MATHEMATICAL MODEL OF CORRELATION BETWEEN THE INJECTION PARAMETERS IN THE BLAST FURNACES CRUCIBLE AND THE MAIN OBJECTIVE FUNCTIONS OF THE PIG IRON OBTAINING PROCESS

Victor ANDREI[1], Nicolae CONSTANTIN[2], Cristian DOBRESCU[3]

This paper aims at presenting a mathematical model for correlating the parameters which intervene in the physic-chemical processes that take place in the blast furnaces crucible, when using auxiliary fuels.

The presented mathematical model establishes correlations between the injection parameters described below, containing a number of equations so that any of the injection parameters can appear as an independent input variable (x_j), but also as an output function (y). The correlations are presented: $y = f(x_j),\ i = 1...n$, *as well as dependencies*: $x_j = f(y, x_i),\ i = 1...n$, $j = 1...n,\ i \times j$.

Keywords: blast furnace, coke, auxiliary fuels, tar, oil pitch

1. Introduction

The equations for the mathematical model were established having as basis actual operating data from the 1700 m^3 ARCELOR MITTAL Galati blast furnace.

For the calculation premises for the injection parameters the following achievable values were considered:

- Theoretical coke specific consumption (with 0% humidity), $K_{t(i)}$, of 600 [kg/t];
- Tar hourly flow injected in the tuyeres, $D_{gdr(i)}$, of 0-5000 [kg/h];
- Oil pitch hourly flow injected in the tuyeres, $D_{cls(i)}$, of 0-5000 [kg/h];
- Methane gas hourly flow injected in the tuyeres, $D_{gm(i)}$, of 0-9000 [Nm^3/h].

[1] PhD. assistant, Dept. of IMOMM, University POLITEHNICA of Bucharest, Romania, e-mail: victorandrei11@yahoo.com

[2] PhD, Dept. IMOMM, University POLITEHNICA of Bucharest, Romania, e-mail: nctin2014@yahoo.com

[3] PhD, Dept. IMOMM, University POLITEHNICA of Bucharest, Romania, e-mail: cristiandobrescu@yahoo.com

2. Preliminaries

The mathematical model contains calculation relations through which the hourly flow of tar, methane gas and oil pitch are being transformed into specific consumption, compared to a tone of pig iron.

The theoretical temperature in the combustion area is presented as an objective function, $T_{za(f)}$ as a dependency on the input parameter values, X_i. It can also be used in the mathematical model as an input variable with predicted values, $T_{za(i)}$, values that are obtained from real data processing operation of blast furnaces. In the equations of the mathematical model the specific heats of air , C_a, water vapors, C_w, and furnace gases, $C_{gf,}$ appear as variables, whose values, depending on the temperature, are found in the scientific literature [1],[2].

For the furnace gas specific heat the following relation was considered:

$$C_{gf} = 0.311 + 0.208 \times (T_{za(i)} - 273) \times 10^{4}, \text{ [kJ/kg×K]} \quad (1)$$

The calculation compositions for tar and oil pitch are presented in Table 1 and Table2.

Table 1

Calculation composition for tar

$C_{unbound}$	C_{total}	CH_4	C_2H_2	H_2O
55%	55.2%	13.6%	28.8%	5%

Table 2

Calculation composition for oil pitch

$C_{unbound}$	C_{total}	CH_4	C_2H_2	H_2O
43%	43.2%	15%	16%	5%

For the replacement index of coke through tar, methane gas and oil pitch the following values were considered [3]:

$$I_{coke}^{tar} = 1.08, \text{ [kg coke/kg tar]} \quad (2)$$

$$I_{coke}^{CH_4} = 1, \text{ [kg coke/Nm}^3 \text{ CH}_4\text{]} \quad (3)$$

$$I_{coke}^{oil\ pitch} = 1.04, \text{ [kg coke/kg oil pitch]} \quad (4)$$

The selected values for the calculation of these replacement ratios can be corrected depending on the functioning of the blast furnace.

