MODELING OF METALLURGICAL CONTINUOUS PROCESSES IN THE BLAST FURNANCE

Pompilia HERA[1], Florin BÎRLAN[2], Iulian OPRESCU[3], Elena-Maria ALEXANDRU[4], Marius HERA[5]

Lucrarea prezintă o analiză pertinentă a parametrilor procesului tehnologic de obținere a fontei de primă fuziune (în furnal). Dintre cei peste 300 de parametri ce intervin în acest proces numai un număr foarte redus (cei de proces) sunt folosiți în diferitele programe de modelare şi conducere automată. În urma analizei, cei peste 40 de parametrii sunt grupați în trei categorii: şarjă, aer consumat şi umiditate. Această operație fiind primul pas pentru un model de conducere cu trei sute de intrări şi una până la trei ieşiri.

This work presents a relevant analysis of the technological process parameters for obtaining first fusion cast iron (in the blast furnace). Of the over 300 parameters involved in this process only a very small number (the process) are used in various programs of modeling and automatic management. In the analysis, more than 40 parameters are grouped into three categories: charge, consumption air and air humidity. This operation is the first step leading to a model with three hundred inputs and one to three outputs.

Keywords: modeling, metallurgical process, automatic management, blast furnace

1. Introduction

The technological process in blast furnaces has the purpose of reduction iron ore and obtaining cast iron with the given structure and temperature. The features which are of interest in terms of automation possibilities are: the large surface of the materials being in thermal and chemical processions; undefined nature of the active parts, at the surfaces which participate at the mass and heat transfer; the coexistence of all forms of thermal transmission (radiation, conduction, convection), which makes difficult the mathematical modeling.

[1] PhD Eng., INTEC SA, Bucharest, Romania, e-mail: pompy19752002@yahoo.com
[2] PhD Eng., OMV PETROM, Bucharest, Romania
[3] Prof., Faculty of Materials Science and Engineering, University POLITEHNICA of Bucharest, Romania
[4] M.S. Faculty of Letters, University of Bucharest, Romania
[5] Eng., MAPN, Bucharest, Romania

The main target of automation consists in creating optimum conditions for carrying out the blast furnace processes. This task is complicated by the fact that the process takes place in the entire volume of the blast furnace and automatic action can be achieved at his side. In the technological process control and regulation of the blast furnace, we distinguish two distinct paths: the upper routing, which involves changing the application ore coke, coke and ore-flux alternation, the mass and distribution of materials, fill level, gas pressure from the entrance of the blast furnace, as well as directing the bottom, which involves changing the quantity, composition, distribution and air temperature and combined natural gas. Leading from the top is more economical, but is characterized by large delays. Leading from the bottom is effective [1]. Schematic diagram of control actions is given in Figure 1.

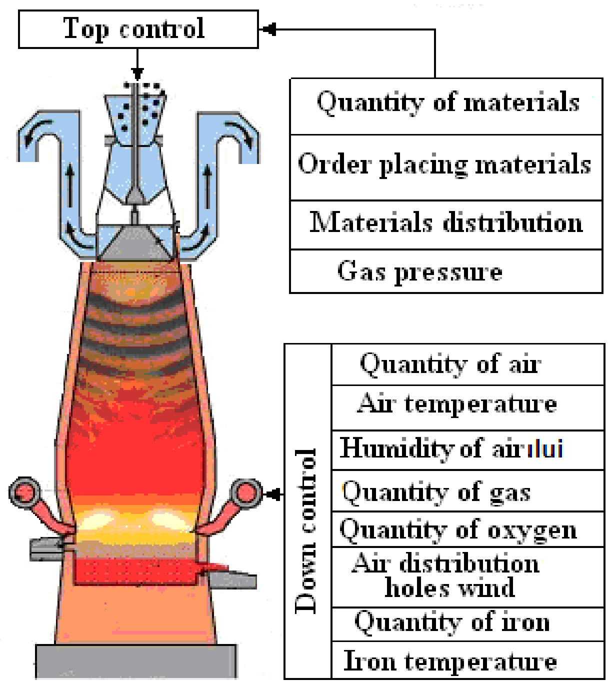

Fig. 1. Automatic Driving of the cast iron preparation

The complexity of physic-chemical phenomena in the blast furnace complicates the problem. However, despite the mutual relationship between the factors acting on the development, the general task of the automation can be divided into a series of partial problems (local) whose solving allows rational selection and stabilization schemes of the blast furnace operation, in particular, we develop methods and means of control (automatic) by introducing a load drop of the load material, and gasodynamic thermal regime of the blast furnace. Each of these particular problems can be solved in turn of stabilizing the system parameters.

2. Automatic control of blast furnace parameters

Driving the process in the blast furnace is made based on information given by the transducers, or the results obtained from physical-chemical analysis of coke or iron ore. The large number of sizes make the process' and the aggregate's analysis difficult to control, which is why they currently use centralized control systems and simulators keyboards. This check is performed on eight main areas:

- the chemical composition and the physical properties of the charge material
- charging the materials
- upper zone of the blast furnace condition (of the charging entrance)
- condition of the blast furnace tank
- parameters of combined air
- the condition of the lower zone of the blast furnace
- techno-economic indicators of the charge
- the air heaters condition (cowpers)

The parameters controlled by each of the elements of Scheme 2 are given in Table 1.

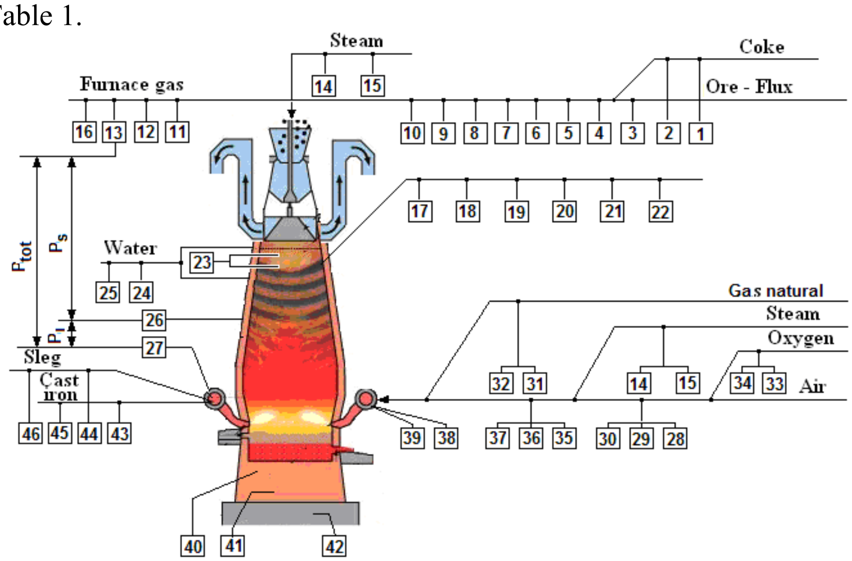

Fig. 2. The scheme of the controlled parameters

Table 1

Automatically controlled parameters of the blast furnace

Nr. from the Scheme	The controlled parameter	Nr. from the Scheme	The controlled parameter
1	Physicochemical structure of the ore and the flux	24	Cooling water consumption
2	Physicochemical structure of the coke	25	Pressure of the cooling water at different positions
3	Ore's charging	26	Pressure in the tank blast furnace
4	Coke's charging	27	Air pressure in the annular pipe
5	The number of charges	28	Cold air quantity
6	The order of charged materials	29	Cold air pressure
7	Cones functioning	30	Cold air temperature
8	The level of the charge	31	Natural gas quantity
9	The position of the rotary distributor	32	Natural gas pressure
10	The distribution of the materials in the blast furnace	33	Oxygen quality
11	The pressure of the evacuated gas	34	Oxygen pressure
12	The temperature of the evacuated gas	35	Oxygen content in the air
13	The pressure of the gas at the charging entrance	36	Hot air humidity
14	Steam consumption	37	Hot air temperature
15	The pressure of the steam introduced in the blast furnace	38	Air distributions in the wind holes
16	Pressure in the space between the cones	39	Natural gas distribution on wind holes
17	Temperature at the circumference of the charging entrance	40	Temperature in the zone of the wind entrances
18	Temperature at the charging entrance	41	Hearth oven temperature
19	The CO contained by the entrance gas	42	Blast furnace base temperature
20	The CO_2 contained by the entrance gas	43	Cast iron temperature
21	The H_2 contained by the entrance gas	44	Slag temperature
22	The CO, CO_2, H_2 in the entrance gas	45	Silicon and sulfur content in cast iron
23	The temperature at the tank's circumference	46	Slag basicity

3. Automatic adjustment of blast furnace operation

The normal functioning process is the one when the column of material goes down uniformly.

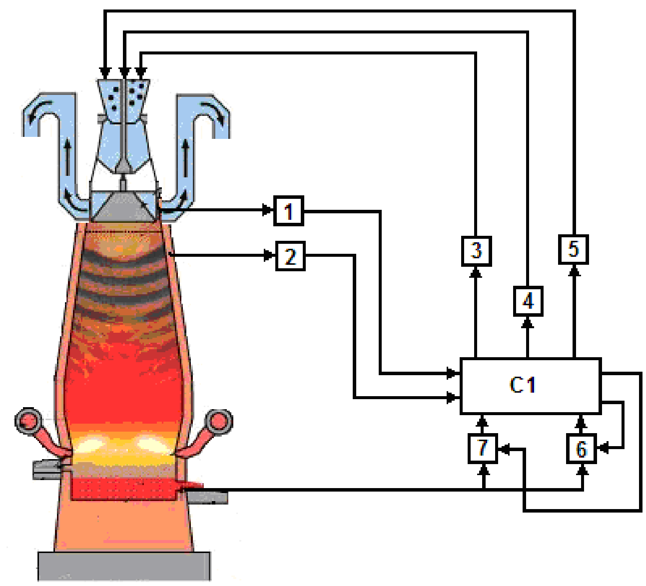

Fig. 3. Blast furnace's scheme of the complex automation
1-CO distribution transducer at the charging inlet; 2- transducer of the temperature distribution; 3 - system for controlling load order of the blast furnace, 4 - control system of the angle of rotation of the rotary distributor 5 - system for filling level control, 6, 7 - transducers for air distribution and natural gas at the wind inlets; C1– PC

Forces acting on the spine are opposite and depend on many factors. The main driving force that opposes weight lifting column is given by the gas stream. There is a critical point in its operation, in which the material remains in suspension.

Direct information about the moving column of material is received from the mechanical probes or isotopes ones, whose accuracy is higher. Indications probe turns into speed of the column material.

Auxiliary information concerning the flow of gas opposite the material column are the ones that refer to the static pressures in several zone of the blast furnace and to the distribution of CO_2 on the diameter of the blast furnace.

The main actions to control the operation of the blast furnace are:

- the charging order of the materials when the functioning conditions are violated on the top of the blast furnace

- changing air consumption and its humidity to raising the resistance in the lower zone of the blast furnace

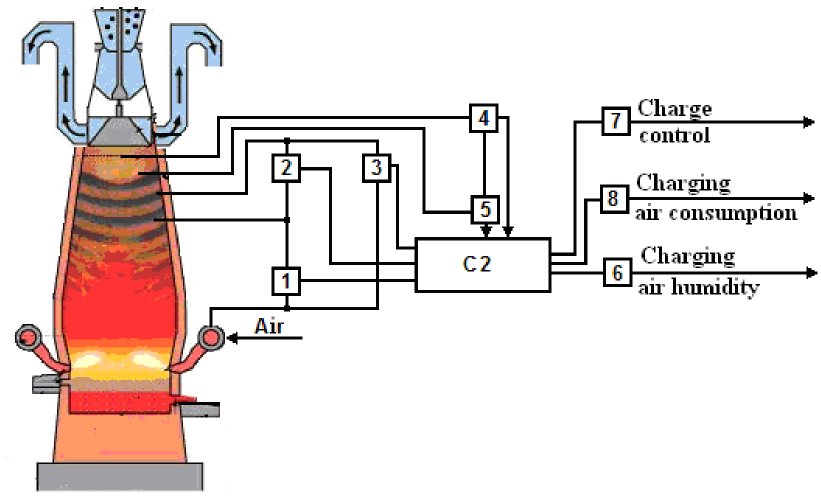

Fig.4. Scheme for automatic blast furnace operation
l, 2, 3 – lower, upper and total fall's pressure transducers, 4 – column's speed transducers, 5 – CO2 distribution transducer, 6 - humidity control system, 7 - system load control, 8 - control air consumption system; C2 – PC

