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OPTIMIZATION OF RICE HUSK, COCONUT SHELL, AND SUGARCANE BAGASSE COMPOSITION USING SIMPLEX LATTICE DESIGN TO IMPROVE THE QUALITY OF ENVIRONMENTALLY FRIENDLY BRIQUETTES

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ABSTRACT

Biomass fuels such as coconut shell charcoal, sugarcane bagasse charcoal, and rice husk charcoal offer significant potential as alternatives to coal in the era of climate-friendly technology; this study aims to optimize biobriquette formulations by reducing moisture content and enhancing calorific value using the Simplex Lattice Design (SLD) method via Design Expert Version 13. The raw materials are processed through pyrolysis, sieving, grinding, mixing with a tapioca based binder, pressing, and drying, followed by evaluations of physical properties including moisture content, ash content, calorific value, compressive strength, and CO emissions. Statistical analysis using a quadratic model reveals that component interactions significantly influence product responses, yielding an optimal formulation with 81.60% coconut shell charcoal, 8.40% sugarcane bagasse charcoal, and 0% rice husk charcoal, which predicts a moisture content of 7.50% and a calorific value of 5324.29 cal/g. Experimental verification closely approximates these predictions and meets SNI standards, although further improvement in compressive strength is needed.

KEYWORDS: charcoal, bagasse, rice husk, Simplex Lattice Design

1. INTRODUCTION

In the face of global challenges stemming from the decline in coal usage due to environmental issues and the growing demand for climate-friendly technology, the search for sustainable alternative energy sources has become crucial. One promising solution is the utilization of biomass as a renewable energy source [1]. Biomass, particularly charcoal produced from coconut shells, sugarcane bagasse, and rice husks offers significant potential as a coal substitute due to its abundant availability, renewable nature, and lower environmental impact. However, the direct use of biomass as fuel still faces challenges such as high moisture content, variable calorific value, and physical properties that adversely affect combustion efficiency [2].

Several previous studies have demonstrated that converting biomass into briquettes through binding and pressing processes can overcome these issues [3]. The advantages of briquettes include a consistent calorific value, reduced bulk of raw materials for easier storage and transportation, and good storage stability. Additionally, briquettes provide higher combustion efficiency with lower emissions of harmful particles and gases compared to raw biomass [4].

The strength and quality of briquettes are influenced by various factors, including the composition of raw materials (fiber content, ash content, and particle size), moisture content, type and amount of binder used, as well as the conditions of the pressing and drying processes [5]. These variables determine the structural integrity and mechanical strength of briquettes during storage and transportation, making the selection of materials and process parameters critical for producing a high-quality product [6].

Based on these considerations, this research focuses on optimizing the formulation of briquettes made from charcoal derived from coconut shells, sugarcane bagasse, and rice husks. The selection of materials is based on their chemical and physical characteristics that support an increased calorific value and reduced moisture content; for instance, coconut shell charcoal is chosen for its high fatty acid content that enhances energy formation, while sugarcane bagasse charcoal and rice husk charcoal are selected for their abundant availability and high potential calorific value [7].

To achieve an optimal formulation, this study employs the Simplex Lattice Design (SLD) method using Design Expert Version 13 software [8]. The SLD method facilitates the identification of the optimal composition through comprehensive statistical analysis, integrating variables such as moisture content, calorific value, compressive strength, and CO emissions. This approach minimizes trial and error in product development and results in briquettes that not only meet national quality standards (SNI) but also offer an environmentally friendly and efficient solution for biomass energy utilization. This research is expected to make a significant contribution to the development of high-quality alternative fuels, support national energy sustainability, and reduce the environmental impact of fossil fuel consumption.

2. MATERIALS AND METHODS

2.1 Materials

In this research, bagasse charcoal, coconut shell charcoal, and rice husk charcoal are used as the primary raw materials for briquette production, with tapioca serving as the binder. Before processing, the raw materials are sieved using a 50-mesh screen. The equipment involved in this study includes briquette molding tools, beaker glasses, stirrers, scales, an oven, a furnace, and various testing instruments to evaluate the briquettes properties.