2.1. Mathematical model

Hourly production of iron is determined using the relation:

$$P_{th} = \frac{Q_f \times n_i}{24}, \text{ [t/h]} \tag{5}$$

where Q_f represents theoretical quantity of iron obtained from a loading unit, [t/UI], n_i - number of units loaded in the blast furnace in one day.

The specific consumption of tar G_{dr}, methane gas G_m, and oil pitch Cls is determined using the equations:

$$G_{dr} = \frac{D_{gdr(i)}}{P_{th}}, \text{ [kg/t]} \tag{6}$$

$$G_m = \frac{D_{gm(i)}}{P_{th}}, \text{ [Nm}^3\text{/t]} \tag{7}$$

$$Cls = \frac{D_{cls(i)}}{P_{th}}, \text{ [kg/t]} \tag{8}$$

The equivalent quantity of coke replaced by auxiliary fuels was computed using the following equation:

$$K_{te} = I_{coke}^{tar} \times G_{dr} + I_{coke}^{CH_4} \times G_m + I_{coke}^{Cls} \times Cls, \text{ [kg/t]} \tag{9}$$

Thus the specific consumption of physical technical coke is determined using the relationship:

$$K_{tf} = K_{t(i)} - K_{te}, \text{ [kg/t]} \tag{10}$$

The hourly consumption of technological coke with humidity W_i is expressed by:

$$K_{th} = K_{tf} \times \frac{100}{100 - W_i} \times P_{th}, \text{ [kg/h]} \tag{11}$$

The quantity of technological coke with humidity, W_i (usually 1-3%), that is introduced in the loading unit is determined using the relationship:

$$K_{ui} = \frac{100 \times K_{th}}{100 - W_i}, \text{ [kg/UI]} \tag{12}$$

Using the combustion thermal balance in the crucible of the blast furnace, various forms of heat equality is generated by the main input parameters and the residual heat with the gas in the furnace. From this balance, a functional relationship between the input parameters and the main objective functions can be extracted.

Hourly gas flow, with a % of O_2 used for the gasification of coke and other auxiliary fuels that has to be introduced in the furnace, is determined using the relationship:

$$D_{gh} = 0.0054 C_k K_{th} + 1.392 D_{gdr(i)} + 2.425 D_{gm(i)} + D_{cls(i)} + \frac{1}{[\%O_2]}(0.729 C_k K_{th} + 97.75 D_{gdr(i)} + 57.5 D_{gm(i)} + 70.15 D_{cls(i)}) \quad (13)$$

where C_k represents the content of the unbound carbon of dry coke produced by its technical analysis (usually this value is between 84% and 88%).

The theoretical temperature can be determined with the following relationship:

$$T_{za(f)} = \{15.912 C_k K_{th} + 1583.24 D_{gdr(i)} + 439 D_{gm(i)} + 1120.94 D_{cls(i)} + D_{ah}[(C_a + 0.01\varphi C_{H_2O}) \times (T_a - 273) - 25.8\varphi]\} \div C_{gf} D_{gh} \quad (14)$$

where T_a and φ represent the air temperature injected in the crucible and its humidity [%].

From the thermal balance area of the crucible from which $T_{za(f)} = f(x_i)$ was extracted, a time relationship can also be extracted: $X_j = f(T_{za(i)}, X_i)$, representing the model of influence on a X_j component of the other input parameters X_i and of the resulting function $T_{za(f)}$ that became $T_{za(i)}$, therefore bearing the predicted values in accordance with the furnace operational requirements [4],[5].

By linearizing the complex expressions, through the method of partial derivatives around a point on the optimum value of the objective function, the following relationship was determined:

$$Y = a_0 + \sum_{i=1}^{n} \varepsilon_i^y \times X_i \quad (15)$$

where a_0- numerical coefficient; ε_i^y - bias coefficient that expresses the influence of the independent parameter X_i on the resulting function Y.

