briquettes had densities ranging from 1.26 to 1.46 g/cm^3. This density range indicates that the briquettes had a relatively compact structure, which can contribute to greater mechanical stability and potentially prolong the burning time.



Figure 1. Durian peel briquettes

Moisture content

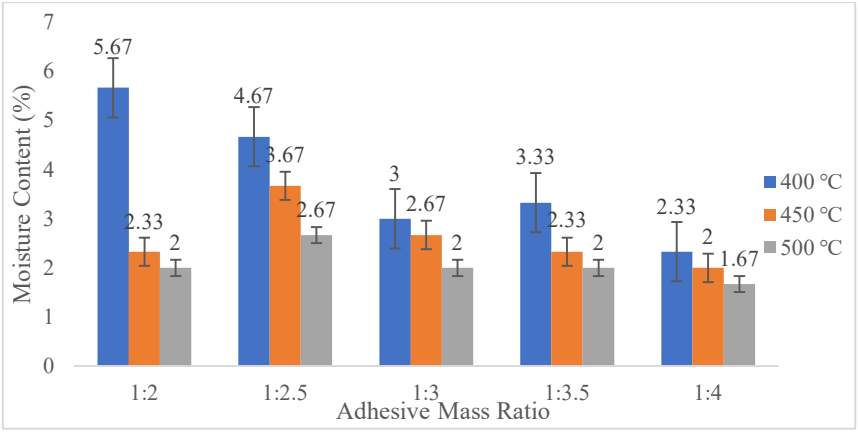


Figure 2. The relationship between carbonization temperature and the ratio of adhesive mass to moisture content

Based on Figure 2, the average moisture content of the briquettes, ranged from 1.67% to 5.67%, with all samples meeting the SNI maximum limit of 8%. The highest moisture content was obtained at 400°C with an adhesive mass ratio of 1:2 (5.67%), while the lowest was observed at 500°C with a ratio of

1:4 (1.67%). Overall, increasing the carbonization temperature from 400°C to 500°C consistently decreased the moisture content, indicating that carbonization temperature influences the final moisture content of the briquettes. This trend is attributed to the greater release of water and volatile components at higher temperatures, which promotes thermal decomposition and reduces moisture content [1].

In contrast, increasing the adhesive mass ratio from 1:2 to 1:4 did not consistently decrease moisture content, as several samples showed an increase. This differs from the expected trend that higher used cooking oil content reduces moisture content by forming a hydrophobic layer that limits water absorption [23]. For example, moisture content increased from 2.33% to 3.67% at 450°C with a ratio of 1:2, by 2% to 2.67% at 500°C with a ratio 1:2, and by 3% to 3.33% at 400°C with a ratio 1:3. These variations may be related to the distribution of used cooking oil within the briquette matrix, as its ability to reduce water absorption depends on adequate incorporation during mixing [9].

Carbonization temperature significantly affected the moisture content of the briquette (F=7.7371 > F-crit value of 4.4589, P value = 0.0134 < 0.05), whereas the adhesive mass ratio did not show a significant effect (F= 2.6522 > F-crit value of 4.4589, p value = 0.1120 > 0.05). Thus, carbonization temperature was the significant factor affecting moisture content.

Ash content

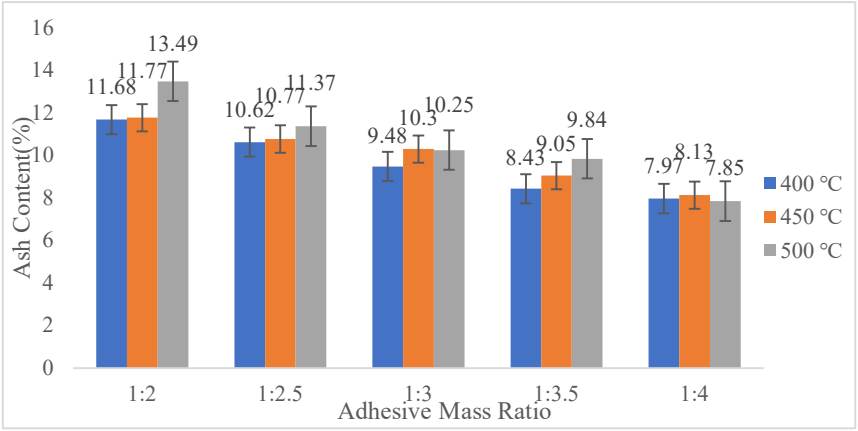


Figure 3. The relationship between carbonization temperature and the ratio of adhesive mass to ash content

