Automatic control scheme development for process of sulfatizing roasting of iron-manganese concretions in fluidized bed

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Abstract. The article describes the problem of regulating the process of sulfatizing roasting in a fluidized bed (FB) furnace of an enlarged laboratory facility for processing iron-manganese concretions (IMC) together with pyrite concentrate in a continuous mode. The features of roasting in the fluidized bed and technological factors affecting the control process and, as a consequence, the quality indicators of the technology are considered. The results of large-scale laboratory studies on a continuous installation of a FB controlled in manual mode are given. There is a scheme of adaptive automatic control of the roasting process in the FB with regulation of feed charge components. It allows maintaining a stable hydrodynamic state of the fluidized bed and control of key parameters, such as granulometric composition of the cinder, dust removal from the FB, blast pressure, temperature, etc., affecting the sulfatization of IMC metals.

1. Introduction
One of the leading directions of technical progress in industry is the intensification of technological processes. The desire to intensify chemical and metallurgical processes has stimulated the widespread introduction of the fluidized bed method. In non-ferrous metallurgy, processes carried out in a fluidized bed have taken a prominent place in the production of zinc, copper, nickel and other metals [1–3]. The intensity of the processes of roasting in the FB determines the need for their automation: in industrial operation under the influence of deep disturbances, only automatic control makes it possible to conduct these processes under technologically optimal conditions.

With the development and implementation of new technological processes carried out in a fluidized bed, new, more complex control problems have arisen [4, 5].

Fluidized bed sulfatizing roasting is a key operation for complex processing of iron-manganese concretions with pyrite concentrate [6]. This type of raw material is the most promising from the point of view of the replacement of continental manganese ore resources with alternative oceanic and marine [7–9]. The involvement of pyrite in the processing of the quality of the sulfatizing agent, as well as the associated extraction of valuable components, for example, cobalt, is also relevant and economically advisable [10–12].

2. Studies of the sulfatizing roasting of IMC as a control object
The fluidized bed as a control object belongs to the class of continuous multidimensional and multi-criteria dynamic objects. Uncontrolled disturbances, the inability to quickly obtain current information about the quality of the cinder, and a significant delay in obtaining information about the composition
of the components of the charge significantly complicate the task of quality control of the roasting process.

In the conditions of industrial FB furnaces, deep perturbations are unavoidable (in terms of load, chemical composition of the charge, etc.). To compensate for their effect on the particle size of the solid phase, it is necessary to change the nominal roasting temperature in a wide range (150-200 °C) [13].

At the same time, the speed of the control providing the transfer to the new nominal mode is very essential: a slow decrease in temperature will not be able to prevent the process from being disturbed. On the contrary, with an increased content of fine fractions in the cinder, it is necessary to raise the roasting temperature; the faster this is done, the less metal losses associated with dust removal will be.

Particularly serious consequences cause deep disturbances (for example, interruptions in the supply of the charge), occurring at the moment when the operator is distracted by the performance of functions that are not related to temperature control and are not able to compensate for disturbances at time. In such situations, it is often not possible to prevent emergency mode until the process stops.

Fearing this, many operators carry out the process “with a reserve”, in modes that are significantly different from the optimal.

At the same time, as practice shows, in order to avoid unjustified losses, it is necessary to maintain a given temperature mode, avoiding long-term deviations exceeding + 20 °C, except for transients during the elimination of deep perturbations.

As a control object in this work, a fluidized bed furnace for roasting iron-manganese concretions is considered. The prerequisites for the improvement of the furnace management process were studies based on the creation of an integrated technology for processing of IMC [14, 15].

Large-scale studies were conducted with samples of Pacific Ocean concretions, the Clarion-Clipperton zone with composition, %: Mn – 25.92; Fe – 11.33; Ni – 1.75; Cu – 1.09; Co – 0.27; and Pyrite with composition, %: Fe – 48.7; S-45; Co - 0.16; SiO2 – 4.7. The degree of sulfatization of non-ferrous metals and manganese was, %: Nickel - 48.97-78.38; cobalt - 56.19-90.41; copper - 48.14-74.57; manganese - 71.56-95.29.

Sulphatizing roasting was carried out in the modes set in the laboratory research. A major factor of steady course of roasting is ensuring particle size distribution, under which a uniform boiling of the cinder is established, which in turn leads to a stable temperature profile in the FB Furnace.

IMC have to be crushed with fineness of -0.4 mm that by results of preliminary research allows reaching uniform boiling with pyrite with fineness of -0.074.

The distribution of the temperature profile in the FB furnace showed that a constant temperature is established in the FB zone (the temperature deviation along the bed height is 15–20 °C). Along the height of the FB layer, the temperature decreases from 550 °C in the furnace layer to 310 °C under the furnace arch. The established temperature profile is optimal, as it provides the range of reactions for the sulfatization of metals of the IMC.

Temperature control in the layer was provided by the pyrite content in the charge and the feed rate of the charge to the furnace. It is established that the minimum temperature in the layer at which it does not decay is 420 °C. The Maximum temperature at which the stable boiling of the cinder is not disturbed is 700 °C.

Analysis of the properties of the control object, as well as a generalization of the experience of manual management of the sulfatizing roasting process, allowed us to formulate the requirements for the automatic control system (ACS).

In particular, it was found that the control actions were to be formed taking into account the current state of the control object, i.e. the ACS should be adaptive.

In order to ensure the stabilization of the roasting temperature in a wide range of nominal roasting mode and under conditions of deep disturbances in the load and content of pyrite sulfur in the charge, it is necessary to maintain a high speed of control. Otherwise, the effects associated with the agglomeration of particles of the solid phase of FB will lead to an emergency disorder of the process when the assumptions made in its mathematical models cease to be true.
3. Developing ACS Scheme

The algorithms of functioning of the ACS of FB include the control action regulating the flow of the roasting charge.

With an increase in the flow rate of the charge loaded into the FB with a low content of pyrite sulfur, the cooling of the FB occurs earlier than it can compensate for the heat generation due to desulfurization. As a result of the decrease in temperature, the rate of pyrite oxidation and, accordingly, the heat production begin to decrease, and this in turn leads to a further decrease in the temperature and the degree of sulfatization of IMC metals.

If at such moment one does not reduce selection of heat from the FB, for example due to the temporary termination of loading of furnace charge or correction of a ratio, then there is loss of thermal stability of the process. Temperature begins to fall sharply that can lead to the emergency furnace of a stop.

Therefore, it is necessary to develop such way of automatic control of process of roasting which would allow one to provide thermal stability of the process and to give all roasted products in the form of a sulphatic cinder end at high extraction of target components.

It is achievable by automatic control of temperature of the FB by means of two managing directors of influences: changes of consumption of the loaded IMC and a pyrite, that is, corrections of components in the furnace charge.

Figure 1 shows the scheme of automatic control of the process of sulfatizing roasting of IMC with pyrite in the fluidized bed. The scheme focused on implementation with automated process control systems roasting processing.

![Figure 1. Automatic control scheme of the process of sulfatizing roasting in the fluidized bed (FB): 1 – IMC feeder; 2 – pyrite feeder; 3, 5 – temperature sensors; 4 – fluidized bed (FB) furnace; 6, 7 – cyclones; 8 – dry filters; 9 – dust bunker; 10 – granulometric composition sensor; 11 – dust amount sensor; 12, 13 – correcting devices; 14 – air flow rate sensor; 15 – temperature correcting block; 16 – master controller; 17 – flow ratio correcting block; 18 – loading ratio controller; 19, 20 – feeders sensors.](image-url)
the setpoint. There are also signals proportional to the derivative of the temperature of the fluidized bed and the concentration of SO$_2$ in the roasting gases. The formation of the first control action on the flow rate of the loaded IMC is carried out by block 16 according to the functional law of dependence on the deviation of the FB temperature from the set value, its derivative and derivative of the SO$_2$ content in the roasting gases over time.

The formation of the second control action is carried out depending on the deviation of the FB temperature from the set value, the SO$_2$ content in the roasting gases, the derivatives of these values in time and the value of the first control action on the flow rate of the IMC. Communication between functional laws provides a hierarchical principle. The control actions formed by the controller 16 are used to control the consumption of the IMC and pyrite loaded into the furnace from the bunkers with the help of feeders. To maintain the specified thermal roasting mode, the pyrite loading is controlled by the feeder 2 using the ratio controller 18 on the basis of information from the sensors 19 and 20. A given flow ratio $\alpha$ serves for the block-corrector 17 system for the maintenance of the consumption ratio, which is the signal of the master controller 16.

The balance of the dust (fine fractions) is estimated according to the information received from the sensor 11, which allows one to determine the amount of dust coming from the cyclones 6, 7 and dry filters 8 in the bunker 9. If the balance is violated, it is necessary to adjust the technological mode. Therefore, the correcting device 12 is set to the value of the stock of small fractions (dusts) M, which must be maintained for stable control of the firing process. The actual stock of fine fractions (dust) from the given corrective device 12 enters into the controller 16. This has a correcting effect on changing the nominal value of the temperature of the fluidized bed on the block 15 for the formation of the control action and on the block 17 on the content of pyrite in the charge, supported by the regulator 18. Correction signals cease to enter after the stock made of fine fractions (dust) M returns to specified limits.

The stability of the hydrodynamic state of the fluidized bed can be estimated by the granulometric composition of the cinder, the pressure under the arch indirectly related to the entrainment of dust from the fluidized bed, fluctuations in the blast pressure and heat transfer coefficient, etc.

Using the information about granulometric composition of the FB obtained by the sensor 10, let us compare the information obtained with the information given by the correcting device 13, taking into account the FB temperature measured by the sensor 5 and the flow rate (air) measured by the sensor 14. This produces corrective actions in the controller 17 to change the nominal value of the FB temperature on the block 15 and forms the control action by the block 16, as well as on the block 17 in the content of the small fractions (dusts) in the charge supported by the regulator 18.

4. Conclusion
The regulatory impact of the ACS is the change in the components consumption of the charge (IMC and pyrite). Regulation is carried out by changing the speed of rotation of feeders’ drives. DC motors should be used as drives to provide the wide range of control required for temperature control.

The developed control scheme will ensure the uniform feeding of the charge components into the fluidized bed furnace and their smooth regulation in a wide range will significantly improve the efficiency of the roasting process since this parameter has a significant impact on the stability of the process, productivity and quality of material processing. Also, the main tasks in this direction are to reduce dust removal and optimization of the sulfatization process in the fluidized bed.

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