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Modelling and Optimisation of Coconut Shell Drying and Carbonisation Using Multi-response Taguchi Method with Multi-response Signal-to-noise Procedure

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ABSTRACT

The main purpose of this research is to optimise the biomass drying and carbonisation process in terms of both proximate analysis and biomass calorific value, simultaneously. The independent variables are drying temperature, drying time, carbonisation temperature, and carbonisation holding time. The dependent variables are proximate analysis and calorific value. The primary methods used are Taguchi and multi-response signal-to-noise (MRSN) procedure. Simultaneous optimisation using MRSN generates a value of 2.48. The result corresponds to a drying temperature of 100°C, a drying time of 24 h, a carbonisation temperature of 650°C, and a carbonisation time of 120 minutes. This best result is achieved through A1B3C3D3 configuration. The optimum expected values of dependent variables obtained in this study are maximum calorific value and fixed carbon of 7744 cal/g and 92.934% respectively, and minimum values of moisture, volatile matter, and ash content of 0.354%, 2.318%, and 1.437% respectively. All the indicators are satisfied as the result models are valid and feasible. The novelty of this research is the simultaneous parameters optimisation of the five response variables having different quality characteristics. Using MRSN procedure, all the parameters are combined into a single best parameter.

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1. INTRODUCTION

The increase of population is strongly associated with the increase of energy needs. In the recent years, energy requirement in Indonesia have primarily been fulfilled from fossil-derived energy sources. However, the availability of the non-renewable energy is decreasing and these sources will eventually be depleted. One approach to reduce the dependence on the fossil fuels is the development of the renewable energy sources [1]. Biomass, a renewable energy source, can be obtained from agricultural, households, and industrial wastes. Coconut shells as one of biomass sources can be utilized as an alternate fuel. To obtain a good-quality fuel from coconut shells, the coconut shells must be dried and be carbonised before undergoing briquetting.

A drying temperature of 22°C, a sawdust mass of 46.66%, and a compression force of 588.6 kN are the optimum values of the briquetting process parameters [2]. Biomass carbonisation involves decomposition of the biomass using heat energy in the absence of oxygen [3]. The biomass material derived from carbon has potential economic value and commercial property in near future [4]. Furthermore, according to [5], the characterization results of the porous structure of prepared AC (Activated Carbon) have major impact. The AC should have numerous heterogeneous active sites in the micro pores. The yield of bio-oil from a pyrolysis process of coconut shell is influenced by pyrolysis temperature, heating rate, and particle size [6].

The difference between this study and the previous researches lies on the use of parameters, orthogonal array, feasibility, and validity of the biomass carbonisation and drying model.

This study applies multi-response Taguchi method to optimise the parameter settings. Researches on the application of the Taguchi method has been performed by [7-11]. Compared to the previous works, this study mainly focuses on the simultaneous parameter

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optimisation of the five response variables with different quality characteristics which are combined into a single best parameter based on the value of the highest MRSN ratio. Furthermore, this work provides extensive contribution to the society by supporting the creation of high-quality renewable fuel.

2. MATERIAL AND METHOD

This work used coconut shells as the carbonised material. The methods implemented are Taguchi and MRSN procedure. Multiple regression analysis is used to model the proximate and calorific value. As the experimental material, samples of coconut shell charcoal after the carbonisation process are tested for proximate analysis and calorific value. All the data are analysed through experimentation and testing methods.

2. 1. Experimental Design To manage simultaneous optimisation of the biomass responses to drying and carbonisation, some levels of the four independent variables are considered: the drying temperature (A) of 100°C, 105°C, and 110°C; the drying time (B) of 12 h, 18 h, and 24 h; the carbonisation temperature (C) of 450°C, 550°C, and 650°C; and the carbonisation holding time (D) of 60, 90, and 120 minutes [12].

