

# Determination of Optimum Point of Composition of Fuel Calories in Producing electrical Energy in Coal Fired Power Plant

Jonathan Dian<sup>1</sup> and Wahyu Wibowo<sup>2</sup>

<sup>1</sup>Department of Technology Management, Institut Teknologi Sepuluh Nopember, Surabaya

<sup>2</sup>Department of Statistics, Institut Teknologi Sepuluh Nopember, Surabaya

*e-mail:* wahyu\_w@statistika.its.ac.id

**Abstract**—Coal-fired power plant (CFPP) is a type of power plant that is widely used for 35,000 MW electricity projects in Indonesia. CFPP must adjust to its operating strategies with the availability of abundant low-rank coal, and it will affect CFPP performance. This study aims to determine the optimum heating value of fuels, the trend of net plant heat rate (NPHR), the cost of electricity production (component C), and the optimum point of the CFPP operation. The data used is from CFPP operations. First, data is analyzed by descriptive statistics and formed into a regression model. The next step is to estimate the parameters of the population data. The regression model obtained was then carried out the goodness of fit test and residual analysis. Then, the variable's values are changed to the Z-score and plotted in the regression model. The model interpretation is carried out and conclusions can be obtained to find out the optimum point. The conclusion of this study is the optimum point of generating electricity in CFPP can be achieved by using coal calorific values of 4,450 kCal/kg, NPHR of 2,683.6 kCal/kWh, and COE (component C) of Rp 436.5/kWh when using coal at a price of 732.2/kg and Net Power of 279 MW.

**Keywords**—Optimum Point, Calorific Value, Net Plant Heat Rate, Cost Of Electricity Production, Z-Score.

## I. INTRODUCTION

COAL-FIRED power plant (CFPP) is a power plant used for 35,000 MW power supply projects in Indonesia [1]. Based on the 2018-2027 PLN RUPTL, the target of the generation of energy mix by the end of 2025 is coal 54.4%, therefore coal become very important as a power plant fuel. Coal prices play a very important role because these costs support around 60 - 80% of the total electricity production costs. This drives coal power plant in Indonesia to buy low rank (low calorie) coal. Coal power plants must adjust to their operating strategy with abundant low rank coal. Mixing coal with different coal heating values can be done to save costs [2]. In mixing coal, limiting coal parameters according to heating values, ash, humidity and sulfur content needs to be considered [3]. Using coal which has different specifications from coal at the time of commissioning will affect power plant performance parameters [4]. The level of unit efficiency that can increase production costs will have an impact on merit order. Merit order is a method by which the generator with the lowest cost will be prioritized for operation. To improve order, the power plant must provide coal that is used so that the BPP becomes lower and the electricity produced is more competitive. Therefore, monitoring of the efficiency

Table 1.  
Descriptive Statistics of Response Variables

Variabel	Mean	StDev	Minimum	Maximum
Net Power (MW)	277.42	3.24	268.75	289.91
Net Plant Heat Rate (kCal/kWh)	2695.3	47.0	2558.8	2817.2
COE Component C (Rp/kWh)	436.53	24.10	403.41	474.00

Table 2.  
Descriptive Statistics of Predictor Variables

Variable	Mean	StDev	Minimum	Maximum
High Heating Value (kCal/kg)	4310.4	166.2	4008.2	4865.7
Harga Batubara (Rp/kg)	732.0	103.7	620.7	889.0

of generating units must be carried out to support the use of fuel. Required, an analysis is needed to determine the optimal point between HHV, NPHR, Capability, and BPP.

### A. Coal Blending

Coal blending is a system that aligns two or more different coals that have different qualities with or without the same origin. Research on optimizing the combustion of coal blending (mixed coal with different heating value) during operations have widely carried out. Research conducted by Syahputera et al. with the linear regression method, it was found with the increase in the caloric value of the coal used and the increase in power plant load, the value of the heat rate has decreased. Research conducted by Wahyono and Teguh with linear regression method, found that the optimization of plant efficiency obtained by the presence of a mix of coal, namely, in mixing 4:6 an increase of 0.12% from a ratio of 10:0. Santoso, Kurniawan, Setiawan, and Biyanto conducted research using the Finite Impulse Response Neural Network (FIR-NN) method and variable selection was carried out using Principal Component Analysis (PCA) and Partial Least Square (PLS). Optimization results obtained with a blending ratio of 80:20 between low calorie coal and high calorie coal [5]. Research conducted by Hadi shows the value of thermal efficiency obtained by linear regression. Anova Test and Regression Coefficient show that HHV, coal feeder input, generator output, gross heat rate have a significant or very significant effect on thermal efficiency [6]. In addition, there are still some scientific studies regarding

