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How to Make Biomass Briquettes with Their Characteristics Analysis

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ABSTRACT

Durian peels are biomass waste and can be used as an alternative fuel for briquettes. Therefore, processing organic waste (biomass), especially waste from durian peels into briquettes is a solution to replace traditional coal energy with renewable energy. This article contains guidelines that provide a basis for understanding how to make durian peel biomass briquettes and analyzing the results compared to coconut shell and rice husk materials. The test results showed that the highest density value was obtained for 100% rice husk briquettes with a value of 1324.56 kg/m^3, the highest heating value was obtained for 100% coconut shell briquettes at 6479 kcal/kg, the voltage value produced by the voltaic cell Durian peel charcoal is highest when activated with more dilute KOH, in contrast to the durian peel charcoal electrolysis cell, the highest voltage is obtained when activated with more concentrated KOH.

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1. INTRODUCTION

Energy is one of the main problems in the world today. As time goes by, more and more energy is used for human activities. Starting from the kitchen needs energy to support the continuity of human transportation. One of the energies used in daily life comes from fuel oil obtained from plant and animal fossils. With several explorations carried out, large consumption and the increasing population will mean that the availability of conventional energy cannot keep up with the demand for conventional energy needs (Parinduri & Parinduri, 2020). The regular extraction of forest resources for residential and commercial use involves unsustainable harvesting methods that present serious risks to human health, biodiversity loss, climate change, and environmental degradation (Wong *et al*., 2022). To reduce the risks associated with using firewood for cooking, research into more sustainable and alternative ways to meet culinary energy needs, like waste-to-energy, must be advanced. The research conducted by Roder *et al*., (2022) indicates that approximately 634 million metric tons of dry biomass waste can be used annually for value addition purposes worldwide. One of the biomass energies that is currently not well developed and utilized is durian skin and rice husk waste.

One use of biomass is to process it into briquettes. Briquettes are a solution to the scarcity of non-renewable energy (oil and natural gas). The process of making charcoal briquettes from agricultural waste (biomass) can be done by adding adhesive. This adhesive material functions to stick the briquettes together. Thus, they can be shaped as desired. The adhesive material that can support the quality of the briquettes is starch/tapioca. Its role is to maintain the density of the briquettes. Thus, the product is not easily destroyed (Iriany, 2016). During the durian fruit season, the volume of waste experiences a significant increase, which comes from durian fruit skin. The composition of the durian skin reaches 60 to 75%, the flesh is 20 to 35%, and the seeds are 5 to 15%. Unused durian skin eventually becomes waste, which causes environmental pollution, damages the ecosystem, and creates an unpleasant odor.

Durian skin can be used as briquettes because it contains 50-60% cellulose. Conversion of durian skin into briquettes can increase the economic value of the product produced and can also increase the density of the briquettes. Rahmawati *et al*., (2022) investigated the calorific value, water content, ash content, volatile matter value, carbon content limit value, density, and burning rate of durian skin briquettes. Meanwhile, the combination of durian skin briquettes with rice husks and coconut shells has not been the subject of research, even though this raw material is widely discussed because it has good briquette performance. Therefore, this research provides knowledge about the quality of briquettes with the composition of these ingredients when mixed.

2. LITERATURE REVIEW

2.1 Durian Peels

Several biomass energies can be used as biochar briquettes, for example, durian skin waste and rice husks. Durian has a strong taste and aroma, which makes it a distinctive feature, so the presence of durian in Indonesia is still a favorite. Durian contains chemical compounds found in the skin itself. These chemical compounds contain starch, pectin, essential oils, flavonoids, saponins, cellulose elements, lignin, and ethanol.

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Durian skin can be used as a mosquito repellent, and the roots can be used to treat nail infections. Durian skin is also cytotoxic, which can be toxic to fungi. Apart from that, durian skin is one of the natural potentials in waste that has yet to be utilized. Conversion of durian skin into briquettes can increase the economic value of the product produced and the density of the briquettes.

Durian skin can be utilized as a raw material mixture for processed boards and other compressed products since it proportionately has a high cellulose content (50–60%), a low starch content (5%), and a lignin content (5%). In addition, the leftover skin from durian fruits has long fiber cells with sufficiently thick walls to provide a strong bind when combined with mineral or synthetic adhesives. It was further stated that if this was related to the ancient habits of older adults who used durian skin as mosquito repellent or cooking fuel, this was proven based on research results showing that the calorific value of durian skin obtained was 3786.95 cal/g with a low ash content of 4 %. Compared with the calorific value of charcoal from alaban wood of 5422.74 cal/g, this value is similar. For charcoal briquette products, these two ingredients can be combined. Thus, the calorific value is expected to increase.

The carbohydrate content in durian skin is relatively high. Durian skin fiber is a waste from durian fruit. The fiber content of durian skin from durian fruit is around 60 to 75%. Durian skin consists of lignin (15.45%), hemicellulose (13.09%), and cellulose (60.45%).

2.2 Biomass Briquette

Using biomass as an energy source includes making it into bio briquettes. A block of combustible material used as fuel to ignite and sustain a flame is called a briquette. The briquettes that are most frequently utilized are biomass, peat, coal, and charcoal briquettes. Experts and scientists have forecasted that briquettes are an effective and efficient alternative to fossil fuels in addressing the energy resource dilemma.

Briquettes are formed by compacting tiny powder particles with adhesive in a press machine to create a solid shape. The technique of clumping, either with or without the addition of a binder, is used to change the size of the material. To create charcoal briquettes, high-carbon materials are combined, compressed at a particular pressure, and heated at a particular temperature. This process minimizes the fuel's water content and produces a fuel with a high density, high calorific value, and little exhaust smoke.

3. METHODS

3.1 Bibliometric Analysis Method

The bibliometric analysis method combined with computational mapping analysis is one of the techniques employed in this study. Relative analysis, based on fundamental bibliometric theory, examines, explains, and presents quantitatively significant study fields using mathematics and statistics. Forecasting future research trends and hotspots using status and lock points is possible. Five processes were involved in this research: selecting keywords, gathering information, organizing and evaluating information, assessing findings, and formulating conclusions.

3.2 Materials

The raw materials for making briquettes used in this research were durian skin, rice husks, and coconut shells originating from Serang City, Banten Province, Indonesia. In addition, tapioca flour (15 g) and water (75 mL) were used as adhesives. Briquettes are made with a mass of 1 g each, and the ratio for each ingredient is presented according to **Table 1**.

Table 1. Comparison of briquette mixtures

Sample	Biomass		
	Durian peels (% mass)	**Rice husk (%mass)**	**Coconut shells (% mass)**
A	100	-	-
B	-	100	-
C	75	25	-
D	50	50	-
E	25	75	-
F	-	-	100
G	25	-	75
H	50	-	50
I	75	-	25

The tools used include a drum with a capacity of 30 L used for the composing process. The finished durian skin charcoal, coconut shell, and rice husks were ground using a powder grinder with a 600 W specification and a rotation speed of 25,000 RPM. Then, the crushed charcoal powder is sieved using a 28-mesh sieve.