The optimum parameters are determined by using the dependent variables based on the result of the proximate analysis and the calorific value of the coconut-shell charcoal. The experimental procedure used in this research is an $L9(3)^4$ orthogonal array with three replication on each trial. The analysis of the results is based on the average of the data.

2. 2. Analysis of Variance and Development Models Analysis of Variance (ANOVA) is a method of partitioning variability into identifiable sources of variation and the associated degrees of freedom in an experiment [13]. Validation of the models with new set of experiments demonstrated that the curvilinear model is the best and most fixed among the recommended models [14].

Multiple linear regression (MLR) analysis is a quick and commonly used method for revealing analytical relationships between response and independent variation of a formulation. This variation can be easily obtained and used. Nevertheless, this regression method assumes a linear relationship between factors, possibly resulting in a model with modelling errors and constrained ability to interpret important relationships [15].

The multiple linear regression equation is expressed as follow:

$$Y0 = a + b_1X_1 + b_2X_2 + \dots + b_nX_n \quad (1)$$

where $Y0$ is the dependent variable (the predicate value); X_1, X_2, and X_n are the independent variables; a a constant (the $Y0$ value if $X_1, X_2, ..., X_n = 0$), and b_i the regression coefficient.

2. 3. Application of MRSN Procedure The optimum combination of parameters can be obtained through the application of MRSN [16, 17]. Taguchi method offers a simple, logical, and efficient methodology for detecting the significant control parameters. A study explains how to optimize some parameters effectively [18].

Factors identification is needed due to the lack of appropriate and accurate information on required factors for modelling and accurate computation of simulation results [19]. The MRSN procedure is applied as follow [16]:

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

$$\eta_i = \sum_{i=1}^{m} W_i S_{ij} \quad (2) \qquad (2)$$

3. The loss is calculated:

$$C_{ij} = L_{ij} = L_{max} \quad (3) \qquad (3)$$

4. The MRSN is calculated from the TL, such that:

$$MRSN = -\log(TL_{ij}) \quad (4) \qquad (4)$$

5. Verification is performed.

3. RESULTS AND DISCUSSION

The analysis of the raw biomass characteristics is performed based on proximate and calorific value. The particle size of biomass prior to the drying and carbonisation treatment varies from 10 mm to 12 mm. The drying and carbonisation treatments have significant effect on the quality of the raw biomass. It is proven that the initial condition of moisture content decreases from 8.841% to 0.7002% and the volatile matter decreases from 89.801% to 11.574%. Although the ash content increases from 0.529% to 2.058%, however, it is still under 6%, the permitted SNI 19-0428-1989. The improvement of the quality also can be seen in the increase of the fixed carbon from 0.495% to 85.704%, a significant increase of 85.209%.

A Shapiro Wilk normality test with a significance level of $\alpha = 0.0571$ and a number of samples $n \leq 50$ are used. The normal distribution test results show that the moisture, volatile matter, ash, and fixed carbon content P-values, and the calorific P-value, are 0.260, 0.062, 0.190, 0.083, and 0.093 respectively. Thus, the five response variables have normal distribution because their P-values are higher than α (0.05). Thus, the null hypothesis (that the populations are normally distributed) is accepted.

3. 1. Moisture Content Based on the experimental design and the total degree of freedom, the orthogonal array used in this study is $L_9(3)^4$. The initial moisture content of the coconut shells before the drying and carbonisation treatment is 8.841%.

The lowest average moisture content value of the coconut shell charcoal produced under different drying temperatures and drying times is 0.699%. This value is achieved at a drying temperature of 100°C and a drying time of 24 hours. It shows that at 100°C the moisture content of the charcoal decreases and the mass of the charcoal becomes constant. These could occur because on a certain temperature at which the drying rate is constant, the surface of the material is saturated with vapor at temperature equal to that of the wet bulb temperature of the drying air [20, 21]. Along this process, the rate of water diffusion in the material is at the same level with the rate of its vaporisation. This process ended when the free moisture content of the material reached the critical level [20]. The critical moisture content is the lowest level of free moisture content of the material at which the rate of the diffusion of the free moisture to the surface equals to the rate of vaporisation [21]. Related to the carbonisation temperature and carbonisation holding time, the value of 0.699% is achieved at a carbonisation temperature of 650°C and a carbonisation time of 120 minutes. Thus, the optimum conditions to obtain the minimum moisture content are A1B3C2D2, as presented in Table 1 and Figure 1.

