Research Article

Modeling and simulation for the control of post-combustion in the conditions of the nickel reduction process

Abstract

Complex physical and chemical processes occur in reduction furnaces, characterized by multiple inputs and multiple outputs, strong interactions, nonlinearities and dynamic characteristics that vary with time. Attempts to control the oven using classical control strategies have not been successful. Taking into account that the operation is carried out by operators based on their experience, skill and on the historical behaviour of the process variables, experimental identification is carried out in the afterburning area, with the scoop of knowing the dynamics of the process for its better study and understanding. The identification gives us the possibility of obtaining a mathematical model as close as possible to the plant, which can be used to propose a strategy of temperature control in households 4 and 6 of the furnace. A survey is made of the main theoretical aspects related to the processes of nickel reduction and identification, as well as the input signal to excite the system. The experiments that were carried out are described and the mathematical models obtained are validated, using as tool of calculation the "Toolbox" of identification of the MATLAB program finally an economic and environmental analysis of an adequate control in the post combustion is presented.

Keywords: mathematical modelling, reduction, lateritic mineral, identification of systems

Deynier Montero Gongora
Higher Metallurgical Mining Institute of Moa, Cuba

Correspondence: Deynier Montero Góngora, Higher Metallurgical Mining Institute of Moa, Cuba, Tel 24-604476, Email dmonterog@ismm.edu.cu

Introduction

The nickel producing companies have the following mission: Increase and diversify the nickel and cobalt production, reaching the international standards of metallurgical efficiency, production costs and productivity (...).[1] Hence, the scientific research oriented to the knowledge of the process, the development of dynamic mathematical models that represent the physical-chemical phenomena of the plants, the computer simulation of their characteristics and finally the project and implementation of control systems, is a issue of fundamental importance for the current development of the industrial sector.

In the Caron process for obtaining nickel from the laterite ore, one of the most important equipment is the reduction furnace,[2] which is used for the selective reduction of nickel and cobalt oxides to their corresponding metallic forms , which makes them suitable for carbonate-ammonia leaching.

This technology is suitable for processing serpentine and lateritic minerals, but during the reduction there are notable losses due to the formation of crystalline structures of iron spinels, olivines and pyroxenes that trap nickel and cobalt in the form of oxides and to a lesser extent in metallic state, and the appearance of high metallic iron content in the reduced ore, which results in a decrease in the extraction of nickel and cobalt in the leaching process.[3] These losses are increased when the temperature profile and/or the gaseous profile inside the reduction furnace is violated, hence the importance of temperature control therein.

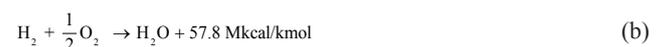The technological process of nickel reduction is a very complex process, it is stated that in homes 4 and 6 of the furnace independent control loops have been previously implemented for the temperatures, which have come into conflict due to the manipulation of both the flow of air from the same duct that branches into two branches.

The need to have a precise mathematical model, usable for control purposes that takes into account the complex dynamics of the post-combustion sub-process is taken as a research problem.

In order to solve the problem, the objective of the research is to obtain a dynamic mathematical model of the process by applying experimental identification techniques, which can be used to propose a temperature control strategy in these households.

Description of the combustion subprocess with secondary air in homes 4 and 6 of the furnace.

In these homes air is introduced for the afterburning of CO and H_2 not consumed in the chemical reaction, with a double purpose; the first one of economic character, since:

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 + 67.6 \text{ Mkcal/kmol} \qquad (a)$$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O + 57.8 \text{ Mkcal/kmol} \qquad (b)$$

As can be seen, exothermic reactions (a) and (b)[4] are produced, and calories are released, which are used in the heating of higher households (4, 3, 2, 1, 0).

The second reason is of a social and economic nature, because when these gases are contacted with the sparks that are frequently produced in the electro-filters by electromagnetic effect, explosions

can occur, so that when values of CO and H$_2$ concentration are detected by Above the permissible limits, the gases are released directly into the atmosphere with consequent losses due to entrainment and the associated environmental contamination.

The physical-chemical phenomena that take place in the home 4 are relatively complicated; if we take into account the heat transfer phenomena that occur in the same and the existence of a certain degree of mineral reduction.[5] An analysis of these phenomena is offered.

