

Modelling and Optimization of the Best Parameters of Rice Husk Drying and Carbonization by Using Taguchi Method with Multi Response Signal to Noise Procedure

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Abstract- The goal of this study is to optimize parameters the rice husk drying and carbonization process in terms a calorific value and proximate analysis simultaneously. The independent variables are the drying temperature (A) at 100, 105, and 110 °C; the drying time (B) at 12, 18, and 24 h; the carbonization temperature (C) at 450, 550, and 650 °C; and the carbonization holding time (D) at 60, 90, and 120 mins. The methods of the research are Taguchi and multi-response signal-to-noise(MRSN) procedure. The results show that simultaneous optimization of the drying and carbonization of rice husk in terms of the proximate analysis and calorific value, is determined by using the MRSN procedure, and it yields a result of 2.042. The best parameters are a drying temperature of 100 °C; a drying time of 24 h; a carbonization temperature of 650 °C; and a carbonization holding time of 120 mins. The optimal estimated calorific value, fixed carbon, moisture, volatile matter, and ash content are 5665 cal/g, 83.2, 0.06, 3.1 and 6.86 %, respectively. The resulting models are valid and feasible. The advantages of this work compared to previous studies are the models and the simultaneous parameter optimization of multi-response variables, which have different quality characteristics into a single best parameter

Keywords - Rice husk, drying, carbonization, calorific value, proximate analysis, MRSN.

1. Introduction

Indonesia has variety of abundant biomass waste. Rice husk is one of the solid biomasses that has 11.8 MJ/ha/y of energy potential [1]. It is one of the wastes that is generated untapped and managed optimally, so it can pollute the environment. The rice husk has cellulose which can be converted into charcoal through carbonization process. Significant result on assessment of residues contented by organic matter, pollution, and clean energy production was accordance with research done by [2]. Furthermore, a study related to this issue has been done by [3], it is stated that renewable energy is used to create more sustainable energy source of future.

These charcoal briquettes are used as good material in creating renewable energy in order to improve quality and economic value of waste rice husk. This effort can meet community needs on fuel in order to reduce their fossil fuel dependence. It could be a method to develop renewable energy sources. Therefore, an in-depth analysis of the country general pattern, capacity, and trends in technological improvement is needed to support the development of renewable energy technology solutions [4].

Biomass as renewable energy source can be acquired from agricultural, household, and industrial waste [5]. Furthermore, to produce biomass fuel, compost can be one alternative material as stated on study [6].

One viable fuel as a substitute for wood fuel is rice husk briquette [7]. Rice husk as one type of biomass can be used as an alternative fuel. It is usually used as a low-value energy resource, burned in the field or waste, which would be unfavourable with the environment [8]. Nevertheless, to achieve good-quality fuel from rice husk, it must be dried and carbonized before undergoing briquetting. The parameters used to evaluate briquettes are compressive strength and proximate analysis [9].

Several previous studies [10-12], stated that the different temperatures for various times in activated carbons were arranged from rice husks by chemical activation with KOH, NaOH, Na₂CO₃ and K₂CO₃. The different drying temperatures of 22, 50, and 100 °C on sawdust utilized prior to briquetting have been inspected [13]. Furthermore, the different carbonization temperatures of 230, 260, and 290 °C for a wood-residue are correspond to the differences of time carbonization of 0.5, 1.0, and 1.5 h, respectively [14]. An increasing process volatile release and a decrease of carbonization is influenced by the production rates of hydrogen and carbon monoxide [15].

Biomass has a high potential as renewable sources and carbon neutral has been supported by [16]. Biomass material determination for carbon production depends on material availability, cost, and capability of the material, also it should be changed over under porous carbon powder after carbonization [17].

Taguchi method is used to define optimal process parameters, to pay equal attention to yield, productive capacity, and cost [18]. The multi-response Taguchi method is used to improve those parameter settings in this work. The applications of the Taguchi method are for the optimization of TiO₂ [19], WEDM [20, 21], and optimization on mechanical performance of coconut shell [22].

The difference between previous research and this study lies on the determination of the variables, experimental design, and feasibility and validity of model the biomass carbonization and drying. The optimal and most valid model can be used to predict the increase or decrease in the values of every dependent variable. Therefore, this work will contribute to giving significant impacts on society, by aiding the production of high-quality renewable fuel.