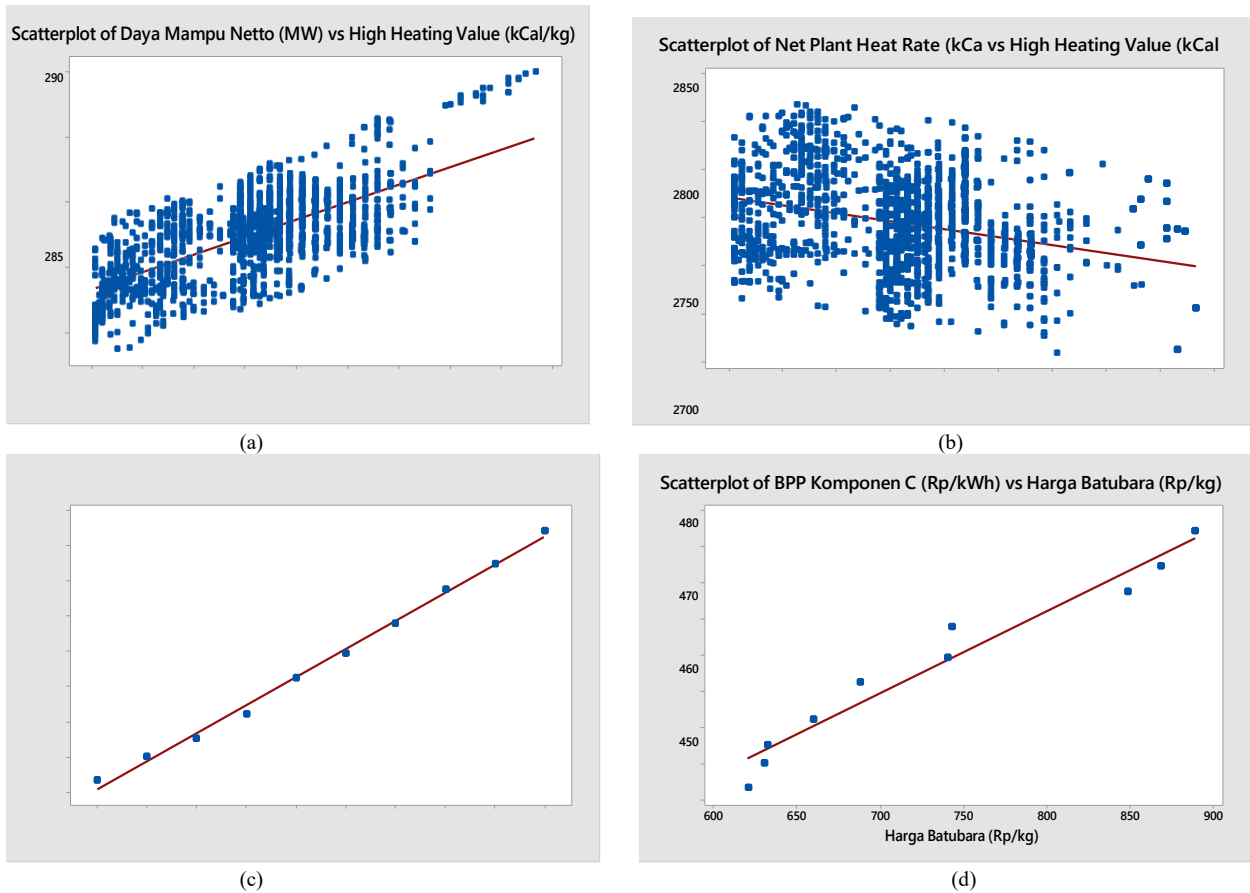


Figure 1. Scatterplots of (a) Net Power-HHV; (b) NPHR-HHV; (c) COE Component C-HHV; and (d) COE Component C-Coal Price.

the optimal solution to the problem of blending. The mixing decision must be based on knowledge of the specific behavior of the coal pair, rather than assuming linear variation in property with the mixed fraction. Increasing constraints such as environmental regulations, maximum efficiency with reduced production costs, increased availability and reliability, etc., are embedded in coal-fired power plants around the world and the continued development of new technologies means that the problem of improving the quality of fuel will continue to be a main factor [7].

**B. Net Plant Heat Rate**

Net plant heat rate (NPHR) is the amount of heat needed to generate an amount of electrical energy (kWh) based on the value of the power that has been supplied to the network expressed in units of Btu / kWh or kJ / kWh or kCal / kWh. Calculation of the heat rate using the input-output method can be determined through the equation [8]:

$$NPHR = \frac{FCV}{NP} \quad (1)$$

where NPHR is Net Plant Heat Rate (kCal/kWh), FCV is Fuel Calorific Value (kCal/kg), FF is Fuel Flow (ton/jam), NP is Net Power (MW).

