Optimizing the Pyrolysis Process and Modelling the Calorific Value of Sawdust Charcoal as Composing Materials of Quality Briquettes

Musabbikhah[1], Samsul Bakri[2]
[1]*Mechanical Engineering Department, Akademi Teknologi Warga Surakarta*
[2]*Accounting Department, Universitas Widya Mataram Jogjakarta*

Keywords: Optimization, Pyrolysis, calorific value, sawdust charcoal, model, briquettes.

Abstract: This study aims to optimize the pyrolysis process and build calorific value model of sawdust charcoal as composing materials of quality briquettes to fulfill the need of renewable fuels. The results showed that the calorific value of sawdust increased by 2344 Cal/g after pyrolysis. The optimum conditions of calorific value were achieved at drying temperature parameters of 60°C, pyrolysis temperature of 600°C, holding time of 120 minutes, and particle size of 100 mesh. The linearity test results between the value of R, R Square, and Adjusted R Square of the calorific value showed there is a strong correlation between drying temperature, pyrolysis temperature, holding time, and particle size. Based on validation test, the calorific value model showed that the residual normality distribution (P-value) was > 0.05 which did not form a certain pattern on the assumption of homoscedasticity, no multicollinearity ($TOL > 1$; $VIF < 10$) and the DW value was between the specified range. The model was declared valid. Based on the feasibility test model, P-value was (0.000) $< \alpha$ (0.05). This means the model of proper calorific value was reliable to be used to predict the sawdust charcoal calorific value.

1 INTRODUCTION

Energy demand is increasing every year with increasing population. One of the main energy sources needed by humans is the energy source from fossils. The availability of this fossil energy source will gradually run out, so that it becomes a serious problem because it cannot be renewed. High dependency on fossil resources combined with the need to reduce CO_2 emissions due to the climate change force people to utilize renewable energy sources, including biomass.

Biomass is a renewable energy source required to meet the energy needs, and is also used for carbon neutrality as a means of preventing climate change. Vargas (Vargas-Moreno et al., 2012) states that advanced societies have replaced the use of fossil fuels with biomass. Wisakha (Wisakha, 2015) explains that biomass is able to produce continuous heat, therefore it can be used to replace fossil fuel. One of the renewable energy from biomass as a constituent material for briquettes is sawdust (Lela et al., 2016).

Pyrolysis is needed by sawdust used to make briquettes. Pyrolysis is a thermal degradation process of solids in the absence of oxygen which allows the occurrence of several thermochemical conversion pathways so that the solid changes into gas, liquid, then back to its solid form (Blasi, 2008). Furthermore, Basu (Basu, 2013) explains that the pyrolysis reaction from biomass is as follows:

$$CnHmOp\sum liquid \rightarrow CxHyOz + \sum gasCaHbOc + H_2O + C \qquad (1)$$

Heat pyrolysis (thermolysis) decomposition is of organic matter, such as coal heated more than 300 C°without atmospheric air. The selection of biomass materials to produce carbon is based on the availability of materials, costs and the ability to be converted into porous carbon powder after carbonization (Kalyani and Anitha, 2013). In this study, the quality of sawdust charcoal is in terms of calorific value which indicates the energy contained in the fuel per unit mass of fuel (cal/g). This research is in accordance with the development of solid bio-fuel using a wood pellet model (Giacomo and Taglieri, 2013).

The research conducted (Lela et al., 2016) concerning the physical, mechanical and thermal properties of sawdust briquettes is used as a reference for fuel quality. The optimal value obtained for the briquette making process parameters is the compression strength of 588.6 KN, sawdust mass of 46.66% and drying temperature of 22 C°. Based on the mathemat-

Musabbikhah, . and Bakri, S.
Optimizing the Pyrolysis Process and Modelling the Calorific Value of Sawdust Charcoal as Composing Materials of Quality Briquettes.
DOI: 10.5220/0009882402630267
In *Proceedings of the 2nd International Conference on Applied Science, Engineering and Social Sciences (ICASESS 2019)*, pages 263-267
ISBN: 978-989-758-452-7

ical model, the optimal values generated are calorific values increased to 17.41 MJ/kg, ash content decreased to 6.62% and maximum compressive strength is of 149.54 $N/mm2$. Research on sawdust briquettes was also carried out by (Stolarski et al., 2013) which showed that the highest calorific value in sawdust briquettes was 18.144 MJ/kg. Moreover, sawdust briquettes have an effect of 0.40% on ash content.