2. Material and Methods

2.1. Material

The biomass material utilized in this study is rice husk charcoal, which was produced via carbonization.

2.2. Methods

2.2.1 Experimental Design based on Taguchi Method

To appraise the effects of various factors on a process, Taguchi classifies the optimal signal-to-noise (S/N) ratio into three types [23].

1) Smaller the Better (STB) :

$$S/N = -10 \log \left(\frac{1}{n} \sum_{k=1}^n y_i^2 \right) \quad (1)$$

2) Nominal the Better (NTB) :

$$S/N = -10 \log \left(\frac{1}{n} \sum_{k=1}^n \frac{1}{y_i^2} \right) \quad (2)$$

3) Larger the Better (LTB) :

$$S/N = -10 \log \left(\frac{1}{n} \sum_{k=1}^n \frac{\mu^2}{\sigma^2} \right) \quad (3)$$

$$\text{where } \mu = (1/n) \sum_{k=1}^n y_i; \sigma^2 = (1/(n-1)) \sum_{k=1}^n (y_i - \mu)^2$$

The predicated S/N ratio under optimal process conditions can be calculated by considering.

$$S/N_{\text{predicated}} = \bar{S}/N + \sum (S/N_j - \bar{S}/N) \quad (4)$$

2.2.2 Experimental procedure

In order to simultaneously optimize the biomass responses to drying and carbonization, the following four independent variables are considered: the drying temperature (A), which varied between 100, 105, and 110 °C; the drying time (B), at 12, 18, and 24 h; the carbonization temperature (C), at 450, 550, and 650 °C; and the carbonization holding time (D), at 60, 90, and 120 mins.

The response variables are used to determine the optimal parameters, based on a proximate analysis (among other considerations) and the calorific value. The experimental procedure used in this study employs an L₉(3)⁴ orthogonal array, in which each calculation is replicated three times and the average data are then determined.

2.2.3 Analysis of Variance and Multiple Regression Analysis

Analysis of variance (ANOVA) is a method of statistical analysis categorized as statistical inference, which is used to test differences in mean data for more than two groups [23].

Multiple linear regression analysis considers the linear relationship between two or more independent variables (X₁, X₂, ..., X_n) and the response variable (Y). This analysis is used to determine the trend direction of the relationship between the independent variables and the response variable, and whether each independent variable has a positive or negative association. This approach is also used to expect the value of the response variable when the independent variable values increase or decrease. The multiple linear regression equations are expressed as [23,24].

$$Y_0 = a + b_1X_1 + b_2X_2 + \dots + b_nX_n; \quad (5)$$

where Y₀ is the response variable (the predicate value), X₁, X₂, and X_n are independent variables, a* is a constant (the Y₀ value if X₁, X₂, ..., X_n = 0), and b* is the regression coefficient (the extent of the increase or decrease).

2.2.4 Application of the MRSN Procedure

The application of the MRSN procedure has been investigated by [25]. The steps are as follows:

- 1) The total loss function (TL) is obtained;
- 2) The weights are calculated, according to;

$$\eta_i = \sum_{j=1}^m W_i S_{ij} \tag{6}$$

- 3) The loss is calculated : $C_i = L_{ij} / L_{max}$ (7)

4) The MRSN is calculated from the TL, such that

$$MRSN = -10 \log(TL_{ij}) \tag{8}$$

- 5) Verification is performed.

3. Results and Discussion

3.1 Result

The calorific values and proximate result data of the rice husk of the charcoal products acquired for the different independent variables values are presented in Table 1.

Table 1. The average of proximate test and calorific value of rice husk charcoal

Trial	Drying temperature (°C)	Drying time (h)	Carbonization temperature (°C)	Holding Time (mins)	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Calorific value (Cal/g)
1	100	12	450	60	0.938	19.910	2.550	76.603	4443
2	100	18	550	90	0.751	10.316	2.154	86.780	5033
3	100	24	650	120	0.368	3.752	1.338	94.523	5534
4	105	12	550	120	0.643	9.358	1.937	88.063	5107
5	105	18	650	60	0.541	7.757	1.726	89.971	5218
6	105	24	450	90	0.776	13.031	2.246	84.289	4894
7	110	12	650	90	0.574	7.125	1.795	90.443	5245
8	110	18	450	120	0.922	19.139	2.507	77.470	4493
9	110	24	550	60	0.790	13.778	2.279	83.192	4857