2.2 Methods

1. Preparation of Raw Materials and Adhesive

Biomass sources such as rice husks, coconut shells, and bagasse are thoroughly cleaned with running water to remove impurities. After washing and drying, the biomass undergoes pyrolysis in a furnace at 500°C for two hours. The resulting char is then ground and sieved to achieve a uniform particle size suitable for briquette production. To create the binding agent, 200 grams of tapioca flour are mixed with one liter of water at 60°C and heated for 30 minutes. This process yields a tapioca-based adhesive, which is incorporated into the briquette mixture at a concentration of 10% by weight.

2. Preparation of adhesive

The processed biomass is combined with the prepared tapioca adhesive to form a homogeneous mixture. This mixture is then compacted using a hydraulic press with a maximum capacity of 200 grams per briquette. Post-pressing, the briquettes are dried in an oven set at 110°C for three hours to reduce moisture content, enhancing their combustion efficiency and storage stability. Once dried, the biobriquettes are stored in PET ziplock containers at room temperature until they are ready for use.

3. Analysis Method

Analysis of physical parameters, including:

a. Moisture content test

To determine moisture content, biobriquette samples are weighed and then heated in an oven at 110°C for four hours until a constant weight is achieved. The moisture content is calculated using the following formula:

$$\text{Moisture Content (\%)} = \frac{M_0 - M_1}{M_0} \times 100 \qquad (1)$$

Description:
M_0 = weight of the sample before drying (g)
M_1 = weigh of the sample after drying (g)

b. Ash content test

The ash content is determined by weighing the biobriquette sample in a porcelain crucible and placing it in a furnace at 800°C for two hours. The ash content is calculated using the equation:

$$\text{Ash Content } (\%) = \frac{\text{Ash weight (g)}}{\text{Weight of sample (g)}} \times 100\ \% \qquad (2)$$

Description:
Weight of sample (g)
Ash weight = (weight of cup and sample after drying - weight of empty cup)
Weight of sample = (weight of cup and sample before drying - weight of empty cup)

c. Compressive strength test

Briquette samples are loaded until they are destroyed, then the data obtained during the test is analyzed to determine the maximum compressive strength.

Analysis using instruments, including:

a. Calorific value

The calorific value of the briquettes is measured using a bomb calorimeter. The test sample must be completely dry before being introduced into the bomb calorimeter. Oxygen is supplied to create optimal combustion conditions, and the sample is ignited to undergo complete combustion. The calorimeter records the heat generated, which is used to determine the calorific value. The calorific value is calculated based on the temperature change observed during combustion and is expressed in calories per gram (cal/g). The device used for this measurement is a 6400 Automatic Isoperibol Calorimeter from Parr Instrument Company, United States.

b. Air emission quality

The air emissions from biobriquette combustion are assessed by measuring carbon monoxide (CO) levels over a one-hour period. The briquettes are burned in a furnace at temperatures ranging from 700-900°C. A specialized emission testing device is then used to quantify the levels of CO present in the combustion smoke, providing an indication of air emission quality.

Analysis experimental

Simplex Lattice Design is an experimental method in statistics and experimental design used to optimize processes by identifying influential factors. This method is useful in product development, process optimization, and experimental research. In briquette production, the biomass component ratio, specifically coconut shell, bagasse, and rice husk affects the calorific value. Therefore, optimization using the Simplex Lattice Design (SLD) method with Design Expert version 13 is employed to determine the optimal composition and component interactions.

3. RESULTS AND DISCUSSION

3.1 Briquette Optimization with Simplex Lattice Design

Optimization of briquettes made from coconut shell, bagasse, and rice husk using the SLD (Simplex Lattice Design) method with Design Expert software version 13 to obtain optimum conditions. The experimental design and response test results of each variable can be seen in Table 1. with 14 experimental runs.

Synergistic and antagonistic effects can be identified in SLD by analyzing the response surface and contour plot. The response surface shows the relationship between the independent and dependent variables, while the contour plot shows the effect of changing one independent variable while keeping the other variables constant. The effect of independent variables (Coconut shell (A), Bagasse (B), and Rice husk (C)) on the response (moisture content and calorific value), briquettes were analyzed using linear, factorial, cubic, super cubic, and quadratic models. The best model was selected based on the coefficient of determination (R2), predicted coefficient of determination (Pred. R2), and adjusted coefficient of determination (Adj. R2). The following is the experimental data for testing the water content and calorific value of briquettes as shown as in Table 1.