Structural diagram of automatic adjustment is given in Figure 4. In the C2 computer are sent the speed 4 signals from the transducers, diameter distribution of CO_2 after 5, total pressure drop in the blast furnace (P_{tot}), higher fall (P_s) 2, and low fall (P_j) 1. In accordance with the adjustment program, the C2 computer gives commands to change the order of loading materials 7, 8 air change consumption and humidity of 6.

4. Proposed mathematical models

Technological complexity, the large number of parameters to be controlled and regulated in the dynamic regime, is very difficult to continue the operation of Automatic Control. Making partial and general models become so not only necessary but mandatory, if you want performance. The basic elements from which to start, are presented below.

The first model has been developed for the simplest case of the blast furnace operation: 100% load crowded auto –slag with high Fe content, null hydrogen reduction (dry air and no hydrogenated coke), and obviously, auxiliary fuel additives [4].

In this model three heat changing zones of the blast furnace are defined:

-top or loading area where solid charged materials are rapidly heated to 950... 1000 °C, the temperature difference between solid and gas gradually decreasing;

-intermediate zone (thermal reserve), in which there were exchanges of heat, solids and gases about the same temperature (950 ... 1000 °C) on a high appreciation from the bottom of the tank;

- the lower zone in which the temperature difference between gas and solid materials is growing very quickly up the wind holes the heat exchanges come back to their intensity.

These three areas of thermal exchange are assimilated with three exchange oxygen zones: in the superior zone the indirect reduction of Fe_2O_3 and Fe_3O_4 by CO to wüstite (FeO) takes place in the intermediate zone the composition of the gas phase corresponds to the iron- wüstite –gas equilibrium and in the lower zone wüstite reduction at iron takes place.

For a charging and a given cast iron quality, the expressions of the thermal balance and of the low zone oxygen make up a system of equations constituting the mathematical model of the blast furnace process.

From the oxygen balance equation an index of productivity per unit of blast furnace, I_p (t cast iron/1000 dm^3 dry air) is derived and the heat balance equation is derived from W_u parameter (kcal/ton of cast iron), which characterizes the thermal state of the development area.

The oxygen balance has:

a) oxygen flow transferred by charging gas:

$$O_2^1 = P_h \cdot O_2^R ,\ [Nm^3 \cdot h^{-1}] \qquad (1)$$

where: P_h is the production of iron products per hour;

O_2^R - low oxygen from oxides.

b) the oxygen brought by the blown air

c)

$$O_2^2 = Q_a \cdot \frac{21}{100} ,\ [Nm^3 \cdot h^{-1}] \qquad (2)$$

where: Q_a is the air flow blown with 21% oxygen

d) oxygen volume corresponding to carbon reduction of the water vapors:

$$O_2^3 = \frac{1}{2} \cdot \left(O_2^{'} - O_2^{''}\right) ,\ [Nm^3 \cdot h^{-1}] \qquad (3)$$

where: $O_2^{'}$ – hydrogen flow evacuated in the blast furnace gas;

$O_2^{''}$-the hydrogen flow brought by coke

Noting with v_g the dry flow gas, in Nm^3/h,

$$O_2^{'} = v_g \cdot \frac{\{\%H_2\}_{gas}}{100} \tag{4}$$

Oxygen volume evacuated in blast furnace gas in form of CO and CO_2:

$$O_2^4 = \frac{1}{2} \cdot v_g \cdot \frac{\{\%CO\}_{gas} + \{\%CO_2\}_{gas}}{100} ,[Nm^3 \cdot h^{-1}] \tag{5}$$

the oxygen balance is:

$$O_2^1 + O_2^2 + O_2^3 = O_2^4 \tag{6}$$

and knowing that the Nitrogen balance is

$$v_g \cdot \frac{\{\%N_2\}_{gaz}}{100} = Q_a \cdot \frac{79}{100} \tag{7}$$

per hour deduction of the blast furnace is derived

$$P_h = Q_a \cdot \frac{0.79 \cdot (A + u \cdot B) - 0.42}{2 \cdot O_2^R - 11.2 \cdot u} , [t_{cast\ iron} \cdot h^{-1}] \tag{8}$$

where:

$$A = \frac{\{\%CO\}_{gas} + 2 \cdot \{\%CO_2\}_{gas} - \{\%H_2\}_{gas}}{\{\%N_2\}_{gas}} \tag{9}$$

$$B = \frac{\{\%CO\}_{gas} + 2 \cdot \{\%CO_2\}_{gas}}{\{\%N_2\}_{gas}} \tag{10}$$

and u is the ratio of H_2 and O_2 contents in the coke.

Productivity index, I_p for 1000 Nm^3 dry air is:

$$I_p = \frac{790 \cdot (A + u \cdot B) - 420}{2 \cdot O_2^R - 11.2 \cdot u} , [t_{cast\ iron} \cdot (10^3 Nm^3 \text{ dry air})^{-1}] \tag{11}$$

In determining the heat balance of the development area its supposed that at the exit of the training area, solid materials have a temperature of 1000 ° C, the temperature is identical to that of gas, the amount of carbon consumed in direct reduction of iron oxides is equal to the amount of gasified carbon.

Considering the reference temperature of 1000 ° C, heat balance includes:

* the enthalpy of humid air (Q_1)
* coke combustion heat input to the CO (Q_2)
* amount of heat consumed for regeneration of carbon monoxide by reaction- Bell-Boudouard (Q_3)
*W_u ceded power to gas for heat losses, indirect reduction with H_2 and CO of iron oxides, the sensible heat of slag and pig iron, direct reduction of oxides:

$$Q_1 + Q_2 = Q_3 + W_u \tag{12}$$

From which results:

$$W_u = Q_1 + Q_2 - Q_3 \text{ , [kcal/t cast iron]} \tag{13}$$

In detail, the model shows the energy W_u given by the relationship:

$$W_u = \frac{1}{I_p} \cdot \left[533 - 1.72h - \left(10 - \frac{t_a}{100} \right)(35.2 + 0.06h) \right] - 3.24 C_{RD} \text{ , [kcal/t cast iron]} \tag{14}$$

where: I_p is the productivity index presented above,
h - absolute humidity of blown air in g/Nm^3,
t_a - blast air temperature, ^oC;
C_{RD} - specific consumption of carbon for direct reduction, kg C/t $_{cast\ iron}$.

From the above, it is apparent that the model is based on the gas blast furnace analysis, the parameters A and B serve as varying the operating parameters of the blown air. Home court experimental determinations showed almost perfect agreement between Wu parameter variation, calculated according to the blast furnace gas analysis and cast iron quality. This shows the validity of the mathematical model presented.

The second model uses as function of performance the specific consumption of coke derived from the heat balance of the area which holds the direct reductions in coke burning.

This model makes reference to the low zone of the blast furnace, direct reduction processes and coke combustion, referred to eq. (15).

$$q_k = \frac{1}{650 + 1.4t_a - 11400\varphi_a} \cdot \{645\eta_{rd}[\%Fe]_f + 1866\eta_d[\%CO_2]_{\lim estone} + 1250[\%Mn]_f + 5460[\%Si]_f + 6290[\%P]_f + \left(200 - 2.7(\%CaO, MgO)_{sg}\right) \cdot Q_{sg} + 13000 + R + \frac{25d + 300}{P_F} + 4 + 0.86[\%Si]_f + 0.22[\%Mn]_f + [\%P]_f + 0.214 \cdot \eta_{rd}[\%Fe]_f + 0.272 \cdot \eta_d[\%CO_2]_{\text{limestone}} \quad (15)$$

where: q_k is the specific consumption of coke;

η_{rd} - direct reduction grade of FeO;

η_d - degree of dissociation of limestone at temperatures above 950 °C,

% E_f - the contents of elements in cast iron,

% $CO_{2limestine}$ - carbon dioxide content in limestone

Q_{sg} - the amount of slag, kg/100 kg cast iron;

R - a constant with values (0) for refining iron Bessemer, (3000) for a gray iron, (5000 ... 6000) for blast furnace ferroalloys;

d - diameter of the crucible blast furnace;

t_a - air temperature, ^oC

φ_a- relative humidity of the blown air.

