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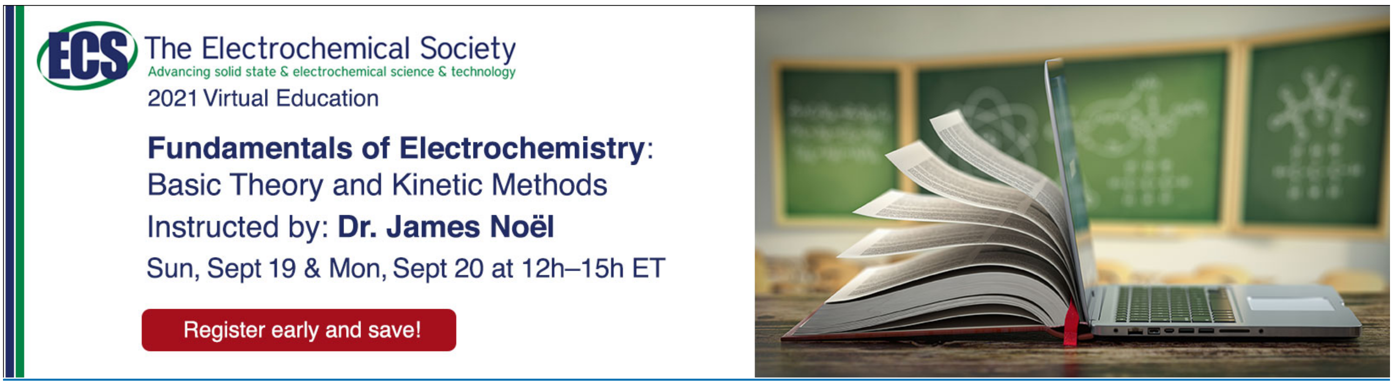

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Simulation of the electromagnetic processes in a metallurgical furnace with two bottom electrodes

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Abstract. The paper presented electromagnetic processes occurring in an ore reduction furnace with two bottom electrodes. The physical and mathematical formulations of the problem are given, as well as the methodology and algorithm for the numerical simulation of the problem.

1. Introduction

The paper devoted to the numerical simulation of electromagnetically processes in a new metallurgical furnace [1]. In comparison with other well-known methods for ironmaking and steelmaking, this furnace is more effective and environment friendly [1-8]. The numerical simulation is widely used in metallurgy, in particular for simulation of processes occurring in steel-smelting furnaces [9-10]. Carrying out experiments in metallurgy is an expensive and extremely complex task. The simplest and most effective way to evaluate processes in furnaces is a numerical simulation. A series of numerical simulation and analysis of the results allows us to optimize and organize the work of steelmaking furnaces. Steelmaking furnaces are constantly needed modernization, and improvement in the quality of the manufactured product, a reduction in the cost of smelting the metal, and improvement of working conditions.

In conditions of high and unstable prices for scrap metal and cast iron used in steelmaking, it becomes urgent to use metalized raw materials obtained not only from ore materials but also from industrial waste (scale, dust, and sludge), as a partial replacement of traditional types of charge. Technogenic wastes accumulated earlier and reproduced at metallurgical enterprises make the development of new energy-efficient, environmentally friendly technologies for their processing relevant. Laboratory investigations of the processing of iron-containing waste in an electric furnace were carried out in two stages: the first stage of solid-phase preliminary recovery, the waste passes in a furnace chamber with a vault for flue exhaust gases, which simultaneously heat the charge, and the second, liquid-phase stage in the bath of the furnace to produce cast iron.

2. The method description and first numerical simulation

According to the technological scheme of the process shown in Figure 1, the production of metal includes the following operations:

– continuous loading of pre-mixed components of the charge in the furnace shaft, wherein the conditions of a countercurrent with hot exhaust gases of the process the preliminary solid-phase reduction takes place;

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– melting of charge materials and liquid-phase metal reduction due to Joule heat released in the slag bath during the passage of electric current between the bottom electrodes, as well as in the oxidation of the charged carbon and the metal bath with gaseous oxygen;

– periodic production of metal melt – reduced liquid metal and slag through special tap holes.