2 MATERIAL AND METHOD

2.1 Material

The material used in pyrolysis is sawdust powder from teak wood.

2.2 Method

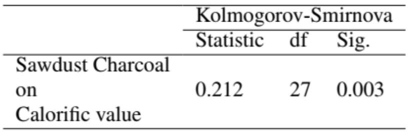
Data collection of pyrolysis process and calorific value refers to orthogonal L9(3)4 arrays. The independent variables used in the study were drying temperature, pyrolysis temperature, holding time, and particle size. The dependent variable to determine the quality of sawdust charcoal is the calorific value. The method for optimizing pyrolysis parameters is Taguchi, while for modelling of calorific value is multiple linear regression model (MLRM) analysis.

3 RESULTS AND DISCUSSION

The effect of level factor differences on the sawdust charcoal calorific value which has the highest average calorific value of 6231 cal/g was achieved at drying temperatures of 60 C°, pyrolysis temperature of 600 C°, holding time of 120 minutes, and particle size of 100 mesh. The calorific value is influenced by water content and carbon content. This study is in line with the research of (Sundaram et al., 2016) which states the water content of the particles changes with the variation of drying time in fluidized bed drying. The same study was also carried out by (Wilk et al., 2016) who stated that the carbonization of wood residue into charcoal occurred during the low temperature process.

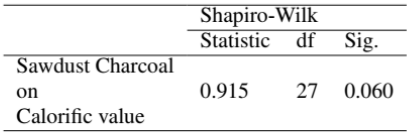
3.1 Normality Test

The normality test of the Sawdust Charcoal calorific value variable uses a significance level of $\alpha = 0.05$ and the Shapiro-Wilk statistical test shows that $P - value = 0.915$. Therefore, H0 is accepted. It means that Calorific value of sawdust charcoal variables are normally distributed and are presented in Figure 1 and Figure 2.



	Kolmogorov-Smirnova		
	Statistic	df	Sig.
Sawdust Charcoal on Calorific value	0.212	27	0.003

Figure 1: Normality Test of calorific value.



	Shapiro-Wilk		
	Statistic	df	Sig.
Sawdust Charcoal on Calorific value	0.915	27	0.060

Figure 2: Normality Test of calorific value (extension).

a Lilliefors Significance Correction

3.2 ANOVA

Based on ANOVA calculations, the four variables namely drying temperature, pyrolysis temperature, holding time, and particle size have a significant influence on the sawdust charcoal calorific value with the percentage value of the contribution consecutively is 7.877%; 54.77%; 11.534%; and 25.817%. In this case, the pyrolysis temperature has the greatest influence on the sawdust charcoal calorific value because the higher the pyrolysis temperature is, the lower the water content and the higher the calorific value. The results of this study was in line with the research of (Mandala et al., 2016) which states that pyrolysis temperature is varied from 200 C°to 500 C°and in using the random wood powder size, there is 29% bio-oil yield occurs at a temperature of 400 C°.

3.3 Optimization

The optimum conditions of calorific value on sawdust charcoal obtained were material drying temperature of 60 C°, pyrolysis temperature of 600 C°, holding time of 120 minutes, and particle size is of 100 mesh as shown in Figure 3 and Figure 4. The difference in mean values between factor effects is shown in Figure 5 and Figure 6. Research on optimization using the Taguchi method was also conducted by ((Azadi et al., 2011) and (Roy, 2010).

