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STATISTICAL MODELLING OF CHARCOAL CONSUMPTION OF V & M DO BRASIL'S BLAST FURNACES IN RELATION TO HOT METAL PRODUCTION AND FERROUS LOADS

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ABSTRACT

The need to increase the blast furnaces productivity indexes and to produce hot metal with costs each time lower has led to deep analysis of the factors that affect the cost and the behavior of these reactors. V & M do Brasil is conducting such studies, which have increased since the economic crisis in late 2008, using historical data on raw materials consumption and blast furnaces hot metal production and turning them into information for evaluate the production cost and achieve better planning and economic results for the company. The models developed are based on statistical techniques of Response Surface Models (RSM) and Linear Regression. These models are used strategically to make a cost immediate estimate and the decisions on the offers and opportunities in the market of raw materials for immediate financial return. This work represents a major step in the blast furnaces operation, with a differential for V & M do Brasil, that left to set standard ferrous loads for blast furnaces and started to operate with greater flexibility and variability in the type of load seeks to achieve better economic results.

Key words: Charcoal consumption, blast furnaces, hot metal production, pellet.

1. INTRODUCTION

The need to always for increasing the blast furnaces productivity indexes and to produce hot metal with lower costs has led to deep analysis of the factors that affect the cost and the behavior of these reactors (GAO, 2009).

The great problem faced in the blast furnaces operation is the low stability due primarily to variations in raw materials quality parameters, in particular charcoal. For this, is very important to know well the raw materials characteristics that fuel the blast furnaces and the consequences for the operation, especially of charcoal, which represents 60% of the hot metal cost, beyond of iron ore, pellet and flux (CRUZ e BARROSO, 2007).

The hot metal manufacturing process is a great challenge in terms of complexity and cost, since it represents the largest cost of an integrated plant due to high prices of raw materials and redactors (CASTRO, 2002).

V & M do Brasil is conducting studies to reduce the hot metal production cost, which were increased at the time of global economic crisis in late 2008, using historical data on raw materials consumption and blast furnaces hot metal production and turning them into information to evaluate the production cost and achieve better planning and results for the company.

This work represents a great step in the blast furnaces operation, with a differential for V & M do Brasil, that left to set standard ferrous loads for blast furnaces and started to operate with greater flexibility and variability in the type of load seeks to achieve better economic results.

2. MATERIALS AND METHODS

The high uncertainty physics and chemistry of charcoal, the use of lump iron ore with significant heterogeneity, the climate great influence on plant, charcoal quality and the uncertainties of sampling and analytical of charcoal, practically unfeasible the use of thermochemical models. Until this problem is alleviated with better technologies of carbonization, it is necessary to use statistical tools (SAMPAIO, 2006).

The developed models to predict the blast furnaces charcoal consumption are based on statistical techniques of Response Surface Models (RSM) and Linear Regression (MONTGOMERY, 2004). RSM consists of mathematical and statistical techniques that are useful for modeling and analysis in applications where the response of interest is influenced by many variables and the objective is to optimize this response. The shape of a response surface is viewed by three-dimensional graphics known as contour plots or contour lines. In most RSM problems, it is unknown how the relationship between response and independent variables (factors) is. Overall, identify an appropriate approach to this relationship through a low degree polynomial in some region of the factors. If the answer is well modeled by a factor linear function, then the approximation function will be the order first model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \qquad (1)$$

Where $y =$ response, $x =$ variables (or factors), $\beta =$ regression coefficients and $\varepsilon =$ errors with normal distribution, mean 0 and standard deviation σ.

If there is curvature, then a higher degree polynomial have to be used as the order second model:

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{i<j}\sum \beta_{ij} x_i x_j + \sum_{j=1}^{k} \beta_{jj} x_j^2 + \varepsilon \qquad (2)$$

To estimate the beta coefficients is used the least squares method, which is the same method used to estimate the regression coefficients in multiple linear regression model.

The first models are based on V & M do Brasil two blast furnaces daily real consumption data from 2003 until 2010. As the blast furnaces have different characteristics, specific models were adjusted for each blast furnace.