Materials and methods

It is not difficult to realize that obtaining a mathematical model that describes the process from the phenomenological point of view would be extremely complicated, since the physical-chemical processes involved would lead to differential equations systems in partial derivatives, consequently non-linear and variable over time, therefore we opted for experimental identification to obtain approximate models for different points of operation.[6]

In this case, for the formal mathematical modelling of this sub process, an experimental identification method was used, consisting in applying as an excitation to the system binary pseudo random signals, which constitute an approximation to white noise, with special characteristics. The SBPA are periodic sequences that are coded by zeros and ones, and that have a period equal to: N=2m-1, where m is the order of the sequence. For the collection of data during the experiments carried out in order to identify the process, the Supervision and Control programs (Citect and EROS) were used.

Several experiments were performed with the SBSA, applying sequences of order 5 to the openings of the air flow regulating valves to homes 4 and 6; variables that were added to the Citect as a result of this study. Several replicas of the sequences were also planned in order to achieve an adequate length of the input signal and the historical records corresponding to the following variables were taken: temperature of homes 4 and 6 (TH4 and TH6), and opening of the regulating valve of air flow to homes 4 and 6 (AbH4 and AbH6).

From the analysis of the step responses prior to the system, a similar 10-minute time constant was estimated for both temperatures (TH4 and TH6). Hence the decision to use a switching time of the SBSA twenty times less than the time constant (30 seconds) and a sampling period of the measured signals of 10 seconds. It was also seen that for a significant change in the temperature of homes 4 and 6 to occur, the amplitude of the change in the opening of the airflow regulating valves to said homes must be at least 20%, for lower values the variables of interest are not sensitive.

The mathematical models that were obtained are parametric models. To process the data, the Identification Toolbox of the MATLAB professional software package[7] was used, which contains tools for obtaining mathematical models of dynamic systems based on the observed input-output data. The following describes the performance of one of the experiments carried out: 190 data were taken corresponding to the variables (TH4, TH6 and AbH4) with a sampling period of 10.0 s, after applying to the latter a SBSA of order 5 with 2 replicas . In this case the opening of the valve in H4 experienced a variation of 30 to 70% of its total travel.

The furnace was operating with a mineral flow of 21tn/h and the valve opening of H6 remained constant at 60%. Figure 1 shows the measurements of the input and output variables. For TH4, the best

model was 0E 231 with an adjustment of 64.86%, which is a model of order 3.

$$G(s) = \frac{TH4(s)}{AbH4(s)} = \frac{0.001031s^2 + 0.0002294s - 5.34\times10^{-7}}{s^3 + 0.06503s^2 - 3.137\times10^{-5}s - 3.416\times10^{-8}} \quad (1)$$
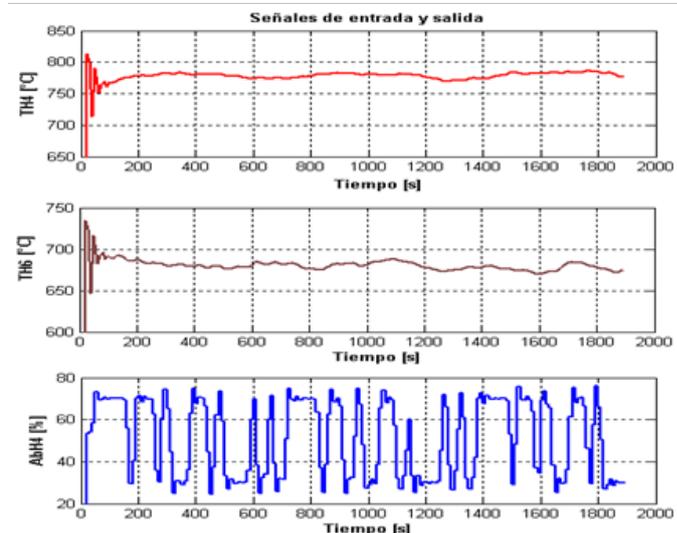

Figure 1 Input data & output of experiment # 1.

It was also taken into account the effect of the variation of the regulating valve of H4 on the temperature in the home 6, resulting also in a model of order 3:

$$H(s) = \frac{TH6(s)}{AbH4(s)} = \frac{0.001134s^2 - 7.854\times10^{-5}s + 1.12\times10^{-5}}{s^3 + 0.1197s^2 + 0.02352s + 0.0006715} \quad (2)$$

