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Modeling the Melting Rate of an *Erythrophleum Suaveolens* Charcoal-Fired Cupola Furnace with Oxygen Enrichment

Olorunnishola, A.A.G[1] and Anjorin, S.A[2]

[1]Department of Mechanical Engineering Technology

Federal Polytechnic, Ado-Ekiti, Nigeria

[2]Department of Mechanical Engineering

Federal University of Technology Akure

Nigeria

ABSTRACT

Scraps of cast iron were melted and the melt ratios for ES charcoal-fired cupola furnace with oxygen enrichment was 9.2:1. Multiple linear regression model was formulated for the effects of air pressure, melting time and fuel consumed on melting rate in the iron melting cupola furnace. An R^2 value of 99.5% confirms the validity of the models and established the existence of statistically significant relationships between the melting rate and the control variables. The coefficients b_{0eco}, b_{1eco}, b_{2eco} and b_{3eco} are -941.940, 918.840, 1.117 and 3.897 respectively; and the results of the t-test indicated that regression coefficients b_{1eco}, b_{2eco} and b_{3eco} were statistically significant and not equal to zero (as given by hypothesis ii) at 0.025 level of significance and 11 degrees of freedom (table t-value=$t_{0.025}$, 11 = 2.201). The residuals' average was zero with the standard deviation of approximately 1.0 implying that residuals were actually independent.

The average variance inflation factor VIF of 1.562 indicated that multi co-linearity was not a problem (i.e. VIF < 4), which clearly demonstrated that air blast pressure; melting time and fuel consumed was not significantly interacting factors. The developed model can be used to develop a computer software to predict the behavior of melting rate of an erythrophleum suaveolens charcoal-fired cupola furnace with oxygen enrichment as a function of air blast pressure, melting time and fuel consumed.

Key words: *Regression model, melting rate, air blast pressure, melting time, fuel consumed, oxygen enrichment, cupola furnace.*

1.0 INTRODUCTION

Several investigators have carried out studies and developed mathematical models concerning the problem of choosing the optimum input parameters. Levi (1947) was the first person to develop a mathematical model between carbon content in the charge and that of the tapped metal in cupola operations. Davis and Decrop (1958) concluded that blast temperature has significant control over metal temperature and hence on carbon pick up. Pehle (1963) developed the first thermo chemical model for predicting cupola performance under various operating conditions. Artificial neural networks (ANN) are useful tools for prediction, function approximation and classification. It is well suited to extracting information from imprecise and non-linear data. Karunakar and Datta (2002) used ANN to model cupola furnace parameters with about 5% error. Regression techniques have a long history of use as forecasting tools in multiple disciplines. Vasin *et al.*, (2008) also developed practical crash prediction regression models for assessing the long-range safety impact of alternative freeway networks for urban areas. In this work, regression modeling was adopted as a modeling technique for its long history of use as predicting tool in multiple disciplines.

2.0 MODELING THEORY

Captions Statistical methods such as cluster analysis, pattern recognition, design of experiments, factor analysis, and regression analysis are some of the statistical techniques which enable one to analyze the experimental data and build empirical models to obtain the most accurate representation of physical situations (Kumar and Singh, 2012). In this work, regression modeling was adopted as a modeling technique. There are a number of variables controllable to varying degrees which affect the quality and composition of the out-coming molten metal. These variables, such as flame temperature, preheat air temperature, blast air pressure, excess air percentage, melting time, fuel consumption and melting rate play significant role in determining the molten metal's properties and should be controlled throughout the melting process (Singh et al, 2006).