Processing the data, the "outliers" were excluded, which are the days when there were shutdowns or reconnected blast furnace, since these could interfere in the adequacy of the fitted models. The parameters used in the model are summarized in Table 1:

Table 1. Parameters used in the models development.

Parameters	**Units**
Response	
Charcoal consumption (top + injection + losses)	kg/t hot metal
Factors	
Production	t hot metal
Injection rate	kg/t hot metal
Type of iron ore	%
Pellet	%
Season	
Rainy (November to March)	1
Dry (April to October)	0

The data were grouped into sets according to the ferrous load composition, i.e., in days groups with similar percentages of ferrous load consumption (% type of iron ore and % pellet). The blast furnace 1 data were grouped into 83 sets and the blast furnace 2 data in 140 scenarios.

The following step was to obtain the means and standard deviations of parameters (response and factors) of each scenario. It was also regarded the “season” that divides the data into the rainy months (January, February, March, November and December) and dry months (April, May, June, July, August, September and October). This worked data set was used for the elaboration of Response Surface Models using the statistical software MINITAB, considering the hypothesis tests for beta coefficients to determine the potential value of each parameter in the model and improving the model effectiveness by adding or removing one or more parameters, and also the multiple determination coefficient (R^2) as a measure of fit the model.

3. RESULTS AND DISCUSSION

3.1. Response Surface Models

The best Response Surface Models adjusted consider individual effects, quadratic and interactions with significance at 10% and have R^2 of 89.4% for the blast furnace 1 and 83.3% for the blast furnace 2.

3.2. Contour Lines

Contour lines (Figure 1), were prepared for the response "Charcoal consumption (kg/t hot metal)" varying according to the "Pellet (%) used in the ferrous load" (X axis) and the "Injection rate of powdered charcoal (kg/t hot metal)" (Y axis), with other parameters fixed, and considering the preset limits by the operation.

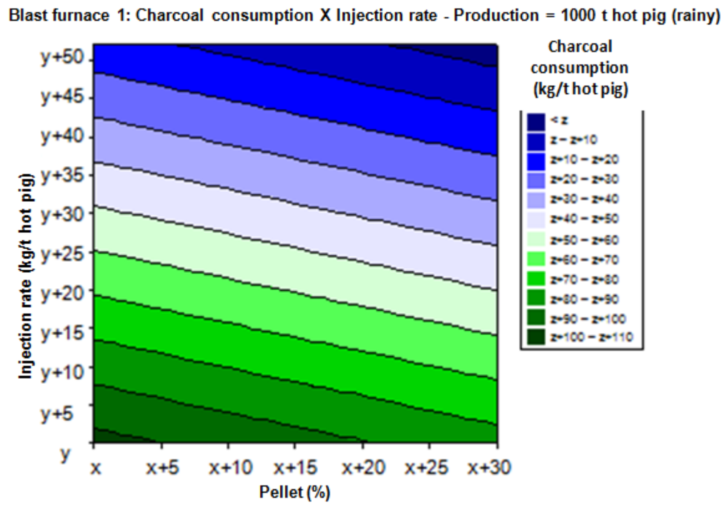

Figure 1. Example of blast furnace contour lines for hot metal production of 1000 tons during the rainy season.

The curves show a cost immediate estimate and are used strategically in front of offerings and market opportunities of pellet and iron ore with immediate financial returns through the achieve better economic results.

3.3. Linear Regression Models

To facilitate the use of obtained information with the contour lines, were drawn Linear Regression Models with the midpoints of each curve drawn so that this information could be used in the monthly and annual macro planning of hot metal production and raw materials consumption for blast furnaces.

Based on the planned daily production of blast furnaces, the first step is to determine what pellet percentage of total ferrous load will be used. Thus, linear regression models were developed as shown in Figure 2. For the blast furnace 1, the model has R^2 of 95.3%, and for the blast furnace 2, 90.9%.

