Analysis and Selection of the Best Model of Biomass Briquette Based on Calorific Value

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Abstract. The purpose of this study was to determine the best model of the briquettes based on calorific value. An experimental design applied was the orthogonal array L32 (21x49). The selection of the briquette models was based on eight criteria: coefficient R, R-Square, Adj.R, Std. Error, Akaike Information Criterion (AIC), Amemiya Prediction Criterion (APC), Mallows' Prediction Criterion (MPC) and Schwarz Bayesian Criterion (SBC) simultaneously. The results of the analysis showed that the expected result of the optimum condition HHV (Y) of 7595 cal/g was achieved in an A2B4C4D3E4F4G4H4I2J4 parameter. The ANOVA gave p-value (0.000) < (0.05) indicating that the HHV model was fit for use. The residual analysis showed that the model is valid. From the three models produced, the model I was found to be the best model. The following results were obtained: coefficient R 0.761, R2 0.578, Adj-R2 0.529, SE 272.14 and AIC 1086.73. The novelties of this study are optimum parameters and the briquette models which have a high HHV based on the eight criteria.

1. Introduction
The availability of fossil energy is dwindling. Efforts to reduce global warming have pushed the use of the biomass briquette as a renewable substitute for fossil fuel. Biomass is an organic material with huge potential for processing into energy. It is available and abundant in Indonesia. However, it has not been processed and utilized optimally. Therefore, it creates environmental pollution.

One of the technologies for converting biomass into charcoal is carbonization. Charcoal is used as a material to produce briquette in order to increase its quality. The use of the biomass briquette as an energy source is one of the solutions for reducing dependence on fossil energy, environmental pollution, and global warming. The calorific value of the fuel indicates the energy contained in the fuel per unit mass of fuel (cal/g).

Furthermore, rice husks have been used as materials to produce fuel briquette [1]. Research on the development of solid bio-fuel wood pellet's using a model [2]. Attempts to get the best model of the briquettes with high calorific value were done using a multiple linear regression (MLR) analysis. Studies have been conducted on the use of the linear regression models to predict the wind speed [3]. There have also been studies which review mathematical models to predict the heating value of biomass raw materials [4]. It was found that the calorific value can be measured using a model based on the results of the analyses that are relatively simple: proximate, elemental, physical structure and chemical analysis. Investigate of modeling of the calorific value of briquette sawdust of charcoal [5],
the proximate analysis model of the biomass [6]. A model to predict the HHV has been designed [7] and the prediction of the HHV in biomass fuel [8].

Previous studies using indicators of the correlation coefficient (R) on the estimate were made by Global Solar Radiation [9] including predicting models [10], [11]. R-Square, Adj-R for decision-making on the calorific value and proximate analysis [5], [12]. The use of AIC and SBC’s application models to predict above-ground biomass. APC is a criterion used to minimize the mean square error of prediction [13]. MPC is a selection criterion based on the size of the bias in the predicted response [14]. However, from the review of previous studies, none of the studies has employed eight criteria simultaneously in selecting the best briquette model. Therefore, this study uses these eight criteria simultaneously in selecting the best model of the biomass briquette based on calorific value.

2. Materials and Method

2.1. Materials
Materials used in this study include Jatropha L. Curcas waste, coconut shell charcoal, rice husk, and sawdust charcoal. Adhesives used was starch.

2.2 Methods
Data collection referring to design of experiments orthogonal array L$_{32}$ ($2^4$) by varying the ten independent variables are presented in table 1. Each briquette sample weighs 60 g. An example of the production of the briquette in the ratio of 20:30:10:5:4 is as follows:

1. The Jatropha waste, 20/69 x 60 g = 17.39 g
2. The coconut shell charcoal, 30/69 x 60 g = 26.08 g
3. The rice husk charcoal, 10/69 x 60 g = 8.69 g
4. The sawdust charcoal, 5/69 x 60 g = 4.37 g
5. The starch, 4/69 x 60 g = 3.47 g

| Table 1. Independent variables research. |
|------------------------------------------|
| Variables                               | Level 1 | Level 2 | Level 3 | Level 4 |
|------------------------------------------|---------|---------|---------|---------|
| A: Particle Size (mm)                    | 0.074   | 0.294   |         |         |
| B: Ratio of Jatropha waste in briquettes | 20      | 25      | 30      | 35      |
| C: Ratio of the coconut shell charcoal in briquettes | 30 | 35 | 40 | 45 |
| D: Ratio of the rice husk charcoal in briquettes | 10 | 15 | 20 | 25 |
| E: Ratio of the sawdust charcoal in briquettes | 5 | 10 | 15 | 20 |
| F: Ratio of the starch in the briquette  | 4       | 5       | 6       | 7       |
| G: Pressure (kg / cm$^2$)                | 200     | 225     | 250     | 275     |
| H: Pressure Holding Time (min)           | 2       | 4       | 6       | 8       |
| I: Drying temperature ($^\circ$ C)       | 50      | 55      | 60      | 65      |
| J: Drying time (hours)                   | 12      | 18      | 24      | 30      |

Furthermore, mixing the starch with boiled water until the mixture turns into glue. Samples of materials that have been scaled were mixed with the starch until they are evenly distributed. Then, molding and pressing following the orthogonal array L$_{32}$ ($2^4$) were done. The dependent variable is the calorific value. Tests were conducted using the Bomb calorimeter. An analysis to produce the model was done using a multiple linear regression model (MLRM).

2.2.1 Multiple Linear Regression Model (MLRM).
The MLRM is a model or multivariate technique used to estimate the relationship between one dependent variable metric (Y) and a set of independent variables X1, X2, X3, ..., Xk [1]. The MLRM is formulated as follows:

$$Y_i = b_0 + b_1 X_{1i} + ... + b_k X_{ki} + e_i$$

(1)
By using the MLRM, researchers can estimate or predict the average value of the population of the dependent variable based on two or more independent variables in the regression model. This study generates a multiple regression model that can be used to explain and predict the calorific value of the briquette as renewable fuel influenced by ten independent variables as presented in Table 1.

2.2.2 Evaluation and selection criteria model.
ANOVA was used to evaluate the feasibility of the model. Then, the validity of the tested model was done using a residual analysis. To support this analysis, the following assumptions were made, namely: normal residual distribution, no heteroscedasticity, no multicollinearity and no autocorrelation. The correlation coefficient (R) is a linear relationship between the response variable and the predictor variable. The coefficient of determination (R²) is a scale used to measure the goodness of fit of the regression line [2]. Adj-R² is a correction to the R-Square, i.e. variance in the dependent variable by the independent variables and other factors [2]. Standard Error (SE) is a measure of the amount of variance in regression [3]. Akaike Information Criterion (AIC) is the selection of the best regression model by considering the number of parameters in the model. It is typically used to forecast the compatibility of the model with existing data and values occurring in the future [4].

\[
AIC = n \ln(SSE) - n \ln (n) + 2p \tag{2}
\]

The Amemiya Prediction Criterion (APC) was formulated as in equation (3).

\[
APC = \frac{(n + p)}{n(n + p)} \frac{SSE}{SSE} \tag{3}
\]

Schwarz Bayesian Criterion (SBC) is a method of selecting several models developed by Schwarz using Bayesian theory to determine the posterior probability [4], [5].

\[
SBC = n \ln(SSE) - n \ln (n) + p \ln(n) \tag{4}
\]

Mallows' Prediction Criterion (MPC) is a selection criterion based on the size of the variance in the predicted response [6], [7].

\[
C_{Pm} = p + \frac{(MSE_p - \sigma^2)}{\sigma^2} \left( n - p \right) \tag{5}
\]

3. Results and Discussion

3.1 Optimum calorific value
The optimum conditions for the calorific value were observed at the A2B4C4D3E4F4G4H4I2J4. The parameters are particle size of 0.294mm, ratio of Jatropha waste in briquettes of 35, the coconut shell charcoal of 45, the rice husk charcoal of 20, the sawdust charcoal of 20, an adhesive of 7, the pressure 275 kg/cm², the pressure holding time of 8 minutes, drying temperature of 55 °C and drying time 30 h.

The optimum conditions for calorific value are shown in Figure 1.
3.2 Model-I

ANOVA was used to test the feasibility of the overall or test models. This was done to determine whether the independent variables influenced simultaneously in the variable of the calorific value. The ANOVA results showed that the p-value is (0.000) < α (0.05). Therefore, H₀ was rejected. It indicates that the model was fit.

3.2.1 Mathematical Model. A mathematical model to predict the calorific value and the validity of model-I is presented in table 2.

| Model | Unstandardized Coefficients | Standardized Coefficients | Sig. | Collinearity Statistics |
|-------|-----------------------------|---------------------------|------|------------------------|
|       | B                           | SE                        | Beta | t         | Tolerance | VIF  |
| (Constant) | 2277.835                  | 480.645                   | 4.739 | 0.000    | 1.000     | 1.000 |
| A     | 1558.239                   | 252.502                   | 0.435 | 6.171     | 0.000     | 1.000 |
| B     | 14.261                     | 4.969                     | 0.202 | 2.870     | 0.005     | 1.000 |
| C     | 10.955                     | 5.045                     | 0.155 | 2.171     | 0.033     | 0.970 |
| D     | -7.052                     | 5.179                     | -0.100| -1.362    | 0.177     | 0.920 |
| E     | 10.313                     | 5.045                     | 0.146 | 2.044     | 0.044     | 0.970 |
| F     | 58.551                     | 25.895                    | 0.166 | 2.261     | 0.026     | 0.920 |
| G     | 4.239                      | 1.036                     | 0.300 | 4.093     | 0.000     | 0.920 |
| H     | 33.033                     | 12.613                    | 0.187 | 2.619     | 0.010     | 0.970 |
| I     | 15.229                     | 5.845                     | 0.216 | 2.605     | 0.011     | 0.723 |
| J     | 10.660                     | 4.204                     | 0.181 | 2.535     | 0.013     | 0.970 |

Based on table 2, the equation for the calorific value on the model-I is

\[
Y_I = 2277.835 + 1558.239 \cdot A + 14.261 \cdot B + 10.955 \cdot C - 7.052 \cdot D + 10.313 \cdot E + 58.551 \cdot F \\
+ 4.239 \cdot G + 33.033 \cdot H + 15.229 \cdot I + 10.660 \cdot J
\]  

(6)

The results of this study are in accordance with [5], which states that compression strength, the mass of sawdust and drying temperature have a positive correlation to prediction HHV. The relationship between each independent variable and the calorific value is discussed as follows:

1. The relationship between particle size (A) and the calorific value is that the greater the particle size, the lower the moisture and the ash contents, therefore the higher the calorific value. This study found that the particle size had a positive effect on the calorific value which produces p contributions (18.813%) > 5%. This result is in accordance with [8] which describes the effect of the particle size of Jatropha Curcas Seed Cake and [9] which discusses the burning of the briquettes from Jatropha waste.

2. The ratio of Jatropha waste (B) has a positive effect on the calorific value as 12.939%. As seen in figure 1, a linear line indicates that the ratio of the Jatropha waste significantly affected the calorific value. The Jatropha waste still contained a fairly high amount of Jatropha oil (11%) so that the calorific value is quite large. Research on the improvement of the characteristics of the Jatropha with torrefaction method [8] which investigates the response surface optimization on the carbon activation of the Jatropha hull.

3. The ratio of coconut shells charcoal in briquettes (C) contributed as much as 6.643% to the calorific value. The linear line shows the relationship between the ratio of the coconut shell charcoal (C) and the calorific value. However, when compared with the Jatropha waste and contributions, the influence of the coconut shell charcoal is smaller due to the high silica content in the coconut shell charcoal. This result is in accordance with [10] which investigates the torrefaction process and optimization of temperature in the coconut shell.
4. The ratio of rice husk charcoal in briquettes (D) shows a negative influence. It can be seen from the graph linearity that decline because the ash and moisture content of the rice husk is very high. This research is in line with [10] that discusses variation exergy efficiency in the rice husks.