Table 2. Test of normality, level of $\alpha = 0.05$

Dependent variable	Statistic	Sig.	Conclusion
Calorific value	0.930	0.069	normally distributed
Moisture content	0.959	0.357	normally distributed
Volatile matter	0.925	0.052	normally distributed
Ash content	0.928	0.062	normally distributed
Fixed carbon	0.953	0.257	normally distributed

Table 3. The residual analysis results of the model calorific value and proximate analysis

Criteria Variable	Residual of normal dist (SW)	Homoscedasticity Certain patterns	No multi-collinearity		DW (Durbin Watson)	Conclusion	
	Sig > 0.05		TOL > 0.1	VIF < 10	dU < D < 4-dU	Feasible	Valid
Calorific value	0.074	No	1	1	1.514 < 2.137 < 4 - 1.514	Yes	Yes
Moisture content	0.357	No	1	1	1.514 < 1.789 < 4 - 1.514	Yes	Yes
Volatile matter	0.052	No	1	1	1.514 < 2.232 < 4 - 1.514	Yes	Yes
Ash content	0.062	No	1	1	1.514 < 1.991 < 4 - 1.514	Yes	Yes
Fixed carbon	0.257	No	1	1	1.514 < 2.042 < 4 - 1.514	Yes	Yes

A Shapiro-Wilk normality test with a number of samples $n \leq 50$ and a significance level of $\alpha = 0.05$ have been utilized. The normal distribution test results show that the calorific value and proximate analysis P-values are presented in Table 2. Thus, the five dependent variables are normally distributed because their P-values are greater, then the null hypothesis is accepted.

The residual analysis is one of the methods for validating the model. The results of the residual analysis to model the calorific value and proximate analysis of the rice husk charcoal are shown in Table 3.

3.2 Discussion

3.2.1. Calorific Value

The quality characteristic of the calorific value is LTB and the optimum conditions to obtain the maximum calorific value are A1B3C3D3. This corresponds to a drying temperature of 100 °C, a drying time of 24 h, a carbonization temperature of 650 °C, and a carbonization time of 120 mins [26].

The optimum conditions are presented in Fig. 1. The study results support by [27], which uses the Taguchi method to investigate the optimum conditions for preparing solid fuel briquettes from rice straw via a piston-molding process.

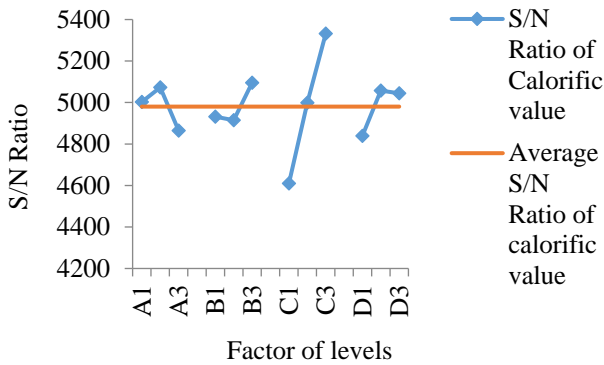


Fig. 1. Response graph of factor effects on calorific value

The ANOVA results show that the four independent variables have a significant effect on the calorific value. This is denoted by the percentage value of the contribution of each variable, i.e 6.495 %, 5.741 %, 77.247 %, and 8.732 % for the drying temperature, drying time, carbonization temperature, and carbonization holding time, respectively.

3.2.1.1 Mathematical Model

The mathematical model for predicting the calorific value as a function of the drying temperature, drying time, carbonization temperature and a carbonization holding time is obtained as follows:

$$HV \text{ (cal/g)} = 3891.009 - 13.811 \cdot A + 13.611 \cdot B + 3.162 \cdot C + 3.422 \cdot D \quad (9)$$

The coefficients R, R-squared, and adjusted R-squared are obtained as 0.950, 0.902 and 0.885 respectively. Higher drying time and carbonization temperature and time produce higher calorific value. However, at a drying temperature and time of 100 °C and 24 h, the highest of the calorific value is 5534 cal/g. It happens when moisture content has evaporated. Thus the increase a drying temperature has no significant contribution to the increase of the calorific value.

