

Product Design for Utilizing Waste Husk in Ciwulan Village into Rice Husk Brickets Using the Taguchi Method

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ARTICLE INFO

Article history:

Received 29 August 2024

Revised 10 December 2024

Accepted 11 December 2024

Available online 17 December 2024

Keywords:

Rice Husk Brickets

Taguchi Method

Waste Husk

ABSTRACT

The village of Ciwulan faces environmental challenges due to the abundance of rice husk waste. This study investigates the Taguchi method for converting rice husk waste into briquettes to improve production quality and efficiency. By evaluating the impact of rice husk charcoal, adhesive, and drying time, the study identifies the optimal combination to enhance combustion efficiency. The experimental results indicate that drying time significantly influences briquette quality, with the optimal combination being 100 grams of rice husk charcoal, 100 grams of adhesive, and 48 hours of drying. This combination resulted in the lowest average burning time of 9.5 minutes compared to other combinations. Using the Taguchi method effectively reduced burning time provided a practical solution for managing rice husk waste, and improved the quality of eco-friendly renewable energy products. This study offers a novel approach to agricultural waste processing with potential economic benefits for rural communities.

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1. Introduction

Ciwulan Village, an agricultural village in Indonesia, relies heavily on rice harvests. However, this also brings environmental challenges, especially in managing rice husk waste. Rice husks, a byproduct of the rice milling process, are often considered waste with no economic value. In fact, with the right approach, rice husks can be processed into high-value products, such as briquettes, which can be used as alternative fuel [1]. Utilizing rice husk waste into briquettes not only helps reduce waste but also provides a renewable energy source that is more environmentally friendly, which is very necessary in the current era [2]. However, the rice husk briquette production process faces various challenges, especially in ensuring the quality and efficiency of the final product. Effective processing methods are essential to achieve optimal results. One approach that can be used to achieve this is the Taguchi method, which effectively optimises production processes by identifying optimal combinations of materials and process conditions [3]. This method offers a systematic approach to improving product quality by controlling the variables that influence the final result. This research is important because previous research on using rice husk waste in briquettes has yet to use the Taguchi method, so there is an opportunity to offer novelty in the method used [4]. The Taguchi method allows this research to focus on the utilization of rice husks and on improving the quality of briquettes by optimizing the production process [5]. Thus, this method is expected to provide a practical and efficient solution for managing rice husk waste [6].

This research will examine four main factors that influence the quality of briquettes: husk charcoal, adhesive (starch and water), and drying time [7]. These factors were chosen because they significantly influence the quality of the briquettes produced [8]. Other studies have demonstrated the importance of controlling process variables to ensure consistent product quality [9]. This research uses the Taguchi method to design effective and efficient rice husk briquette products and determine the optimal combination of these factors [10]. This research was conducted in Ciwulan Village, where a

rice husk milling process warehouse was used as the primary raw material for rice husk briquettes. Previous research also highlights the importance of a structured approach to using agricultural waste to support the rural economy. The search was conducted in Ciwulan Village, where a rice husk milling process warehouse was used as the primary raw material for rice husk briquettes [11]. The research results are hoped to provide practical solutions for managing rice husk waste, improve the economic welfare of village communities, and contribute positively to efforts to reduce waste and preserve the environment [12]. Moreover, the involvement of local communities in the production process is a key factor in ensuring the success and sustainability of this initiative. By engaging local stakeholders in the research process, from collecting rice husk waste to producing and distributing briquettes, the research fosters a sense of ownership and empowerment among the villagers. This participatory approach enhances the likelihood of long-term adoption and success as it builds local capacity and knowledge in sustainable waste management practices. Furthermore, disseminating research findings through local workshops and training sessions will further empower the community, ensuring that this research's benefits are realised on a broader scale [13].

The Taguchi method is crucial in optimizing the rice husk briquette production process by systematically identifying the most effective combinations of factors and levels to enhance product quality. By controlling key variables such as husk charcoal, adhesive, and drying time, the Taguchi method ensures that the briquettes produced meet the desired quality standards. This systematic approach is essential for achieving optimal results, reducing production costs, and minimizing waste. It provides a structured framework to enhance the final product's performance and consistency, which is critical for producing high-quality briquettes from rice husk waste [14].