**C. Net Power**

Net Power (NP) is the maximum power of a generating unit that operates continuously in a stable and safe condition after being reduced by its own usage capacity [9]. Furthermore, the calculation of DMN is as follows.

$$DMN (MW) = \text{Gross Power (MW)} - \text{Self-used Power Consumption (MW)} \quad (2)$$

The power generated by a generator based on the input energy received from the fuel, is stated in: [10]

$$\bar{Q} = \sum_{i=1}^n a_i L_i^{n-1} \quad (3)$$

where:  $\bar{Q}$  = input energy in kCal within different load  $i$ ,  $i = 1, 2, 3, \dots, m$ ;  $a_j$ ,  $j = 1, 2, 3, \dots, n$  is an unknown coefficient of the  $n-1$  polynomial;  $L_i$  = electrical energy output (kWh) at various load values  $i$ . The heat rate, HR, curves in kCal / kWh, are reduced by taking each corresponding input load, namely:

$$HR = \frac{\bar{Q}}{L} \quad (4)$$

where: HR is Net Plant Heat Rate (kCal/kWh);  $\bar{Q}$  is input energy (kCal);  $L$  is electrical power output (kWh)

Table 3.  
Regression Model Summary

Variables Relationship Model	S	R-sq	R-sq(adj)	R-sq(pred)
Net Power (MW) to HHV (kCal/kg)	2.34784	77.54%	77.51%	77.37%
NPHR (kCal/kWh) to HHV (kCal/kg)	44.9246	80.18%	80.17%	80.12%
COE Component C (Rp/kWh) to HHV (kCal/kg)	1.72292	99.55%	99.49%	99.19%
COE Component C (Rp/kWh) to Coal Price (Rp/kg)	5.42808	95.49%	94.93%	93.24%

Table 4.  
Coefficients of Net Power (MW) to HHV (kCal/kg)

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	219.47	1.60	137.24	0.000	
High Heating Value (kCal/kg)	0.013444	0.000371	36.26	0.000	1.00

Table 5.  
Analysis of Variance of Net Power (MW) to HHV (kCal/kg)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Error	1451	7998	5.51		
Lack-of-Fit	74	2634	35.60	9.14	0.000
Pure Error	1377	5364	3.90		
Total	1452	15248			

Table 6.  
Coefficients of NPHR (kCal/kWh) to HHV (kCal/kg)

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3053.6	30.6	99.79	0.000	
High Heating Value (kCal/kg)	-0.08313	0.00709	-11.72	0.000	1.00

D. Cost of Electricity Production

Cost of electricity (COE) production is the cost of fuel needed to produce electrical energy of 1 kWh. Furthermore, the calculation of the cost of electricity production is as follows.

$$COE = \frac{\text{coal price (per kg)}}{\text{Fuel Flow (ton/h)}} \times \text{Net Power (MW)} \tag{5}$$

Where: COE is Cost of Electricity Production (Rp/kWh), FF is Fuel Flow (ton/h), NP is Net Power (MW)

E. Descriptive Statistic

Descriptive statistics function to describe or give an idea of the object under study through sample data or population [11]. Examples of the presentation of data in descriptive statistics are tables, diagrams, and graphs [12]. Data presented in descriptive statistics are usually in the form of centralized data measures [13]. One measure of centralized data that is commonly used is the mean [14].

F. Linear Regression

1) Definition of Regression and the Form of Regression Model

In general the relation of Y and X defines as follow:

$$Y_i = m(X_i) \epsilon_i \tag{6}$$

where m (x) is a regression function that is unknown and wants to be estimated, and Xi is a random variable that represents the variation of Y [15].

2) Regression Model Test

1. Heteroscedasticity Examination

The examination of heteroscedasticity aims to see whether in the regression model there is an inequality of variance from the residuals of one observation. The dots formed must spread randomly and not have a regular pattern. If this condition is met then heteroscedasticity does not occur so that the regression model is feasible to use. [16]

2. F-Test

The null hypothesis proposed in this test is that all independent variables used in the simultaneous regression equation model do not affect the dependent variable if the significance value is greater than 0.05 [17]. The steps for testing using the F Test are as follows:

a. Formulate Hypothes

The hypothesis is accepted if  $\beta_1 = \beta_2 \neq 0$ , meaning that there is at least one variable X1 and variable X2 influencing the variable Y.

b. Determine the level of significance of  $\alpha = 5\%$  with DF = n - (k + 1)

c. Measure F Test (F-Test)

d. Decision Making Criteria:  $H_0$  is rejected if  $F_{count} > F_{table}$ , thus individually there is a significant

Table 7.  
Analysis of Variance of NPHR (kCal/kWh) to HHV (kCal/kg)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Error	1451	2928442	2018		
Lack-of-Fit	74	596819	8065	4.76	0.000
Pure Error	1377	2331623	1693		
Total	1452	3205640			

Table 8.  
Coefficients of COE Component C (Rp/kWh) to HHV (kCal/kg)

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	83.06	8.46	9.82	0.000	
High Heating Value (kCal/kg)	0.07943	0.00190	41.88	0.000	1.00

Table 9.  
Analysis of Variance of COE Component C (Rp/kWh) to HHV (kCal/kg)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Error	8	23.75			2.97
Total	9	5229.18			

influence of the variables studied.