Table 1. Experimental data for testing water content and calorific value of briquettes

Sample Number	Independent Variables			Response	
	Coconut shell (%)	Sugarcane Bagasse (%)	Rice Husk (%)	Water content (%)	Calorific Value (Cal/g)
1	90	0	0	6.42	5237.35
2	0	90	0	6.76	5133.09
3	0	0	90	15.62	4500.52
4	45	45	0	8.45	5450
5	45	0	45	13.03	5336.66
6	0	45	45	15.23	4993.43
7	60	15	15	10.66	5200.10
8	15	60	15	9.016	5303.26
9	15	15	60	13.78	4943.42
10	30	30	30	12.77	5465
11	90	0	0	6.36	5324.35
12	0	90	0	6.53	5263.9
13	0	0	90	16.74	4794.55
14	45	45	0	10.64	5470.76

3.1.1 Statistical test of briquette water content

The briquette water content test will be related to the quality of the briquette, high water content can reduce the calorific value and combustion power of the briquette so that the quality of the briquette becomes poor. Conversely, low water content will increase the calorific value and combustion power of the briquette. The resulting water content must be in accordance with the briquette quality standards. According to SNI, the water content of the briquette must not exceed 8% to meet the national briquette quality standards. In this study, a statistical fit test was carried out and lack of fit is used to assess the quality or suitability of the resulting regression model with experimental data. The following are the results of statistical fit and lack of fit as shown in Tables 2 and 3.

Table 2. Fit summary water content with Design Expert 13

Source	Sum of squares	df	Mean square	F value	P value	
Model	168.57	5	33.71	28.65	<0.0001	
Mixture	147.62	2	73.81	62.72	<0.0001	Significant
AB	10.72	1	10.72	9.11	0.0166	
AC	1.5	1	1.5	1.28	0.2909	
BC	7.81	1	7.81	6.64	0.0328	
Residual	9.41	8	1.18			
Lack of Fit	6.35	4	1.59	2.07	0.2486	Not significant
Pure Error	3.06	4	0.7655			
Total Cast	177.98	13				

Table 3. Lack of fit test water content response with Design Expert 13

Source	R^2	Adj R^2	Pred R^2
Quadratic	0.9471	0.914	0.7883

The results of the analysis of variance (ANOVA) in Table 2 show that the selected model for the water content response is the quadratic model, because this model has a larger R2 compared to the other models, namely 0.9471. Pred The R^2 of 0.7883 is quite consistent with the Adj R^2 of 0.914, meaning the difference is less than 0.2.

Based on Table 3, the F-value of the Model is 28.65, implying that the model is significant. There is only a 0.01% chance that an F-value of this size can occur due to interference. A P-value of less than 0.05 indicates a significant model. A value greater than 0.1 indicates that the model is not significant. Lack of Fit F- value of 2.07 implies lack of fit is not significant relative to pure error. There is a 24.86% chance that a Lack of Fit F-value of this magnitude could occur due to interference. Lack insignificant fit is a requirement for a good model [9]. The results of the water content evaluation were then analyzed using Design Expert software. 13 to determine the effect of each base or the interaction between the three on the water content of the briquettes. The mathematical equation obtained from the program is a linear equation, as seen in equation (3).

$Y = 6.59 (A) + 6.50 (B) + 16.10 (C) + 10.75 (A)(B) + 4.83 (B)(C) +11.00(C)(A)$ (3)

Noted:

Y = Response water content
A = Composition shell coconut
B = Composition baggase
C = Composition rice husks

The ANOVA analysis conducted produced data that would be transformed and analyzed using the Quadratic approach model. The relationship model between variables as shown in Figure 1.