3.3 Method

3.3.1 Preparation of materials

Durian peels and coconut shells are dried in the sun for seven days (7 hours per day from 09.00 – 16.00 WIB) until dry. Make durian skin charcoal by burning it in an iron drum for 5 hours until the dried durian skin turns into charcoal. Smooth the durian skin, which has become charcoal, using a 300 W powder grinder and 25,000 revolutions per minute (RPM) for 1 minute. Sift the durian skin charcoal powder using a 100-mesh nylon sieve. This process is carried out to select a smaller powder size.

3.3.2 Briquette making

Make adhesive from a mixture of tapioca flour and water using a ratio of 1:5 (15 g tapioca flour and 75 mL water), then heat using a stove over low heat and stir the adhesive solution for 2 minutes until the material thickens like glue. Mix the durian skin charcoal powder with tapioca chili glue and add a little water until the mixture can be formed. Print the mixture on a pipe that has been cut, measuring 3.81 cm in diameter and 3 cm high, then apply pressure. Then, remove the briquettes from the pipe mold onto a large piece of clear plastic and dry them in the sun until dry.

3.3.3 Making durian peel briquettes voltaic cells

Make a KOH solution of 1, 2, 3, and 4 M. Mix 20 g of durian skin charcoal powder with 30 mL of various KOH solutions. All variations of the mixture were heated and stirred with Magnetic Stirring Bars on a magnetic stirrer hotplate at 200 RPM rotation and a temperature of 800°C for 4 hours. The mixture was then left for one day until a precipitate formed. The carbon is then washed by adding distilled water and filtered with filter paper until a pH close to neutral is obtained. This is done 7-10 times washing. Then, physical activation was carried out by drying the carbon in an oven at 1100°C for 4 hours for all variations in KOH concentration. Remove the carbon in the used battery, then add the durian skin charcoal, which has not been activated and has been activated by 1, 2, 3, and 4 M KOH solution.

Measure the current and voltage of each battery with different contents of durian skin charcoal with a multimeter.

3.3.4 Production of durian peel briquette electrolysis cells

Creating a potassium hydroxide (KOH) solution with varying concentrations of 1, 2, 3, and 4 M is crucial for conducting accurate scientific experiments with reliable results. Therefore, kindly make the solution with the specified concentrations to ensure the success of the experiments. Mix 20 g of durian skin charcoal powder with 30 mL of various KOH solutions. All variations of the mixture were heated and stirred with Magnetic Stirring Bars on a magnetic stirrer hotplate at 200 RPM rotation and a temperature of 800°C for 4 hours. The mixture was then left for one day until a precipitate formed. The carbon is then washed by adding distilled water and filtered with filter paper until a pH close to neutral is obtained. This is done 7-10 times washing. Then, physical activation was carried out by drying the carbon in an oven at 1100 °C for 4 hours for all variations in KOH concentration. Dissolve 20 g of durian skin charcoal activated by KOH 1, 2, 3, and 4 M with 30 mL of distilled water. Dip the zinc connected to the multimeter's positive and negative poles to measure the solution's current and voltage.

3.3.5. Testing the characteristics of briquettes

3.3.5.1. Density

Density testing was carried out using a mass scale, namely a digital balance with an accuracy of 0.01 g. The height and diameter of the briquettes were measured using a digital caliper with an accuracy of 0.01 mm following ASTM B-311-93.

3.3.5.2. Drop test

Based on ASTM D 440-86, solid fuel quality in the testing process is reviewed from the particles lost not exceeding 1%. The fewer particles released or lost from the Drop Test test, the better the quality of the briquettes. The briquette Drop Test calculation procedure uses the ASTM D 440-86 R02 standard as follows Eqs. 1 and 2.

$$\text{Size stability \%} = (100 \times s)/S \qquad (1)$$

$$\text{Friability \%} = 100 - \text{size stability} \qquad (2)$$

Where S is the mass of the briquette before it is dropped (grams), and s is the weight of the briquette after it is dropped (grams).

3.3.5.3. Sulfur content

The total sulfur parameter test refers to the ASTM D4239-18 standard using an infrared sulfur analyzer instrument with the principle of burning the sample in a furnace with oxygen. Thus, an oxidation process occurs, converting sulfur into sulfur dioxide gas. The combustion gas is read by a detector using infrared rays to detect the amount of sulfur present oxidized.

3.3.5.4. Gross calorific value

The calorific value shows the heat produced when a certain amount of coal is burned. The calorific value is determined from the temperature rise when a certain amount of coal, usually in the (ADB) condition, is burned in a calorimeter with excess air. The gross calorific value (GCV) is obtained at constant volume. The results of this calculation are expressed in megajoules per kilogram (MJ/kg) or kilocalories per kilogram (kcal/kg). The gross calorific value parameter test refers to the ASTM standard D5865/D5865M-19 uses a bomb calorimeter instrument. The formula for calculating Gross Calorific Value is Eq. 3.

$$GCV = [(tEe) - e1 - e2 - e3 - e4]/m \quad (3)$$

With, *CGV* is the gross calorific value (kcal/Kg); *t* is the correction for temperature increase to 10.70; *Ee* is the heat capacity of the calorimeter (J/°C or cal/g); *e1* is acid correction; *e2* is the correction fuse; *e3* is the sulfur determination correction; *e4* is the burning correction; and *m* is the mass of the sample (g).

3.3.5.5 The effect of sulfur content on gross calorific value

The effect of sulfur content on gross calorific value was tested using linear regression. The linear regression equation with one independent variable that can be used is Eq. 4.

$$Y= b_0+b_1X \quad (4)$$

Where Y is the gross calorific value; b_0 is a constant; b_1 is the regression coefficient, and X is the sulfur content.

3.3.5.6 Voltaic cells and electrolysis cells

Current (mA) and voltage (mV) were identified with a Krisbow KW06-276 digital multimeter. Voltaic cell testing was done by replacing the carbon powder in the 1.5 V battery with durian peel charcoal. In contrast, electrolysis cell testing was done by mixing durian peel charcoal powder with distilled water. So the equation to be able to determine how big the potential difference is in a voltaic cell is Eq. 4.

$$E°cell = E° \text{ cathode} – E° \text{ anode} \quad (5)$$

With *E°* of the cell is the standard cell potential difference (always positive), which is obtained from the electrical potential difference resulting from the density difference between the two electrodes; *E° anode* is the electrode potential difference that occurs during the oxidation reaction (smaller value than the cathode) and *E° cathode*: Occurs during the reduction reaction at the electrode (more significant value than the anode).

4. RESULTS AND DISCUSSION

In many fields of study, bibliometrics has been utilized to support research analysis (Mibulo *et al.*, 2023; Malnar *et al.*, 2023; Muazu *et al.*, 2022; Kurtyka *et al.*, 2022; Bot *et al.*, 2023; Mainkaew *et al.*, 2023; Wibawa *et al.*, 2023; Ferronato *et al.*, 2023; Nonaka *et al.*, 2023; Kraszkiewicz *et al.*, 2022; Vaish *et al.*, 2022; Souza *et al.*, 2022; Font *et al.*, 2023; Rudiyanto *et al.*, 2023; Roman *et al.*, 2023; Bovenkerk *et al.*, 2023; Qi *et al.*, 2022; Gao *et al.*, 2022; Kuś *et al.*, 2022). Between 2013 and 2024, 409 articles with research on biomass briquettes were published. Relevance to the identified research themes was assessed to filter titles, abstracts, and article data. **Figure 1** shows the development of research on biomass briquettes. Between 2013 and 2019, fewer studies were generally carried out. The most publications were in 2022 and decreased in 2021.