Based on Table 1 and Figure 1, it can be seen that A1B3C2D2 result is obtained at 100°C of drying temperature, 24 hours of drying time, 550°C of carbonisation temperature, and 90 minutes of carbonisation holding time.

TABLE 1. Optimum condition of moisture content

Column/Factor	Level Description	Level
A. Drying temperature	100°C	1
B. Drying time	24 h	3
C. Carbonisation temperature	550°C	2
D. Carbonisation holding time	90 mins	2

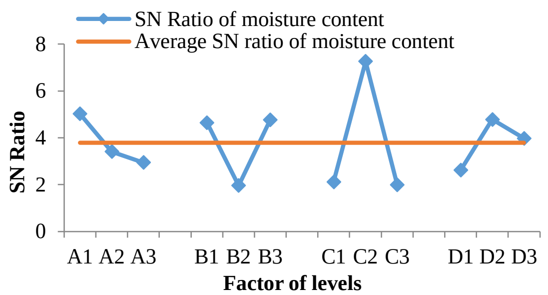

Figure 1. SN-ratio response of moisture content of coconut-shell charcoal

The ANOVA calculation results show that the four independent variables, i.e., the drying temperature, the drying time, the carbonisation temperature, and the carbonisation holding time, significantly affect the moisture content. The contribution of each variable, i.e., 6.701, 6.921, 77.127, and 9.249% for the drying temperature, the drying time, the carbonisation temperature, and the carbonisation holding time, respectively, become a proof of this significant effect.

The results of this work support the statement of [22] which emphasises that the test samples of the sawdust briquettes have significant effects on the moisture content, the durability, and the calorific value at P-values < 0.05.

The moisture contents obtained under current production condition vary widely and become smaller at the optimum condition. It is because the materials already dried before carbonised. The moisture content of the coconut shells begin to evaporate at 100°C. The 24-hours drying time significantly reduces the moisture content. Thus, when coconut shells carbonised at a temperature of 550°C, the moisture content remaining in the shells will also be diminished along the time of carbonisation.

The longer the drying time, the less the moisture content remaining in the material, so that the calorific value gained is higher. On the contrary, the higher the moisture content, the lower the calorific value of the coconut shell charcoal. The level of the calorific value is also influenced by the amount of the moisture content of the charcoal. The heat stored in the material is used firstly to evaporate the moisture in the sample of material. Therefore, the generated heat is used as combustion heat. This finding is in accordance to [2] which states that the moisture content decreases with the decrease of the mass and the increase of the carbonisation temperature. A comparison between the moisture content results of the current condition and the ones of the optimum conditions is shown in Figure 2.

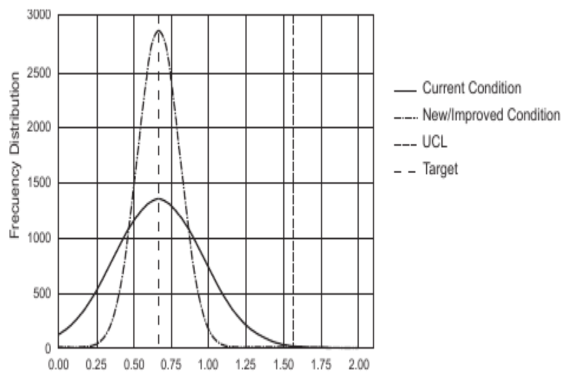

Figure 2. Moisture content under optimum conditions and currently used conditions

3. 1. 1. Mathematical Model The mathematical model for predicting the moisture content as a function of the independent variables is:

Moisture content (%) = 1.238 + 0.008A−0.006B −0.002C−0.002D (5)

Based on equation (5), the drying time, the carbonisation temperature, and the carbonisation holding time have significant influence on the decrease of the moisture content of the coconut shells charcoal.