Numbers of heats were produced by varying some of the critical input parameters and output as melting rate was observed from the regressive experiments. According to Kumar and Singh (2012), the Critical input Parameters affecting the melting rate are:
1. Blast air pressure (in Pa): the pressure of the air supplied by the blower.
2. Melting Time (in Minutes): this is the melting time of metal.
3. Fuel Consumed (in Kilogram): fuel consumed in melting the metals.
Therefore, to keep the experiments manageable, the above mentioned critical variables with their nominal values were selected. Melting Rate is taken as single output Parameter. Melting Rate (M), which is a function of Blast air Pressure (P), Melting Time (T) and Fuel Consumed (F), is as follows:

$$M = C_o \times P^{C_1} \times T^{C_2} \times F^{C_3} \quad (1)$$

On taking logarithm of both the sides,

$$In\, M = InC_o + C_1\, In\, P + C_2\, In\, T + C_3\, In\, F \quad (2)$$

The regression model for this problem involves three variables; therefore their dependency relationship can be mathematically expressed as follows:

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \quad (3)$$

This is a natural extension of the simple linear regression model. In matrix notation, it can be written as:

$$Y = X\beta + \varepsilon \quad (4)$$

Y - Is a linear function of k control variable x_1......, x_k and ε is an error term. Using sample data, model parameters can be estimated using the coefficients $\beta_0, \beta_1, \beta_2, \beta_3 ..... \beta_k$ of the regression equation, associating response variable Y with its control variables $x_1, x_2, x_3 .... x_k$

2.1 Variables selection

The relationship of air blast pressure (P), melting time (T) and fuel consumed (F), all independent variables with melting rate (M)), a dependent variable, is to be derived. The specific definitions and units of measurements of these variables are defined as follows; Blast air pressure measures in bar, is the pressure of the air supplied by the blower; Melting time (T) measures in Minutes, is the melting time of metal; Fuel Consumed (F) measures in Kilogram, is the fuel consumed in melting the metals and Melting rate (M) measures in Kg/min., is the amount of metal melted per minute.
The above factors are selected as control variables influencing melting rate of iron based on;

i) The presence of physical or logical influence of these factors on Melting rate. For example, as air pressure increases the velocity of the air in the tuyere increases and hence accelerates the melting of the iron in contact with the solid fuel.

ii) It is predicted that as the amount of iron melted per unit time changes, it is logical to conclude that melting rate in kg/min. would change accordingly (Chastain, 2000).

To justify the presence of such informative relationships between these factors, scatter diagrams are used to clearly indicate the validity of initial selection of control variables.

2.2 Models assumptions

The following assumptions are made:

i. There was a linear relationship between the melting rate and the related control variables (application of scatter diagrams).

ii. That multi-co-linearity was not present among the control variables (air pressure, melting and fuel consumed).

iii. That the random errors (o) are independent and normally distributed with constant variance and zero mean.

3.0 FORMULATION OF MULTIPLE LINEAR REGRESSION MODELS (MLRM)

3.1 Models formulation.

Based on the selected variables and model assumptions, the multiple linear regression models was formulated for a cupola furnace using *Erythrophleum Suaveolens* charcoal with oxygen enrichment (E_{so}).

Model: for a cupola furnace using *Erythrophleum Suaveolens* charcoal as fuel with oxygen enrichment.

$$Exp(M / P, T, F) = b_{oeco} + b_{1eco}P + b_{2eco}T + b_{3eco}F \quad ...37$$

Where:

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$Exp(M/P,T,F)$ - is the expected value of melting rate in Kg/min. given the independent variables P, T and F, b_{oeco} is intercept, b_{1eco} is regression coefficient associated with air pressure, b_{2eco} is regression coefficient associated with melting time and b_{3eco} is regression coefficient associated with fuel consumed.

3.2 *Hypothesis 1: Testing model validity*

Model hypothesis: for a cupola furnace using *Erythrophleum Suaveolens* charcoal with oxygen enrichment as fuel is presented as in equation 6:

$$H_0 : \beta_{jeco} = 0, \ j = 1,2,3$$
$$If\ H_0\ is\ rejected,\ then\ H_1 : at\ least\ one\ \beta_{jeco} \neq 0 \quad (6)$$

This hypothesis is intended to test validity of the presence of a relation between melting rate of the furnace and the independent variables. If the null hypothesis is rejected, then there are some independent variables that do actually affect melting rate.

3.3 *Hypothesis II: Individual testing of coefficients of the multiple linear regression model.*

Hypothesis II for any independent variable is as presented in equation 7.

$$H_0 : \beta_{1-3eco} = 0 \ \ vs \ \ H_1 : \beta_{1-3eco} \neq 0 \quad (7)$$

The null hypothesis assumed that there was no statistically significant relationship between melting rate and any of the independent variables.