We have provided an extensive compilation of bibliometric articles in **Table 2**. Our investigations and references to previous research are also included.

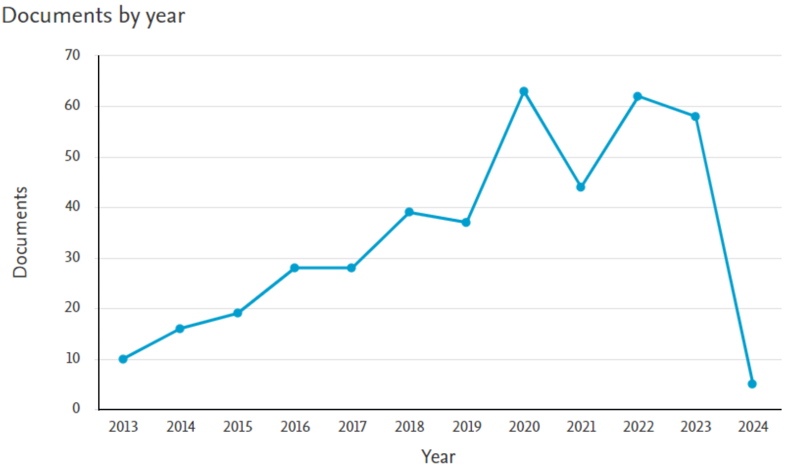

Figure 1. Biomass briquettes document graphic

Table 2. Previous studies on bibliometric

Author	Title	Result
Barbosa & Galembeck (2022)	Mapping research on biochemistry education: A bibliometric analysis	The research analyzed 66 years of biochemistry education using bibliometric analysis to gain insights into publication trends, key contributors, emerging topics, and potential research gaps.
Shidiq *et al.* (2021)	The use of simple spectrophotometer in STEM education: A bibliometric analysis	The study utilized the VOSviewer program and discovered that modified spectrophotometers are frequently used in chemistry and STEM teaching, offering potential for future research and addressing issues.
Setiyo *et al.* (2021)	The concise latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis	The bibliometric study of 127 papers showed the benefits of diesel engine fuel B100. However, it also highlighted the need for further research on engine sizes, raw materials, and testing conditions.
Soegoto *et al.* (2022)	A bibliometric analysis of management bioenergy research using vosviewer application	The study utilized VOSViewer to analyze 180 articles on bioenergy management published from 2017 to 2021. The study identified research topics and suggested ways to integrate them with other areas of study.
Mudzakir *et al.* (2022)	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	In this study, VOSviewer was used to investigate the use of benzotriazolium salt-ionic liquids (ILs) as solvents in oil palm EFB waste processing. The analysis revealed their maximum solubility, increased cellulose crystallinity, and lignin content.
Santoso *et al.* (2022)	Management information systems: bibliometric analysis and its effect on decision making.	The study examined how management information systems impacted decision-making in archives among 120 administrative workers in Bandung. The results demonstrated high levels of quality and efficacy while bibliometric analysis revealed current trends in this field of study.
Nordin (2022b)	Correlation between process engineering and special needs from bibliometric analysis perspectives.	VOSviewer, a process engineering tool for mapping analysis, has seen a decrease in publications on "process engineering special demands" between 2017 and 2021.

Table 2 (Continue). Previous studies on bibliometric.

Author	Title	Result
Bilad (2022)	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	Analyzing articles on chemistry and special education using VOSviewer and Publish or Perish revealed a decline in publications during 2017. However, there has been a rise in publications during 2021.
Riandi *et al.* (2022)	Implementation of Biotechnology in Education towards Green Chemistry Teaching: A Bibliometrics Study and Research Trends	After conducting a bibliometric analysis of research trends on biotechnology in education, it was found that teaching green chemistry in schools is a significant concept potential. Journals were identified as the most prevalent source.
Nordin (2022a)	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	A study using VOSviewer and Perish apps found a significant drop in teaching, science, and engineering research due to the pandemic.
Wirzal & Putra (2022)	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by google scholar?	Between 2018 and 2022, 800 relevant papers were analyzed using VOSviewer software to investigate the connection between chemical engineering and special needs.
Nandiyanto *et al.* (2021)	A bibliometric analysis of materials research in Indonesian journal using VOSviewer	A bibliometric analysis of Indonesian materials using VOSviewer indicates that “acid” was the most researched topic from 2016 to 2021, with 43 publications and 8 foreign linkages.
Maryanti *et al.* (2022)	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis.	The bibliometric analysis is a crucial tool in science education, providing a comprehensive understanding of the subject and highlighting its vital role in facilitating research on the SDGs.
Nandiyanto & Al Husaeni (2021)	A bibliometric analysis of chemical engineering research using VOSviewer and its correlation with covid-19 pandemic condition.	Although research in chemical engineering has declined since 2019, the field still utilizes VOSviewer software for bibliometric analysis, which provides valuable insights into research trends and themes.
Ragadhita & Nandiyanto (2022)	Computational bibliometric analysis on publication of techno-economic education.	A study on science and Islamic research using Scopus database 2012-2022 and VOSviewer for bibliometric analysis found a reduction in research, mainly in Indonesia and Malaysia.
Al Husaeni and Al Husaeni (2022)	How to calculate bibliometric using VOSviewer with Publish or Perish (using Scopus data): science education keywords	VOSviewer is a powerful tool for analyzing bibliometric data, offering step-by-step insights into research advancements in scientific education through its 200 documents from 2013 to 2023.
Al Husaeni & Nandiyanto (2022)	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSviewer	A study using VOSviewer revealed a recent increase in nanopropolis research on nanoparticles, propoli, and propolis.
Nandiyanto *et al.* (2023)	Particulate matter emission from combustion and non-combustion automotive engine process: review and computational bibliometric analysis on its source, sizes, and health and lung impact	This study analyzes the growth trend of scientific publications on particulate matter based on categories such as citation, publisher, author, country, and affiliation.

Renewable energy learning technologies from biomass materials have been the subject of extensive research. However, the analysis of biomass learning mapping using a bibliometric approach focused explicitly on understanding publication trends in learning technologies for science using the Scopus database still needs to be improved, and this is a novelty in this study. This is especially true for bibliometric analysis conducted in the last ten years (2018-2023) using the VOSviewer application.

This experiment consists of three stages, including: (1) pre-treatment, (2) printing stage, and (3) testing stage. The steps are explained in further detail in the sections that follow.

4.1. Step 1: Preparation phase

In the preparation stage of this research, several steps were taken, namely as follows:

(i) Clean durian skin, rice husks, and coconut shells and cut them into 5-8 cm pieces using a machete as in **Figure 2**.

Figure 2. Durian skin cutting.

(ii) Dry the durian skin, coconut shell, and rice husks in the sun. The drying process for durian skin and coconut shells is carried out for seven days, while for rice husks, it takes four days (7 hours per day starting from 09.00 – 16.00 WIB). This drying is done to reduce the water content in durian skin, coconut shells, and rice husks. Drying is done in the yard as in **Figure 3**.

Figure 3. Durian skin drying process.