#### G. Standard Score Method (Z-Score)

Analysis of needs ranking will be better if using the standard score method (Z-Score) because it is able to compare the quality of achievement of a datum against the average distribution of data in groups based on the standard deviation values [18]. To calculate the Z score, we need to find the mean and standard deviation of the sample.

$$z = (X - \mu_n) / \sigma \tag{7}$$

where: z is Z-Score; X is data value,  $\mu_n$  is average from n data, and  $\sigma$  is deviation standard.

Standard deviation is used to calculate the spread of data and find out whether the data is close to the average value or far from the average value.

$$\sigma = \sqrt{V} \tag{8}$$

where:  $\sigma$  = deviation standard and V= variance

## II. METHOD

### A. Data Source

The author collected data through secondary data sourced from the electricity production process of a coal fired power plant. Production process data used starts from the plant's operation on January 1<sup>st</sup> until June 30<sup>th</sup>, 2019.

### B. Research Variabel

#### 1) Independent Variable

This variable influences or cause the changes or the emergence of the dependent variable. The independent variables in this study are the High Heating Value (HHV) and Fuel Prices.

Table 10.  
Coefficients of COE Component C (Rp/kWh) to Coal Price (Rp/kg)

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	270.2	12.9	20.96	0.000	
Harga Batubara (Rp/kg)	0.2272	0.0175	13.02	0.000	1.00

Table 11.  
Analysis of Variance of COE Component C (Rp/kWh) to Coal Price (Rp/kg)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Error	8	235.7	29.46		
Total	9	5229.2			

#### 2) Dependent Variable

Dependent variable is a variable that is affected, or which becomes a result, because of the independent variable. The dependent variable in this study are the Net Plant Heat Rate (NPHR), Net Power, and Cost of Electricity Production (Component C).

### C. Data Analysis Methods

#### 1) Analysis of Data Description

Descriptive data analysis is a descriptive statistical analysis method related to the collection and presentation of data to produce information as needed. To analyze data, statistical methods are used, because statistical methods are effective and efficient in a research. The statistical method used is a method that is relevant to the research conducted.

#### 2) Regression Model Specification

Regression model specifications are made based on the number of independent variables that have been determined previously. The specifications of the regression model are intended to predict how the rise and fall of the dependent variable, if there are two or more independent variables as a predictor of manipulation (increase the value).

#### 3) Parameter Estimation

Parameter estimation is estimating population parameter values based on data / statistics. The characteristics of a population can be known by estimating the sample. One estimation method that is often used in statistics to estimate or estimate parameters is ordinary least squares (OLS), which has 5 assumptions that must be met by deviations or errors, namely normality, linearity, homoscedasticity, non-multicollinearity and non-autocorrelation. [19].

#### 4) Testing the Feasibility of the Model

The F test is used to assess the feasibility of the regression model that has been formed. Testing is done by comparing the value of F table with F count. The significance level used is 5% with the degree of freedom (df) numerator = k-1, and the denominator df = n-k, where n is the number of respondents and k is the number of variables. The test criteria are used, i.e. if  $F_{count} > F_{table}$ , then  $H_0$  is rejected and  $H_a$  is accepted.