3.2.1.2. Model Validation

The results regarding the feasibility and validity of the model indicate that the residual analysis is normally distributed according to the Shapiro-Wilk test. These results are presented in Table 3, with a P-value of 0.074 > 0.05. There is no pattern which indicates homoscedasticity, nor is there any multicollinearity, because TOL(1) > 0.1 and VIF(1) < 10. Therefore, the assumption is valid. The DW value of 2.137 is in the range of 1.514 < 2.137 < 4 - 1.514. Since, there is no positive or negative autocorrelation, the model for predicting the calorific value is feasible and valid.

3.2.2 Moisture Content

The Taguchi quality characteristic of the moisture content is STB. The smallest value of the moisture content is 0.06 %. The high and low moisture contents are inclined by the amount of the moisture vapor in the air, the old cooling

process, and the hygroscopic properties of charcoal [28]. The optimum conditions to obtain the minimum moisture content are A1B3C3D3, and the data is presented in Fig. 2.

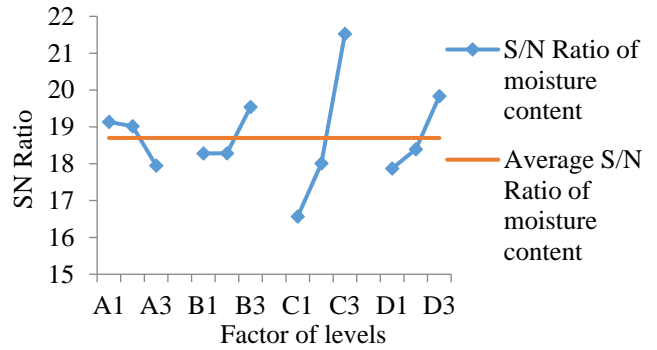


Fig. 2. Response graph of factor effects on moisture content

This condition corresponds to a drying temperature of 100 °C, a drying time of 24 h, a carbonization temperature of 650 °C, and a carbonization time of 120 mins. The result of this work supports by [29], which states that deduction from the energy recovery efficiency (ERE) results at approximately 220 °C. It yields optimum reaction temperature for a cellulose mixture.

The ANOVA results show that the four independent variables have a significant effect on the moisture content. This is denoted by the percentage value of the contribution of each variable, i.e 5.03%, 6.188%, 76.626%, and 12.154% for the drying temperature, drying time, carbonization temperature, and carbonization holding time, respectively. The results of this work are in accordance with [25]. It reveals the effect of the temperature. Furthermore, the drying rate increases as the temperature is higher.

3.2.2.1. Mathematical Model

The mathematical model for estimating the moisture content as a function of the independent variables is:

$$\text{Moisture content (\%)} = 0.249 + 1 \cdot 10^{-3} \cdot A - 1 \cdot 10^{-3} \cdot B + 3.2 \cdot 10^{-4} \cdot C + 3.9 \cdot 10^{-4} \cdot D \quad (10)$$

The R value, R-Squared and Adjusted R-Squared obtained are 0.957, 0.915, and 0.9, respectively. These results are suitable with the results of the study [13]. In the previous study, reducing the mass of saw dusk in briquettes and the increase of drying temperature can reduce the moisture content.

3.2.2.2. Model Validation

The residual analysis is one of the methods for validating the model. The results of the residual analysis to model the moisture-content response of the rice husk charcoal are shown in Table 3. From Table 3, P-value of 0.357 > 0.05. There is no pattern which indicates homoscedasticity, nor is there any multicollinearity, because TOL(1) > 0.1 and VIF(1) < 10. Therefore, the assumption is valid. Furthermore, the DW value of 1.789 is in the range of 1.514 < 1.789 < 4 - 1.514. Therefore, there is no positive or negative autocorrelation. It is apparent that the model of the moisture content response to the various input parameters is feasible and valid. Thus, this model can be used to predict the moisture content subjected to a particular carbonization and drying process.

3.2.3. Volatile Matter Content

The lowest average moisture content, produced using under different independent variable values, is 3.107 %, attained at a drying temperature of 100 °C, a drying time of 24 h, a carbonization temperature of 650 °C, and a carbonization time of 120 mins. Higher or lower volatile matter of a substance is influenced by the chemical components of charcoal as their substantial extract of raw material charcoal. These results are suitable with study [30], which stated that the moisture content of the particle has changed with respect to time during fluidized bed drying.