(iii) Make durian skin and coconut shell charcoal by burning them in an iron drum for 5 hours, alternating between durian skin and coconut shell until they dry and turn into charcoal as in **Figure 4**.

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Figure 4. Durian peel charcoal.

(iv) Grind the durian skin, coconut shell, and rice husks, which have become charcoal separately, using a 300 W powder grinder and 25,000 revolutions per minute (RPM) for 1 minute as in **Figure 5**.

Figure 5. Process of smoothing durian skin charcoal using a powder grinder.

(v) The durian skin charcoal powder, coconut shells, and rice husks separately using a 28-mesh sieve as in **Figure 6**. This process is carried out to select a smaller powder size.

Figure 6. Durian peel charcoal powder sieving process.

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(vi) Make adhesive from a mixture of tapioca flour and water using a ratio of 1:5 (15 g tapioca flour and 75 mL water), then heat it using a stove over low heat and stir the adhesive solution for 2 minutes until the material thickens like glue as in **Figure 7**.

Figure 7. Adhesive manufacturing process.

(vii) Make a mold from a paragon measuring 3.81 cm in diameter and 3 cm high using a hacksaw as in **Figure 8**.

Figure 8. Briquette mold.

4.2. Step 2: Printing stage

In the printing stage, there are several steps taken, namely as follows:

(i) Prepare durian skin powder, coconut shells, and rice husks for printing briquettes. The coconut shells and rice husks in **Figure 9** are burned and then ground like durian skin.

Source: Mitalom.com
(a)

Source: istockphoto.com
(b)

Figure 9. (a) coconut shells, (b) rice husks.

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(ii) Mix the adhesive with each of the nine briquette ingredients.
(iii) Print the briquettes using a manual press machine with a pressure of 18 kN/m^2 using a pestle handle as the press and paragon as the printing container as in **Figure 10**, then hold for 2 minutes, then remove the briquettes from the pinnacle. Printing was carried out at the Physics Laboratory, Sultan Ageng Tirtayasa University.

Figure 10. Briquette printing.

(iv) Dry the molded briquettes in the sun as in **Figure 11** for five days starting from 09.00 – 16.00 WIB.

Figure 11. Briquette drying process.

4.3. Step 3: Testing stage

Tests were conducted on variations in biomass material composition. This was done to analyze the characteristics of the materials and the mixing of the materials. Each briquette sample was tested for density, drop test, gross calorific value, and sulfur content. Durian peel samples were further analyzed by measuring the voltage and electric current produced when the samples were made into voltaic cells and electrolysis cells.

4.3.1. Density

Density analysis on the nine briquette samples was successfully carried out and produced varied data. The molding that has been carried out produces solid briquettes in the shape of cylindrical tubes. Briquette molding tool in the form of a cylindrical pipe with a diameter of 3.81 cm and a mold height of 5 cm. The results of the density test are shown in **Figure 12**. The way to measure density is:
(i) Weigh the briquettes. For example, sample A briquettes weigh 0.0389 kg.
(ii) Measure the volume of the briquette from the cylinder volume equation ($V = \pi r^2 t$). From a diameter of 3.81 cm and a mold height of 5 cm, the volume of each briquette is 1137.91 kg/m^3.
(iii) Use the density Eq. 6.

$$\rho = \frac{m}{v} \quad (6)$$

Where ρ is density (g/cm^3), m is briquette mass (g), and v is briquette volume (cm^3).

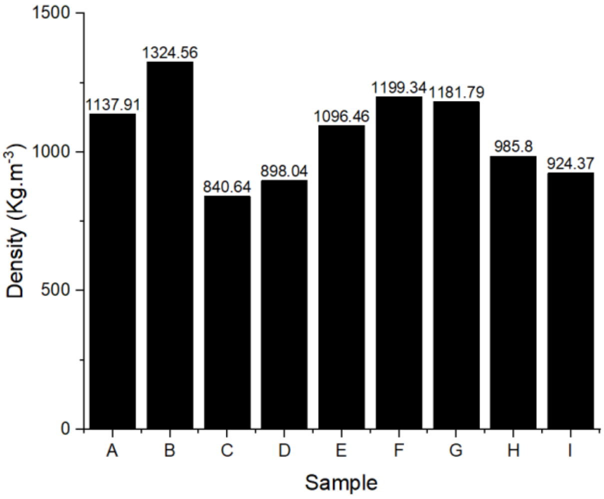

Figure 12. Briquette density graph

Figure 12 shows that the briquette density of each sample varies. This is caused by variations in the composition of the materials in the briquettes, which affect the density value. It can be seen that sample B, namely 100% rice husk, has the highest density, namely 1324.56 kg/m^3. Meanwhile, the lowest density value was obtained in sample C, namely briquettes with a mixture of 75% durian skin and 25% rice husk, namely 840.64 kg/m^3.

The briquette density value obtained from **Figure 12** shows that the rice husk material greatly influences the briquette density. The greater the percentage of rice husk material in the briquette, the greater the density value. This is because, after refining the material, rice husks produce smaller particle sizes compared to durian skin and coconut shells. So, in the filtering process, more rice husk material is filtered, affecting the density. The smaller the particle size, the smaller the distance between the particles. Therefore, when the briquette is pressed, these particles will quickly occupy the space in the briquette.

Another influence on density is the size of the briquette particles. The larger the briquette particle size, the larger the briquette pore size. The larger the pore size of the briquettes, the more water they will store. However, due to the drying process, the pores filled with water will be filled with air, so the mass of the briquettes will be lighter. The density of a briquette decreases as its mass reduces while the volume remains constant. Therefore, briquettes mixed with rice husks have a higher density than briquettes mixed with durian skin and coconut shells.

4.3.2 Drop test

To test the durability of the briquettes, a drop test is carried out to determine how much resistance the briquettes have when they hit a hard object. This testing is needed for packaging, distribution, and storage purposes. Based on ASTM D 440-86, the particle loss should not exceed 1%. Good test results are determined by the fewer particles released or lost during the drop test. The drop test results are presented in **Figure 13**. How to test drop test:

(i) Weigh the briquettes. For example, the initial mass of sample B briquettes is 45.30 g.
(ii) Drop the briquettes at a height of 1.8 m from the ground.
(iii) The weight of the material that is released or lost from the briquette after testing is measured using a scale or digital balance with an accuracy of 0.01 g. Sample B briquette after being dropped at a height of 1.8 m had a mass of 45.08 g, so we could calculate the

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particles lost as the initial mass of sample B briquette subtracted from sample B briquette after being dropped. The result of particle loss is 0.22 g.

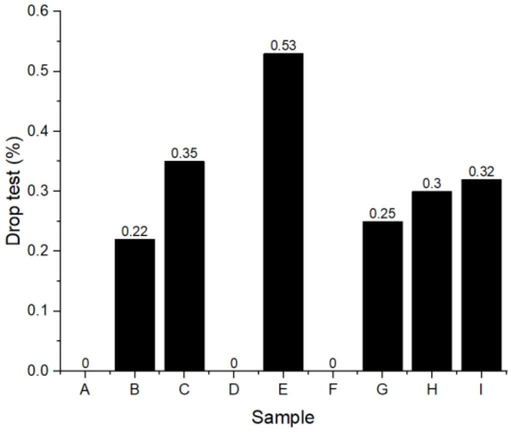

Figure 13. Drop test results.