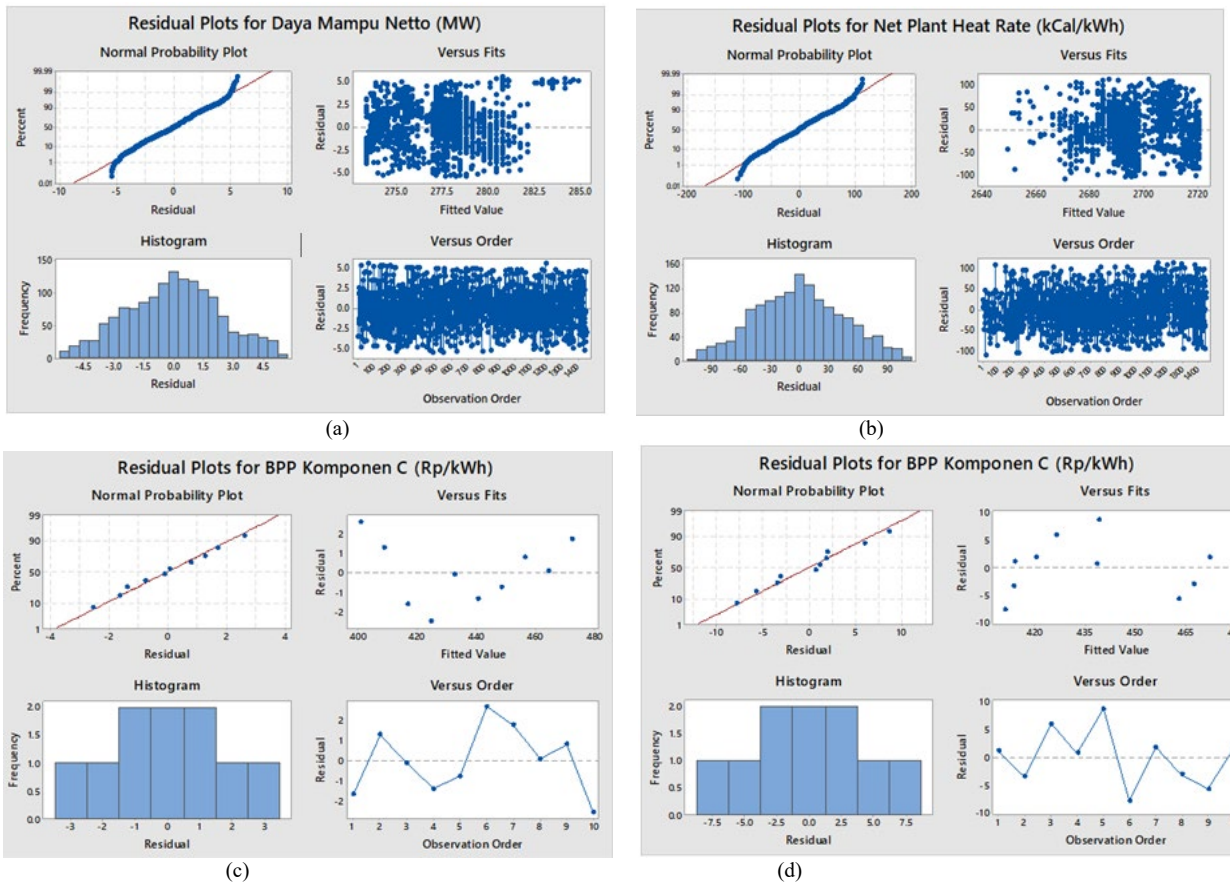


Figure 2. Residual Plots of (a) Net Power-HHV; (b) NPHR-HHV; (c) COE Component C-HHV; and (d) COE Component C-Coal Price.

### 5) Analyze Residuals

There are three residual assumptions that must be met in the regression analysis, which are identical, independent, and normally distributed.

#### a. Examination of Identical Residual Assumptions

A data if the residual plot spreads randomly and does not form a certain pattern then the data can be said to assume identical residuals. You can use Glejser test statistics. The hypothesis used is  $H_0: \sigma_1^2 = \sigma_2^2 = \dots = \sigma_n^2 = \sigma^2$  [20]

#### b. Examination of Independent Residual Assumptions

To test the freedom between residuals can be done using the Durbin-Watson test with the following hypothesis [21]. The hypothesis used is  $H_0$ : Residual data is independent. Independent residual testing can also be seen visually namely the ACF plot, if nothing comes out of the line then it can be said to be independent residuals

#### c. Examination of Residual Normality Assumptions

Normality test in the regression model is used to test whether the residual values generated from the regression are normally distributed or not. A good regression model is one that has a normally distributed residual value.

### 6) Changing the Data to Z-Score

The data range of each variable will be analyzed. From each range earlier, it will be converted into Z-scores to then be used as a range in plotting the regression graph that will be formed.

## III. RESULT AND DISCUSSION

### A. Descriptive Data Analysis

Descriptive statistics used are mean, minimum, and maximum values. In addition, the data will be presented in to scatter plot to see the data distribution visually. The data used are secondary data from the results of the PLTU operating patterns during January 1<sup>st</sup> to June 30<sup>th</sup>, 2019. Table 1 is a descriptive statistic for the response variable. Meanwhile Table 2 is descriptive statistics for predictor variables.

The purpose of presenting scatter plots is to look at the data distribution of the response and predictor variables. Figure 1 states the scatter plots between the independent and dependent variables. It appears that the distribution of data produces linear lines. Only Figure 1 (b) has a downward trend, where the higher the HHV value will cause a decrease in NPHR.

### B. Regression Model Specification

Regression model specifications are carried out to find the model that best meets the criteria for the goodness of fits. The coefficient of determination ( $R^2$ ) is used to determine the proportion of total diversity in the dependent variable (Y) which can be explained by the independent variable (X).

Table 3 shows that the  $R^2$  of Net Power (MW) to HHV (kCal/kg) is 77.51%. This indicates that 77.51% of the total diversity of Net Power can be explained by the HHV value.