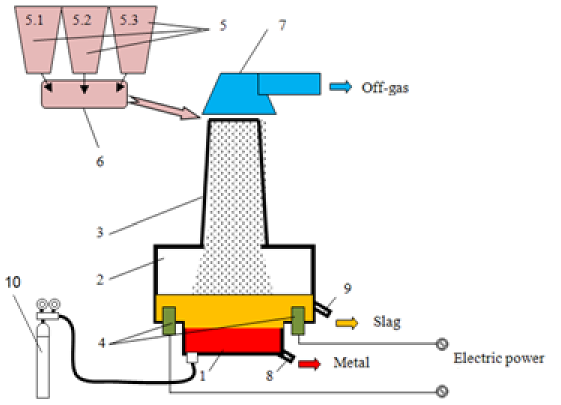

Figure 1. Technological scheme of the metallurgical furnace and process (designations are given in the text).

The main parts of the metallurgical furnace are a melting furnace, consisting of a hearth – a piggy bank 1 and a housing 2, lined with refractory materials, and a shaft 3 for feeding into the furnace and preliminary restoration of the initial charge materials. Button electrodes 4 are installed in the furnace hearth. The installation is equipped with a charging system for loading materials including a hopper 5 for iron-containing materials 5.1, a reducing agent 5.2 and slag-forming materials 5.3, as well as a mixer 6. The evacuation of dust and gas emissions from the furnace is carried out using a gas removal system 7. For evacuation of liquid metal and slag are provided slots 8 and 9. The hearth-collector is equipped with a system for purging the liquid bath with oxygen 10.

A liquid-phase carbon-thermal melting-reduction process in an electric furnace with button electrodes was developed and tested in laboratory conditions [1]. The process is not critical to the choice of charge iron-containing materials: scale, dust, and sludge from blast furnace and steelmaking processes.

The use of bottom electrodes [11] can significantly reduce investment costs for equipment, increase energy efficiency and environmental safety of the process.

The numerical simulation will allow a detailed study of the physical processes in the volume of the metal, as well as improve the operation of the metallurgical furnace and suggest methods to reduce wear of the refractory layer between the electrodes.

This installation can be presented as a flat model. The processes occurring in the installation are unsteady, but they proceed quite slowly and can be described as stationary. We assume that liquid steel is in the installation bath. Physical characteristics of the medium (conductivity, viscosity, thermal conductivity, etc.) are assumed to be homogeneous and isotropic and independent of temperature and pressure. Also, in this model, chemical reactions in the melt are not taken into account when an electric current passes through it, and the medium itself is considered non-magnetic. The geometry parameters are given in millimeters in Figure 2.

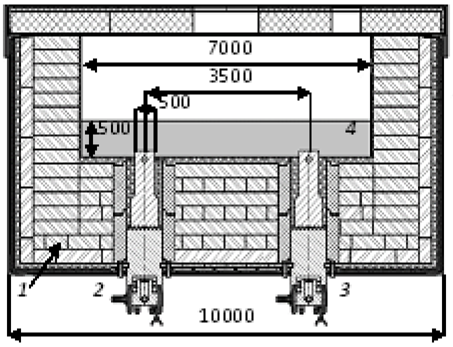

Figure 2. Electric furnace with bottom electrodes 1 – furnace body, 2, 3 – bottom electrodes, 4 – molten metal bath.

To obtain the characteristics of the processes in the melt, such as the distribution of current density and Joule heat, numerical simulation was used. The geometry is completely covered by the computational mesh. It is advisable to use unevenly mesh on the calculated region: the grid in the gap between the electrodes should consist of smaller elements than within the electrodes or at the boundaries of the regions. In this area located the largest gradients of electromagnetic parameters and maximal intensity of the ongoing processes.

The parameters of steel in the furnace bath are density $\rho = 7.3 \cdot 10^3$ kg/m^3, specific conductivity $\sigma = 9 \cdot 10^5$ S/m, steel temperature $T = 1600$ °C. The electrodes 2 and 3 are copper, the specific conductivity of which is $\sigma = 58.1 \cdot 10^6$ S/m [12].

Under the accepted physical assumptions the processes in the metallurgical furnace can be described by the following governing equations

the Maxwell's equations

$$\nabla \times \vec{B} = \mu_0 \vec{j}\,, \nabla \cdot \vec{B} = 0, \quad (1)$$

$$\nabla \times \vec{E} = 0\,, \nabla \cdot \vec{E} = \frac{\rho_e}{\varepsilon_0}, \quad (2)$$

the Ohm's law

$$\vec{j} = \sigma\left(\vec{E} + \vec{u} \times \vec{B}\right), \quad (3)$$

and the charge conservation law

$$\nabla \cdot \vec{j} = 0\,, \quad (4)$$

where $\vec{j}$ – current density, ρ_e – charge density, $\vec{B}$ – magnetic induction intensity vector, $\vec{E}$ – electrical field intensity, σ – specific conductance, μ_0 – permeability of free space, ε_0 – the permittivity of free space.

The boundary conditions are

– for electric field $E_{\tau 1} = E_{\tau 2}$, $D_{n1} = D_{n2}$,
– for magnetic field $B_{n1} = B_{n2}$, $B_{\tau 1} = B_{\tau 2}$,
– the electric potential on the electrodes in range 0 … 8 V.

The numerical simulation was carried out for an ore-reducing electric furnace with bottom electrodes. The distributions of electromagnetic fields, current density and Joule heat in a flat two-dimensional formulation are obtained. The good agreement of the results of the numerical calculations done by different methods with analytical approximations and experimental data proves the reliability of the methods and the significance of the results. The numerical simulation results have both theoretical and applied value.

Based on the mathematical equations (1)–(2) it is possible to simulate the current density distribution shown in Figure 3. The current density distribution in a metallurgical furnace with two bottom electrodes is homogenous distributed between the bottom electrodes and arises a value of $3.1 \cdot 10^7$ A/m^2.

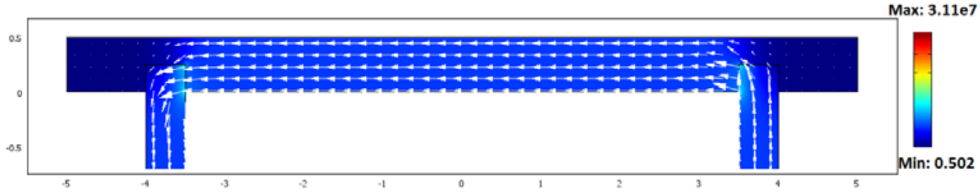

Figure 3. Vector and outline field of the current density distribution in [A/m^2].

Based on the current density distribution and equation (3), it is possible to simulate the Joule heat between the bottom electrodes. The distribution of the Joule heats between the two bottom electrodes in a metallurgical furnace is presented in Figure 4. The maximum value of volumetric Joule heat comprises 1.83*10^7 W/m^3 and the average between bottom electrodes around 1*10^3 W/m^3.

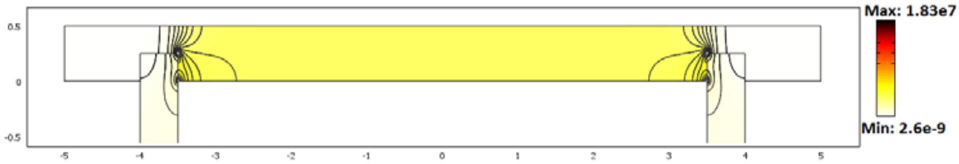

Figure 4. Contour field distribution of Joule heat in [W/m^3].

3. Conclusions

A liquid-phase carbon-thermal melting-reduction process in an electric furnace with two bottom electrodes was developed and tested in laboratory conditions. The process is not critical to the choice of charge iron-containing materials. It can be scale, dust, and sludge from blast furnace and steelmaking.

The use of bottom electrodes can significantly reduce investment costs to equipment, increase energy efficiency and environmental safety of the process. The possibility of producing liquid iron from the main types of technogenic iron-containing wastes of metallurgical production is shown. The yield is 71 ... 94%, the energy consumption is 2.12 ... 2.29 kWh/t of product, the total energy consumption is 12 ... 13 MJ/kg of product.

The numerical simulation of electromagnetic processes in molten metal is carried out. The numerical simulation has shown suitable distribution of the current density and Joule heat between the bottom electrodes.

Acknowledgements

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