Number	Column/Factor
1	X1: Drying Temperature
2	X2: Pyrolysis Temperature
3	X3: Holding Time
4	X4: Particle size
	Total contribution all factor

Figure 3: Optimum condition of calorific value.

Description of level	Level	Contribution
60 °C	2	161.889
600 °C	3	290.666
120 minutes	3	605.888
100 *mesh*	3	291.444
		1349.886

Figure 4: Optimum condition of calorific value (extension.).

Number	Column/Factor	Level 1st
1	X1: Drying Temperature	6316.67
2	X2: Pyrolysis Temperature	5697.44
3	X3: Holding Time	6009.56
4	X4: Particle size	5783.67

Figure 5: Factor Effects of calorific valu.

Number	Column/Factor	Level 1st
1	X1: Drying Temperature	6316.67
2	X2: Pyrolysis Temperature	5697.44
3	X3: Holding Time	6009.56
4	X4: Particle size	5783.67

Figure 6: Factor Effects of calorific value (extension).

The average sawdust calorific value obtained before pyrolysis was 3887 cal/g, and after pyrolysis the average sawdust charcoal calorific value was 6231 cal/g. The effect of drying and pyrolysis are very significant in increasing the sawdust calorific value. This sawdust charcoal has fulfilled the Indonesia National Standard so that sawdust charcoal is suitable as a high quality briquette maker. This study is in accordance with the results of (Wilk et al., 2016) which used pyrolysis of wood waste material by varying carbonization temperatures of 230, 260 and 290 C°and carbonization times of 0.5, 1.0 and 1.5 hours. The same study was also carried out by (Al-Refaie et al., 2010) who explained that the HHV from torrefied samples increased with increasing temperature. The highest HHV was found at 26.09 MJ/kg obtained at 60 minutes and 300 C°.

3.4 Building a Calorific Value Model

Linearity test is a procedure to find out whether linear data distribution is or not. The relationship of the response variable sawdust charcoal calorific value and predictor variables is shown in Figure 7 and Figure 8.

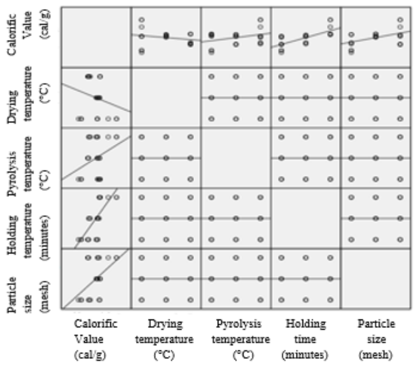


Fig 1. Relationship between independent variable and calorific value

Figure 7: Relation between independent variable and calorific value

	Kolmogorov-Smirnova		
	Statistic	df	Sig.
Sawdust Charcoal on Calorific value	0.212	27	0.003

Figure 8: Model Summary^b.

Based on Figure 8, the value of R=0.935 shows a fairly close degree of linear relationship between the response variable of the calorific value and the predictor variable. The R Square=0.875 and Adjusted R Square=0.852 showed that 85.2% of the variance in the calorific value variable can be explained by the independent variable. Meanwhile, St. Error=1.682 states the magnitude of the variance of the regression model. Thus, there is a linear relationship between the variables sawdust charcoal calorific value with drying temperature, pyrolysis temperature, and holding time and particle size. This modelling research is in accordance with the results of (Sundaram et al., 2016) that describe the process of drying materials using temperature variations of 55, 60 and 65 C°; speeds of 2.2, 2.4 and 2.6 m/s and moisture content of 27.5, 30 and 32.5% of the total weight.

3.5 Overall Test (Model Feasibility)

The feasibility test of multiple regression models at the level of significance: α0.05 using the F test is shown in Figure 9 and Figure 10. Based on ANOVA in Figure 9, P-value (0.000) < α (0.05). H0 is rejected, meaning the sawdust charcoal calorific value model is suitable for use.