A positive value (+) of the coefficient ε indicates a proportional dependency between X_i and Y, also a negative value (-) shows an inverse dependency, respectively for $\varepsilon_i^y > 0$, the increase of X_i leads to the increase of Y and for $\varepsilon_i^y < 0$, the increase of X_i leads to a decrease of Y.

The absolute value of the coefficient ε_i^y shows, for several values of (i), the influence share of the X_i coefficient over the function Y, meaning that $|\varepsilon_1^y| > |\varepsilon_2^y|$ shows an influence greater of X_1 over Y than X_2.

Dependencies between parameters that intervene in the combustion zone are depicted in the following linear equations:

$$T_{za(f)} = 0.031K_{tf} + 0.036D_{gdr(i)} + 0.01D_{gm(i)} + 0.025D_{cls(i)} + 0.079D_{ah} - 270.21 \quad (16)$$

$$K_{th(f)} = 31.70T_{za(i)} - 1.143D_{gdr(i)} - 0.317D_{gm(i)} - 0.809D_{cls(i)} - 0.219D_{ah} - 8608.95 \quad (17)$$

$$D_{gdr(f)} = 0.425T_{za(i)} - 0.874K_{th} - 0.277D_{gm(i)} - 0.707D_{cls(i)} - 0.219D_{ah} + 52656.395 \quad (18)$$

$$D_{gm(f)} = 99.98T_{za(i)} - 2.996K_{th} - 3.606D_{gdr(i)} - 2.551D_{cls(i)} - 0.793D_{ah} - 32254.73 \quad (19)$$

$$D_{cls(f)} = 39.18T_{za(i)} - 1.174K_{th} - 1.74D_{gdr(i)} - 0.39D_{gm(i)} - 0.31D_{ah} - 12725.03 \quad (20)$$

$$D_{ah(f)} = 126.05T_{za(i)} - 3.77K_{th} - 4.546D_{gdr(i)} - 1.26D_{cls(i)} - 3.21D_{cls(i)} - 40871.57 \quad (21)$$

$$T_{za(f)} = 1.29\times10^{5}T_{za(i)} - 3838.23K_{tf} - 4656.58D_{gdr(i)} - 1291.17D_{gm(i)} - 3294.11D_{cls(i)} + 75.88D_{ah} + 955.53\times10^{5} \quad (22)$$

where T_{za} theoretical temperature from the combustion zone, [K]
W_{gdr} - water content from tar and the steam used at injecting the tar. [%]
D_{gdr}, D_{gm}, D_{Cls}–technological coke specific consumption, [kg/t];
D_{ah} - hourly air flow necessary for burning the fuel at the tuyeres, [Nm^3/h];

3. Conclusions

The equations were obtained from the mass and energy balances, applied in the combustion zone in the furnace crucible, starting with the physic-chemical relationships between the parameters in the combustion zone (C_k, K_{tf}, D_{gdr}, D_{gm}, D_{Cls}, O_2) as defined above.

For the cokes replacement ratio through various auxiliary fuels, values were used that were adopted by all field specialists, values confirmed by the furnace real data.

The presented mathematical model is used for the process of obtaining pig iron in the blast furnace, assisted by the computer.

If in the process simulation using an initial input set of values, abnormal results are obtained, then a new set of values is used that can lead to results similar to those obtained in the real practice.

The simulation is done using the equations from the model; out of the simulation, important conclusions are drawn and the correction coefficient for some equations can be determined.

A model can be obtained that can precisely reproduce the development of the process in the combustion area of the blast furnace. This model can contribute to the implementation of the advanced techniques regarding the obtainment of pig iron in optimal conditions, through a perfect correlation of the injection parameters.

The mathematical model presented in the paper represents a computer software support that can be used to conduct dynamic and conversational processes in the furnace. By this date no furnace is being fully conducted using process computers.

Maximum productivity, in conditions of minimum specific consumption, could be obtained using a conversational system.

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