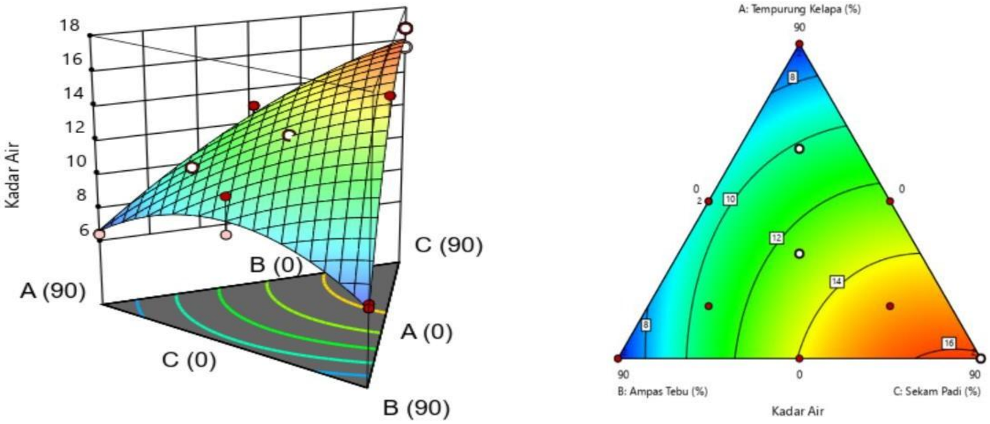

Figure 1. 3D surface & contour plot of briquette component interaction with water content

The equation obtained from the program is a quadratic equation. In equation (3) it means that if the increase in each component can increase the water content, this is indicated by a coefficient that has a positive value. Rice husks have a higher coefficient value than coconut shells and sugarcane bagasse with a value of 1 6.10 so that rice husks have a dominant effect in increasing the water content. This is related to the total carbon content in rice husks which is quite high compared to coconut shells and sugarcane bagasse, the higher the carbon content of plant biomass, the higher the heat energy needed to do useful work so that the combustion process is less effective compared to coconut shells and sugarcane bagasse [10]. Based on Table 1, it can be seen that the highest briquette water content is formula 13 which contains a water content of 16.74% with a ratio of coconut shell, bagasse, and rice husks of 0; 0; and 90%, respectively. While the lowest water content is Formula 11 with a ratio of 6.36 coconut shell, bagasse, and rice husks of 90%; 0; and 0, respectively. Table 1 also shows the difference in the composition of the same formula, namely in Formula 1-4 with Formula 11-14, after statistical processing with Design Expert 13 software , the difference in the data has a different value that is not significant, this is stated in the model parameters that have significant values and the Lack parameter of Fit which has an insignificant value, which means that the response of the replication formula with the same variation in the number of components shows the same response.

3.1.2 Statistical test of briquette calorific value

The calorific value test of briquettes will be related to the quality of briquettes, high calorific value indicates better quality of briquettes because briquettes can produce more heat energy. Conversely, low calorific value indicates poor quality of briquettes. In this study, a statistical fit test was conducted and lack of fit is used to assess the quality or suitability of the resulting regression model with experimental data. The following are the results of statistical fit and lack of fit in Tables 4 and 8.

Table 4. Fit summary calorific value response with Design Expert 13

Source	Sum of squares	df	Mean square	F value	P value	
Model	8.8×10^5	5	1.76×10^5	10.57	0.002	Significant
Mixture	6.8×10^5	2	3.42×10^5	8.60	0.007	
AB	70025.75	1	70025.75	4.02	0.074	
AC	1.2×10^5	1	1.17×10^5	6.44	0.032	
BC	6540.80	1	6540.80	0.44	0.55	
Residual	1.5×10^5	8	18330.51			
Lack of Fit	90965	4	22741.50	1.63	0.378	Not Significant
Pure Error	55678.11	4	13919.53			
Total Cast	1.04×10^6	13				

Table 5. Lack of fit calorific value with Design Expert version 13

Source	R^2	Adj R^2	Pred R^2
Quadratic	0.8685	0.7863	0.6297

The ANOVA results in Table 4 show that the selected model for the water content response (quadratic model), because this model has a larger R2 compared to other models, namely 0.8685. The predicted R^2 of 0.6297 is quite in accordance with the adjusted R^2 of 0.7863, meaning the difference is less than 0.2 [11].

The Model F-value of 10.57 implies that the model is significant. There is only a 0.23% chance that an F-value of this magnitude could occur due to noise. A P-value less than 0.05 indicates that the model term is significant. A value greater than 0.1 indicates that the model term is not significant. Lack of fit F value of 1.39 implies that there is a 37.84% chance that Lack of fit F This value can occur due to interference. An insignificant Lack of Fit value is a requirement for a good model because it indicates that the yield response data is in accordance with the model [12].

Based on the analysis with Simplex Lattice Design, the equation for the calorific value of briquettes was obtained:

$$Y = 5255.24(A) + 5207.50(B) + 4638.20(C) + 868.92(A)(B) + 1315.6\,(A)(C) + 318.31\,(B)(C) \qquad (4)$$

Noted:
Y= Response heat value
A = Composition shell coconut
B = Composition dregs sugarcane
C = Composition of rice husk

The ANOVA analysis conducted produced data that would be transformed and analyzed using the Quadratic approach model. The relationship model between variables is shown in Figure 2.