Ash content the residual inorganic minerals that remain after combustion and generally originates from the adhesive and raw materials [23]. Based on Figure 3, only briquettes carbonized at 400°C and 500°C with an adhesive mass ratio of 1:4 met the SNI requirement, with ash contents of 7.97% and 7.85%, respectively, while the other variations such as briquettes carbonized at 400°C with an adhesive mass ratio of 1:2; 1:2.5; 1:3; 1:3.5, with ash contents of 11.68%, 10.62%, 9.48% and 8.43%, respectively, briquettes carbonized at 450°C with an adhesive mass ratio of 1:2; 1:2.5; 1:3; 1:3.5, 1:4 with ash contents of 11.77%, 10.77%, 10.3%, 9.05% and 8.13%, respectively, briquettes carbonized at 500°C with an adhesive mass ratio of 1:2; 1:2.5; 1:3; 1:3.5, with ash contents of 13.49%, 11.37%, 10.25% and 9.84%, respectively, which exceeded the maximum limit that is maximum of 8%. Clay contributes substantially to ash formation because it contains inorganic minerals, including 75.4% silica, 0.7% calcium oxide, 0.71% magnesium oxide, 0.01% iron oxide, and 14.1% aluminum carbonate [18], which remain after combustion [1] [23]. Theoretically, increasing carbonization temperature tends to increase ash content because carbon, hydrogen, oxygen, and volatile components are released as gases, leaving a higher proportion of inorganic minerals in the charcoal [1]. This trend was generally observed in the briquettes carbonized at 400°C, 450°C, and 500°C. However, the 500°C briquettes with adhesive ratios of 1:3 and 1:4 showed irregular ash contents. This deviation may be associated with partial oxidation during carbonization. Although the carbonizer box limited direct air contact, the process was not conducted under a controlled inert atmosphere, allowing residual oxygen to oxidize some carbonaceous material and potentially increase ash formation [24].

Meanwhile, increasing the adhesive mass ratio from 1:2 to 1:4 consistently decreased ash content, indicating that adhesive composition also influenced ash formation. This trend is consistent with the higher used cooking oil content reducing ash because the oil does not leave a solid residue after combustion and

its hydrophobic properties may limit water absorption and subsequent mineral uptake into the briquettes [23].

Both carbonization temperature (F= 5.1228 > F-crit value of 4.4589, P value = 0.0134 < 0.05), and adhesive mass ratio (F= 39.1307 > F-crit value of 4.4589, P value = 0.0000269 > 0.05) significantly affected the ash content of the briquettes. The adhesive mass ratio showed a stronger statistical effect than carbonization temperature.

Volatile Matter

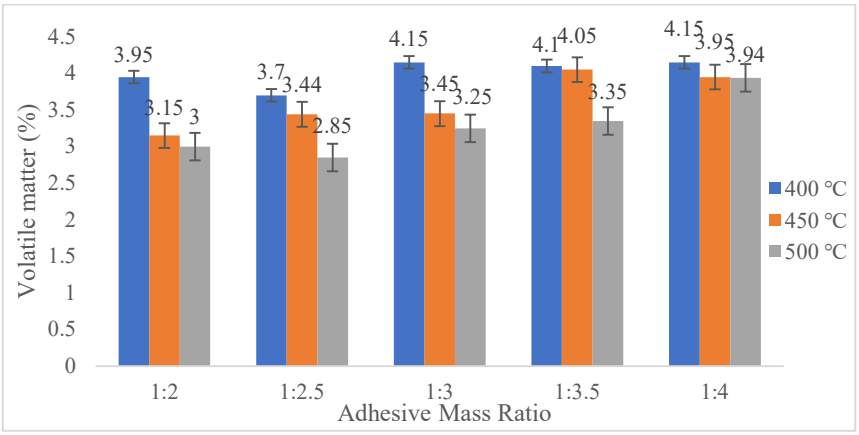


Figure 4. The relationship between carbonization temperature and the ratio of adhesive mass to volatile matter

Volatile matter represents the compounds other than water that are released as gases during briquette combustion, including hydrogen, hydrocarbon, CO_2, CO, and methane [23]. Based on Figure 4, all samples met the SNI maximum limit of 15%, with volatile matter ranging from 2.85% to 4.15%. The highest value was obtained at 400°C with an adhesive mass ratio of 1:4 (4.15%), while the lowest was observed at 500°C with a ratio of 1:2.5 (2.85%). Overall, increasing the carbonization temperature from 400°C to 500°C consistently decreased volatile matter, indicating that temperature influences its content. This decrease is attributed to the decomposition of hemicellulose, cellulose, and lignin into gases such as, CO_2, CO, methane, and water vapor during carbonization [1].