The results of residual analysis from other factors have not been successfully identified yet. It can be noted that the adjusted R^2 value is a correction for the R^2 result. These results fit to the result of [2]. On that study, based on the developed mathematical model, the optimum independent variable values can generate a maximum calorific value of 17.41 MJ/kg with a minimum moisture content of 6.62% and a maximum pressure strength of 19.54 N/mm^2.

3. 1. 2. Model Validation An approach can be used to validate the model is residual analysis. The result of the residual analysis on the model of moisture content response is shown in Table 2.

It is shown 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 drying and carbonisation.

3. 2. Volatile Matter Content The lowest average volatile matter content value obtained from various independent variable values is 3.752%. This value is achieved at a drying temperature of 100°C, a drying time of 24 hours, a carbonisation temperature of 650°C, and a carbonisation holing time of 120 minutes. According to the model, if the carbonisation temperature, the carbonisation time, and the drying time is higher, the moisture content will be lower. The longer carbonisation time will cause the pores of coconut shells to open wider and release the moisture content of the material. However, the drying temperature variable (D) has positive regression coefficient, thus it runs in two ways. This drying temperature affects the drying time and the after-drying-material quality. The higher the drying temperature, the shorter the drying time.

The R value of 0.950 indicates a sufficient degree of linearity in the relationship between the moisture content variable and the predictor variables. Further, R^2 = 0.902 and the adjusted-R^2 = 0.884 indicates 88.4% variance in the moisture content, as the independent variables affect the moisture content. This study is in line with [23], which states that the model development can be applied of the intake temperature for cooling system [23].

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These results have the same values as those on [24]. The results indicate that in addition to a loss in weight, the heat treatments decrease the volatile matter content and increase the carbon content of the biochar. The optimum conditions of the volatile matter content are shown in Table 3.

From Table 3, it can be seen that the optimum condition of the volatile matter required drying temperature of 100°C and drying time of 24 hours. The longer the drying time, the better the quality of the material, because evenly drying will decrease the moisture content, and in turn, reduce the volatile matter content. The higher carbonisation temperature, 650°C, and the longer carbonisation time, 30 hours, decrease the volatile matter. In this case, the levels of carbon is high, so that the quality of the charcoal increases and the combustion time of the coconut shell becomes longer.

TABLE 2. The results of the residual analysis on the moisture content model of coconut shell charcoal

The normal distribution (Shapiro Wilk)	Homo-schedasticity	No Multicollinearity		DW (Durbin Watson)	Conclusion	
Sig>0.05	Certain patterns	TOL>0.1	VIF<10	1,514< D<4-1,514	Feasible	Valid
0.101	No	1	1	1.550: (no auto correlation (+) and (-)	Yes	Yes

TABLE 3. Optimum condition of volatile matter

Column/Factor	Level Description	Level
A. Drying temperature	100°C	1
B. Drying time	24 h	3
C. Carbonisation temperature	650°C	3
D. Carbonisation holding time	120 mins	3

The level of the volatile matter content is also affected by the type of the material and the level of the moisture content. The decomposition of the volatile matter is caused by oxidation reaction. This reaction occurs on the surface and its reaction rate controlled by oxygen diffusivity in the material.

Optimisation of the volatile matter parameters of coconut shell charcoal are shown in Figure 3.

In relation to ANOVA results, the four independent variables are positively correlated to the volatile matter content. The percentage of the contribution of the drying temperature, drying time, carbonisation temperature, and holding time of 6.618%, 5.806%, 77.042%, and 10.531% respectively, show the positive contribution.