The optimum condition to yield the minimum volatile matter content is A1B3C3D3, corresponding to a drying temperature of 100 °C, a drying time of 24 h, a carbonization temperature of 650 °C, and a carbonization time of 120 mins. The optimum conditions are shown in Fig. 3.

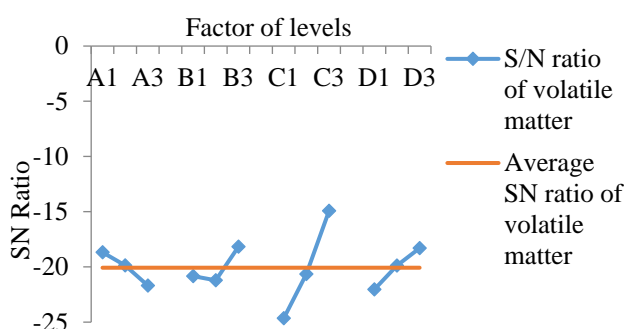


Fig. 3. Response graph of factor effects on volatile matter

The higher the temperature and time of carbonization, the lower of volatile matter content. However, at a temperature of 450 °C and carbonization time of 120 mins, the volatile matter content increases. It occurs due to the interaction between a carbon with air, so the volatile matter content of the substance increases.

According to the ANOVA results, the four independent variables have a positive contribution to the volatile matter content. This is indicated by the contribution percentage values of each, which are 7.099 %, 8.523 %, 73.558 %, and 10.818 %, for the drying temperature, drying time, carbonization temperature, and carbonization holding time, respectively. These results are in accordance with the results of the study [31], which reports that reducing toxic emissions from its unfinished carbonization and offset bio-residue management problems can use briquette technology as a waste-to-energy process.

3.2.3.1. Mathematical Model

The mathematical model for predicting the volatile matter content as a function of the independent variables is:

$$\text{Volatile matter (\%)} = 29.477 + 2.03 \cdot 10^{-1} \cdot A - 2 \cdot 10^{-1} \cdot B - 5.7 \cdot 10^{-2} \cdot C - 5.1 \cdot 10^{-2} \cdot D \quad (11)$$

Here, R value = 0.951, indicates that the degree of linearity in the relationship between the volatile matter content (%) and the predictor variables is sufficient. Further, R-squared = 0.904 and the adj R-squared = 0.89, indicate an 89 % variance in the volatile matter content, which can be expounded by

considering the effects of the independent variables. Another factor which has not yet been explained is the residual.

3.2.3.2. Model Validation

The results of a residual analysis to model the volatile matter content response are shown in Table 4. From Table 4, P-value is 0.052 > 0.05. There is no pattern which indicates homoscedasticity, nor is there any multicollinearity, because $TOL(1) > 0.1$ and $VIF(1) < 10$. Therefore, the assumption is valid. Furthermore, the DW value of 2.232 is in the range of $1.514 < 2.232 < 4 - 1.514$. Therefore, there is no positive or negative autocorrelation. It is apparent that the model of the volatile matter content response to the various input parameters is feasible and valid. Thus, this model can be used to estimate the volatile matter content subjected to carbonization and drying process. This result is in accordance with result of study [24], which stated that the regression model is a function of temperature, relative humidity, and wind speed, allow different modifications in the response variables for more natural evaporation data synthesis.

3.2.4. Ash Content

The lowest average ash content produced for the different independent variable values is 6.813 %, which is achieved at a drying temperature of 100 °C, a drying time of 12 h, a carbonization temperature of 450 °C, and a carbonization time of 60 mins.

The optimum conditions to yield the minimum ash content is A1B1C1D1, corresponding to a drying temperature of 100 °C, a drying time of 12 h, a carbonization temperature of 450 °C, and a carbonization time of 60 mins. The optimum conditions are displayed in Fig. 4.

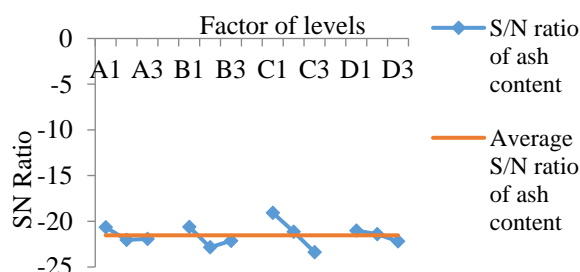


Fig. 4. Response graph of factor effects on ash content

These findings are supported by [22], which states that the application of the Grey-Taguchi method to optimization on mechanical properties of coconut shell powder and coir fiber reinforces polyester composites.