From the drop test results in **Figure 13**, it can be seen that the briquettes with the best durability are sample A (100% durian skin), sample D (50% durian skin and 50% rice husk), and sample F (100% coconut shell), with values loose particles is 0%. This means that the three briquettes did not experience particle release. Meanwhile, sample E was the most fragile briquette that lost the most particles (25% durian skin and 75% rice husk). This briquette lost 0.53% of particles. This is because briquettes made from rice husks tend to be more dense. So according to Gandhi (2010), this causes the briquettes to have difficulty drying and become more fragile because they still contain much water.

The next most fragile briquettes are sample C (0.35%), sample H (0.30%), and sample I (0.32%). This is because these samples have an imbalance of particles in the briquettes. So, the adhesive cannot optimally bind the particles in the briquettes.

In addition, **Figure 13** shows that particle release occurs in briquettes that experience a mixture of two of the three main ingredients. The mixture consists of durian skin with rice husks and durian skin with coconut shells. This is due to the influence of particle differences between durian skin, rice husks, and coconut shells. So, in variations of the briquette mixture, the adhesive does not optimally bind the particles in the briquettes.

4.3.3. Gross calorific value

The heating value shows the amount of heat produced from burning briquettes. In this research, the calorific value tested is Gross Calorific Value (GCV), determined from the increase in temperature when the briquettes are in Air Dried Base (ADB) conditions or the briquettes are in standard temperature and humidity conditions. The gross calorific value test was conducted in the laboratory, and the gross calorific value parameter test refers to the ASTM D5865/D5865M-19 standard using a bomb calorimeter instrument. Previously known as the American Society for Testing and Materials, ASTM is a worldwide standards organization that develops and disseminates voluntary consensus technical standards for a range of products, services, systems, and materials.

Preparation steps for briquettes to be sent for laboratory testing:

(i) After the density and drop tests, the nine briquette samples were refined using a powder grinder.

(ii) Then, the briquettes that have become powder are filtered using a nylon mesh 100 sieve.

(iii) When pulverizing and screening the briquette powder, equipment, and environmental conditions are kept dry at room temperature.
(iv) Ensure that equipment and environmental conditions are kept dry at room temperature when pulverizing and screening the briquette powder.
(v) After that, the briquette powder that has been filtered is then weighed using a balance sheet with a mass of 20 g each.
(vi) After weighing, the briquette powder was put into water vapor-tight plastic to avoid condensation and keep the sample in an air-dried base (ADB) state.
(vii) Each sample was labeled to facilitate testing, starting from samples A to I.
(viii) All labeled samples were put into a second watertight container and packed by expedition to be sent to the testing laboratory, Balai Pendidikan dan Pelatihan Tambang Bawah Tanah Sumatera Barat.

Procedure for Charcoal Powder Samples by ASTM D5865/D5865M-19:

(i) Weigh the sample into a sample holder (0.8–1.2 g). Weight should be recorded to the closest 0.0001 g.
(ii) Use the method for determining heat capacity as outlined in 10.2-10.5. For standardization and analysis, a pressure of 3 MPa (30 atm) must be used for the heating value of charcoal. The initial temperature utilized for the determination must not exceed 60.5°C from the temperature used for the heat capacity calculation.
(iii) To ensure accurate corrections to other bases, determine the moisture content of a different component of the analytical sample using Test Method D3173 or D5142. This should ideally be done the same day as the calorific value measurement, but no later than 24 hours.
(iv) Sulfur analysis should be carried out using Test Method D3177 or D4239. To get the sulfur adjustment, take the weight percentage of sulfur.
(v) Within 24 hours of preparation, analyze the oxidation-prone charcoal for the eight-mesh sample.
(vi) Combustion aids such as benzoic acid, ethylene glycol, mineral oil, or gelatin capsules can be used for samples that don't burn all the way through. Use of combustion assistance should not be less than 0.4 g. To the closest 0.0001 g, record the weight. Change the mass of the sample to achieve a satisfactory ignition and to ensure that the overall amount of heat produced is the same as the amount produced during calibration.

From the test results, the GCV value shows differences in the heating value of each variation of the briquette. The difference in heating value data can be seen in **Figure 14**.

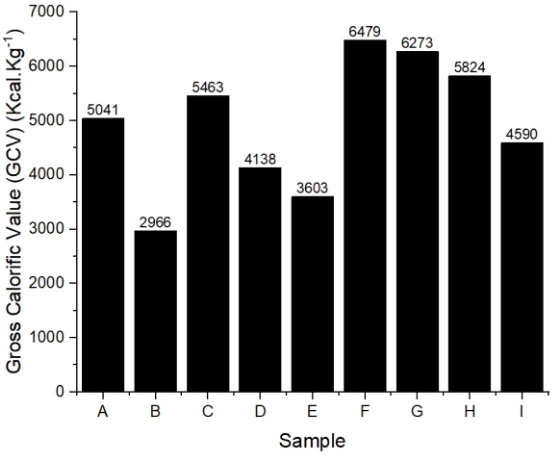

Figure 14. Gross calorific value (GCV) analysis results.

Based on the results of the Gross Calorific Value test analysis show that briquettes made from durian skin affect GCV. It can be seen that when the percentage of coconut shells in the briquettes increases, the GCV will be higher (Gantina, 2019; Iriany *et al*., 2016). However, if the percentage of rice husks is added, the GCV will be lower (Saptyaji & Yunaidi, 2021). Based on **Figure 14**, the three highest GCVs were produced from briquettes of sample F (100% coconut shell) at 6479 kcal/kg^1, sample G (75% coconut shell and 25% durian skin) at 6273 kcal/kg^1 and sample H (50% coconut shell and 50% durian skin) of 5824 kcal/kg^1.

Several factors influence the low calorific value of rice husk briquettes and the variations in the mixture. The first factor is the silica content found in rice husks. The combustion process can turn the high silica content of rice husks, which ranges from 87% to 97%, into a source of silica (Mujiyanti *et al*., 2021). Silica content is inversely proportional to calorific value (Gandhi, 2010). The more silica in a material, the smaller the calorific value produced. The silica content in a material can inhibit the combustion process, so the combustion of a material does not work optimally. Meanwhile, silica content is not found in coconut shell charcoal and durian skin. So, the combustion process for briquettes with variations of coconut shell and durian skin is better than briquettes with variations of rice husks.

The second factor influencing the GCV produced between durian skin briquettes, coconut shells, and rice husks is the cellulose and lignin content. Cellulose is the main element in making paper and affects the calorific value. Cellulose is in the form of fibers, which, when burned, burn very quickly but cannot store heat inside. This is very helpful in making alternative fuels because it can make combustion easier. Next is lignin. Lignin is found between cells and in cell walls. Between cell walls, lignin functions as a binder for cells because it is an organic compound that has complex properties. If lignin is burned, it will produce charcoal, which can store heat inside; this is the main potential that briquettes must have, namely having a high calorific value (heat) that can be used for daily activities.