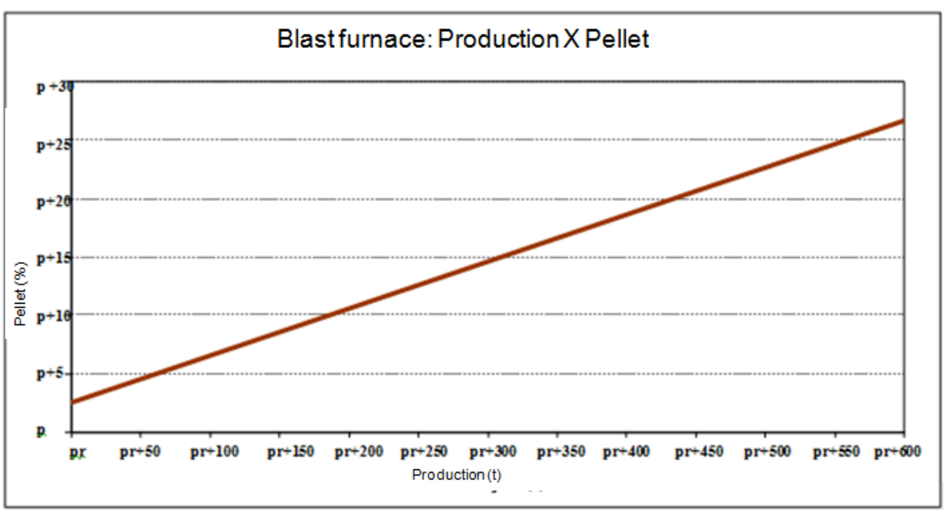

Figure 2. Model that determines the pellet percentage to be used in blast furnace ferrous load due to the daily hot metal production (t).

With the determined pellet percentage to be used in ferrous total load, the following step is to predict the blast furnace charcoal consumption in kg/t hot metal, considering whether the season is rainy or dry. This prediction is made by Linear Regression Models as exemplified in Figure 3.

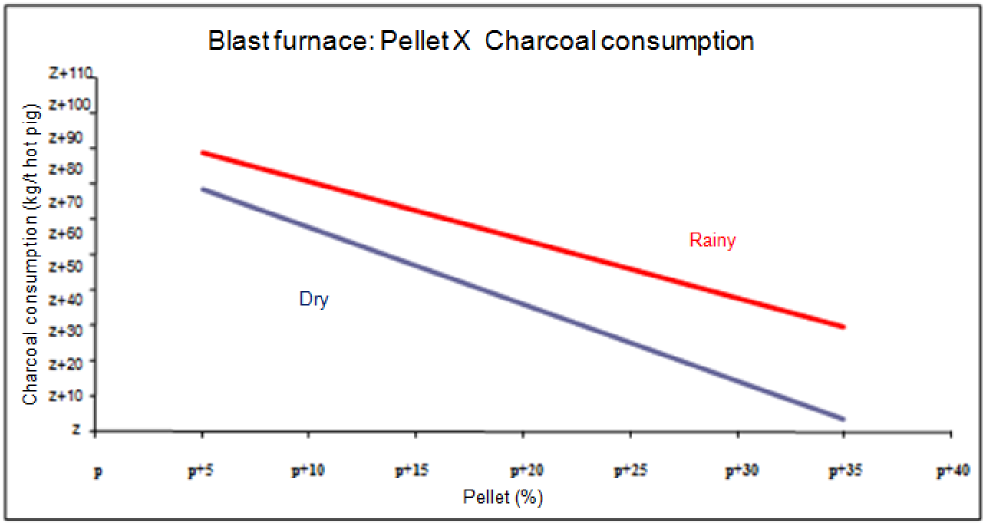

Figure 3. Models that determine the charcoal consumption (kg/t hot metal) versus the pellet percentage in the blast furnace total ferrous load.

4. CONCLUSIONS

Since July 2010 these models have been used to set targets for ferrous load and charcoal consumption and are showing good prediction.

The following step of this work is to build new models, considering also the 2011 data and correlating raw materials quality and heterogeneity, to assess their impact on the charcoal consumption. Thus, based on the qualities and expected changes in raw materials and their interactions, will be possible to predict the cost and evaluate the attendance with respect to the margin that the company wants to sell.

Having prepared this information, the company is able to act preemptively to make innovative business, and establish actions to reduce the hot metal production cost, to improve the raw materials processing, till the iron ore mine in another region, to seek charcoal from other farms, negotiate contracts, have visibility of what use and the price that can afford ferrous load, among other actions to work in the supply for blast furnaces with raw materials at minimum cost.

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