Finally, the research aims to contribute to the academic discourse on sustainable waste management and renewable energy production by providing empirical evidence of the effectiveness of the Taguchi method in optimizing production processes. The findings from this research are expected to fill existing gaps in the literature, particularly in the context of developing countries where access to advanced technology and resources may be limited. By demonstrating the practical applicability of the Taguchi method in a rural setting, this research not only advances academic knowledge but also offers practical solutions that can be implemented in similar contexts worldwide. This contribution to both theory and practice highlights the overall importance of the research in addressing global challenges related to waste management, energy production, and sustainable development.

In this context, ANOVA (Analysis of Variance) complements the Taguchi method by offering a statistical basis to evaluate the effects of different factors on the quality of the briquettes. ANOVA helps in understanding how variations in experimental conditions impact the results, thus validating the effectiveness of the Taguchi method's optimization efforts. By analyzing the variance among different experimental runs, ANOVA provides insights into which factors have a significant influence on the quality of the briquettes. This integration of ANOVA with the Taguchi method ensures that the process improvements are based on rigorous statistical analysis, leading to reliable and effective optimization of the rice husk briquette production process. Thus, this research seeks to answer the question of how to optimize the rice husk briquette production process to achieve the best quality, as well as identify the factors that most influence the quality of the briquettes. This focus on the Taguchi method not only offers a new approach to similar research but also aims to make a real contribution to improving the quality and efficiency of rice husk briquette production.

2. Methods

2.1. Research Process Flow

After determining the Taguchi method in this research, the product design stage was carried out, the whole of which can be seen in Figure 1.

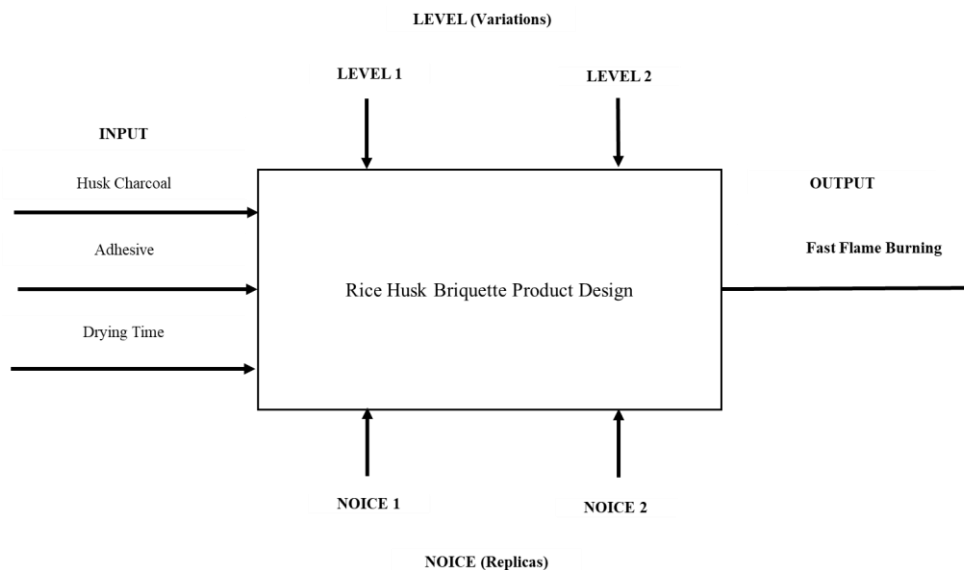


Figure 1. Diagram of the rice husk briquette product design process

The image above shows the factors that can be controlled (input), which consist of charcoal husk, adhesive, and the length of time for the drying process, which will later be processed according to the product experimental design that has been determined. Then, there are things that will influence the process, namely, variations in different mixing ratios between each input and the number of product replicas that will be produced from the ratio that has been determined later. Finally, product output is described as a characteristic of the final product that can be measured, namely, the speed at which the embers ignite.

2.2. Research Object

The research was carried out by taking rice husks in Ciwulan Village, Jl. Sukakarya, Telagasari District, Karawang District, West Java 41381. The rice mill warehouse and the office of the village-owned enterprise, or BUMDES, are located in the exact location and provide rice husk waste. The waste will be processed into briquettes using the Taguchi method to optimize the quality of the briquette products.