4.0 DATA COLLECTION

Cast iron scraps were sourced from car engine blocks. In the experimentation, firstly, a predetermined quantity of metal (17 kg) was melted with 3 kg of ES charcoal per charge. Each charge was accompanied with 1 kg of limestone in order to separate the slag from the molten iron. Also 1 kg of ferrosilicon was introduced to the charge at an interval before the iron was tapped in order to improve the machinability of the cast iron. This experiment was conducted at different values of air blast pressure of 1.03 and 1.02 bars, while using ES charcoal with the introduction oxygen at start up for 10 minutes to melt the charge. The total quantity of oxygen consumed was 2.22 m^3.The temperature readings were obtained by using digital multi-meter with k type thermocouple. The values of melting temperature and tapping temperature are 1670^{o}c and 1500^{o}c respectively.

While conducting the experiment the variations of the rate of melting, fuel consumption and melting time with air blast pressure were recorded as shown in Table 1.

Table 1: ES Charcoal Fuel Based Experiment with Oxygen Enrichment

Air blast Pressure(P) (bar)	Melting Time (T) (min.)	Fuel Consumed (F) (Kg)	Melting Rate ($\dot{M}_{2exp}$) (Kg/min.) x 10^1
1.03	10	2.4	21.66
1.03	20	4.77	42.99
1.03	30	7.18	64.95
1.03	40	8.77	85.78
1.03	50	11.89	108.19
1.03	60	14.03	128.98
1.02	10	2.28	18.60
1.02	20	4.45	36.89
1.02	30	6.78	55.77
1.02	40	8.97	73.99
1.02	50	10.96	93.02
1.02	60	13.65	111.55
			$\dot{M}_{2m} = \frac{1}{n}\sum_{i=1}^{n} M_i = \frac{1}{12}(842.37) = 70.2 \times 10^{-1}\ kg/min.$

5.0 MODEL VALIDATION RESULTS AND DISCUSSION

SPSS (version 16.0) was used to validate the data obtained in Table 1and the results are shown in Table 2.

5.1 Model validation and discussion

Table 2: Model Summary for a Cupola Furnace using E_{so} as Fuel

		ANOVA					RESIDUALS				
Parameter	Value	Parameter	Sum of squares	Parameter	Condition index	Coefficients	VIF	T-Statistic	Parameter	Mean (μ)	Std. Deviation (σ)
R^2	0.995	Regression	14424.419	Constant (b_{0eco})	1.00	-941.940		-4.435	Predicted value	70.198	36.212
F-Statistic	582.766	Residual	66.004	P (b_{1eco})	4.334	918.840	1.562	4.433	Residual	0	2.450
Significance of F-statistic	0.000	-	-	T (b_{2eco}) F(b_{3eco})	90.161 709.351	1.117 3.897		1.278 1.019	-	-	-

Scatter diagram shown in Figure 1 was plotted which clearly indicates the validity of initial selection of variables. The model summary shown in Table 2, gave a computed value for the R^2 as 0.995, thus indicating that the regression was significant as about 99.5 % of the variation in melting rate could be accounted for by the control variables. The *ANOVA* analysis in the regression result, shown in Table 2, gave a computed value for the *F*-statistic as 582.766 while the corresponding table value of 3.98 at 0.05 level of significance (q) and (2,11) degrees of freedom showed that the multiple linear regression models was significant and valid. Large regression sum of squares (14424.419) in comparison to the residual sum of squares (66.04) indicated that the model accounts for most of variation in the dependent variable. The coefficients b_{0eco}, b_{1eco}, b_{2eco} and b_{3eco} shown in Table 2 are -941.940, 918.840, 1.117 and 3.897 respectively; and the results of the *t*- test indicated that regression coefficients b_{1eco}, b_{2eco} and b_{3eco} were statistically significant and not equal to zero (as given by hypothesis ii) at 0.025 level of significance and 11 degrees of freedom (table t-value=$t_{0.025}$, 11 = 2.201) (*Neave, 1978*). Therefore, the regression equation of melting rate of iron in kg/min. can be given by equation 8. It should be noted that the assumptions made were valid for this model with respect to multi co-linearity and residuals' distribution. As seen from Table 2, the condition indexes values of 4.334, 90.161, and 709.351 are for P, T and F respectively. From Table 2 the predicted value of mean was 70.198 with standard deviation of 36.212 implying that control variables were actually independent. From Table 2 and Figure 2, the residuals' average was zero with standard deviation of approximately 1.0 implying that residuals were actually independent. The average variance inflation factor *VIF* of 1.562 indicated that multi co-linearity was not a problem in this application (i.e. *VIF* < 4) (*Neave, 1978*), which clearly demonstrated that air pressure; melting time and fuel consumed were not significantly interacting factors.