In contrast, increasing the proportion of used cooking oil was theoretically expected to increase volatile matter because the oil contains hydrocarbons, including aliphatic and aromatic compounds [23]. The result generally followed this trend, with volatile matter increasing from the 1:2 to 1:4 adhesive ratio. However, several variations showed decreases, namely at 400°C for ratios of 1:2.5 and 1:3.5, at 450°C for 1:4 and at 500°C for 1:2.5. These deviations may be attributed to uneven distribution of used cooking oil during mixing =, which can affect the amount of volatile compounds released during heating and consequently the measured volatile matter content [9].

Both carbonization temperature (F = 14.0138 > F-crit value of 4.4589, P value = 0,0024 < 0,05) and adhesive mass ratio (F = 5.4400 > F-crit value of 4.4589, p value = 0.0204 < 0.05) significantly affected the volatile matter content. Carbonization temperature showed a stronger statistical effect than the adhesive mass ratio,

Fixed carbon content

volatile matter are removed. It is therefore calculated as the remainder after subtracting these three components from 100% [23]. Based on Figure 5, all samples met the SNI minimum requirement of 77%, with values ranging from 78.7% to 86.54%. The lowest value was obtained at 400°C with and adhesive mass ratio of 1:2 (78.7%), while the highest was observed at 500°C with a ratio of 1:4 (86.54). Increasing carbonization temperature generally increased fixed carbon because greater decomposition and removal of moisture and volatile components leave a higher proportion of carbon in the charcoal [23]. This result generally followed this trend, although the 450°C briquettes at a 1:2 ratio had higher fixed carbon than those at 500°C with the same ratio. This deviation corresponds to the higher ash content at 500°C, which reduced the calculated fixed carbon because ash is one of the components subtracted from 100%.

Fixed carbon content represents the carbon remaining in the briquettes after moisture, ash, and Increasing the used cooking oil proportion also generally increased fixed carbon by reducing the relative proportion of moisture, ash, and volatile matter, potentially contributing to higher calorific value [23]. However, at 450ºC, fixed carbon decreased at the 1:2.5 ratio compared with 1:2. This decrease was associated with the higher ash content at the 1:2.5 ratio, which consequently reduced the calculated fixed carbon content [23].

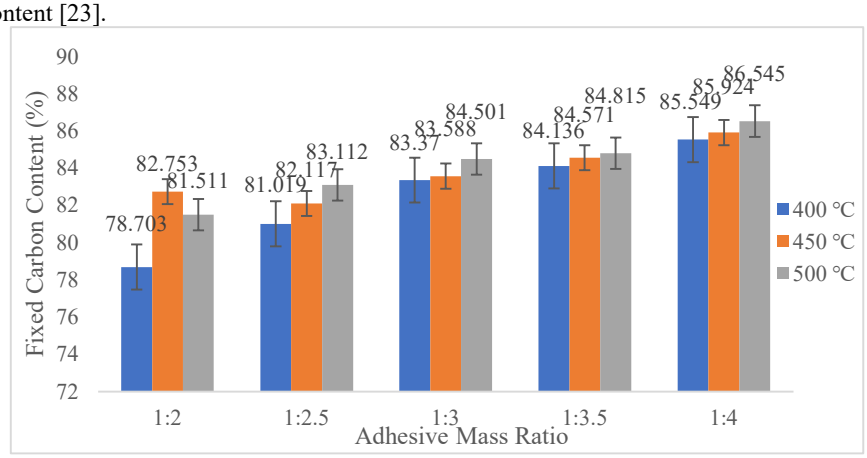


Figure 5. The relationship between carbonization temperature and the ratio of adhesive mass to fixed carbon

Both carbonization temperature (F=4.7514 > F-crit value of 4.4589, p=0.0436 < 0.05) and adhesive mass ratio (F=16.8135 > F-crit value of 4.4589, p=0.0604 < 0.05) significantly affected the fixed carbon content. The adhesive mass ratio showed a stronger statistical effect than carbonization temperature.

