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Optimisation of Biobriquette Production Enriched with Burning Lighter Material

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Abstract. The increasing trend of fossil fuel consumption is inversely proportional to the available natural gas reserves. Renewable energy sources derived from biomass are needed to become alternative fuels, such as biobriquettes. This study aims to optimize biobriquette production by adding burning initiator materials to obtain the best composition that meets the Indonesian National Standard (SNI) and exhibits good ignition characteristics. The experimental design was based on the Taguchi method with an L9 (3^4) orthogonal array, and the results were statistically analyzed using Grey Relational Analysis (GRA) to evaluate multiple responses. Although the highest Grey Relational Grade (GRG) indicated the theoretical optimum, the confirmation test revealed a slightly different composition with better burning performance. The optimal composition consisted of 3 g of OPEFB (A1), 16 g of PKS (B2), 40% pine sap (C3), and 20% sulfur (D3), producing a moisture content of 1.148%, ash content of 10.75%, volatile matter content of 12.36%, calorific value of 7,223.5 cal·g^{-1}, initial ignition time of 1.83 s, and burning rate of 0.237 mg·min^{-1}. These results indicate that the produced biobriquettes meet SNI standards for moisture, volatile matter, calorific value, and have good burning ease.

Keywords: biobriquette; biomass; grey relational analysis; optimization; taguchi

INTRODUCTION

The use of energy from fossil fuels is increasing every year, which can lead to the depletion of oil and natural gas reserves. The trend in natural gas reserves in Indonesia has been declining every year from 101.22 TSCF in 2016 to 35.30 TSCF in 2023 (Direktorat Jenderal Minyak dan Gas Bumi, 2024). One example of fossil fuel usage is LPG gas. LPG consumption in the household sector was 4,824 thousand tons in 2012 and has increased annually to 8,211 thousand tons in 2022 (Kementerian ESDM, 2022). This growing dependency underscores the urgency of developing renewable and locally sourced alternative energy.

Biobriquettes are an alternative energy source in the form of solid fuels that have specific dimensions, utilizing simple and appropriate technology. Biobriquettes are charcoal that is formed into biobriquettes as an alternative energy to replace kerosene and LPG gas (Aziz et al., 2019). Biobriquette raw materials come from biomass waste, including agricultural waste, forestry waste, energy plantation plants, and organic waste. Biobriquette made from biomass can be helpful for cooking, lighting, and industrial needs (Sutisna et al., 2021).

Energy sources derived from renewable organic materials, such as those from animals, plants, or by-products of natural or artificial transformation, are called biomass (Cabrales et al., 2020). The potential for biomass exploitation is very high due to the abundance of raw materials, low costs, and sustainability.

The availability of oil palm raw materials in Indonesia is very abundant, and Indonesia has the largest oil palm plantation area in the world, with an estimated oil palm area of 15,380.981 hectares in 2022 and an estimated production volume of 48,235.405 tons (Direktorat Jenderal Perkebunan, 2021). The abundant availability of solid palm oil waste has been selected as the raw material for producing renewable energy sources. The utilization of this waste as raw material for biobriquettes supports waste reduction and promotes circular bioenergy development.

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Biobriquettes have the characteristic of being difficult to burn when compared to liquid fuels. The inhibiting factor for burning biobriquettes is the large activation energy required at the start of burning. Therefore, it is necessary to add a burning igniter and an adhesive that has flammable properties so that the ignition temperature is lower and the biobriquette is more flammable. Research by Pratiwi & Mukhaimin (2021) and research by Saputra et al (2023) stated that pine resin is a flammable material. According to previous study, sulfur and pine resin have flammable qualities that can raise the briquettes' propensity for fire. (Setiyana, 2010; Zeng et al., 2021). Based on the characteristics of the material, pine sap, which contains pine resin as an adhesive, and sulfur as a lighter, is chosen in the production of biobriquettes.