There are differences in cellulose and lignin content between durian skin, coconut shell, and rice husk. Where durian skin is mainly composed of polysaccharides, namely cellulose (40–60%), hemicellulose (15–25%), then lignin (15–30%), and ash (5–10%) (Luh *et al*., 2021). The contents of coconut shells include lignin (29.4%), cellulose (43.6%), ash (0.6%), and nitrogen (0.11%) (Aria *et al*., 2022). Meanwhile, the main elements in rice husks are cellulose (38%), hemicellulose (18%), lignin (22%), and silica (Solihudin *et al*., 2020). It can be seen that the cellulose and lignin content in coconut shells and durian skin is higher than the content in rice husks. So, this affects the resulting GCV.

The results of this calorific value test are based on research by Imam *et al*. (2022), which explains that the calorific value or energy of the constituent materials influences the quality of the calorific value of a briquette. In this study, briquettes containing coconut shells and durian skin had a significant effect on increasing GCV. The research results on the calorific value of coconut shell briquettes with durian skin already have good calorific qualities. This is reinforced by SNI 01-6235-2000, which explains that the calorific value of coconut shell and durian skin must reach a minimum calorific value of 5000 kcal/kg^1. It can be concluded that briquettes containing coconut shells and durian skin can be used as a renewable fuel.

4.3.4. Sulfur content

Sulfur content testing was conducted in the laboratory with ASTM D4239-18 standard using an infrared sulfur analyzer instrument with the principle of burning the sample in a furnace with oxygen. Thus, an oxidation process occurs, converting sulfur into sulfur dioxide gas. In fuels such as coal or briquettes, sulfur content will not be avoided, especially in plants that produce organic sulfur (formed from bacterial activity). Sulfur in fuels such as coal and briquettes is usually undesirable because it can cause slagging, or the ash particles formed can stick to the walls' surface in the combustion zone (Samarinda, 2019). Sulfur value analysis is used as an additional correction to the briquettes' Gross Calorific Value (GCV) value.

Procedure for Charcoal Powder Samples by ASTM D4239-18:

(i) Instrument Preparation:
  (a) Assemble the analytical device in compliance with the manufacturer's guidelines. To prevent leaks, carefully inspect every connection.
  (b) Preheat the furnace to 1350°C.
  (c) Following the manufacturer's instructions, set the oxygen flow rate.
  (d) Preheat a furnace to 1350°C. Transfer 150 mg of charcoal sample into a boat. For a minimum of two minutes, or until the sample is entirely burned, the sample boat should stay in the furnace's hot zone. All of the equipment's functionalities will be conditioned by this action.

(ii) Calibration:
  (a) Choose a standard reference material (SRM) with sulfur concentrations that fall within the range of the sample that will be examined. 150 mg of the pre-dried charcoal standard should be weighed, and the weight should be noted to the closest 0.1 mg.
  (b) Input the standard reference material sample's weight and sulfur content into the analyzer's memory.
  (c) Place the SRM sample into the furnace's 1350°C zone.
  (d) The titration factor should be recorded as milligrams of sulfur per milliliter of titrant (mgS/mL) after the endpoint is attained, preferably within two minutes. If the analyzer lacks an integrated computer, note the amount of titrant used and compute the titrant factor according to the guidelines.
  (e) After removing the sample boat, repeat Steps A through D twice more.
  (f) Perform the necessary manual calculations if the analyzer does not automatically average the titrant factors acquired during the calibration step and feed that average into the microprocessor. The titrant factors produced by successive calibrations have to be within 0.01 mgS/mL of one another.

(iii) Analysis Procedure:
  (a) Make use of a calibrated and conditioned device.
  (b) Weigh the charcoal analysis sample into the boat to the nearest 0.1 mg.
  (c) Input the sample weight into the memory of the sulfur analyzer.
  (d) Place the sample of charcoal in the furnace at 1350°C.
  (e) Once the endpoint is reached, which should take at least two minutes, note the sample's sulfur concentration. Calculate the sulfur concentration by recording the amount of titrant used, if the analyzer lacks an integrated computer.

The total sulfur test results are shown in **Figure 15**.

Based on the sulfur value test analysis results, **Figure 15** shows that sample F (100% coconut shell) has the lowest sulfur value compared to other briquette variations, with a sulfur value of 0.03%. Meanwhile, the highest sulfur values were found in samples A (100% durian skin) and I (75% durian skin and 25% coconut shell), which had a value of 0.16%. Likewise, sample C (75% durian skin and 25% rice husk) has a content of 0.15%. The sulfur value increases as the durian skin content in the briquettes increases. This shows that briquettes made from durian skin have higher sulfur emissions than coconut shells and rice husks. Sulfur can affect the environment. The sulfur content in organic materials is influenced by bacterial activity, especially in durian skin. During the drying process, the durian skin appears to experience significant decay, emitting a pungent odor and changes in physical

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form. This is different from coconut shells and rice husks, which do not emit an odor and also do not change their physical form significantly. Thus, the sulfur content with the highest content is found in 100% durian skin briquettes, or briquettes that contain the most dominant durian skin content.

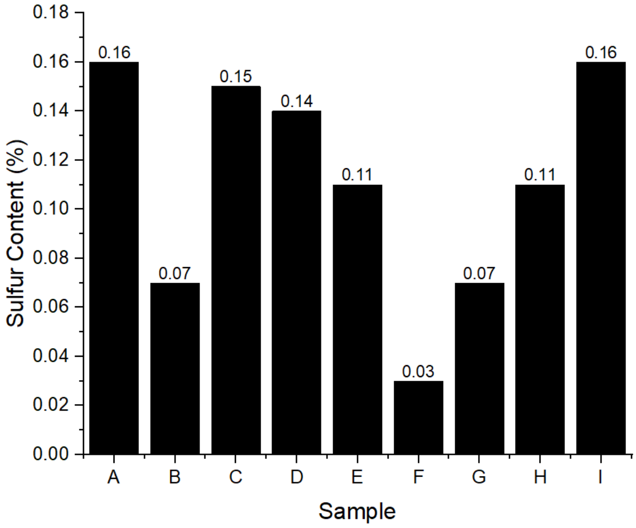
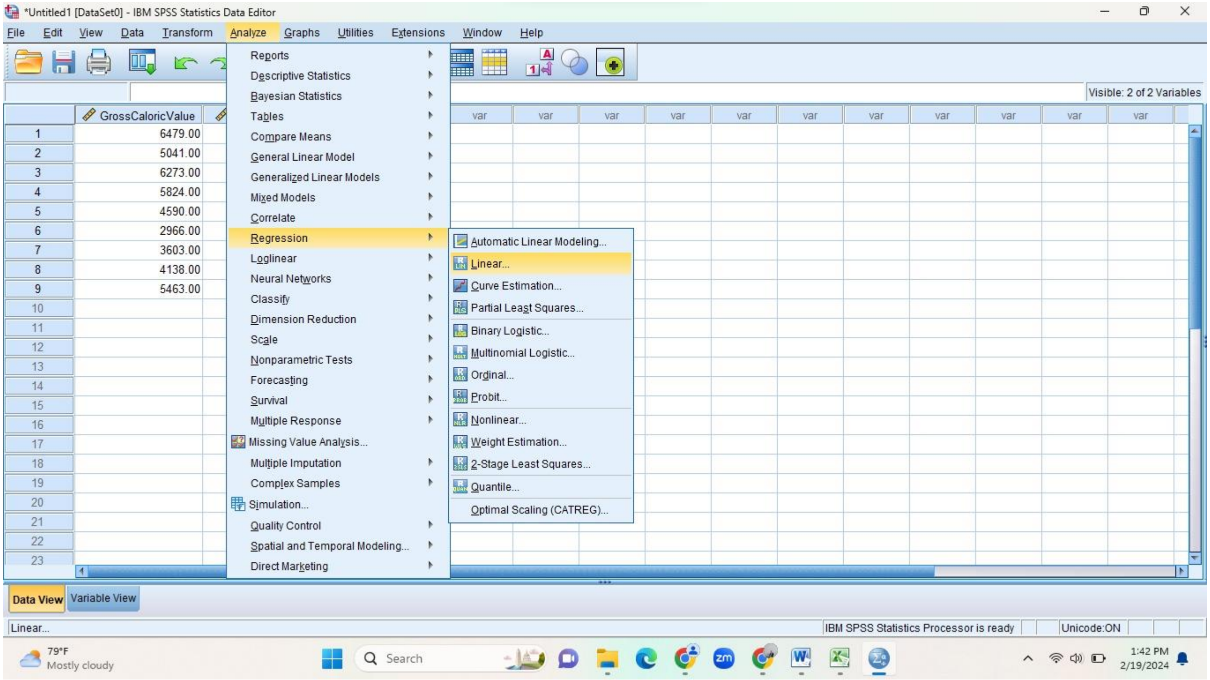