2.3. Tools and Materials Used

The author divides the equipment used into equipment and materials for making rice husk briquettes and equipment for data processing.

a. Equipment and Materials for Making Briquettes:

In the process of making rice husk briquettes, tools are used, namely, digital scales, mixing containers, dryers (ovens or sun dryers), briquette-forming tools, stopwatches, and standard laboratory equipment. The materials used are charcoal husks and adhesive (starch and water).

b. Data Processing Equipment:

The experimental results will then be processed using the Taguchi method approach and statistical analysis using SPSS software.

2.4. Research Stages

a. Research Design

This research was conducted using an experimental approach with the Taguchi experimental design method [15]. In determining the factor level, attention is paid to factors that influence the quality of rice husk briquettes, such as the amount of husk charcoal, adhesive (starch and water), and drying time [16]. This research uses a fixed model experiment, where factors and levels are determined before the research begins. The research steps are as follows: Determination of levels and

factors in Table 1, Selection of an Orthogonal Array (OA) Matrix in Table 2, and one-way variation analysis and signal-to-noise ratio (SNR) values [17].

Table 1. Levels and Experimental Factors of Rice Husk Briquettes

Code	Factor	Level 1	Level 2
A	Husk Charcoal	100 grams	50 grams
B	Adhesive (Starch and water)	100 grams	50 grams
C	Long Drying Time	24 hours	48 hours

The Taguchi method is used with an L4 2³ orthogonal array matrix to conduct experiments. The following table shows the arrangement of factors and levels in the experimental design.

Table 2. Selection of Orthogonal Array (OA) Matrix

Experiment	Factor		
	A (g)	B (g)	C (hour)
1	100	100	24
2	100	50	48
3	50	100	48
4	50	50	24

In making rice husk briquettes using the Taguchi method, controlled factors are used for assignment to the orthogonal array table. The following are the experimental steps for making rice husk briquette samples, starting from material preparation, material mixing, the briquette moulding process, the drying process, and testing the characteristics of the briquettes.

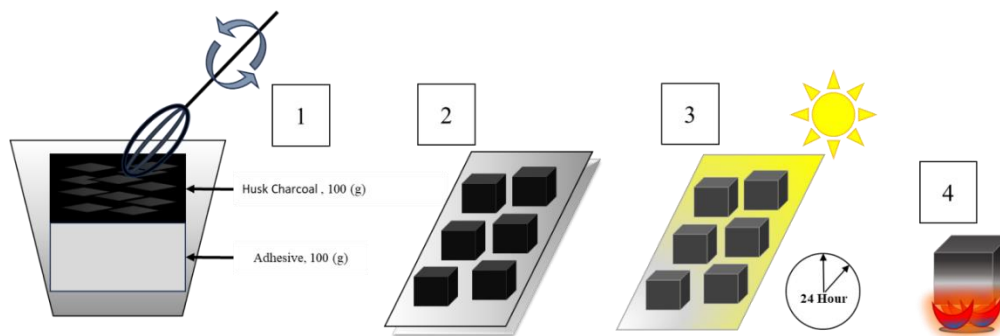


Figure 2. Experimental Design for the Process of Making Rice Husk Briquette Products 1

The picture above shows the experimental steps for making rice husk briquettes. Process number 1: starting with material preparation, namely collecting rice husks as the main ingredient and selecting additional materials such as natural adhesive, namely tapioca flour, and mixing the materials by determining the ratio of the rice husk mixture to adhesive based on the experimental design, then using a mixer to mix the ingredients until homogeneous. Process number 2: Next is briquette moulding, where the mixture of materials is put into a mould and used under a certain pressure to form briquettes according to the experimental design. Process number 3: the moulded briquettes are dried naturally in the sun or using a drying oven by determining the drying duration based on the experimental design. Finally, process number 4: testing the briquettes' characteristics by testing the briquettes' compressive strength to determine the quality and measuring the burning time to determine the burning efficiency.

After making the experimental design, 12 specimens were printed. The data collected included product mass, dimensions, production time, and husk burning test results. Combustion testing uses the observation method. The data obtained is then processed and analyzed using SNR and ANOVA. The criterion used for the duration of the combustion response time in the SN Ratio is Smallest is Better (STB), which is calculated using the following equation:

$$SN_{STB} = -10 \log_{10} \left(\frac{1}{n} \sum_{i=1}^n y_i^2 \right) \quad [18] \quad (1)$$

where n = the number of repetitions (replications) of experiments in an experiment and y_i = burning time on the i -th replication.