The ANOVA calculation results demonstrate that the four independent variables have a significant effect on the ash content. This is indicated by the percentage value of each contribution, at 9.087 %, 10.12 %, 75.296 % and 5.494 % for the drying temperature, drying time, carbonization temperature, and carbonization holding time, respectively. The results of this study are in accordance with [7], which investigated that reducing the overall thickness of pavement on rice husk ash could be performed by adding it with different percentage to natural soil and its maximum dry density, optimum moisture content and CBR (California Bearing Ratio) value.

3.2.4.1. Mathematical model.

The mathematical model to estimate the ash content of the rice husk charcoal as a function of the independent variables is :

$$\text{Ash content (\%)} = -20.623 + 1.2 \cdot 10^{-1} \cdot A + 1.49 \cdot 10^{-1} \cdot B + 2.8 \cdot 10^{-2} \cdot C + 1.9 \cdot 10^{-2} \cdot D \quad (12)$$

The coefficients R, R-squared and adjusted R-squared obtained are 0.958, 0.918 and 0.903 respectively.

3.2.4.2. Model Validation

The results of the feasibility test and residual analysis indicate that the data are normally distributed (based on the Shapiro-Wilk test) and are presented in Table 3, with a P-value of $0.062 > 0.05$. There is no pattern which indicates homoscedasticity and multicollinearity do not occur because $TOL(1) > 0.1$ and $VIF(1) < 10$. Thus, the assumption is validated. Furthermore, the DW value of 1.991 is in the $1.514 < 1.991 < 4 - 1.514$ range. Thus, there is no positive or negative autocorrelation. It can be concluded that the model for predicting the ash content is feasible and valid.

3.2.5. Fixed Carbon

Fixed carbon has the LTB of quality characteristic. The maximum average fixed carbon produced for the different independent variable values is 81.401 %, which is achieved at a drying temperature of 100 °C, a drying time of 12 h , a carbonization temperature of 650 °C, and a carbonization time of 120 mins. The optimum conditions to yield the maximum fixed carbon is A1B3C3D2, corresponding to a drying temperature of 100 °C, a drying time of 24 h, a carbonization temperature of 650 °C, and a carbonization time of 90 mins. The optimum conditions are shown in Fig. 5. Similar results were found by [32] which explicated that proper choices of carbonization temperature and activation time can produce a high specific surface area which activates carbon from coconut shell.

According to the ANOVA results, the percentage contributions of each factor are as follows: drying temperature (A): 20.399 %, drying time (B): 7.893 %, carbonization temperature (C): 52.376 %, and carbonization time (D): 19.321 %. These results are in suitable with [22], which reported that coir diameter has 35.10% contribution, and coir length has 25%, Coconut shell powder (CSP) content has 2.4%, and CSP size has 37.5% on the multiple performance characteristics.

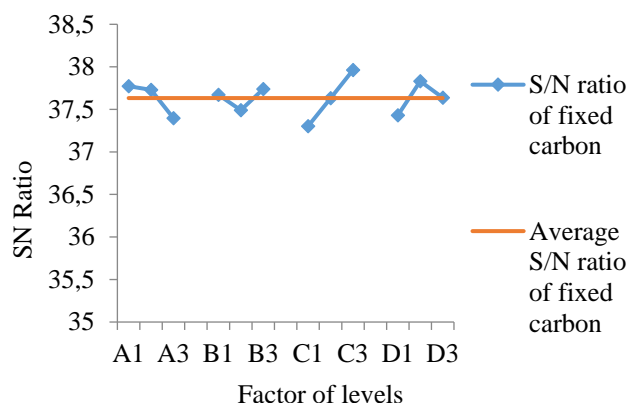


Fig. 5. Response graph of factor effects on fixed carbon

3.2.5.1. Mathematical Model

The fixed carbon models, variable drying time (B) does not have a significant influence, so these variables are not included in the modeling. It is shown from the results of the feasibility test P-value coefficient ($0.496 > 0.05$); therefore, making new models does not include the variable B.