Calorific value

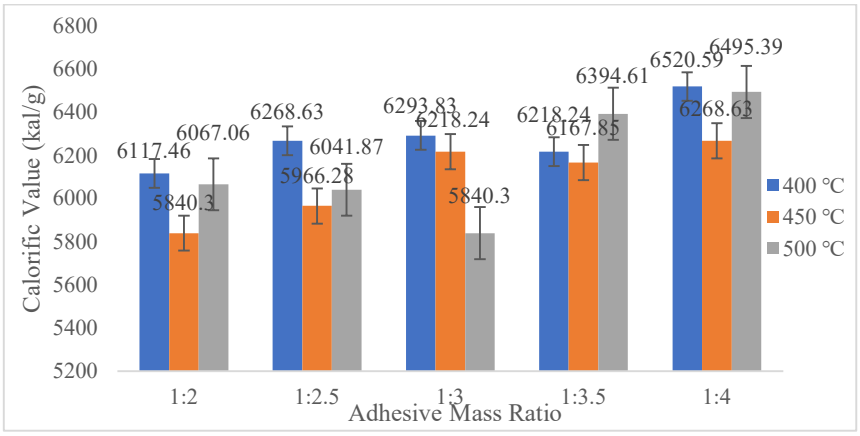


Figure 6. The relationship between carbonization temperature and the ratio of adhesive mass to calorific value

Calorific value represents the heat energy released during briquette combustion and is an important indicator of fuel quality, as a higher value indicates greater energy production [23]. Based on Figure 6, all samples met the SNI minimum requirement of 5,000 Cal/g, with values ranging from 5,840.3 to 6,520.59 Cal/g. The lowest value was 5,840.3 Cal/g, obtained at 450ºC with and adhesive ratio of 1:2 and at 500ºC with a ratio of 1:3, while the highest value was obtained at 400ºC with a ratio of 1:4 at 6,520.59 Cal/g. Carbonization temperature did not produce a consistent trend in calorific value, with several deviations from the expected pattern. This may be attributed to partial oxidation during carbonization. Although the carbonizer box limited direct air contact, the process was not conducted under a controlled inert atmosphere, allowing residual oxygen to partially oxidize carbonaceous material into ash and reduce the combustible fraction [24]. Thus, the results differ from the general expectation that higher carbonization temperatures increase calorific value by reducing moisture and volatile matter. Excessive temperature may instead increase ash content, which does not contribute to combustion energy and can reduce calorific value [1].

In contrast, increasing the adhesive mass ratio generally increased calorific value, indicating that used cooking oil contributed to the energy content of the briquettes. This is consistent with the high combustion energy of organic compounds in the oil [23]. However, decreases occurred at 400ºC and 450ºC for the 1:3.5 ratio compared with 1:3, and at 500ºC for 1:3 compared with 1:2.5. These deviations may result from uneven oil distribution during mixing, causing differences in the actual oil content incorporated into each briquette and limiting its contribution to measured calorific value [9].

Neither carbonization temperature ($F=2.0110 < F\text{-crit}$ value of 4.4589, $p=0.1960 > 0.05$) nor adhesive mass ratio ($F=3.5388 < F\text{-crit}$ value of 4.4589, $p=0.0604 > 0.05$) significantly affected calorific value of the briquettes. However, the adhesive mass ratio showed a relatively greater statistical effect than carbonization temperature.

Conclusion

Carbonization temperature had a greater influence on briquette characteristics than the clay cooking oil adhesive mass ratio. The highest calorific value was obtained at 400°C with a 1:4 ratio, reaching 6520,59 cal/g, with moisture, ash, volatile matter and fixed carbon contents of 2.33%, 7.97%, 4.15%, and 85.55%, respectively. However, the 500°C briquettes showed better overall characteristics, with lower moisture, ash, and volatile matter and higher fixed carbon. Therefore, the optimum briquettes were obtained at 500°C with a 1:4 ratio, achieving moisture, ash, volatile matter, fixed carbon, and calorific matter of 1.67%, 7.85%, 3.94%, 86.55%, and 6495.39 cal/g, respectively, meeting SNI 01-6235-2000 requirements. Further research suggests using a more airtight pyrolysis reactor to minimize oxygen ingress and charcoal oxidation. In addition, future studies should investigate clay in combination with other organic adhesive, such as tapioca flour or durian seed flour, to determine the adhesive formulation that provides the best balance between mechanical strength, ash content, fixed carbon and calorific value in the briquettes produced.

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