One-Way ANOVA (Analysis of Variance) is employed to assess whether there are statistically significant differences between the means of different experimental conditions or groups. The P-value is calculated using the formula derived from the statistical test being used. For ANOVA, the P-value is obtained from the F-distribution, which compares the variance between group means to the variance within groups. The formula for P-Value in ANOVA:

$$P = P(F > F_{observed}) \tag{2}$$

where $F_{observed}$ = is the F-ratio calculated from the ANOVA and $P = P(F > F_{observed})$ = represents the probability of observing an F-ratio as extreme or more extreme than $F_{observed}$, under the null hypothesis.

3. Results and Discussions

3.1. Product Experimental Test Results

Tests were carried out on 12 husk briquettes from 4 experiments based on the L4 2³ orthogonal array matrix table. Each factor in the experiment is indicated as factors A, B, and C, with levels 1 and 2. The sample used was 300 grams of rice husk charcoal, with a replica of 12 rice husk briquettes. As a comparison, one rice husk briquette without an optimization process produces an average burning rate of 14 minutes.

Table 3. Product Experimental Test Results

Experimental Results (long burning flame on rice husk briquettes)			Calculation		
1	2	3	Mean	Variance	S/N smaller the better
13	14	12	13	0.667	-22.296
10	11	9	10	0.667	-20.029
9	8	10	9	0.667	-19.120
15	14	16	15	0.667	-23.535
average S/N					-21.245

The analysis of the experimental data, structured in Table 3 of Product Experimental Test Results, reveals key insights into the performance of different combinations of factors in determining the ignition time of rice husk briquettes. After calculating the average S/N value, which was found to be -21.245, it is evident that the overall quality improves with smaller values due to the application of the “smaller the better” concept. This indicates that a lower S/N ratio correlates with a shorter ignition time, which is the desired outcome.

Each column in the table represents different conditions or trials conducted during the experiment, with results for three factors: the amount of rice husk charcoal, adhesive, and drying time. The Mean column summarizes the average ignition time across these trials, offering a clear view of the central tendency. In contrast, the variance column highlights the consistency of the results, and lower variance suggests more reliable performance. The critical S/N, the better the column quantifies the effectiveness of each trial, with more negative values indicating better performance. Initial observations suggested that Run Number 3 might be the optimal combination due to its relatively less harmful S/N ratio.

From the results of Smaller the Better S/N Analysis, it is known that the optimal combination of the three previously determined factors is A2, B2, and C1, with the factors and levels being 50 grams of husk charcoal and 50 grams of adhesive, and the drying time being 24 hours. This optimal combination was identified based on its ability to minimize the ignition time of the rice husk briquettes, leading to the best performance outcome in this context.

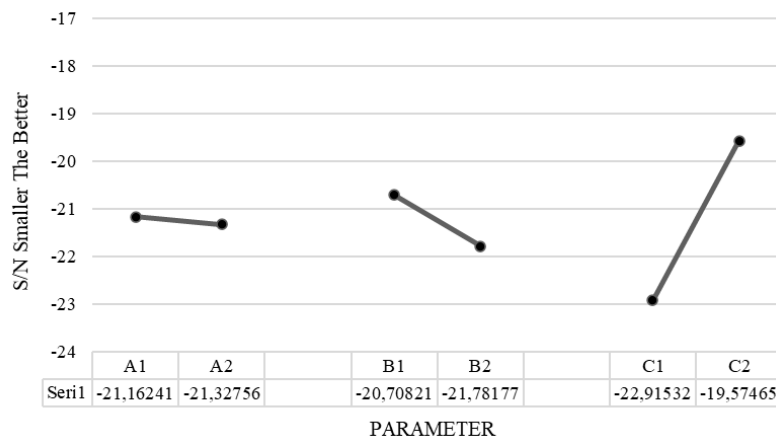


Figure 3. Results of Smaller the Better S/N Analysis

Further analysis of the Table of Product Experimental Test Results reinforces this conclusion. The average S/N value across all trials was calculated to be -21.245, emphasizing that smaller values correspond to better quality due to the "smaller the better" principle. The S/N ratio for the A2 B2 C1 combination emerged as the least negative among all trials, confirming its status as the optimal setting. Additionally, the variance in ignition times was consistently low for this combination, indicating reliable and repeatable results.

Table 4. The Average Occurrence of Each Factor at the Level

<i>Code</i>	<i>S/N smaller the better</i>	Mean
A1	-21.162	11.5
A2	-21.328	12.0
B1	-20.708	11.0
B2	-21.782	12.5
C1	-22.915	14.0
C2	-19.575	9.5

To find out the factors that most influence product quality, the average occurrence of the Smaller, the Better S/N value results, which was previously carried out, was used.

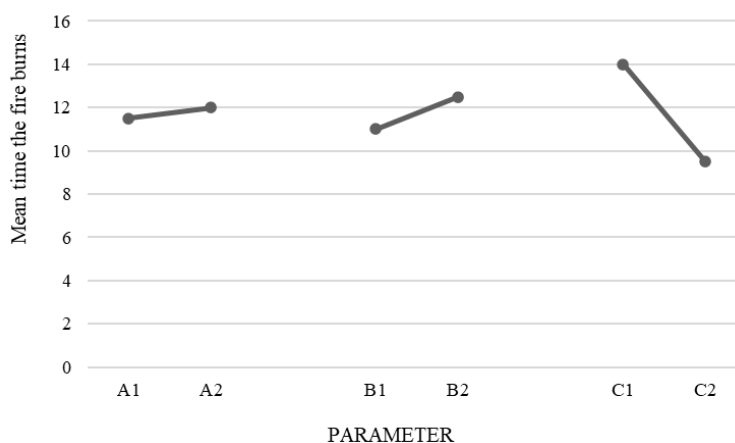


Figure 4. Graph of the appearance of factors against parameters

From the graph above, it can be seen what factors most influence the design process of rice husk briquette products, as seen from the S/N mean results using the Smaller, The Better approach. The most influential factor is C2, namely the length of the drying process for husk briquettes.

To understand the impact of various experimental factors and for further analysis, it is crucial to optimize the conditions that influence the results of a study. In this context, ANOVA (Analysis of

Variance) is a key statistical tool for assessing differences among multiple conditions and determining which factors significantly affect the outcomes.

Dependent Variable: Result
 Bonferroni

(I) Run_Number	(J) Run_Number	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Run Number 1	Run Number 2	3.00000*	.81650	.038	.1595	5.8405
	Run Number 3	4.00000*	.81650	.007	1.1595	6.8405
	Run Number 4	-2.00000	.81650	.240	-4.8405	.8405
Run Number 2	Run Number 1	-3.00000*	.81650	.038	-5.8405	-.1595
	Run Number 3	1.00000	.81650	1.000	-1.8405	3.8405
	Run Number 4	-5.00000*	.81650	.002	-7.8405	-2.1595
Run Number 3	Run Number 1	-4.00000*	.81650	.007	-6.8405	-1.1595
	Run Number 2	-1.00000	.81650	1.000	-3.8405	1.8405
	Run Number 4	-6.00000*	.81650	.000	-8.8405	-3.1595
Run Number 4	Run Number 1	2.00000	.81650	.240	-.8405	4.8405
	Run Number 2	5.00000*	.81650	.002	2.1595	7.8405
	Run Number 3	6.00000*	.81650	.000	3.1595	8.8405

*. The mean difference is significant at the 0.05 level.

Figure 5. One Way ANOVA Test Analysis

The ANOVA analysis and the Bonferroni post hoc test reveal significant and non-significant differences among the experimental conditions. Significant differences were found between Run Number 1 and Run Number 2, Run Number 1 and Run Number 3, Run Number 2 and Run Number 4, and Run Number 3 and Run Number 4, with p-values indicating that these differences are statistically significant. Specifically, changes in experimental factors, such as the amount of factors A and B and the duration of factor C, impact the results significantly. Notably, factor B (the amount of B) has been identified as having the most substantial influence on the outcomes. For instance, the significant difference observed between Run Number 1 (100g A, 100g B, 24 hours C) and Run Number 2 (100g A, 50g B, 48 hours C) underscores the impact of varying the amount of B and the duration of C. The results suggest that variations in factor B are particularly influential, with significant mean differences observed in several comparisons involving different levels of B. On the other hand, some comparisons, such as between Run Number 1 and Run Number 4, showed no significant differences, indicating that not all factor combinations have a substantial impact. Overall, factor B is crucial in affecting the experimental outcomes, making it the most influential factor in this study.