Figure 15. Results of sulfur content analysis

4.3.5. Effect of sulfur content on gross calorific value

The effect of sulfur content on gross calorific value was calculated by SPSS with the following steps:

(i) Select “Analyze -> Regression -> Linear” as in **Figure 16**.



	GrossCaloricValue
1	6479.00
2	5041.00
3	6273.00
4	5824.00
5	4590.00
6	2966.00
7	3603.00
8	4138.00
9	5463.00

Figure 16. Linear regression analysis.

(ii) From the list on the left, select the variable “Gross Calorific Value” as “Dependent” and the variable “Sulfur content ” as the “Independent(s)”. Click “OK” as in **Figure 17**.

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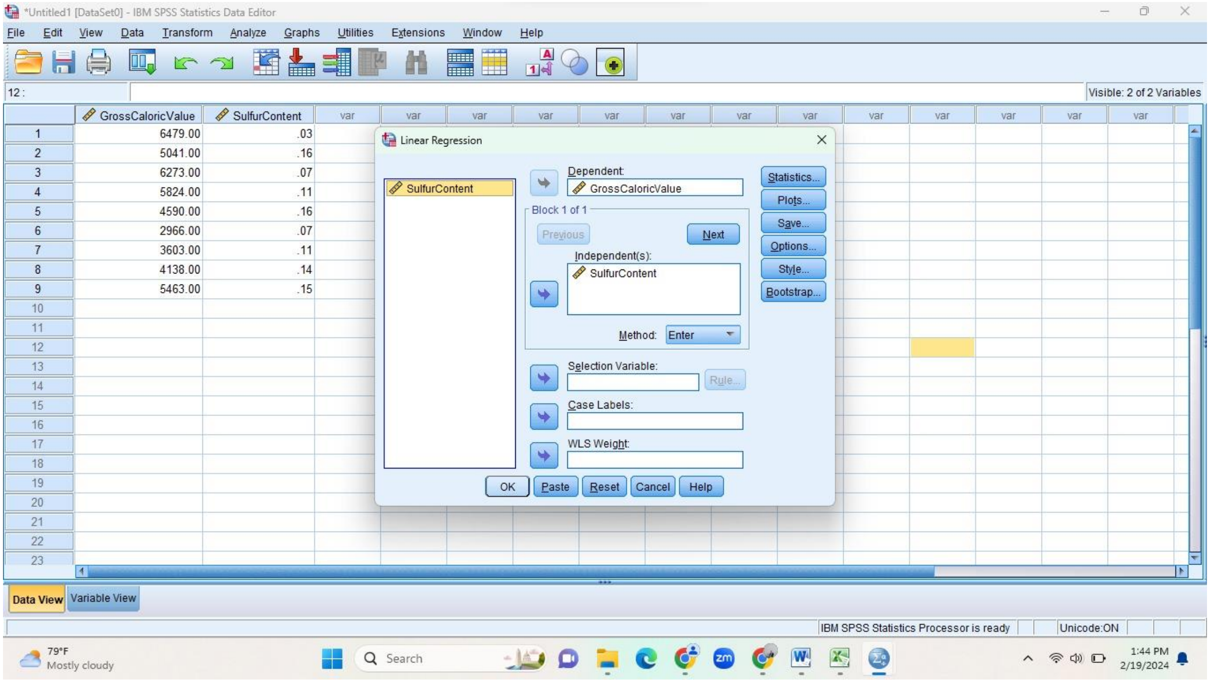

*Untitled1 [DataSet0] - IBM SPSS Statistics Data Editor

	GrossCaloricValue	SulfurContent
1	6479.00	.03
2	5041.00	.16
3	6273.00	.07
4	5824.00	.11
5	4590.00	.16
6	2966.00	.07
7	3603.00	.11
8	4138.00	.14
9	5463.00	.15

Linear Regression

Dependent: GrossCaloricValue

Block 1 of 1

Independent(s): SulfurContent

Method: Enter

Figure 17. Variable “Gross Calorific Value” as “Dependent” and the variable “sulfur content ” as the “Independent(s)”.

(iii) The results now pop out in the “Output” window.

The results of the simple linear regression test analysis between sulfur content and gross calorific value are shown in **Table 3**.

Table 3. Analysis of the influence of sulfur content on gross calorific value

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5665.354	1139.951		4.970	0.002
	Sulfur Content	-6611.183	9551.320	-0.253	-0.692	0.511

a. Dependent Variable: Gross Calorific Value

By looking at sig. 0.511>0.05, so it can be concluded that this study does not influence sulfur content on gross calorific value. Meanwhile, if we continue to obtain the regression equation, it can be derived from **Table 4**.

Table 4. Regression output.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.253^a	0.064	-0.070	1248.59136

a. Predictors: (Constant), Sulfur Content

From **Table 4**, the equation is obtained

$$Y = 5665.354 - 6611.183X$$

The magnitude of the influence of sulfur content on gross calorific value is only 6.4% (can be seen in **Table 4** column R Square), while other factors influence 93.6% of gross calorific value. These results are by research conducted by Nur *et al.*, (2019), which explains that the total sulfur content dramatically influences the calorific value of biomass fuel; the higher the total sulfur content with an increase of 0.5%, the higher the gross calorific value—amounting to 69.79 cal/g. However, there is conflicting research, namely Dian *et al.*, (2021), which explains that the higher the total sulfur, the lower the GCV.