The optimization of biobriquette qualities is essential, as product quality is significantly influenced by the composition of raw materials and processing conditions. Most prior research has concentrated solely on individual factors or restricted performance metrics. In contrast, this work does multi-response optimization by combining the Taguchi approach with Grey Relational Analysis (GRA). This allows the identification of the optimal factor combination that concurrently improves numerous performance measures. The Taguchi method is one of the optimization methods by setting the right parameters in the process (Musabbikhah et al., 2015). This method is used to improve product and process quality by minimizing costs and raw materials. The Grey Relational Analysis (GRA) method is employed as a multi-response analysis method within the Taguchi framework, enabling the determination of optimal conditions for the biobriquette characteristics based on several parameters. To determine the optimal characteristics of biobriquettes, tests were carried out based on several parameters, namely proximate tests (moisture content, ash content, volatile matter content), calorific value tests and burning tests (initial ignition time, burning rate). This study aims to optimize the production of biobriquettes from palm oil solid waste enriched with burning ignition materials using the Taguchi method and grey relational analysis to obtain the best composition with optimal characteristics based on SNI 01-6235-2000 and burning tests.

METHODS

This study used raw materials, namely oil palm empty fruit bunches (OPEFB), palm kernel shells (PKS), pine sap adhesive, and sulfur lighters. The raw materials used came from several regions on the island of Java. The equipment used for experiments and testing was a drying oven, 40 mesh sieve, hydraulic briquette molding tool, grinder, pyrolysis tool, analytical scales, digital scales, containers, stirrers, measuring cups, crucible pliers, bomb calorimeter, lighter, petri dish, ash cup, desiccator, furnace, and simultaneous thermal analyzer (STA).

The stages in this study were to design an experiment using the Taguchi method, namely, determining factors, factor levels, and orthogonal arrays. The next stage involved implementing the biobriquette production experiment, which tested the characteristics of the biobriquettes, including moisture content, ash, volatile substances, calorific value, initial ignition time, and burning rate. Furthermore, data analysis of the test results was carried out using the Taguchi method and gray relational analysis (GRA). The last stage was to conduct a confirmation experiment based on the best composition.

Every experimental trial in the L9 (3^4) orthogonal array was executed with two replicates to enhance data dependability and minimize random error. The replication level was sufficient to achieve acceptable statistical power for detecting main effects under the Taguchi design framework. Potential bias in the results could be introduced by variations in chemical composition brought on by source and storage conditions. All of the raw ingredients, such as sulfur lighters, pine sap, and oil palm

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wastes (OPEFB and PKS), came from various parts of the island of Java.

The experimental design was developed using the Taguchi method based on the factors and factor levels that serve as parameters in the experiment. The combinations of factors and levels, as well as the experimental design for each treatment using the orthogonal array L9 (3^4), can be seen in Table 1 and Table *2*.

Table 1. Combination of factors and factor levels

Code	Factor Control	Factor Level		
		1	2	3
A	Concentration of OPEFB Raw Material	3 g	4 g	5 g
B	Concentration of PKS Raw Material	15 g	16 g	17 g
C	Concentration of Pine Sap Adhesive Material	20%	30%	40%
D	Concentration of Sulfur Igniter Material	10%	15%	20%

Table 2. Experimental design for each treatment

Experiment	Factor Level			
	Concentration of OPEFB Raw Material (A)	Concentration of PKS Raw Material (B)	Concentration of Pine Sap Adhesive Material (C)	Concentration of Sulfur Igniter Material (D)
1	3 g	15 g	20%	10%
2	3 g	16 g	30%	15%
3	3 g	17 g	40%	20%
4	4 g	15 g	30%	20%
5	4 g	16 g	40%	10%
6	4 g	17 g	20%	15%
7	5 g	15 g	40%	15%
8	5 g	16 g	20%	20%
9	5 g	17 g	30%	10%

The procedure for conducting the bio-briquette production experiment includes reducing the size of the OPEFB material, separate pyrolysis of the OPEFB material at a temperature of 350 °C and the PKS material at a temperature of 500 °C for 3 hours, followed by a process of grinding, the sieving process with a mesh of 40, optimization of the mixing process of OPEFB, PKS, and pine sap according to the experimental design, optimization of the molding process and coating of sulfur lighter materials, and the drying process using an oven at a temperature of 115 °C for 6 hours. The pyrolysis process transforms biomass into char and eliminates volatile substances, hence enhancing fuel quality.

