The MHD stability investigation of an aluminum electrolyzer under various process conditions

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Abstract. For analysis, the MHD electrolyzer was adapted to a three-dimensional mathematical model, which uses a multiphase approach to the description of the medium (aluminum, electrolyte and gas), as well as to hydrodynamic, electromagnetic, thermal and electrochemical processes in the bath. