Predictive control of thermal state of blast furnace

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Abstract. The work describes the structure of the model for predictive control of the thermal state of a blast furnace. The proposed model contains the following input parameters: coke rate; theoretical combustion temperature, comprising: natural gas consumption, blasting temperature, humidity, oxygen, blast furnace cooling water; blast furnace gas utilization rate. The output parameter is the cast iron temperature. The results for determining the cast iron temperature were obtained following the identification using the Hammerstein-Wiener model. The result of solving the cast iron temperature stabilization problem was provided for the calculated values of process parameters of the target area of the respective blast furnace operation mode.

1. Introduction

Traditional approaches to simulating and investigating the dynamics of various processes, including the most blast furnace cast iron production processes as well, often distort the vision of true objects’ behaviour. These circumstances result in the decreased efficiency of activities aimed at optimization, automation and improvement of the blast furnace production processes [1-5].

The modern methods for analysis of blast-furnace smelting processes are based on the achievements of multiple fields of science and technology. The issues of mathematical and physical simulation of the blast-furnace smelting processes, the experimental research are provided in the works [6-12]. However, the problem of all the existing models is the insufficient accuracy.

The main challenge in simulating the blast-furnace process facilities is that different multiple physical and chemical processes occur simultaneously within them [13]. In addition, the parameters stipulating the behaviour of these processes are difficult to measure and the set of controlling actions allowing one to perform experiments at the facility is limited [14]. With the traditional approach, common description of the system behaviour is based on the synthesis relying on the analysis of elementary situations and the laws acting in them. This approach, when applied to complex systems, due to a number of reasons (the occurrence of complex chaotic movements, the lacking visibility of the final result, the increased instability of the obtained result in case of the improved object description accuracy, etc.) results in the impossibility to obtain the properties of the whole by studying its parts [15-17].

The result of the above mentioned circumstances is that in simulating the blast-furnace processes it is necessary, while staying within the framework of the non-linear dynamics theory, to use the approach at which the model development is based on the indisputable generally accepted provisions being consistent for specialists, with excluding all the secondary processes, as well as non-observable and non-measurable parameters and variables from the model. The given class of models allow confirming and explaining the observable peculiarities of the blast-furnace processes and discovering new ones, solving the problems of optimization and automation of the blast-furnace process [18].
The purpose of the work is the development of bond models for the blast furnace processes effectiveness indicators and controlling factors and mode parameters.

2. The system for predictive control of the thermal state of a blast furnace

Figure 1 shows the structural diagram of the predictive control system of the thermal condition of a blast furnace.

Figure 1. The structural diagram of the system for predictive control of the thermal state of a blast furnace

In figure 1: F – measured values of influencing factors: natural gas usage, air blasting temperature, \( O_2 \), blast-furnace gas temperature, moisture content, \( Q_{cw} \), \( \frac{CO_2}{CO + CO_2} \), etc.; \( CR \), \( CR' \) – coke rate; \( T_{cT}^*, T_{cT}^M, T_{cT} \) – desired, model-made and actual cast iron temperatures; R – control regulator for the thermal state of a blast furnace.

The set (desirable) value of the cast iron temperature is at the input of the model shown in Fig. 1. The simulating predictive model is used to calculate the coke rate considering the measured values of the factors influencing the blast-furnace smelting process. The blast furnace thermal state control regulator is used to adjust the coke rate considering the deviation of the cast iron temperature calculated based on the model from the set value.

This model represents a non-linear dynamic MISO object (Multiple Inputs, Single Output) and may be set by the polynomial in the form of:

\[
T_{cT}(t) = \sum_{i=0}^{M} \left[ \int_{0}^{t} h_i(\tau_1, \ldots, \tau_i) : u(t - \tau_1) \cdots u(t - \tau_i) d\tau_1 \cdots d\tau_i \right],
\]

where \( T_{cT} \) is an output parameter – cast iron temperature, \( \tau_1, \ldots, \tau_i \) – the input parameters: coke rate; theoretical flame temperature that includes natural gas usage, air blasting temperature, moisture content and \( O_2 \); \( \frac{CO_2}{CO + CO_2} \); water for blast furnace cooling \( (Q_{cw}) \); blast-furnace gas efficiency \( (Q_{BFG}) \).

In practice, not the general Volterra-Wiener model is frequently used as the non-linear model, but its special cases - Hammerstein model and Hammerstein-Wiener model. The represented non-parametric identification methods employ the apparatus of integral equations. An alternative method of solving the identification problem was the neural network approach. While the application of integral equations for solving the non-parametrical identification problems is based on the known functional analysis theorems on linear and non-linear functional, the application of neural networks is based on the completeness theorems. Actually, it means that neural networks may be used to simulate...
any non-linear relationship provided the correct selection of network architecture and its correct learning.

3. The results of solving the cast iron temperature stabilization problem
As a result of identification using the Hammerstein-Wiener model, the experimental results for determining cast iron temperature were obtained. The comparison between the actual cast iron temperature and the calculated one, obtained from the model, is given in figure 2.

![Figure 2](image)

**Figure 2.** The comparison between the actual cast iron temperature and the calculated one, obtained from the model.

To stabilize the cast iron temperature in the system of the predictive control of the thermal state of a blast furnace, the coke rate value is adjusted.

Figure 3 represents the results for the experimental operation of the expert system for solving the cast iron temperature stabilization problem.
Figure 3. The results for the experimental operation of the expert system for solving the cast iron temperature stabilization problem.

During the experimental operation of the expert system to support the control of the blast-furnace process efficiency, the values of process parameters of the target area were calculated for the given operation mode of a blast furnace.

4. Conclusion
The work proposes the structure of the system for predictive control of the thermal state of a blast furnace. The calculated cast iron temperature was obtained following the identification using the Hammerstein-Wiener model. The result of solving the cast iron temperature stabilization problem was provided for the calculated values of process parameters of the target area of the respective blast furnace operation mode.

5. Acknowledgments
The work was supported by Act 211 of the Government of the Russian Federation, contract No. 02.A03.21.0011.

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