These results strengthen the findings of [22] which reported that the test samples used in that study have significant effects on the volatile matter content, durability, and calorific value of the resultant sawdust briquettes. They have P-value < 0.05.

3. 2. 1. Mathematical Model The mathematical model of the volatile matter content as a function of four independent variables is expressed as follows:

$$\text{Volatile matter content (\%)} = 28.526 + 0.202A - 0.162B - 0.056C - 0.051D \quad (6)$$

The coefficients R, R-squared and adjusted-R squared are 0.944, 0.890, and 0.870, respectively.

The value of R = 0.944 shows very strong linear relationship between drying temperature, drying time, carbonisation temperature, and carbonisation holding time with the level of the volatile matter of coconut shell charcoal.

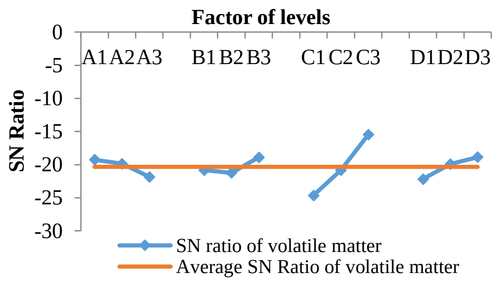

Figure 3. SN-ratio response of volatile matter content ofcoconut shell charcoal

3. 2. 2. Model Validation The residual analysis shows that normal distribution of data based on the Shapiro-Wilk test with a P-value of 0.06 > 0.05 does not form a specific pattern indicating homoscedasticity. Furthermore, there is no multicollinearity because TOL (1) > 0.1 and VIF (1) < 10. Thus, the assumptions are validated. Therefore, the Durbin Watson (DW) value of 2.134 lies on the range of 1.514 < 2.134 < 4−1514. Thus, there is no positive and negative autocorrelation. Moreover, this model is feasible and valid.

The increase of carbonisation temperature and holding time, and also drying time, affect significantly the decrease of the volatile matter content of the coconut shell charcoal. This volatile matter content is inversely related to burning, especially when the volatile matter content getting higher. The higher the volatile matter content, the burning would be lower and the time of start ignition would be shorter. The temperature of cooling water intake in a power generator can be predicted based on environmental factors using linear regression models [23].

3. 3. Ash Content The lowest average ash content yielded from various independent variable values is 1.3379%, attained at a drying temperature of 100°C, a drying time of 24 hours, a carbonisation temperature of 450°C, and a carbonisation time of 120 minutes. Figure 4 shows the optimum conditions. This study is in accordance to [25], who states that the Taguchi method is used to determine the optimum conditions in the manufacture of briquette fuel. Furthermore, research on the application of the Taguchi method of the sheet composite by [26]. The optimum conditions to obtain the minimum ash content are A1B3C1D3 as presented in Figure 4.

The ANOVA for ash content indicates that the four independent variables have significant effects, as shown by the percentage value of parameters' contribution; 6.935% for the drying temperature, 5.324% for the drying time, 78.167% for the carbonisation temperature, and 9.572% for the carbonisation holding time.

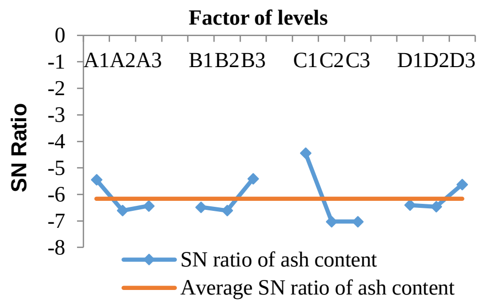

Figure 4. SN-ratio response of ash content of coconut-shell charcoal

The results reinforce the findings of [24] which previously observed the characteristics of biomass-waste rice straw, bagasse, and coconut shell. It is also in accordance to a similar study [27] on a performance evaluation of cashew shell carbonisation, while switchgrass of carbonisation [28].