$$Exp(\dot{M}_2 / P, T, F) = -941.940 + 918.840P + 1.117T + 3.897F \qquad (8)$$

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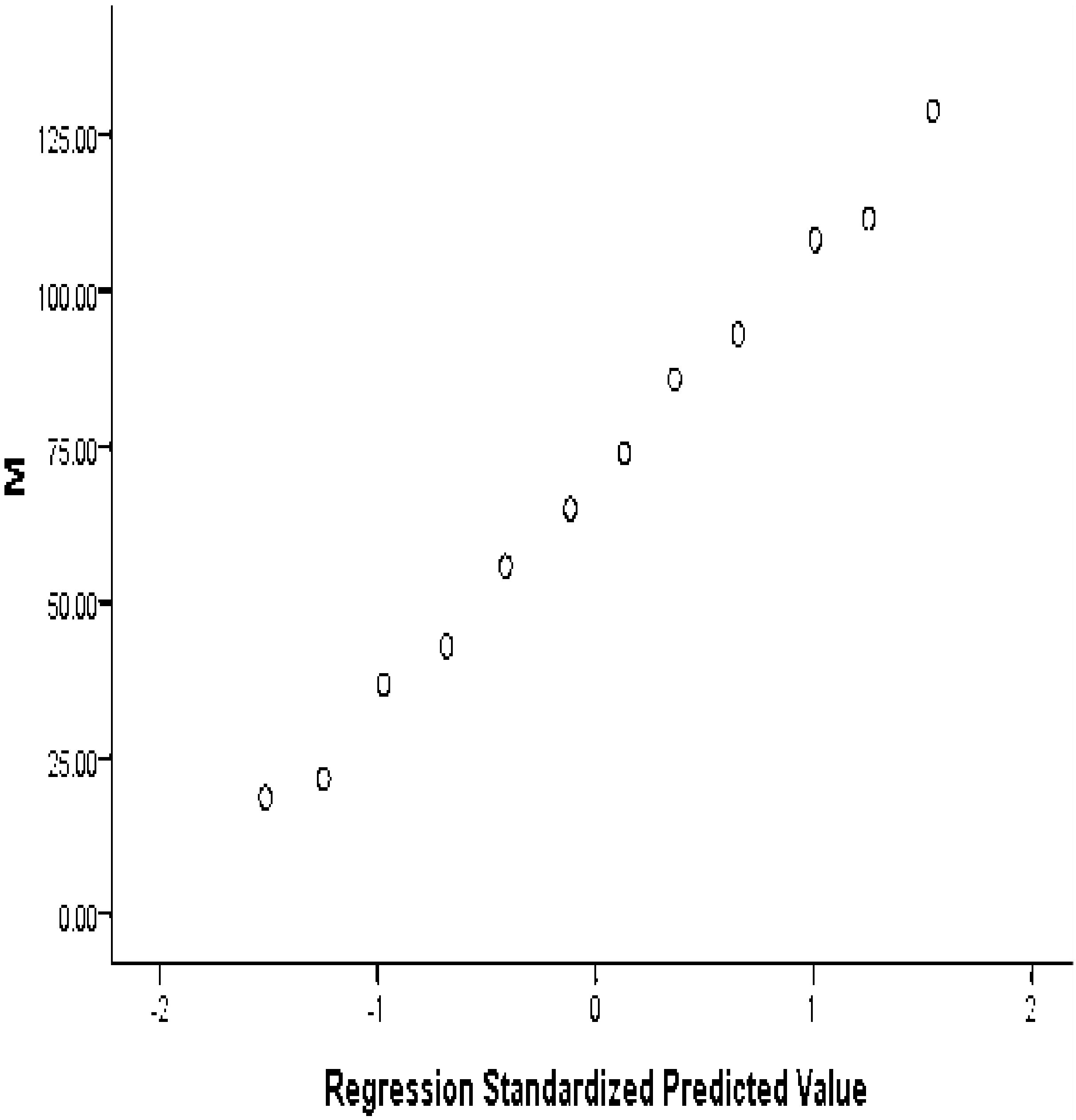