The uniqueness of this research lies in the biobriquette production process. Coating of sulfur lighter material does not involve the use of additional adhesives, but the coating of lighter material utilizes pressure during the molding process, so that the lighter material can adhere well to the surface of the biobriquette.

The testing of bio-briquette characteristics for moisture content, ash content, volatile matter content, and calorific value followed the procedures outlined in SNI 01-6235-2000 regarding wood charcoal

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briquette standards. The initial ignition time test method was modified from the research by Hestiyantini et al (2022) where the initial ignition time was measured using a stopwatch from the moment the igniter was lit on the biobriquette surface until a flame appeared. The burning rate test procedure was based on the research by Lubwama et al (2020) where the initial mass was weighed between 5 mg and 20 mg, temperature settings and heating rates are adjusted according to the purpose and specifications of the equipment used. In this study, the temperature used ranges from 50 °C to 850 °C, and the heating rate is 20 °C/min. The sample is then burned until it turns to ash, and the weight reduction is calculated at each time interval.

RESULTS AND DISCUSSION

Analysis of Each Response Based on the Taguchi Method

An analysis was conducted on the results of testing the characteristics of biobriquettes for each response. The response factors in this study were moisture content, ash content, volatile matter content, calorific value, initial ignition time, and burning rate. Nine experiments were conducted based on the experimental design, followed by testing of product characteristics. The Signal-to-Noise Ratio (SNR) was classified as smaller-is-better for parameters including moisture, ash, volatile matter content, initial ignition time, and larger-is-better for calorific value, and burning rate. The SNR value signifies the reliability of the response; a higher SNR denotes that the outcome is not just ideal but also more consistent and less influenced by noise or experimental variability.

The results of the biobriquette product characteristic testing and the SNR calculations for each response factor can be seen in Table 3 and Table 4.

Table 3. Result of the biobriquette characteristic test

Experiment	Test Result					
	Moisture Content (%)	Ash Content (%)	Volatile Matter Content (%)	Calorific Value ($cal \cdot g^{-1}$)	Initial Ignition Time (s)	Burning Rate ($mg \cdot min^{-1}$)
1	1.996	14	19.765	7,053.510	5.250	0.1404
2	1.447	14.25	14.958	6,897.428	3.865	0.1515
3	1.497	13.5	12.998	6,616.921	2.075	0.1885
4	1.799	17	14.289	7,042.610	2.385	0.1758
5	1.548	15	12.998	7,018.140	3.715	0.2111
6	1.949	20	20.499	6,866.901	4.520	0.2164
7	1.897	14	14.289	6,951.848	3.515	0.2025
8	1.897	16.75	19.048	6,849.677	2.660	0.1824
9	2.745	15	19.799	7,084.791	3.645	0.1956

Based on Table 3 regarding the results of bio-briquette characteristic testing, the moisture content response factor ranges from 1.447% to 2.745%. This moisture content is considered low and meets the SNI 01-6235-2000 standard, which specifies a maximum of 8%. According to Saputra et al (2023) higher moisture content can lead to a decrease in biobriquette quality. The ash content results range from 13.5% to 20%. The ash content produced is slightly above the standard maximum of 8%. Ash is the residue during

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burning, consisting of minerals and silica, which has a negative impact on calorific value (Ristianingsih et al., 2015). The optimal volatile matter content is 12.998%. This result meets the standard with a maximum of 15%. High volatile matter content produces more smoke when ignited (Ristianingsih et al., 2015) . The characteristics of good biobriquettes are that they produce less smoke. The calorific value of the biobriquettes ranged from 6,616 cal·g^{-1} to 7,084 cal·g^{-1}. The calorific value of biobriquettes is quite high, and has met the minimum standard of 5,000 cal·g^{-1}. The quality of biobriquettes improves along with the high calorific value of the biobriquettes (Rahmadani et al., 2017). The best initial ignition time for biobriquettes is 2.075 s, and a highest burning rate was 0.2164 mg·min^{-1}.