3. 3. 1. Mathematical Model As an outcome of the multiple regression analysis, the mathematical model of the independent variables of the ash content is attained in the following equation:

$$\text{Ash content (\%)} = 3.005 + 0.018A - 0.012B - 0.004C - 0.004D \quad (7)$$

In this case, the attained R, R-squared, and Adjusted R-Squared were 0.957, 0.916, and 0.900, respectively. The Adjusted R-Squared of 0.9 indicates that 90% of variance in the ash content variable can be explained by considering the independent variables.

3. 3. 2. Model Validation The feasibility test and residual analysis show that the data are normally distributed (based on the Shapiro-Wilk test) with a P-value of 0.088 > 0.05. There is no multicollinearity because TOL (1) > 0.1 and VIF (1) < 10. Therefore, the model is validated. The DW value of 0.980 is in the 0.878 < 0.980 < 1.514 range. There is no positive autocorrelation. Thus, the model for expecting the ash content of the coconut-shell charcoal is considered feasible and valid. The high ash content could make the calorific value of the coconut shell charcoal getting decrease because the ash is the residual material of drying process which has no more calorific value or carbon. High ash content could yield pores plug on the charcoal so that the surface area decreases.

3. 4. Fixed Carbon The optimum conditions to attain the maximum amount of fixed carbon are a drying temperature of 105°C, a drying time of 24 hours, a carbonisation temperature of 650°C, and a carbonisation time of 90 minutes. The optimum conditions are displayed on Figure 5.

These findings are in accordance to [24], which states that the carbonisation time within the range observed (1–4 hours) has small effect on the char yield, the thermal, and the chemical properties of the material. However, it gives more effect on the textural characteristics.

The percentage of the contributions of every factor from ANOVA result can be explained as follow: drying temperature, drying time, carbonisation temperature and carbonisation time of 7.35%, 4%, 79.363% and 9.336%, respectively.

These results fit to [23], which states the same conditions for the increase of heating value (HV) and fixed carbon of biochar from 17.6 to 21.9 MJ/kg and from 22.5% to 44.9%, respectively. The higher the fixed carbon in the material, the higher the calorific value gained. These results match [22], which examines the strength properties and calorific value of sawdust by considering the high burning value of a substance and its effect on the calorific value.

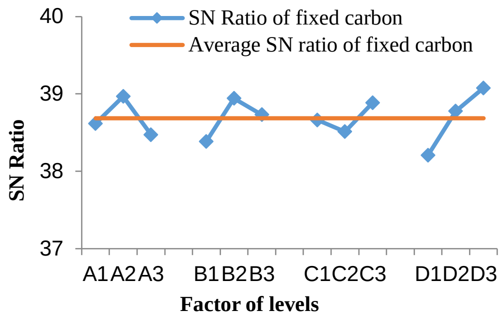

Figure 5. SN-ratio response of fixed carbon of coconut-shell charcoal

3. 4. 1. Mathematical Model The mathematical model for the expected fixed carbon of the coconut-shell charcoal is represented by the following equation:

$$\text{Fixed carbon (\%)} = 67.381 - 0.227A + 0.192B + 0.061C + 0.057D \quad (8)$$

In this case, the obtained R, R-squared and Adjusted R-Squared were 0.943, 0.889, and 0.869, respectively. The Adjusted R-Squared of 0.869 indicates that a 86,9% of variance in the fixed carbon variable can be explained by considering the independent variables.

3. 4. 2. Model Validation The feasibility test and residual analysis indicate that the data are normally distributed (based on the Shapiro-Wilk test) with a P-value of 0.338 > 0.05. There is no pattern representing the homoscedasticity, and the multi collinearity does not appear because TOL (1) > 0.1 and VIF (1) < 10. Therefore, the model is validated. The DW value of 2.042 is in the range of 1.514 < 2.042 < 4−1.514. There is no positive autocorrelation. Hence, the model for expecting the ash content of the coconut-shell charcoal is feasible and valid. The higher the fixed carbon, the higher the calorific value, and the burning process will be faster.

