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STUDY OF HYDROGASDYNAMIC PROCESSES IN A SYSTEM OF TSL-REACTOR–SETTLER UNITS BY COLD MODELING METHODS

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A laboratory unit is assembled, criteria are substantiated, and tests are performed for the cold modeling of Ausmelt-furnace–settler systems. The article shows the potential of this approach for evaluating the overall productivity of the process, the condition of the bath, and the completeness of phase separation in the settler.
Keywords: *modeling, Ausmelt, autogenic processes, submersible lance, settling, phase separation.*

Top Submerged Lance (TSL) units – furnaces with a submersible lance (Fig. 1) – have come into wide use internationally for the production of nonferrous metals and the recycling of various types of technogenic materials. Furnaces of this type are characterized by their simple control. For example, by submerging or raising the lance, it is possible to control the rate of mixing of the bath and, if necessary, to control the completeness of the settling operation directly in the refining unit. Other advantages of the process are the low thermal inertia of the unit and the fact that the furnace can be shut down (or idled while hot) for an extended period of time and then quickly reheated after a "stoppage." The high unit productivity and the relatively low construction and maintenance costs must also be mentioned.

At the same time, certain limitations regarding the process of phase separation in the furnace proper lower the overall productivity of the refining operation. As a result, tensile units are also equipped with an external settler (electric furnace or mixer). The processes of forming and separating the metallic (matte) and slag melts are completed in the settler.

A furnace-mixer or rotary-furnace/settler (Rotary Holding Furnace, RHF) was initially used in international practice to make copper [1]. Later, copper smelters began to employ a system of units consisting of several parallel-operating mixers or electric furnaces [2, 3]. The main function of the settling unit is to obtain a slag which contains as little as possible of the component being recovered. The goal of this approach is to minimize mechanical losses of valuable metals while maintaining a relatively high settling rate.

The large number of different types of physicochemical, hydrogasdynamic, and mass- and heat-transfer processes that take place in the bath during its bubbling and the fact that these processes affect one another create certain problems in establishing general rules for blowing of the bath in pyrometallurgical processes. Thus, such rules might be most easily and most reliably found by cold modeling. The similarity theory and dimensional theory that serve as the foundation of cold modeling are now fairly complete [4, 5]. With the use of common assumptions, this firm foundation makes it possible to take the results obtained from studies employing transparent model liquids and visual observation and apply them to industrial equipment [6, 7].

Description of the model complex. The objective of this preliminary stage of the investigation is to evaluate the feasibility of using cold-modeling methodology to assess how the rate of mixing of two phases in a refining furnace and the rate (completeness) of the subsequent settling of the phases in the external unit of the overall TSL-furnace–settler system affect the productivity of the complex as a whole.

We chose to use 1:10 as the geometric scale, since this scale is the simplest to realize in an experiment and to use in subsequent calculations.

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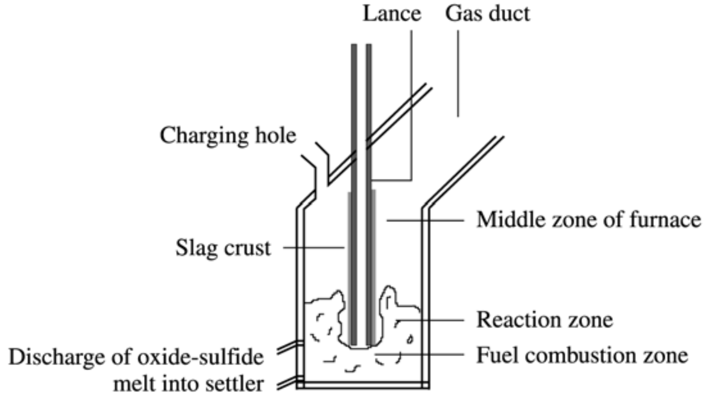

Fig. 1. Schematic diagram of an Ausmelt furnace and its main zones.

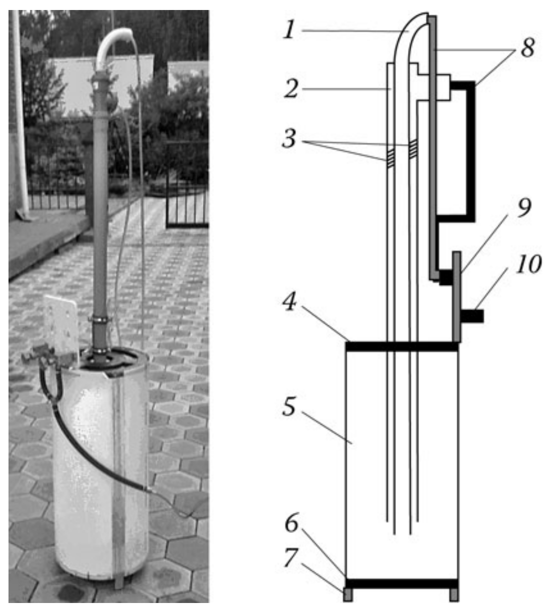

Fig. 2. General view and design of the model: *1*) internal tube of lance; *2*) external tube of lance; *3*) replaceable blocks of swirlers; *4*) top cover; *5*) housing; *6*) bottom cover; *7*) vanes; *8*) air lines to lance; *9*) panel with attached flowmeters; *10*) inlet reducers ahead of the flowmeters.

The model was made of plexiglass, plastic, and wood and had flexible hoses to deliver the air being injected. The main advantage of the model was that it made it possible to change the geometric parameters of different elements of the unit without having to completely disassemble it. A general view of the model and the flow scheme by which the unit operates are presented in Fig. 2.

We chose to use technical-grade oil (to model the slag) and water (to model the matte and the highly concentrated pulp) in preliminary tests. The ratio of the density of the phases was chosen as the main similarity criterion:

$$(\rho_1/\rho_2) - \text{idem}, \quad (1)$$

where ρ_1 and ρ_2 are the density of the slag and the density of the matte (kg/dm^3), respectively.

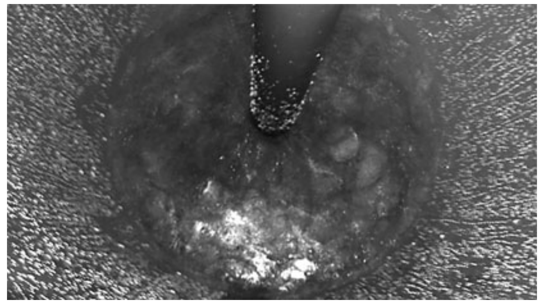

Fig. 3. Typical view of the bubbled region.

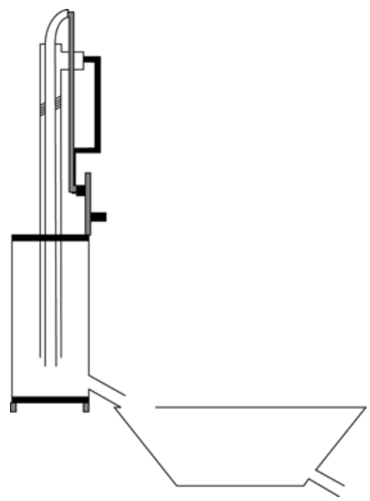

Fig. 4. Diagram of the master TSL-furnace–settler model.

Glycerin has been used to model slag in aqueous solutions [8], but its use in case being examined here would cause problems with the satisfaction of Eq. (1).

The source of the injected air was a compressor with a productivity of 250 liters/min. The power of the compressor could be regulated in accordance with the specifics of the modeling problem being solved.

The laboratory model was used to perform several trial experiments in which photographs and videos were taken of the bath. It was determined that a video camera with a speed of 100 frames/sec was adequate to quantitatively evaluate and diagram the rates of processes in the bubble zone. Such speeds can be obtained with standard digital cameras (Fig. 3).

During the tests, we examined different operating regimes in which air was delivered only through the outer or inner parts of the lance. The results show that the outer tube (the larger-diameter tube) has the most effect on the development of the hydroaerodynamic process (in the case of a one-phase system). However, the internal tube exerts the greater effect in the presence of two media differing in density. Evaluation of the hydrodynamic conditions established that the overall pattern of injection of the liquid with the use of submerged nozzles is different from the well-known data obtained in [9, 10] with the use of a simpler methodology for other furnace models.

The next stage of the investigation was to create a settler-containing master model (Fig. 4) that provides for the flow of material from the tensile-furnace model through a gate-equipped trough into a simplified settler model. In the case of a furnace-mixer, modeling of the settler does not present any problems because the dynamic regime of the furnace is affected only by the incoming mass of material. The effect of the burner installed in the upper part of the furnace on the hydrodynamics of the bath is slight and can be ignored. The settling process in the furnace-mixer is depicted in general form in Fig. 5.

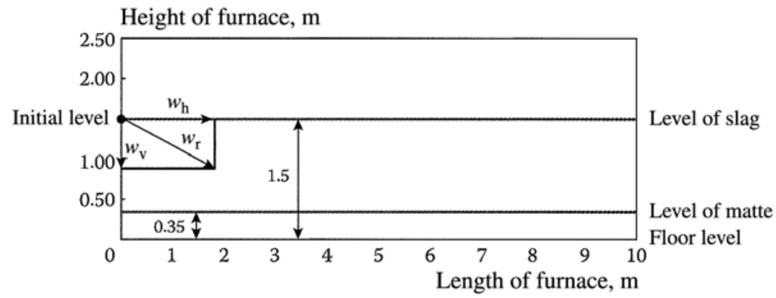

Fig. 5. Diagram of settling in a furnace-mixer with furnace length of 10 m.

When an electric settler is used (such as at the Tongling plant in China [9]), the settling process becomes more complicated because the presence of roof electrodes inevitably leads to thermal convection of the melt in the region near the electrodes. Agitation of the bath in the settler can adversely affect the completeness of the phase separation. This is separate topic that merits its own investigation on cold models.

The *mathematical description* reduces to three main parts: construction of the balances (material and heat balances); modeling of the mixing and settling processes with the use of different software packages; analysis of the data obtained from cold experiments to correct the mathematical models.

The Weber and Archimedes criteria can be used as the main criteria for the mixing and interpenetration of the fluids in tensile furnaces. The process of separation of the phases in the mixer can be described by means of the Stokes and Froude criteria.

We created a *simplified settling model* based on the calculated material and heat balances and operational data from metallurgical plants. The model is shown in Fig. 5 (where w_v and w_h are the vertical and horizontal components of velocity (m/sec), and w_r is the resulting velocity (m/sec)). It is described by the equation

$$w_v = (1/18\mu) g d^2 (\rho_2 - \rho_1), \tag{2}$$

where μ is the viscosity of the slag; g is acceleration due to gravity; $\rho_2 - \rho_1$ is the difference between the density of the matte and the density of the slag; and d is particle diameter.

The horizontal component of velocity w_h can be calculated from the formula

$$w_h = V_m / F, \tag{3}$$

where V_m is the volume of the pulp entering the settling tank per unit of time, m^3/sec; F is the cross-sectional area of the furnace, m^2.

This model makes it possible to calculate the number of matte particles that are captured by the slag phase over an arbitrarily chosen settling time.

The modeling of mixing processes is a more complex problem, since the software packages that have been developed for liquid media require a large amounts of computing power and time in order to numerically interpret operations in a system with prescribed parameters. One of the most widely used packages is Open FOAM, which makes it possible to construct complex liquid models – including models with multiple phases. This software can be used with a module that processes images from video recordings of the agitation of a one-phase liquid to convert the images to a set of two-dimensional diagrams of the type shown in Fig. 6.

A similar analysis is performed for two-phase systems. The recorded data is used to construct more complex three-dimensional models. Those models can then be used together with factory data on the temperature distribution at different levels of a piece of equipment to construct temperature profiles.

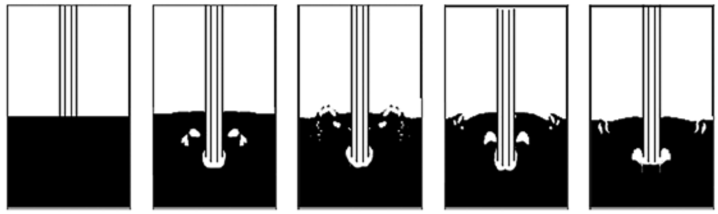

Fig. 6. Dynamics of the process of agitating a one-phase liquid.

As a result, it becomes possible to obtain a field of velocity vectors that shows the degree of interpenetration of two phases and the extent to which particles of the denser phase are entrained by the flow of the less-dense phase. Such information is important for correcting the input parameters of settling models.

The use of a comprehensive approach such as that described above makes it possible to create models that account for the actual hydrodynamic conditions in the bath of a unit equipped with a submersible lance and the effects of those conditions on the subsequent settling process and the quantities of valuable components lost with the slags.

Conclusions. Cold modeling is the only method that allows reliable and visually observable physical simulation of the processes of mixing and settling in pyrometallurgical units. By mathematically interpreting the results obtained from cold modeling which is performed on the basis of actual production data and theoretical studies, it becomes possible to design a laboratory unit for evaluating the effects of different dynamic parameters of these processes on the settling regime and the losses of valuable components. Trial experiments that were performed showed that it is possible to use cold modeling to predict the technical-economic indices of a TSL-reactor–settler unit.

In the future, it would be expedient to construct detailed multiphase models with the use of more accurate measuring instruments and more accurate methods of analyzing the results. It would also be advisable to more fully integrate the results obtained from dynamic modeling into the process balances and control systems of an Ausmelt complex.

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