Figure 2 shows the residuals, where it can be seen that both the correlation function and the cross correlation function are within the confidence levels For the validation of the model in H4, the comparison of the output of the model with the real output was made, which is shown in Figure 3, where it is observed that the output of the model is quite close to the real one.
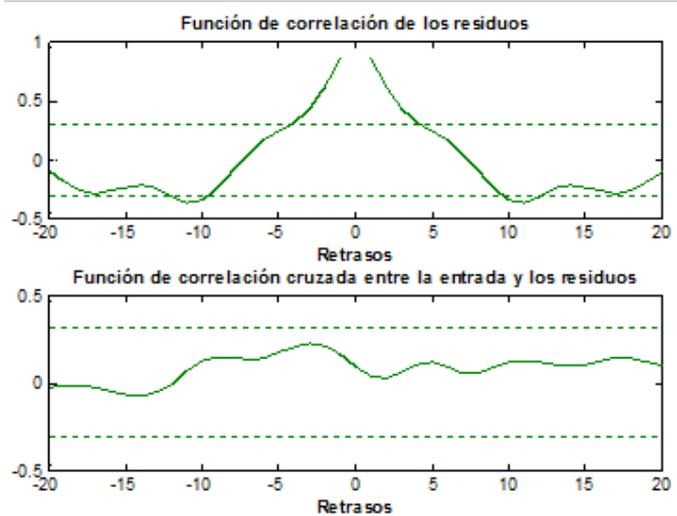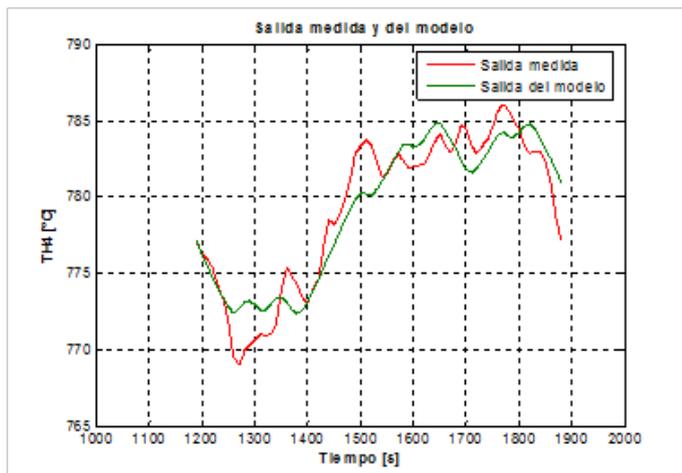

Figure 2 Residues.

Figure 3 Comparison of the output of the model with the output of the system.

Results and discussion

The process under control was characterized and the main variables were determined from its analysis as an object of automatic regulation, resulting in a multivariable system. Validation of the mathematical model was carried out by classical techniques; the comparison of experimental data obtained from the real process with the data obtained by the model was carried out, and the adequacy of the model was demonstrated to the object of study. It was observed that the waste is completely small compared to the levels of the output variables that are, reasonably, not correlated with the input and between them. As an economic effect, it can be suggested that the dynamic mathematical models obtained. For the post-combustion sub-process, the behavior of the variables will be studied of interest to design a control strategy in the afterburning area that contributes to guarantee an optimum temperature profile in the oven. Once the strategy of control must achieve efficient control of the furnace reducing atmosphere, thus decreasing the amount of gases (CO and H_2) that go to the dust recovery system, where you can produce faults in the electro filters, which would cause the output of them directly to the atmosphere with the consequent losses of ore due to entrainment and environmental pollution in area.

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflicts of interest.

References

1. Quintana R. *Conference on the Cuban Nickel Industry.* II Seminar on Perfection of Paintings, ISMM; 1999.

2. Castellanos J. Production of oxidized nickel minerals by the carbonate-ammoniacal scheme. *Mining and Geology.* 1986;4(2):77–80.

3. Miranda J, Chaviano L, Miranda JR. *New chemical-mineralogical interpretations of the lateritic and serpentine ores through the pyrometallurgical process in carbonate-ammoniacal technology.* CIL, Moa; 1998.

4. Tavio G. *Optimization of the reduction of nickel in reduction furnaces equipped with PRIOR cameras.* XVI Chemistry Conference, Santiago de Cuba; 1999.

5. Angulo M. *External control of the temperature in the home 4 of a nickel reduction furnace.* Technical University of Prague, Czechoslovakia; 1982.

6. Nath NK, Chakrabortiand NR, Shekhar. Reduction of Indian nickeliferrous ore in a fixed bed reactor with gas flowing vertically through the bed. *Scandinavian Journal of Metallurgy.* 1998;27:14–22.

7. Lennart Ljung. *System Identification Toolbox User's Guide.* The MathWorks Inc; 1988–1997.