Model		Sum of Squares	df
1	Regression	434.057	4
	Residual	62.274	22
	Total	496.331	26

Figure 9: ANOVA[a].

Mean Square	F	Sig.
108.514	38.336	0.000b
2.831		

Figure 10: ANOVA[a] (Extension).

a Dependent Variable: calorific value (cal/g)

b Predictors: (constant), drying temperature (°C), pyrolysis temperature (°C), holding time (minutes) and particle size (mesh)

3.6 Coefficient Feasibility Test

The coefficient feasibility test is used to determine the level of feasibility of the independent variable coefficients in the formation of a model of calorific value. The output of the coefficient feasibility test of the sawdust charcoal calorific value is presented in Figure 11 and Figure 12.

Model		Unstandardized Coefficients	
		B	SE
1	(Constant)	149.644	8.777
	Drying Temperature (°C)	-0.338	0.079
	Pyrolysis Temperature (°C)	-0.236	0.066
	Holding Time (minutes)	-0.040	0.004
	Particle size (mesh)	-0.057	0.013

Figure 11: Coefficient feasibility test[a].

Standardized Coefficients	t	Sig.
Beta		
	17.049	0.000
-0.322	-4.265	0.000
-0.269	-3.568	0.002
-0.768	-10.174	0.000
-0.328	-4.348	0.000

Figure 12: Coefficient feasibility test[a] (extension).

a Dependent Variable: calorific value (cal/g)

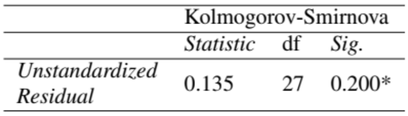
Based on Figure 11 and 12, all the independent variables in the model significantly affect the sawdust charcoal calorific value variable. The mathematical model to predict sawdust charcoal calorific value as a function of drying temperature, pyrolysis temperature, holding time and particle size are:

$$\hat{Y}(cal/g) = 4708.58–33.23X_1 + 42.71X_2 + 5.70X_3 + 12.32X_4 \quad (2)$$

Based on the above equation (2), the higher of pyrolysis temperature, holding time and particle size are significant to the higher the calorific value. This happens because the higher the pyrolysis temperature, the higher the water content lost, the material becomes dry so that the water content becomes low and the carbon is bound as high which results in a high calorific value. The results of this study is in accordance with (Lela et al., 2016) which states that the mathematical model and optimal value produces a calorific value increased to 17.41 MJ/kg, ash content decreased 6.62% and maximum compressive strength of 149.54 N/mm^2. The same study was alsocarried out by (Al-Refaie et al., 2010) which explained that the optical mal parameter design with regression technique and grey relational analysis. Research on optimization and regression modelling were also conducted by (Vishwakarma et al., 2012).

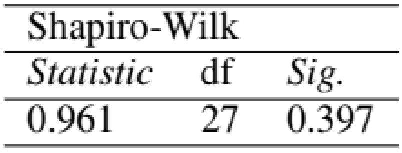
3.7 Model Validation

Residual analysis is a way to validate the sawdust-charcoal calorific value model. The results of residual analysis summary to determine the validity of the response model to the sawdust charcoal calorific value is presented in Figure 13. The model validation test results show that the residual normality distribution (P-value) is 0.563> 0.05, no particular pattern is formed on the assumptions of homoscedasticity, no multicollinearity ($TOL > 1; VIF < 10$) and the DW value is in the range of 0.878<1.456 <1.514.



	Kolmogorov-Smirnova		
	Statistic	df	*Sig.*
Unstandardized Residual	0.135	27	0.200*

Figure 13: Residual normality test of calorific value.



Shapiro-Wilk		
Statistic	df	*Sig.*
0.961	27	0.397

Figure 14: Residual normality test of calorific value (extension).

Based on Figure 13 and Figure 14, it can be concluded that the sawdust charcoal calorific value model has met the eligibility requirements, and model validation, so that the resulting model is declared feasible and valid and can be used to predict the sawdust charcoal calorific value. The drying and pyrolysis treatment has a positive effect on increasing the calorific value. It is proved because the initial sawdust calorific value of 3887 cal/g increased to 6231 cal/g after drying and pyrolysis. Therefore, there was an increase in the calorific value of 2344 cal/g.