5. The ratio of sawdust charcoal in briquettes (E) shows a positive effect, as seen from the upward trend in the linear graph. But compared with the coconut shell charcoal and Jatropha waste, the effect of these materials is lower. This is because the moisture content of sawdust reached 7.7% at a drying temperature of 22°C [11]. Another cause is that the ash content of the charcoal sawdust is very high at 12.47% at a pressure of 588.6 KN [11].

6. The influence of the adhesive composition on briquettes in calorific values showed a positive relationship. The contribution of the adhesive to the calorific value was 7.202%. The stronger the adhesive, the stronger the bonds between the particles, therefore the closer the pores. However, the ash content becomes higher so that the calorific value is low. This study agrees with the results of research [9] that describes the ratio between the binder and seeds cake powder of 10%: 90%.

7. The pressure (G) contributed 12.8% to the calorific value and shows a positive relationship, but the contribution is not as high as the particle size. The higher the pressure, the higher the moisture from the briquettes. However, as the pressure increases, the briquettes become solid so that it takes a quite long time to start igniting. This research is in accordance with [12] which explains that the pressure applied to the wood pellet is about 8-25 MPa. However, the results differ from the study [11] which states that the pressure has no effect on the HHV saw dust briquettes.

8. The pressure holding time (H) contributed 8.119% to the calorific value of the briquettes. The longer the pressure holding time, the denser the briquettes. The pressure holding time had a positive relationship with the calorific value.

9. The drying temperature (I) contributed 5.26% to the calorific value. These contributions tend to be smaller because the raw materials have been carried out since the first drying. The drying temperature has a positive effect on the calorific value, because of the higher the temperature of the drying, the faster the drying time, hence the lower the moisture content so that the calorific value increases. However, at a certain temperature where the sample weight becomes constant, an increase in the drying temperature has no significant impact on the moisture content. This research is in accordance with [13], [14].

10. The drying time (J) contributed 7.837% to the calorific value. There was a positive relationship between drying time and the calorific value. This research is in suitable with [15], which explains that pre-drying can improve the quality of the material.

3.2.2 Coefficient Feasibility. The results of the feasibility test coefficients presented show that the variable D (0.177) > α (0.05). It indicates the ratio of the rice husk charcoal in the briquettes does not significantly affect the calorific values. This phenomenon occurs because the rice husks have a high ash content and low fixed carbon so that the calorific value remains low. Therefore, the regression analysis was repeated by removing the variable “D” from the regression model.

3.3 Model II

The ANOVA results showed that the p-value is (0.000) < α (0.05). Therefore, H₀ is rejected. It indicates that the model is fit for use. The using similar method with a coefficient of feasibility test in model-I, the mathematical model-II to predict the calorific value of briquettes is

\[
y_{II} = 2057.296 + 1558.239.A + 14.261.B + 11.292.C + 9.976.E + 55.744.F + 4.127.G + 32.191.H + 17.475. I + 10.941. J
\] (7)

These results are appropriate with [4] which investigates vegetable oils and animal fats done some chemical analysis to get a model of the HHV.

The results of the test of coefficient feasibility presented show that value obtained for the variable E is (0.052) > α (0.05). It indicates that the sawdust charcoal in the briquettes did not significantly affect calorific value. This is because the sawdust charcoal has a high moisture content so that the calorific value is low. Therefore, the regression analysis was repeated by removing the variable “E” from the regression model.
3.4 Model-III
The ANOVA results showed the p-value (0.000) < α (0.05). Therefore, H₀ is rejected. It indicates that the model is feasible for use. A mathematical model to predict the calorific value and the validity of model-III is:

\[ Y_{III} = 2098.375 + 1558.239. A + 14.261. B + 11.570. C + 53.427. F + 4.034. G + 31.496. H + 19.328. I + 11.172. J \]  