In this relationship,% E_f, % $CO_{2limeston}$, Q_{sg}, d varies slowly and in small range so they couldn't be considered constant.

T_a, φ_a sizes are independent controllable variables, continuously measured and their values are introduced in the calculation.

η_{rd} and η_d sizes are also controllable independent variables that determine the continuous analysis of blast furnace gas. Also having the base of a blast furnace heating system a reduction criterion (ε) was also established

$$\varepsilon=\eta_{rd}+a_1 \cdot \frac{M}{K}+a_2.\varphi_a-a_3.t_a, \quad (16)$$

where: $\cdot\frac{M}{K}$ is the ratio of ore/coke in the charge, and a_1, a_2, a_3 - constant for a given blast furnace.

Another area studied on the basis of models is the crucible. From the heat balance of the area crucible it results the optimal amount of heat in this area:

$$Q_c=Q_a \frac{12 \cdot H_1\varphi_a(1-C_a)\{\%O_2\}_{air} + 0.5\varphi_a}{22.4 + C_{a\cdot} \cdot t_a - H_2 \cdot \varphi_a} \text{ , [kcal]} \quad (17)$$

where: H_1, H_2 are the thermal effects of carbon combustion reaction, namely dissociation of water vapors, kcal / mol,

C_a - the air specific heat, kcal/m^3.grad

Q_v (the heat quantity resulted by burning the coke in the wind holes) is given by:

$$Q_v=n.Q_a.C_g.t_g, \text{ [kcal]} \quad (18)$$

where: n is a coefficient given by the volume of gas / air volume,

C_g, t_g- specific heat and gas temperature.

Another theoretical model developed by assessing the thermal blast furnace contains three indicators:

$$a=\frac{(O_2)_{gas}}{(C)_{gas}}=\frac{O_2 quantity\ \ that\ \ passes\ into\ the\ gas}{the\ \ quantity\ of\ \ C\ from\ coke\ that\ \ passesin\ \ gas}; \quad (19)$$

$$b=\frac{(O_2)R_i}{(C)_{gas}}; \quad (20)$$

q- heat consumption per unit of cast iron weight,

where: (Q_2) R_i is the amount of oxygen that results in indirect reduction processes.

These three factors are expressed in terms of gas composition.

Based on continuous analysis and control of air blowing parameters, the computer determines the instantaneous values a, b, q and compares them with reference values a_0, b_0, q_0 established by previous analysis from which was obtained the cast iron of superior quality.

Adjustment is performed by varying parameters indicators of the blown air (t_a, f_a) and of its flow Q_s whose needed values result from the relationships:

$$t_a=\frac{q_0\cdot a-(1254+6040b)}{\frac{50}{(O_2)_{air}}(1-2a+2b)+C_a} \quad (21)$$

$$a=\frac{1}{9.38}t-\frac{q_o\cdot a-(1254+6040b)}{\frac{50}{(O_2)_{air}}\cdot(1-2a+2b)+C_a} \quad (22)$$

5. Conclusion

Developing iron the first merger is a complex process which contributes to perfection a large number of parameters: you load of power system, the sealing system, components of the load of air and / or fuel to enhance combustion of slag , etc. of iron. Automatic management of this process taking into account all parameters must be forcefully. This work was a first step in developing a management model with hundreds of inputs (input parameters) and one to three outputs.

Problems with the complexity of metallurgical processes of continuous type can be solved by using modern methods of Automatic Control: modeling and simulation management.

Abandoned old ideas because IT capabilities (software - hardware) that could be applied at the time, deserves to be reconsidered and reversed. The results of these replays are spectacular given the right development in areas such as the first fusion iron.

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