3. 5. Calorific Value The coconut shell calorific value at the initial condition is 4667 cal/g. It becomes 7744 cal/g after the drying and the carbonisation treatment. Thus, there is an increase in calorific value of 3077 cal/g. The optimum conditions are listed in Figure 6, corresponds a drying temperature of 105°C, a drying time of 24 h, a carbonisation temperature of 650°C, and a carbonisation time of 120 minutes. These results match with [12,27,28]. The results is in line with [25] in which Taguchi method is used to identify the optimum conditions in the application of solid fuel briquettes.

3. 5. 1. Mathematical Model The mathematical model for calorific value prediction as a function of the independent variables obtained as follows:

$$HV\ (cal/g) = 4{,}480.270 - 2.624A + 0.199B + 4.369C + 5.130D \quad (9)$$

For this model, the obtained coefficients R is 0.979, R-Squared is 0.958, and Adj. R-Squared is 0.95. The result of the calorific value from equation (9) meets the SNI 19-0428-1989, the standard requirement of the minimum calorific value of 7000 cal/g for coconut shell charcoal.

3. 5. 2. Model Validation The residual analysis results show that the normal distribution of the data based on the Shapiro-Wilk test, with a P-value of 0.839 > 0.05 does not form specific pattern indicating the homoscedasticity. Further, there is no multi-collinearity because TOL (1) > 0.1 and VIF (1) < 10. Thus, the assumptions are validated. Here, the Durbin Watson (DW) value is 2.609 in the range of 1.514 < 2.609 < 4−1514. There is no positive and negative autocorrelation. The model of calorific value is feasible and valid.

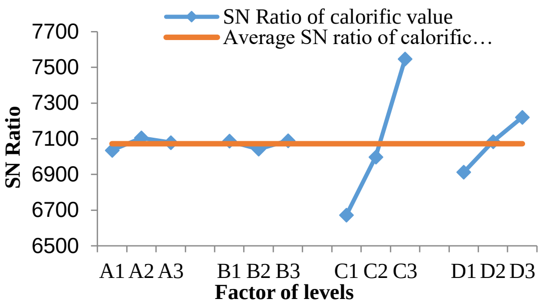

Figure 6. SN-ratio response of calorific value

The level of the calorific value is affected by the moisture content of the charcoal.

3. 6. Implementation of MRSN Procedure

1. Total loss function (TL): The magnitude units for the dependent variables with different quality characteristics included moisture content, volatile matter, and ash content are STB, while those for the fixed carbon and calorific value are LTB.
2. Calculating weights from Eq. (2). It was found that w1 = 0.08, w2 = 0.08, w3 = 0.08, w4 = 0.38, and w5 = 0.38. The results of the MRSN procedure are shown in Table 4.
3. The MRSN calculation of the TL is performed using Equations (3) and (4). The highest MRSN value of 2.48 for the A1B3C3D3 parameter configuration is displayed in Table 4. This relates to a drying temperature of 100°C, a drying time of 24 hours, a carbonisation temperature of 650°C, and a carbonisation holding time of 120 minutes.

   The A1B3C3D3 is the best parameter taken from the combination of the optimum conditions of moisture, volatile matter, ash content, fixed carbon, and calorific values. Furthermore, these parameters can be used as the basis for the industrial scale application.

4. CONCLUSIONS

The simultaneous optimisation of the coconut-shell carbonisation and drying in terms of regulated dependent variables by using the MRSN procedure provides the best result of 2.48. This best condition is attained through A1B3C3D3 configuration. It corresponds to a drying temperature of 100°C, a drying time of 24 hours, a carbonisation temperature of 650°C, and a carbonisation holding time of 120 minutes. The models of calorific value and the proximate analysis are feasible and valid.