The mathematical model for predicting the fixed carbon content is :

$$\text{Fixed carbon(\%)} = 91.826 - 3.27 \cdot 10^{-1} \cdot A - 2.9 \cdot 10^{-2} \cdot C - 3.2 \cdot 10^{-2} \cdot D \quad (13)$$

For this model, the coefficients R, R-squared, Adjusted R-squared and standart error were obtained as 0.852, 0.726, 0.691 and 1.871 respectively. Furthermore, the value of AIC, SBC and CpM were obtained as 37.517, 42.7 and 4.00 respectively. Criteria for selection of the best models on the fixed carbon are shown in Table 4. Model 2 is the best model to expecting calorific value.

3.2.5.2. Model Validation

The results concerning the feasibility and validation of the coefficient model show that the residual analysis is normally distributed according to the Shapiro-Wilk test, with a P-value of $(0.257) > (0.05)$. Furthermore, no specific pattern indicating homoscedasticity forms, and there is no multi collinearity because $TOL(1) > 0.1$ and $VIF(1) < 10$. Therefore, the assumption is fulfilled. The DW value of 2.042 is in the range of $1.514 < 2.042 < 4 - 1.514$. Thus, there is no positive or negative autocorrelation. The model for predicting the fixed carbon is feasible and valid.

Table 4. The selection of the best models fixed carbon of rice husk charcoal

Model	R	R-square	Adj R-Square	Std error	AIC (Akaike Information Criterion)	SBC (Schwarz Bayesian Criterion)	Cp Mallows (Criterion Prediction)
Model 1	0.856^a	0.732	0.683	1.89310	38.934	45.413	5.000
Model 2	0.852 ^a	0.726	0.691	1.87158	37.517	42.700	4.000

The effect treatments of the drying temperature, drying time, carbonization temperature and the carbonization holding time of rice husks in improving the quality of materials in terms of calorific value and the proximate analysis are presented in Fig. 6 and 7.

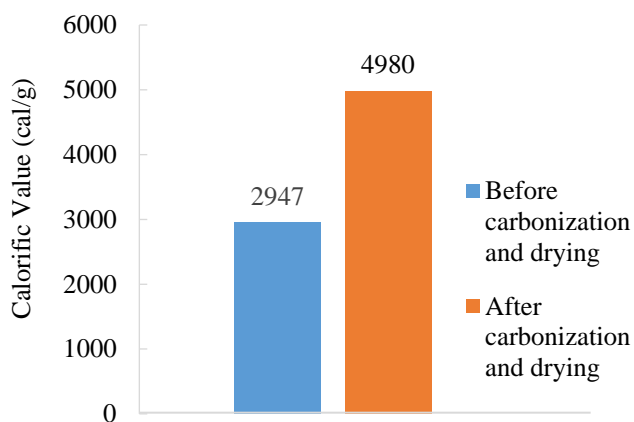


Fig. 6. The different calorific value before and after carbonization and drying

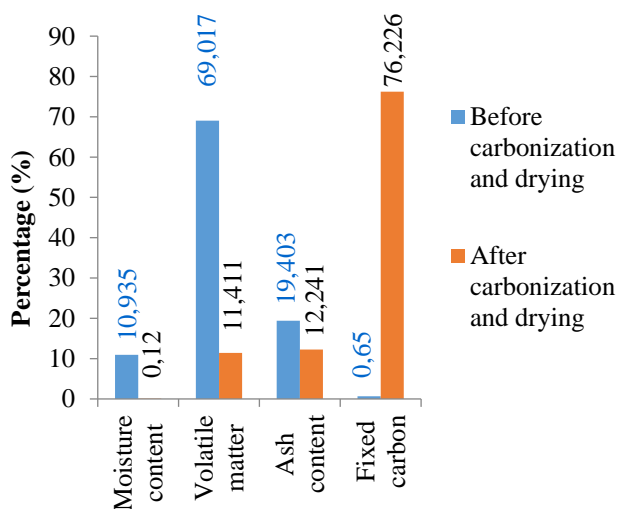


Fig. 7. The different proximate analysis before and after carbonization and drying

3.2.6. Application of the MRSN Procedure

1) Total loss function (TL):

The measurement units for the response variables differ, i.e., the quality characteristics of the fixed carbon and calorific value are LTB, whereas the measurement units for the moisture content, volatile matter, and ash content are STB. The TL is normalized between zero (0) and one (1).