4 CONCLUSIONS

The optimum condition of the pyrolysis process which can increase the calorific value of sawdust is the drying temperature of 60 C°, the pyrolysis temperature of 600 C°, holding time of 120 minutes, and particle size of 100 mesh. The linearity test results show that the value of R; R Square; and Adjusted R Square at the calorific value to have a strong correlation with drying temperature, pyrolysis temperature, holding time, and particle size. The result calorific value model is $\hat{Y}(cal/g) = 4708.58–33.23X1 + 42.71X2 + 5.70X3 + 12.32X4$. The validation test results of the heat value model show that the residual normality distribution (P-value)$>$ 0.05 does not form a certain pattern on the assumption of homoscedasticity, no multicollinearity (TOL$>$ 1; VIF $<$10) and the DW value is within the specified range so the model is declared valid. The model feasibility test results in a P-value (0.000) $<$ α (0.05) so that the calorific value model is declared feasible and can be used to predict the calorific value of sawdust charcoal to produce a quality briquette.

ACKNOWLEDGEMENTS

This research was funded by the Directorate General of Research and Development, Ministry of Research, Technology and Higher Education for the period 2017-2019.

REFERENCES

Al-Refaie, A., Al-Durgham, L., and Bata, N. (2010). Optimal parameter design by regression technique and grey relational analysis. volume 3. Proceedings of the World Congress on Engineering.

Azadi, M. M., Kolahan, F., and Golmezerji, R. (2011). Multi objective optimization of turning process using grey relational analysis and simulated annealing algorithm. pages 2926–2932.

Basu, P. (2013). *Biomass Gasification, Pyrolysis and Torrefaction: Practical Design and Theory*. Elsevier Inc, 2nd edition.

Blasi, C. D. (2008). Modeling chemical and physical processes of wood and biomass pyrolysis. 34:47–99.

Giacomo, G. D. and Taglieri, L. (2013). Modeling chemical and physical processes of wood and biomass pyrolysis. 2(3):255–260.

Kalyani, P. and Anitha, A. (2013). Biomass carbon & its prospects in electrochemical energy systems. 38:4034–4045.

Lela, B., Barišic, M., and Nizˇetic, S. (2016). Cardboard/sawdust briquettes as biomass fuel: Physical–mechanical and thermal characteristics. 47:236–245.

Mandala, W. W., Cahyono, M. S., Sukarjo, S., and Wardoyo, H. B. (2016). Influence of temperature to yield and caloric value of plastic waste pyrolysis oil. 1.

Roy, R. K. (2010). A primer on the taguchi method: Society of manufacturing engineers. 21.

Stolarski, J. M., Szczukowski, S., Tworkowski, J., Zaniak, K., Gulczynski, P., and Mleczek, M. (2013). Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass. 57:20–26.

Sundaram, P., Sudhakar, P., and Yogeshwaran, R. (2016). Experimental studies and mathematical modeling of drying wheat in fluidized bed dryer. 9(36):1–8.

Vargas-Moreno, J. M., Callejón-Ferre, A. J., Pérez-Alonsoa, J., and Velázquez-Martí, B. (2012). A review of the mathematical models for predicting the heating value of biomass materials. 16:3065–3083.

Vishwakarma, M., Parashar, V., and Khare, V. (2012). Regression analysis and optimization of material removal rate on electric discharge machine foren-19 alloy steel using tungsten copper electrode. 2(6):785–792.

Wilk, M., Magdziarz, A., Kalemba, I., and Gara, P. (2016). Carbonisation of wood residue into charcoal during low temperature process. pages 507–513.

Wisakha, P. (2015). Sustainability approach for energy production using biomass at household and community levels. a case study in thailand. 5(3):859–872.