The SNR calculation results in Table 4 indicate that the experiment with the highest SNR value for each response factor signifies that the experiment is the optimal combination of factor levels producing the best and most consistent response quality. The factors and levels influencing each response factor can be determined by calculating the main effect plot for SN ratios, as shown in Figure 1.

Table 4. SNR calculation for each response factor

Experiment	SNR					
	Moisture Content	Ash Content	Volatile Matter Content	Calorific Value	Initial Ignition Time	Burning Rate
1	-6.046	-22.945	-25.924	76.968	-14.404	-17.072
2	-3.215	-23.088	-23.531	76.774	-11.744	-16.415
3	-3.524	-22.613	-22.288	76.413	-6.346	-14.508
4	-5.309	-24.643	-23.109	76.955	-7.551	-15.108
5	-3.837	-23.522	-22.288	76.924	-11.399	-13.519
6	-5.799	-26.023	-26.257	76.735	-13.104	-13.305
7	-5.562	-22.928	-23.109	76.842	-10.919	-13.875
8	-5.611	-24.481	-25.597	76.713	-8.498	-14.796
9	-8.782	-23.522	-25.984	77.007	-11.234	-14.181

The most influential factors and levels with the highest SNR values on moisture content, ash content, volatile matter content, calorific value, initial ignition time, and burning rate in sequence as shown in Figure 1 are factor B level 2 (raw material concentration OPEFB 16 g), factor A level 1 (raw material concentration OPEFB 3 g), factor C level 3 (pine sap adhesive concentration 40%), factor D level 1 (sulfur lighter concentration 10%), factor D level 3 (sulfur lighter concentration 20%), and factor C level 3 (pine sap adhesive concentration 40%). Calculation of the main effect plot SN ratios can determine the best level composition of each factor. The best composition of each response factor in sequence is A1B2C3D3, A1B1C3D1, A2B2C3D3, A2B1C2D1, A3B3C3D3, and A2B3C3D2. Subsequently, an analysis of variance (ANOVA) was conducted to determine the percentage contribution to each response factor, which can be seen in Figure 2.