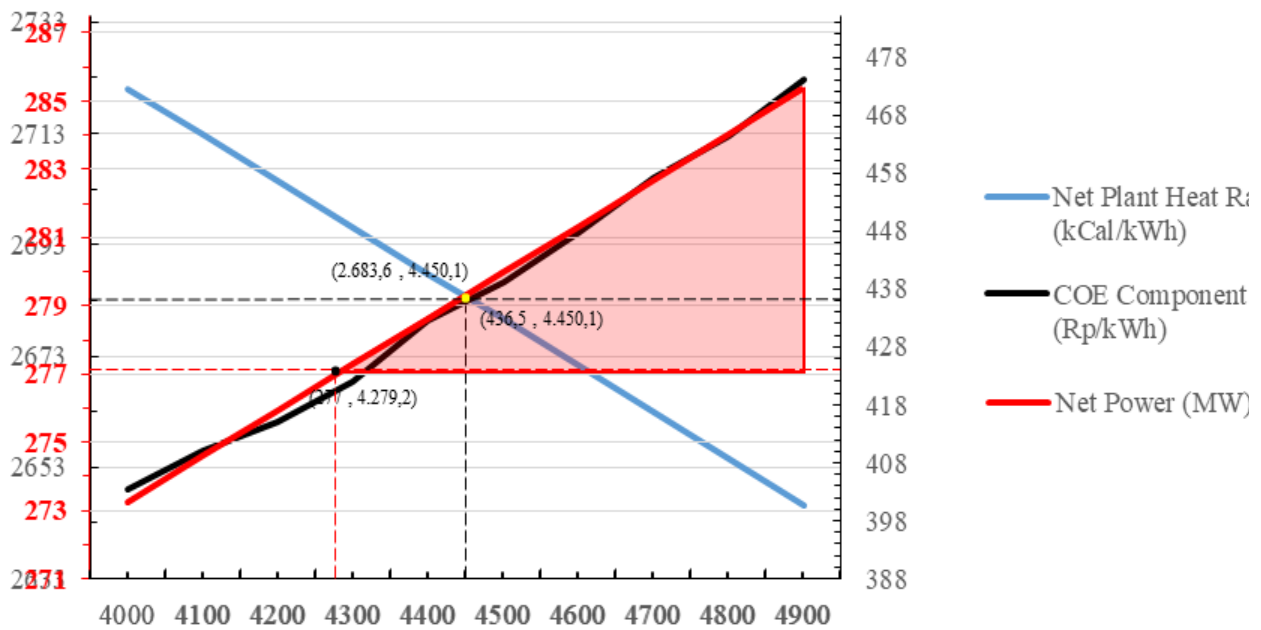


Figure 3. Optimum Point of Generating Electricity.

The highest  $R^2$  value is at the relation between COE Component C (Rp/kWh) to HHV (kCal/kg) with 99.55%.

C. Parameter Estimation

In solving this problem, Ordinary Least Square (OLS) method is used for each variable relationship. The parameter is formed by the equation  $Y_{\diamond} = \beta_0 + \beta_1 X_{\diamond} + e_{\diamond}$ . To find the residual value, we used the equation  $e_{\diamond} = Y_{\diamond} - \hat{Y}_{\diamond}$ .

1) Net Power (MW) to HHV (kCal/kg)

From Table 4, we get the coefficient for parameter estimation with  $b_0 = 219.47$  and  $b_1 = 0.013444$ . By estimating parameters using OLS, we get the sum of squared residual (SSR) is 7,998, the variance ( $s^2$ ) = 5.51 and the standard deviation (s) is 2.347 as shown in Table 5.

2) NPHR (kCal/kWh) to HHV (kCal/kg)

From Table 6, we get the coefficient for parameter estimation with  $b_0 = 3,053.6$  and  $b_1 = -0.08313$ . By estimating parameters using OLS, we get the sum of squared residual (SSR) is 2,928,442, the variance ( $s^2$ ) = 2,018 and the standard deviation (s) is 44.9246 as shown in Table 7.

3) COE Component C (Rp/kWh) to HHV (kCal/kg)

From Table 8, we get the coefficient for parameter estimation with  $b_0 = 83.06$  and  $b_1 = 0,07943$ . By estimating parameters using OLS, we get the sum of squared residual (SSR) is 23.75, the variance ( $s^2$ ) = 2.97 and the standard deviation (s) is 1.72292 as shown in Table 9.

4) COE Component C (Rp/kWh) to Coal Price (Rp/kg)

From Table 10, we get the coefficient for parameter estimation with  $b_0 = 270,2$  and  $b_1 = 0,2272$ . By estimating parameters using OLS, we get the sum of squared residual (SSR) is 235.7, the variance ( $s^2$ ) = 29.46 and the standard deviation (s) is 5.42808 as shown in Table 11.

D. Goodness of Fit Model

1) Net Power (MW) to HHV (kCal/kg)

The goodness of fit model is carried out by the F-Test. Based on Table 8, the  $F_{count}$  is 1,315.12.  $F_{table}$  value obtained with  $\alpha = 5\%$  is 3.85. From the test results found that:  $F_{count} > F_{table}$ , thus individually there is a significant influence of the variables studied. In addition, the p-value  $< 0.05$ , so a decision can be taken to reject  $H_0$ .