4.3.6. Volta cells and electrolysis cells

Charcoal from durian skin, apart from being used as fuel for briquettes, also has an electrical value that can produce an electric current. So, tests were carried out on durian skin charcoal if it was used as a voltaic and electrolysis cell. Electrical current and voltage testing were performed by activating durian peel charcoal in KOH solutions with varying concentrations. The voltaic cell here is a battery, so the carbon content of the used battery is removed and then replaced with durian skin charcoal to obtain the resulting electric current and voltage data as follows. The way to measure current and voltage in a voltaic cell is:

(i) Prepare KOH solutions with molarities of 1, 2, 3, and 4 M.
(ii) Dissolve 20 g of durian skin charcoal with 20 mL of KOH
(iii) All variations of the mixture (**Table 1**) are heated and stirred with Magnetic Stirring Bars on a magnetic stirrer hotplate at 200 RPM and a temperature of 80°C for 4 hours.
(iv) The mixture was then left for one day until a precipitate formed.
(v) The carbon is then washed by adding distilled water and filtered with filter paper until a pH close to neutral is obtained. This is done 7-10 times cleaning.
(vi) Then, physical activation was carried out by drying the carbon in an oven at a temperature of 110°C for 4 hours for all variations in KOH concentration.
(vii) Remove the carbon from the used battery, then add the durian peel charcoal, which has not been activated and has been activated by 1, 2, 3, and 4 M KOH solution.
(viii) Measure the current and voltage of each battery with different contents of durian peel charcoal with a multimeter.

From **Figure 18**, it can be seen that the voltage value is higher if the KOH activation molarity is smaller. So, the more the KOH concentration is diluted, the more it affects the voltage of durian skin charcoal. From the experiment, it was found that KOH with a small concentration or molarity produced a large voltage, this could be due to the small concentration being able to bind the charcoal powder. Thus, it is more active, resulting in a greater voltage.

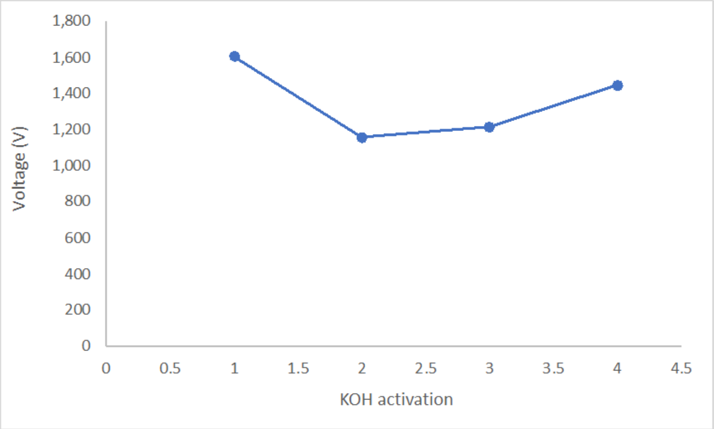

Figure 18. Graph of electric current and voltage produced by the durian skin charcoal voltaic cell.

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Electrolysis cell testing was carried out by mixing durian peel charcoal with distilled water to obtain the resulting electrical current and voltage data as follows. The way to measure current and voltage in an electrolysis cell is:

(i) Dissolve 20 g of durian skin charcoal that has been activated by KOH 1, 2, 3, and 4 M with 30 mL of distilled water.

(ii) Dip the zinc connected to the multimeter's positive and negative poles to measure the solution's current and voltage as in **Figure 19**.

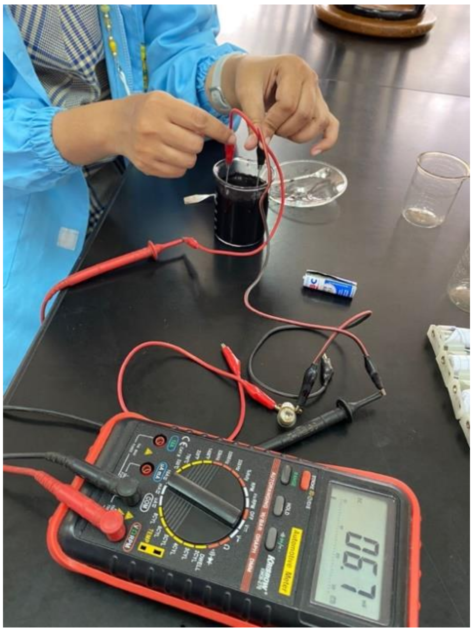

Figure 19. Measure current and voltage in an electrolysis cell.

Unlike voltaic cells, **Figure 20** shows that the higher the molarity of KOH activation, the greater the voltage produced. However, the highest voltage is obtained when durian skin charcoal is not activated with KOH. From the experiment, it was found that KOH, whose concentration or molarity is large, produces a large voltage; this can be caused because a large concentration of KOH can bind the charcoal powder to be more active to produce a greater voltage. For current, everything has the same value.

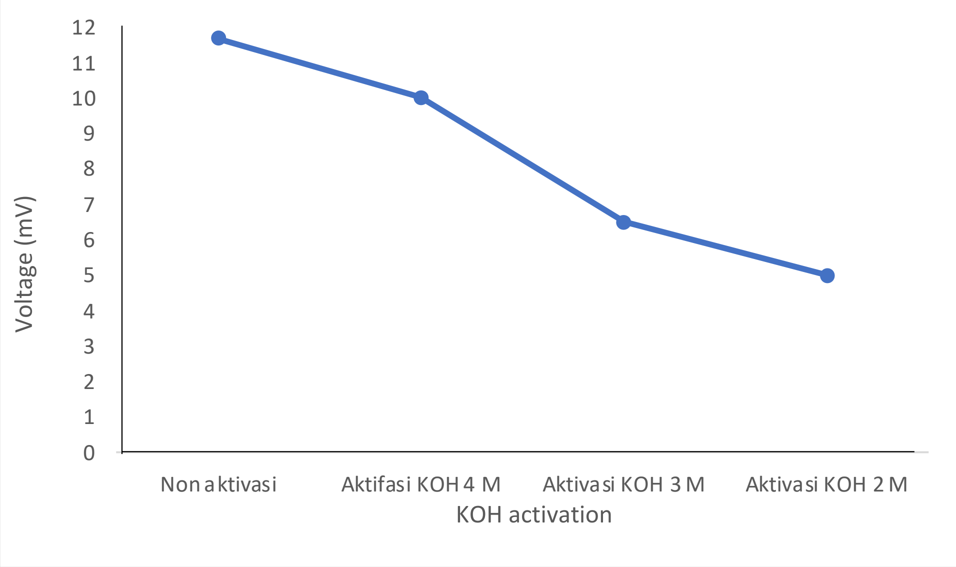

Figure 20. Current and voltage graph for electrolysis of durian skin charcoal.

5. CONCLUSION

Based on the research results, briquettes can be made using durian skin waste, coconut shells, and rice husks. The highest density value was obtained in 100% rice husk briquettes with a 1324.56 kg/m^3 value. Moreover, the smallest density value was obtained in briquettes mixed with 75% durian skin and 25% rice husk, weighing 840.64 kg/m^3. Meanwhile, for the drop test, the five briquette samples were declared to have passed the test because the particles released were less than 1%. In testing the highest calorific value, 100% coconut shell briquettes were obtained at 6479 kcal/kg^1. The briquettes with the next highest calorific value are mixed with 75% coconut shell and 25% durian skin, namely 6273 kcal/kg^1. The two briquette mixtures can be used for industrial needs and the rest for home needs. The calorific and sulfur values are closely related and directly proportional. When the sulfur value rises, the sulfur value also gets higher. Meanwhile, the voltage value produced by the durian peel charcoal voltaic cell was highest when activated with more dilute KOH; in contrast to the durian peel charcoal electrolysis cell, the highest voltage was obtained when activated with more concentrated KOH.

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the data and the paper are free of plagiarism.

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