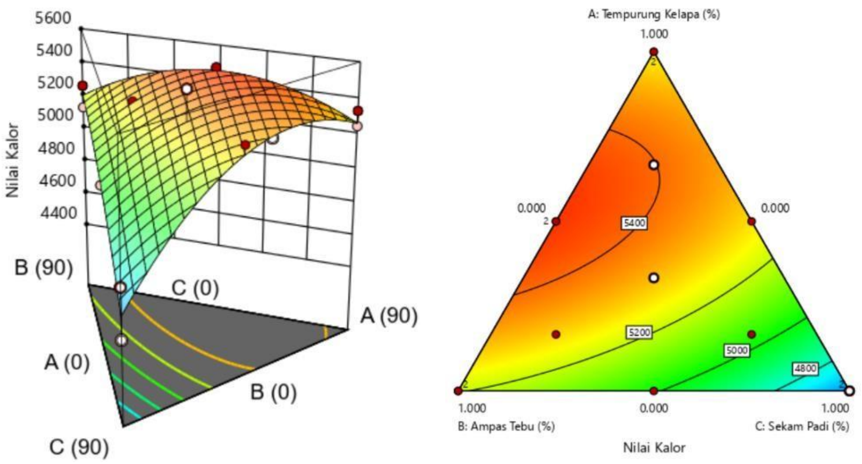

Figure 2. 3D surface & contour plot of briquette component interaction on calorific value

Equation (4) obtained from the software is a quadratic model equation. In this calorific value response, a quadratic equation is used because the data obtained cannot be described using a linear equation so it needs to be developed into a quadratic equation. Based on Table 3, it can be seen that the lowest calorific value of the briquette is formula 2 which contains a calorific value of 4500.52 with a ratio of coconut shell, bagasse, and rice husk respectively of 0; 0; and 90%. While the highest calorific value is Formula 8 with a calorific value of 5470.76 which is a ratio of coconut shell, bagasse, and rice husk respectively of 45%; 45%; and 0.

Based on equation (4), it can be seen that the interaction between the optimized components affects the calorific value response. Each component shows a positive coefficient. This is because each biomass has a hydrogen content, hydrogen is very flammable and releases a large amount of energy when it reacts with oxygen. This energy release can increase the combustion rate and overall briquette efficiency, especially if the hydrogen content is high in the biomass material used to produce briquettes [13]. The highest hydrogen content in sequence is found in coconut shells, bagasse, and rice husks, causing the high and low numbers in equation 2 above.

3.2 Optimization of Briquette Formula

Formula optimization was conducted using the Simplex Lattice Design approach with Design Expert Version 13. The optimal formula was determined by inputting the target response to be achieved and the degree of importance. The available response goals include minimize, maximize, target, in range, and equal to. The degree of importance indicates how crucial each response is in determining the optimal formula, ranging from less important (+) to highly important (+++++).

The response analysis of briquette properties, including moisture content and calorific value, was incorporated into the Simplex Lattice Design. The optimization data for the briquette formula is presented in Table 6.

Table 6. Optimization Data of the Optimum Briquette Formula Using Design Expert

Name	Goal	Lower Limit	Upper Limit	Importance
A :	In range	0	90	-
B :	In range	0	90	-
C :	In range	0	90	-
Moisture Content	Minimize	6,37	16,74	++++
Calorific Value	Maximize	4500,52	5470,76	++++

Coconut shell, bagasse, and rice husk were selected as the studied factors and set to "in range." The degree of importance for moisture content was set at (++++), with the goal to minimize, as lower moisture content improves briquette quality. The degree of importance for calorific value was also set at (++++), with the goal to maximize, as a higher calorific value indicates better briquette performance.

After inputting all responses, the software generated multiple solutions with varying compositions of materials and predicted response values. Each solution had a desirability score ranging from 0 to 1. A desirability value closer to 1 indicates a solution that better meets the optimization criteria. The solution with the highest desirability was selected [14].

In this study, one solution was identified with a desirability value of 0.921. The optimal composition consisted of 81.60% coconut shell, 8.40% bagasse, and 0% rice husk, based on the total weight of the briquette mixture. The predicted physical properties of the optimal formula are presented in Table 7.