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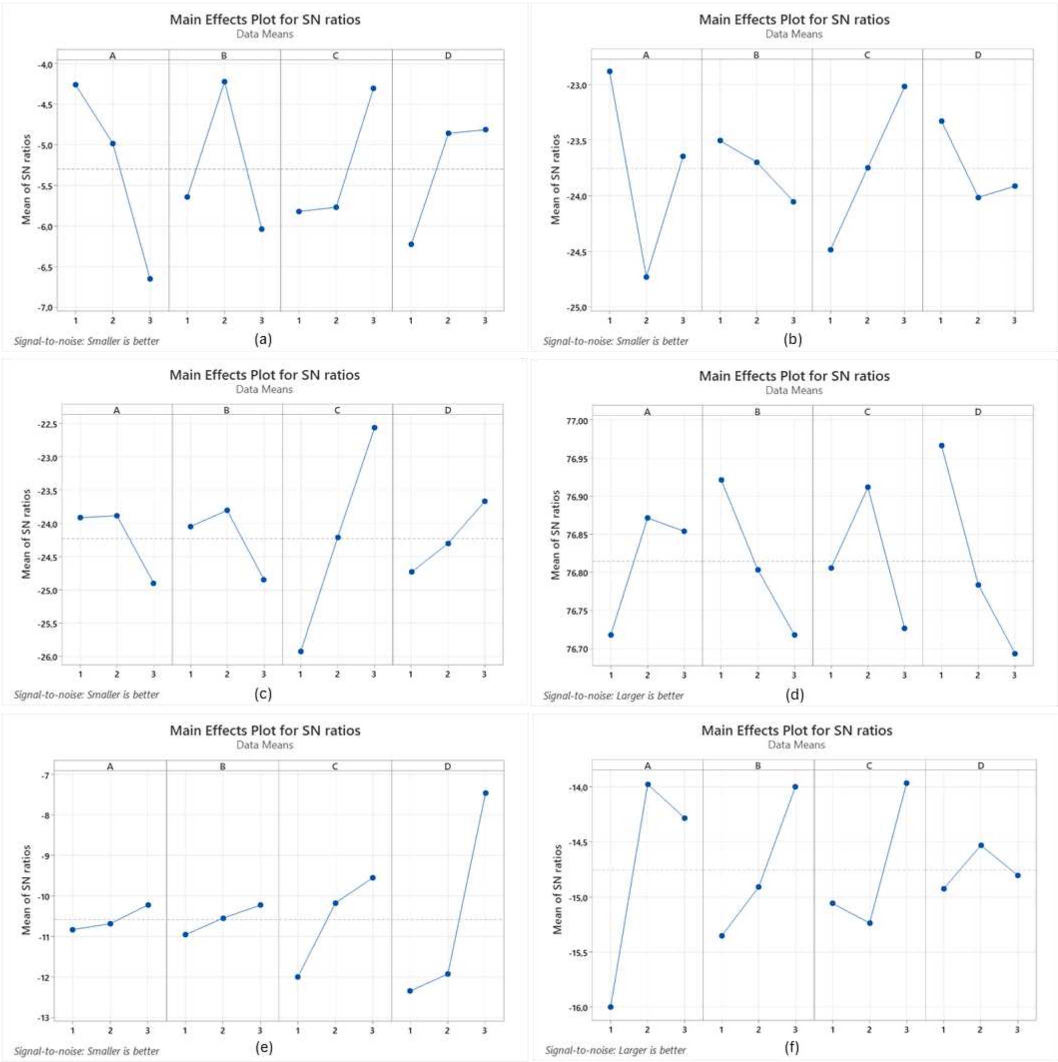

Figure 1. Main effect plot SN ratios (a) moisture content, (b) ash content, (c) volatile matter content, (d) calorific value, (e) initial ignition time, dan (f) burning rate

The concentration factor of oil palm empty fruit bunches (OPEFB) raw materials has the largest percentage contribution to moisture content of 39%, ash content of 51%, and burning rate of 54%. OPEFB raw materials have a moisture content of 32.12%, which is the highest moisture content. In line with the research of Suryadri et al (2022) OPEFB has a high moisture content of 67%. The high moisture content in the material will affect the moisture content of the biobriquette product produced. The effect of high moisture content can reduce the flame temperature during burning, and reduce the heat generated (Suryadri et al., 2022). Therefore, the burning rate of biobriquettes is influenced by the high moisture content of the OPEFB material. In line with the research by Pratama & Praswanto (2022) the burning rate is influenced by moisture content; the higher the moisture content, the slower the burning rate. A better burning rate can be achieved with lower moisture content (Pambudi et al., 2018).

The oil palm empty fruit bunches used did not undergo pre-treatment processes such as washing with water or chemicals. This allows a high level of impurities to remain in the material. The impurities in oil palm empty fruit bunches include mineral content, metal compounds, and silica (Ristianingsih et al., 2015; Erwinsyah et al., 2015). Impurities during the burning process leave a lot of ash residue because these impurities cannot be burned or oxidized by oxygen (Ristianingsih et al., 2015).