TABLE 4. The results of MRSN procedure

Trial	Moisture Content		Volatile Matter Content		Ash Content		Fixed Carbon		Calorific Value		TNQL	MRSN
	Loss	C_{ij}	Loss	C_{ij}	Loss	C_{ij}	Loss	C_{ij}	Loss	C_{ij}		
1	61.818	1.000	34,370.0	1.000	365.34	1.000	0.0038	1.000	0.000046	1.000	1.0000	0.000004
2	39.642	0.641	9,255.0	0.269	260.69	0.714	0.0030	0.779	0.000041	0.876	0.7616	1.182842
3	9.563	0.155	1,236.2	0.036	100.68	0.276	0.0025	0.657	0.000033	0.718	0.5649	**2.480626**
4	29.002	0.469	7,606.2	0.221	210.80	0.577	0.0029	0.757	0.000039	0.848	0.7150	1.457102
5	20.582	0.333	5,245.5	0.153	167.38	0.458	0.0028	0.725	0.000037	0.803	0.6607	1.799866
6	42.241	0.683	14,798.8	0.431	283.50	0.776	0.0032	0.833	0.000045	0.969	0.8385	0.765030
7	23.137	0.374	4,447.4	0.129	181.63	0.497	0.0027	0.718	0.000035	0.749	0.6414	1.928631
8	59.828	0.968	31,778.6	0.925	353.60	0.968	0.0037	0.978	0.000043	0.932	0.9545	0.202414
9	44.023	0.712	16,470.8	0.479	292.52	0.801	0.0032	0.841	0.000042	0.914	0.8285	0.817177

Therefore, the models are confirmed suitable for expecting the influences of four independent variables on the five response variables. The optimum predicted values obtained in this work are divided into two kinds. The first one includes maximum calorific value and fixed carbon of 7744 cal/g and 92.934% respectively. The second one includes the minimum value of moisture, volatile matter, and ash content of 0.354%, 2.318%, and 1.437% respectively. Based on the residual analysis, all the parameters are satisfied. Thus, the developed model is feasible and valid.

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Modelling and Optimisation of Coconut Shell Drying and Carbonisation Using Multi-response Taguchi Method with Multi-response Signal-to-noise Procedure

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چکیده

هدف اصلی این تحقیق، بهینه سازی فرایند خشک کردن و کربن سازی زیست توده از نظر تحلیل تقریبی و ارزش حرارتی زیست توده به‌طور هم‌زمان است. متغیرهای مستقل عبارتند از دمای خشک شدن، زمان خشک شدن، دمای کربن سازی و زمان نگهداری فرایند کربن سازی. متغیرهای وابسته تحلیل تقریبی و ارزش حرارتی است. روشهای اصلی استفاده از روش تاگوچی و سیگنال به نویز چندگانه (MRSN) است. بهینه سازی هم‌زمان با استفاده از MRSN مقدار 2.48 را به دست می‌دهد. در نتیجه، دمای خشک شدن 100 درجه سانتی‌گراد، زمان خشک شدن 24 ساعت، دمای کربن سازی 650 درجه سانتی‌گراد و زمان کربن سازی 120 دقیقه مطابقت دارد. این بهترین نتیجه از طریق تنظیمات A1B3C3D3 به دست می آید. مقدار مطلوب متغیرهای وابسته به دست آمده در این مطالعه حداکثر مقدار کالری و کربن ثابت به ترتیب 7744 کالری و 92.934 درصد و حداقل مقدار رطوبت، مواد فرار و خاکستر به ترتیب 0.354 درصد، 2.318 درصد و 1.437 درصد است. تمام شاخص‌ها به عنوان مدل‌های نتیجه معتبر و قابل اجرا هستند. نوآوری این تحقیق بهینه سازی پارامترهای هم‌زمان پنج متغیر با ویژگی های کیفی مختلف است. با استفاده از روش MRSN، تمام پارامترها به شکل یک پارامتر بهین ترکیب می‌شوند.

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