2) NPHR (kCal/kWh) to HHV (kCal/kg)

Based on Table 10, the  $F_{count}$  is 137.35.  $F_{table}$  value obtained with  $\alpha = 5\%$  is 3.85. From the test results found that:  $F_{count} > F_{table}$ , thus individually there is a significant influence of the variables studied. In addition, the p-value  $< 0.05$ , so a decision can be taken to reject  $H_0$ .

3) COE Component C (Rp/kWh) to HHV (kCal/kg)

Based on Table 12, the  $F_{count}$  is 1,753.57.  $F_{table}$  value obtained with  $\alpha = 5\%$  is 5.12. From the test results found that:  $F_{count} > F_{table}$ , thus individually there is a significant influence of the variables studied. In addition, the p-value  $< 0.05$ , so a decision can be taken to reject  $H_0$ .

4) COE Component C (Rp/kWh) to Coal Price (Rp/kg)

Based on Table 14, the  $F_{count}$  is 169.48.  $F_{table}$  value obtained with  $\alpha = 5\%$  is 5.12. From the test results found that  $F_{count} > F_{table}$ , thus individually there is a significant influence of the variables studied. In addition, the p-value  $< 0.05$ , so that decisions can be taken rejecting  $H_0$ .

5) Residuals Analysis

The first assumption of residuals that must be fulfilled is the assumption of identical by using heteroscedasticity test. Heteroscedasticity test can be done by looking at the scatter plot of the residual variance. If the scatter plot

shows that the residuals distribution is random, it can be concluded that the assumptions is fulfilled. The scatter plot of the residual versus fit plot in Figure 2 shows random distribution so that it can be concluded that all of the residuals is identical.

The second assumption of residuals that must be fulfilled is the assumption of independent residuals by using the Durbin- Watson test. Based on the Durbin-Watson test statistics from all models, it was found that the decision failed to reject  $H_0$ , in these models because the calculated value,  $d_{count}$  were higher than  $d_U$  for every models and did not meet the  $d_L < d_{count} < d_U$ . Then the null hypothesis is accepted, so all the residuals is independent. [21]

The last assumption is the residual normality assumption which is done by looking at the histogram comparing the observational data with the distribution approaching the normal distribution. The histogram graphs obtained on the assumption of normality residuals are in the form of a normal distribution. In addition, another method is to look at the normal probability plot. Normal distribution will form a diagonal straight line, and plotting data will be compared with a diagonal line. The data spread around the diagonal line and follow the direction of the diagonal line or the histogram graph shows a normal distribution pattern, then the regression models meet the normality assumption.

### E. Changing the Data to Z-Score

By using calculation (7), we got the new score for each variable to be plotted. From the Z-score, a new simple linear regression equation is obtained using Minitab:

- NPHR ( $y_1$ ) = 14.6979 - 0.003303 HHV (x)
- COE Component C ( $y_2$ ) = -14.664 + 0.003296 HHV (x)

So, in finding the optimum point, we need to state the constraints in this problem. The constraints include:

1.  $\diamond\diamond\diamond R = 14,6979 - 0,003303$  High Heating Value (kCal/kg)
2.  $\diamond C\diamond\diamond = -14,664 + 0,003295$  High Heating Value (kCal/kg). From this two equations, we got that the optimum point is when the x valued 4.450,1. So, the observed points are (2,683.6 ; 4,450.1) and (436.5; 4,450.1)
3. Because the net power of the CFPP observed must be greater than 277 MW, so  $\diamond\diamond\diamond\diamond\diamond er > 277$   
 $\diamond\diamond\diamond\diamond\diamond er = 219,47 + 0,013444$  High Heating Value (kCal/kg)  $> 277$ . From this equation, we got that the optimum point is when the x valued 4.279,2. So, the observed point is (277; 4,279.2)
4.  $\diamond C\diamond\diamond = 270,2 + 0,2272$  Coal Prices. We got that the optimum point is when the coal price valued Rp 732,152/kg.

The optimum point shown by yellow point in Figure 3. The optimum point of generating electricity in CFPP can be achieved by using coal calorific values of 4,450 kCal/kg, NPHR of 2,683.6 kCal/kWh, and BPP (component C) of Rp 436.5/kWh when using coal at a price of 732.2/kg and DMN of 279 MW.

## IV. CONCLUSION

Based on findings from this study, it can be concluded that; (1)The optimum fuel used is coal with a calorific value of 4,450 kCal/kg; (2)The optimum NPHR value achieved by using coal with different calorific values is 2,683.6 kCal/kWh; (3)The value of BPP (component C) achieved in generating electricity with the use of coal with different calorific values is Rp 436.5/kWh; (4)The optimum point of operating a power plant in generating electricity can be achieved using coal calorific values of 4,450 kCal/kg, NPHR of 2,683.6 kCal / kWh, and BPP (component C) of Rp 436.5/kWh when using coal at a price of 732.2/ kg and DMN of 279 MW.