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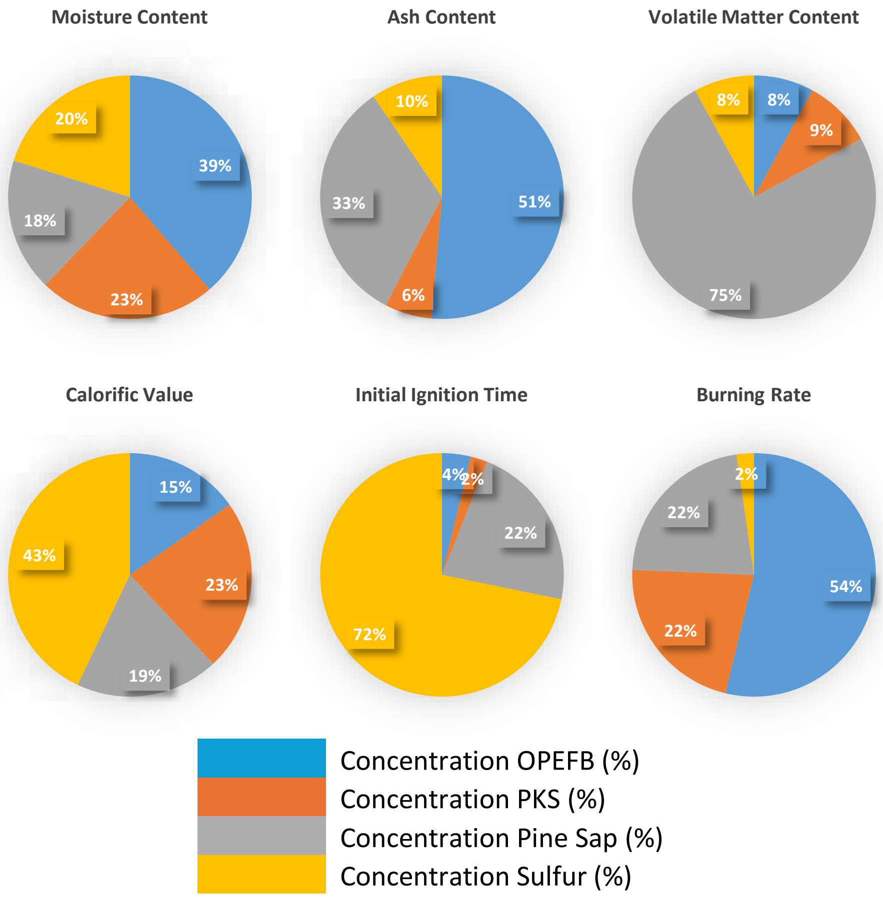

Figure 2. Percentage contribution of factors to each response factor

The calorific value is the heat value of the biobriquettes produced. The higher the calorific value, the higher the quality of the biobriquettes (Rahmadani et al., 2017; Siregar et al., 2022). The largest percentage contribution to the calorific value parameter, and the initial ignition duration is the sulfur igniter concentration factor of 43% and 72%. The type of raw material is a factor influencing the calorific value of biobriquettes (Iriany et al., 2023). Sulfur is the first material to burn during the calorific value test and the initial burning time test, acting as an igniter to help other materials burn and release their thermal energy potential. Sulfur acts as a burning igniter because this material is easily ignited at a low ignition temperature of 476 K or 202.85 °C (Zeng et al., 2021).

The volatile matter content is influenced by the pine sap adhesive concentration of 75%. Pine sap contains 70% – 75% gondorukem and 20% – 25% terpentin (Permatasari et al., 2018). Terpentin compounds have high volatility (Permatasari et al., 2018). Based on the compounds contained, pine sap adhesive can influence the volatile substance content of the biobriquettes produced. In line with the research by Amalia et al (2020) adhesive concentration affects volatile substance content, as adhesives contain volatile compounds. Impurities in pine sap can also affect the volatile matter content. Pine sap has an impurity content of 8.27% – 9.26% (Samosir et al., 2015).

Multi-Response Analysis Using The Grey Relational Analysis Method

Analysis using the Grey Relational Analysis (GRA) method was conducted to complement the limitations of the Taguchi method in working with various performance

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characteristics. Taguchi-based GRA can provide multi-response optimization solutions with various performance characteristics (Thapa & Engelken, 2020). Multi-response analysis using GRA was conducted to obtain the best composition with optimal biobriquette characteristics.