Figure 1: Scatter Plot for the Model

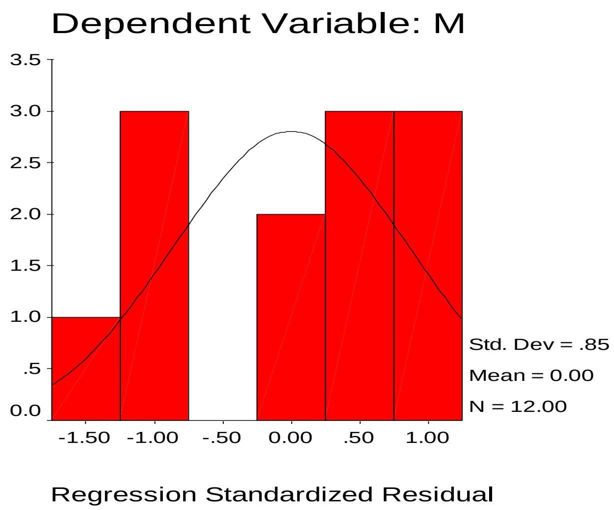

Figure 2: Regression plot for the model

6.0 CONCLUSION

The developed model with R^2 of 0.995 and significance of F-statistic of 0.000 which is less than 5% shows that the model is fit and when used to develop a computer software could be used to predict the behavior of meting rate of erythrophleum cupola furnace using oxygen enrichment for a start up as a function of air blast pressure, melting time and fuel consumed.

REFERENCES

1. Chastain, D.S. (2000). Iron Melting Cupola Furnaces for the Small Foundry. 1st Edition, Jacksonville, FL; USA, pp. 6-30.
2. Davis F. and Decrop, M. (1958). Influence of blast input, coke size and melting coke ratios on cupola performance. *Foundry Trade Journal*, pp. 319-325.
3. Karunakar, D. B. and Datta , G. L. (2002). Modeling of Cupola Furnace Parameters Using Artificial Neural Networks. [Electronic version]. *Indian Foundry Journal*, 48: 29- 39.
4. Kumar, P. and Singh, R. (2012). Neural Networks and Regression Modeling of Eco- friendly Melting Furnace Parameters Using Bio-fuels. [Electronic version]. *Interna tional Journal of Computer Applications*, 43 (1): 10-12.
5. Levi, W. W. (1947). Variables Affecting Carbon Control in Cupola Operation. *Transactions of APS*, 55: 626-632.
6. Neave, H. R. (1978). Statistics Tables for Mathematicians, Engineers, Economists and the Behavioural and Management Sciences. George Allen and Unwin publishers Ltd. London, pp. 41-62.
7. Pehle, R. D. (1963). Thermo-Chemical Model of Computer Prediction of Cupola Performance. *AFS Transactions*, 71: 580-587.
8. Singh, R., Radha, K.M., Patvardhan, C. and Rana, G. (2006). Rotary Furnace: Effect of Rotational Speed on Rate of Melting, Fuel Consumption and Pollution. [Electronic version]. *India Foundry Journal*, 52 (2): 38-40.

9. Vasin, K., Arun, C., Joseph, E.H., and Mary, S.Y. (2008). Planning Level Regression Models for Crash Prediction on Interchange and Non-Interchange Segments of Urban Freeways. *Journal of Transportation Engineering*, 134 (3):10-18.

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