Table 7. Composition and Predicted Optimal Briquette Formula

No	Coconut shell	Sugarcane Bagasse	Rice Husk	Moisture Content	Calorific Value	Desirability
1.	81,60	8,40	0.000	7.500	5324,29	0.921

3.3 Verification of Optimal Results

The optimal formula predicted by the Simplex Lattice Design was validated by remanufacturing briquettes using the same method as in the orientation phase. Physical tests, including moisture content and calorific value analysis, were conducted. The verification results were analyzed to determine the percentage error in the sample. This error percentage analysis was performed to compare the average research results with the predicted data.

After re-testing the briquettes with a composition of 81.6% coconut shell charcoal and 8.4% bagasse, the results for moisture content, ash content, calorific value, compressive strength, and CO emissions were obtained, as shown in Table 8.

Table 8. Moisture Content and Calorific Value Testing for Optimal Briquette Variable

Composition			Moisture Content (%)	Percent Error Moisture Content (%)	Calorific Value (kal/gr)	Percent Error Calorific Value (%)
CS	SB	RH				
81,60	8,4	0	7,43	0,93	5226,75	1,84

From Table 8, it can be observed that the percentage errors for moisture content and calorific value are very small, indicating that the model is statistically significant and aligns well with the predicted data (accurate). The obtained optimal formula was further tested against national biobriquette standards through ash content, compressive strength, and CO emission tests. The test results for the optimal variable are presented in Table 9.

Table 9. Ash Content, Compressive Strength, and CO Emission Testing for Optimal Briquette Variable

Composition			Ash Content	Compressive Strength	CO Emission
BK	AT	SP	(%)	(N/cm$^{2)}$	(ppm)
81,60	8,4	0	5,7	1,4	4713

From Table 9, the ash content is found to be 5.7%, which meets the SNI No.1/6235/2000 standard, where the maximum permissible ash content is 8%. This indicates that the biobriquette's ash content is within an acceptable limit, ensuring good combustion residue quality.

Additionally, the compressive strength of the biobriquette was measured at 1.4 N/cm^2, which is slightly below the SNI 01 - 6235-2000 standard that requires a minimum compressive strength of 1.5 N/cm^2. Although slightly lower than the standard, this value suggests that the biobriquette is still usable but requires further attention to its mechanical strength. A lower compressive strength may cause the briquettes to break or crumble easily, leading to material loss and decreased efficiency. Furthermore, the CO emission of the biobriquette with 81.60% coconut shell charcoal and 8.40% bagasse was recorded at 4713 ppm, which is within the permissible limit set by SNI 19-7117.2-2005 for biomass briquettes, with a maximum allowable CO emission of 10,000 ppm. CO emissions from briquette combustion result from incomplete combustion due to insufficient oxygen supply. Incomplete combustion occurs when stacked briquettes inside the stove obstruct airflow, reducing oxygen

availability [15]. While the CO emission value is within the acceptable range, high CO emissions indicate incomplete combustion, which can impact energy efficiency and environmental sustainability.

In conclusion, the moisture content, ash content, calorific value, compressive strength, and CO emissions of the coconut shell charcoal and bagasse-based biobriquettes comply with the applicable SNI biobriquette standards. Overall, the combination of coconut shell charcoal and bagasse briquettes exhibits high energy potential. However, CO emissions need to be carefully monitored to maintain air quality and environmental sustainability. This approach can improve air quality management and contribute to sustainability [16].

4. CONCLUSIONS

Rice husk, bagasse, and coconut shell charcoal positively influence the moisture content and calorific value of briquettes, but with varying degrees of impact. The briquette with the highest calorific value, composed of 45% coconut shell charcoal, 45% bagasse, and 0% rice husk, achieved a calorific value of 5470.76 cal/g, while the briquette with the highest moisture content, composed of 0% coconut shell charcoal, 0% bagasse, and 90% rice husk, had a moisture content of 16.7424%. The best-performing biobriquette was obtained from a biomass composition of 81.6% coconut shell charcoal and 8.4% bagasse, meeting the SNI biobriquette standard with a moisture content of 7.43%, ash content of 5.7%, compressive strength of 1.4 N/cm², calorific value of 5226.75 cal/g, and CO emission of 4713 ppm.

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