The steps in multi-response analysis using the GRA method are normalizing the Signal Noise Ratio (SNR) value, calculating the deviation sequence, grey relational coefficient (GRC), grey relational grade (GRG), and calculating the main effect plot for SNR GRG. The analysis steps as presented in Table 5, Table 6, Table 7, and Figure 3.

Table 5. Calculation on SNR normalization

Experiment	Normalization SNR					
	Moisture Content	Ash Content	Volatile Matter Content	Calorific Value	Initial Ignition Time	Burning Rate
1	0.491	0.903	0.084	0.065	0	1
2	1	0.861	0.687	0.392	0.330	0.826
3	0.945	1	1	1	1	0.319
4	0.624	0.405	0.793	0.087	0.851	0.479
5	0.888	0.733	1	0.138	0.373	0.057
6	0.536	0	0	0.457	0.161	0
7	0.578	0.908	0.793	0.277	0.432	0.151
8	0.570	0.452	0.166	0.494	0.733	0.396
9	0	0.733	0.069	0	0.393	0.233

Table 6. Deviation sequence calculation

Experiment	*Deviation Sequence (Delta)*					
	Moisture Content	Ash Content	Volatile Matter Content	Calorific Value	Initial Ignition Time	Burning Rate
1	0.509	0.097	0.916	0.935	1	0
2	0	0.139	0.313	0.608	0.670	0.174
3	0.055	0	0	0	0	0.681
4	0.376	0.595	0.207	0.913	0.149	0.521
5	0.112	0.267	0	0.862	0.627	0.943
6	0.464	1	1	0.543	0.839	1
7	0.422	0.092	0.207	0.723	0.568	0.849
8	0.430	0.548	0.834	0.506	0.267	0.604
9	1	0.267	0.931	1	0.607	0.767

The multi-response analysis calculation resulted in experiment 3 being the best experiment based on the highest GRG value. A higher GRG value means it is closer to the ideal value (Thapa & Engelken, 2020) The main effect plot for SN ratios of GRG was calculated to determine the optimal composition of factors and factor levels. The main effect plot for SN ratios is shown in Figure 3.

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Table 7. Calculation of GRC and GRG

Experiment	GRC										GRG
	Factor				Moisture Content	Ash Content	Volatile Matter Content	Calorific Value	Initial Ignition Time	Burning Rate	
	A	B	C	D							
1	1	1	1	1	0.496	0.837	0.353	0.348	0.333	1	0.395
2	1	2	2	2	1	0.782	0.615	0.451	0.427	0.741	0.546
3	1	3	3	3	0.900	1	1	1	1	0.423	0.817
4	2	1	2	3	0.571	0.457	0.707	0.354	0.770	0.490	0.476
5	2	2	3	1	0.817	0.652	1	0.367	0.444	0.346	0.547
6	2	3	1	2	0.519	0.333	0.333	0.479	0.374	0.333	0.340
7	3	1	3	2	0.543	0.844	0.707	0.409	0.468	0.371	0.495
8	3	2	1	3	0.537	0.477	0.375	0.497	0.652	0.453	0.423
9	3	3	2	1	0.333	0.652	0.349	0.333	0.452	0.395	0.353

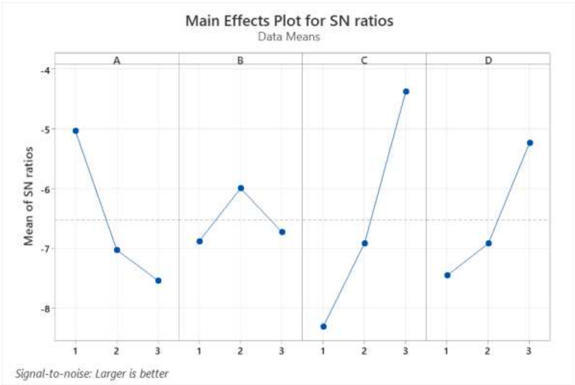

Figure 3. Main effect plot SN ratios GRG

The best factor composition and factor level with optimal biobriquette characteristics based on the main effect plot SN ratios GRG are the concentration of 3 g TKKS raw material (A1), the concentration of 16 g CKS raw material (B2), the concentration of 40% pine sap adhesive (C3), and the concentration of 20% sulfur lighter (D3).