## ACKNOWLEDGMENT

I would like to express my deep gratitude to Dr. Wahyu Wibowo, my research supervisors, for his patient guidance, enthusiastic encouragement, and useful critiques of this research work. I would also like to thank the other lecturers during the work of this paper, for their advice and assistance in keeping my progress on schedule. My grateful thanks are also extended to engineers in office for their help in doing the data collecting, and people who always give supports until the study is done.

## REFERENCES

- [1] M. I. Syahputera *et al.*, "Analisis pengaruh nilai kalori batubara terhadap konsumsi bahan bakar dan biaya produksi listrik," *ISSN 2085-2762 Semin. Nas. Tek. Mesin*, pp. 474–483, 2018.
- [2] Wahyono and H. Teguh, "Penggunaan Mix Coal Terhadap Efisiensi Pembangkit dan Biaya Produksi Listrik (BPL) di PLTU Tanjung Jati B Unit 3," *EKSERGI J. Tek. Energi*, vol. 11, no. 2, pp. 53–60, 2015.
- [3] M. Yörükoğlu, "Coal blending for thermal power stations," *Madencilik*, vol. 56, no. 3, pp. 109–116, 2017.
- [4] Amiral Aziz and Andi Rinaldi Hasan, "Evaluation of Heat Rate and Efficiencies of a Steam Power Plant Using the Different Coal Specification From the Design Specification," *Energi Lingkungan*, vol. 11, no. 1, pp. 1–6, 2015.
- [5] H. H. Santoso, W. Kurniawan, H. Setiawan, and T. R. Biyanto, "Optimization of Coal Blending to Reduce Production Cost and Increase Energy Efficiency in PT . PJB UP Paiton," *Int. J. Eng. Sci. Invent.*, vol. 5, no. 8, pp. 25–30, 2016.
- [6] *et. al.* Hadi, "Analisi Pengaruh Nilai Kalori Dan Heat Rate (Laju Kalor) Batubara Terhadap Efisiensi Thermal PLTU-Embalut 2X25 MW PT Cahaya Fajar Kaltim," pp. 1–10, 2010.
- [7] Sathyanathan, "Blending of Coals in Power Stations Dr V T Sathyanathan," pp. 1–3, 2012.
- [8] L. A. Hamzah, "Analisa Pengaruh Produksi Energi Listrik Terhadap Konsumsi Bahan Bakar Pada Pembangkit Listrik Tenaga Uap ( PLTU) NII Tanasa," vol. 04, no. 02, pp. 1–5, 2019.
- [9] E. G. Prasetyo, Sulasno, and S. Handoko, "Studi Tentang Indeks Keandalan Pembangkit Tenaga Listrik," *Univ. Diponegoro*, no. January 2011, 2011.
- [10] A. Poullikkas, "Heat rate curve approximation for power plants without data measuring devices," *Int. J. Energy Environ.*, vol. 3, no. 5, pp. 651–658, 2011.
- [11] Sugiyono, *Metode Penelitian Pendidikan (Pendekatan Kuantitatif, Kualitatif dan R&D)*. Bandung: Alfabeta, 2016. [12] V. Gaspersz, *Metode Perancangan Percobaan*, vol. 1. Bandung: CV. Armico, 1991.
- [13] D. Kuswanto, *Statistik Untuk Pemula dan Orang Awam*. Jakarta: Laskar Aksara, 2012. [14] A. Fauzy, *Statistik Industri*, 1st ed., vol. 1. Jakarta: Erlangga, 2009.
- [15] D. Barry and W. Hardle, *Applied Nonparametric Regression*, vol. 156, no. 1. 1993.
- [16] S. Sunjoyo, R. Carolina, V. N. Magdalena, and A. Kurniawan, *Aplikasi SPSS untuk SMART Riset (Program IBM SPSS 21.0)*, 1st ed. Bandung: Alfabeta, 2013.
- [17] I. Ghozali, *Aplikasi Analisis Multivariate dengan Program IBM SPSS 21*. Semarang: BPFE Universitas Diponegoro, 2012.

- [18] V. Hegde and M. S. Pallavi, "Descriptive analytical approach to analyze the student performance by comparative study using Z score factor through R language," *2015 IEEE Int. Conf. Comput. Intell. Comput. Res. ICCIC 2015*, pp. 0–3, 2016.
- [19] P. Erviana, "Faktor-Faktor yang Mempengaruhi Keberhasilan Belajar Mahasiswa Pendidikan Matematika dengan Regresi Logistik," *J. Kegur. dan Ilmu Pendidik.*, 2014.
- [20] D. R. Gujarati, *Dasar-Dasar Ekonometrika*, 1st ed. Jakarta: Erlangga, 2006.
- [21] N. R. Draper and H. Smith, *Applied Regression Analysis, Third Edition*. New York: John Wiley & Sons, 1998.