- 2) Calculating weights from Eq. (6). It is found that $w_1 = 0.3849$, $w_2 = 0.0767$, $w_3 = 0.0767$, $w_4 = 0.0767$ and $w_5 = 0.3849$.
- 3) The MRSN calculation of the TL is performed by using Eqs. (7) and (8):

The results of the MRSN procedure calculated based on Table 1, Fig. 1, Fig. 2, Fig. 3, Fig. 4 and Fig. 5 are shown in Table 5.

The yields of the highest MRSN value are 2.042. Therefore, the simultaneous parameter optimization of the multi-response variables having different quality characteristics into a single best parameter is A1B3C3D3. This corresponds to a drying temperature of 100 °C, a drying time of 24 h, a carbonization temperature of 650 °C, and a carbonization time of 120 mins.

4. Conclusion

Simultaneous optimization of the drying and carbonization of the rice husk in terms of the calorific value and proximate analysis is determined by using the MRSN procedure that yields a result of 2.042. The parameters are necessary to achieve this value of the drying temperature of 100 °C, the drying time of 24 h, the carbonization temperature of 650 °C, and the carbonization holding time of 120 mins. These parameters are best achieved by using the A1B3C3D3 configuration.

The feasibility test of the model and coefficients was performed. Additionally, the model validation was also conducted by considering the calorific value and the moisture, volatile matter, ash, and fixed carbon content. Hence, the model was declared to be suitable for predicting the effects of the four independent variables on the five dependent variables.

Table 5: The result calculating MRSN procedure of rice husk charcoal

Trial	Calorific Value		Moisture Content		Volatile Matter Content		Ash Content		Fixed Carbon		TNQL	MRSN
	Loss	C _{ij}	Loss	C _{ij}	Loss	C _{ij}	Loss	C _{ij}	Loss	C _{ij}		
1	$7.6 \cdot 10^{-5}$	1.000	1.865	1.000	35876.4	1.000	3150	0.198	$3.03 \cdot 10^{-3}$	0.922	0.909	0.416
2	$5.9 \cdot 10^{-5}$	0.779	1.195	0.641	9455.8	0.264	9297	0.584	$2.67 \cdot 10^{-3}$	0.813	0.727	1.384
3	$4.9 \cdot 10^{-5}$	0.645	0.288	0.155	874.01	0.024	15924	1.000	$2.45 \cdot 10^{-3}$	0.744	0.625	2.042
4	$5.8 \cdot 10^{-5}$	0.757	0.875	0.469	7939.6	0.221	11555	0.726	$2.71 \cdot 10^{-3}$	0.823	0.717	1.446
5	$5.5 \cdot 10^{-5}$	0.725	0.621	0.333	5475.4	0.153	15594	0.979	$2.74 \cdot 10^{-3}$	0.834	0.712	1.472
6	$6.3 \cdot 10^{-5}$	0.825	1.275	0.683	15447.4	0.431	6751	0.424	$2.75 \cdot 10^{-3}$	0.836	0.757	1.207
7	$5.5 \cdot 10^{-5}$	0.718	0.698	0.374	4642.3	0.129	12503	0.785	$2.59 \cdot 10^{-3}$	0.788	0.678	1.685
8	$7.4 \cdot 10^{-5}$	0.978	1.559	0.836	33171.5	0.925	7382	0.464	$3.29 \cdot 10^{-3}$	1.000	0.932	0.306
9	$6.4 \cdot 10^{-5}$	0.837	1.328	0.712	15444.1	0.430	12252	0.769	$3.02 \cdot 10^{-3}$	0.918	0.822	0.851

According to the mathematical model, the optimal predictive values are as follows: the maximum values for the calorific value and fixed carbon content are 5665 cal/g and 83.2 %, respectively, and the minimum values for the moisture content, volatile matter, and ash content are 0.06 %, 3.1 %, and 6.8 %, respectively. Based on the residual analysis, all the indicators are fulfilled. Thus, the resulting model is both valid and feasible. The novelty in this work is the simultaneous parameter optimization of the multi-response variables into a single best parameter. It is the A1B3C3D3 configuration.

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