3.2. Product Testing Confirmation

To verify the previously identified optimal combination (A2 B2 C1) of 50 grams of husk charcoal, 50 grams of adhesive, and a drying time of 24 hours, a follow-up experiment was conducted to confirm its effectiveness. The experiment was repeated under the same conditions to assess the consistency and reliability of the results. The data obtained from the follow-up experiment further supports the initial findings.

The follow-up experiment demonstrates that the combination of 50 grams of husk charcoal, 50 grams of adhesive, and a drying time of 24 hours consistently produces shorter ignition times with low variance, confirming the reliability and effectiveness of this combination. The Mean Ignition Time across the trials remained low, averaging around 9 minutes, and the variance was minimal, indicating consistent results. The S/N Ratio values, calculated using the "Smaller, Better" method, show that this combination is optimal as it consistently yields the least negative S/N Ratio. These results reinforce the initial conclusion that factors A2 B2 C1 are the most effective for producing high-quality rice husk

briquettes with the shortest ignition time. The consistency of these findings across multiple trials underscores the robustness of this combination.

Table 5. Test Confirmation Table

Run Number	Husk Charcoal (g)	Adhesive (Starch and water) (g)	Long Drying Time (hours)	Ignition Time 1 (min)	Ignition Time 2 (min)	Ignition Time 3 (min)	Mean Ignition Time (min)	Variance	S/N Ratio (Smaller, Better)
1	50	50	24	10	11	9	10.0	1.0	-20.0
2	50	50	24	9	10	8	9.0	0.6667	-19.0848
3	50	50	24	9	8	10	9.0	0.6667	-19.0848
4	50	50	24	8	9	8	8.33	0.3333	-18.4183

Table 6. Comparison of Product Experimental Test Results with Previous Products

S/N Prediction		S/N Existing	
Parameter	S/N	Parameter	S/N
Average S/N	-21.245	Average S/N	-21.245
A2	-21.328	A1	-21.162
B2	-21.782	B1	-20.708
C1	-22.915	C1	-22.915
P _{opt}	-2.2897	P _{exist}	-1.051
Prediction		Confirmation	
Existing Design	-1.051	Existing Design	-21.604
Optimum Design	-2.290	Optimum Design	-2.290
Gain	1.239	Gain	19.314

The results of the comparison of experimental tests have been analyzed to assess the gain achieved. The baseline S/N Ratio, calculated from the provided data, is -21.495, while the average S/N Ratio from the experimental results is -21.245. The gain obtained from the experiment, calculated as the difference between the optimal and existing S/N values, is 1.239. This positive gain value indicates an improvement in performance compared to the baseline. Specifically, the gain of 1.239 suggests that the adjustments made during the experiment resulted in a higher S/N Ratio, reflecting better product quality or performance. This positive gain confirms that the changes implemented have successfully enhanced the experimental outcomes, demonstrating a significant advancement from the baseline measurement.

4. Conclusion

ANOVA has been utilized to evaluate significant differences among various factor combinations in rice husk briquette production. The analysis revealed significant differences between several experimental combinations, identifying the factors most affecting briquette quality. Further analysis indicated that factor B (amount of adhesive) had the greatest impact on the final results, with significant differences observed among combinations involving variations in B levels. Follow-up testing reinforced these findings by demonstrating that the combination of 50 grams of husk charcoal, 50 grams of adhesive, and a drying time of 24 hours consistently produced shorter ignition times with low variance. The average ignition time in these trials remained low, around 9 minutes, and the variance was minimal, indicating consistent results. The S/N ratio values, calculated using the “Smaller, Better” method, showed that this combination is optimal, as it consistently yields the lowest negative S/N ratio. These results confirm the initial conclusion that the combination of factors A2 B2 C1 is the most effective for producing high-quality rice husk briquettes with the shortest ignition time. The consistency of these findings across multiple trials underscores the robustness of this combination in the briquette production process.

Acknowledgement

The researcher would like to thank God Almighty for all His blessings and guidance during this process. The researcher is very grateful for the valuable guidance from Mr. Dicky Suryapranatha, S.T., M.T., and the invaluable guidance from Mrs. Amalia, S.T., M.T., in completing this final assignment. Thank you also to the Ciwulan Village Business Entity and all my fellow students who have provided endless support. My beloved mother, N. Euis Sumarni, S. Pd., was very patient and tireless in helping to provide support in the form of presence and prayer, which was very meaningful for researchers.

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