These results are in accordance with [13], which explains that to predict the HHV models base on proximate analysis, the correlation between the HHV and dry ash content of the biomass. The results of the test of the coefficient feasibility in table 3 show all variables significantly influence the calorific value. Therefore, there is no need to make a new model. Furthermore, from the three models produced, it was selected the models based on the eight selection criteria as presented in table 3.

| Model | R  | R-Square | Adj R-Square | Std error | AIC  | APC  | SBC  | CPM Mallows |
|-------|----|----------|--------------|-----------|------|------|------|-------------|
| Model-I | 0.761 | 0.578 | 0.529 | 272.14 | 1086.73 | 0.531 | 1114.93 | 11 |
| Model-II | 0.754 | 0.569 | 0.524 | 273.48 | 1086.80 | 0.531 | 1112.44 | 10 |
| Model-III | 0.742 | 0.550 | 0.508 | 277.97 | 1089.03 | 0.543 | 1112.11 | 9 |

3.5 Best model selection criteria
In the selection of the best value model for the calorific value, criteria R, R-Square and Adj R-Square of the selected models had the greatest value. SE, AIC, SBC, and CPM selected had the smallest value. Based on the selection criteria in table 3, model-I was selected as the best model as it fits most of the criteria. This result of the study is in suitable with [2], [5]–[7] which develops selection criteria for the best models.

3.6 Validity model test
Model-I as a model of the best calorific value has further tested the validity of the model using the residual analysis. Residual normality test was conducted using a Kolmogorov-Smirnov test for the amount of data> 50. The result for the p-value test gave p-value (0.317)> 0.05. Thus, it can be concluded that the residuals were normally distributed. The results showed that all independent variables had VIF<10 and TOL> 0.1. Thus, there was no multicollinearity. Conversely, if the data did not form a specific pattern, it can be said that the homoscedasticity assumptions were fulfilled. In this study, the model I had a Durbin Watson value of 1.759 in the range of 1.690 <1.759 <2.310, it indicates that there is no positive or negative autocorrelation. Based on autocorrelation analysis residuals, all assumptions were achieved. Therefore, the model is valid. The MLRM produced is:

\[ \hat{Y} \text{ (cal/g)} = 2277.835 +1558.239. A + 14.261. B + 10.955. C + 10.313. E + 58.551. F + 4.239. G + 33.033. H + 15.229. I + 10.660. J. \]

Based on the first model equation (equation 10), it can be interpreted that the independent variables A, B, C, E, F, G, H, I, J have positive regression coefficient. This shows that for the variables of A, B, C, E F, G, H, I, J, calorific values are in one direction. Any increase from independent variables A, B, C, E F, G, H, I, J will be followed by an increase in calorific value. The variable “D” has a negative regression coefficient, it indicates that the effect of this variable is two-way. An increase in the variable “D”, it will be followed by a decline in variable Y (calorific value). This research is in accordance with [8] that discusses optimization using multiple regression.
4. Conclusion
The results of the analysis showed that the expected result of the optimum condition of the calorific value of 7595 cal/g was achieved in the A2B4C4D3E4F4G4H4I2J4 parameter. The ANOVA results showed that the p-value is (0.000) < α (0.05). It implies that the model for the calorific value was fit for use. The results of the test of the coefficient feasibility showed that the variable D did not significantly affect the calorific value. The results of the residual analysis showed that the p-value is (0.317 > 0.05). Therefore, there was no homoscedasticity, no multicollinearity, and no autocorrelation (VIF <10, or the value of TOL> 0.1) which indicates that the models were valid.

From the three models produced, Model I was found to be the best model. The results obtained for correlation coefficients (R), R-Square, Adj-R Square Std Error and AIC were 0.761, 0.578, 0.529, 272.14 and 1086.73, respectively. The model of the calorific value is given as follows: Ŷ (cal/g) = 2277.835 + 1558.239. A + 14.261. B +10.955. C – 7.052D +10.313. E + 58.551. F +4.239. G + 33.033.H + 15.229.I + 10 660.J. Therefore, this model is appropriate and valid to be applied in predicting the calorific value.

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