Confirmation Test

The confirmation test aims to confirm the analysis results based on the optimal parameter level (Thorat & Thakur, 2018). The optimal design parameter level is used to estimate the best characteristics (Thapa & Engelken, 2020). The calculation of the confidence interval between optimal conditions and confirmation experiments is presented in Table 8.

The results of the confirmation experiment on moisture content, volatile matter, and calorific value have met the SNI 01-6235-2000 standard. The initial ignition time parameter was 1.83 s; this result of initial ignition time is faster than the study by Patandung & Silaban (2017), which was 14.02 s with the addition of coconut ash lighter, and the study by Setiyana (2010), which was 12.67 s using pine resin lighter. The combination of pine sap adhesive and sulfur lighter can improve initial ignition quality. The combustion rate parameter is 0.2369.mg·min^{-1}, this result is greater than previous research that did not use lighter materials by Firnanda et al (2023) was 0.0149 mg·min^{-1} for biobriquettes made from a mixture of fish bones and coconut shells with tapioca adhesive, as well as compared to the study by Camalia et al (2023) on biobriquettes made from a mixture of durian peel and corn husk with tapioca adhesive, which had a burning rate of 0.1330 mg·min^{-1}. This indicates that the addition of sulfur as a starting material can increase the burning rate.

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Table 8. Confidence interval calculations

No	Parameter	Confidence Interval	Result	Lower Limit	Upper Limit	Description
1	Moisture Content (%)	Optimal Condition	1.064±0.306	0.758	1.37	Confirmed
		Confirmation Experiment	1.148±0.446	0.702	1.594	
2	Ash Content (%)	Optimal Condition	11.25±1.205	10.045	12.455	Confirmed
		Confirmation Experiment	10.75±1.757	8.993	12.507	
3	Volatile Matter Content (%)	Optimal Condition	10.90±1.969	8.931	12.869	Confirmed
		Confirmation Experiment	12.36±2.870	9.49	15.23	
4	Calorific Value (cal/g)	Optimal Condition	7,244.5±9.359	7,235.141	7,253.859	Confirmed
		Confirmation Experiment	7,223.5±13.643	7,209.857	7,237.143	
5	Initial Ignition Time (seconds)	Optimal Condition	1.618±0.089	1.529	1.707	Confirmed
		Confirmation Experiment	1.83±0.131	1.699	1.961	
6	Burning Rate (mg/minute)	Optimal Condition	0.2373±0.009	0.2283	0.2463	Confirmed
		Confirmation Experiment	0.2369±0.013	0.2239	0.2499	

The confidence interval calculation is at a 95% confidence level. Based on the confidence interval calculation results of all observed response factors, the confirmation experiment results are within the optimal condition interval, so the confirmation experiment on all response factors has been confirmed.

CONCLUSION

The best composition of biobriquettes with optimal characteristics is the concentration of 3 g of empty oil palm bunches, 16 g of oil palm shells, 40 % pine sap adhesive, and 20 % sulfur lighter. The biobriquettes meet the standards of SNI 01-6235-2000 in the parameters of moisture content, volatile matter content, and calorific value. Biobriquettes enriched with burning lighter material produce a good initial ignition time of 1.83 seconds.

The optimized biobriquettes developed in this study may diminish reliance on fossil fuels, providing substantial economic and environmental advantages for industries employing biomass energy sources, especially in areas rich in oil palm waste like empty fruit bunches and palm shells.

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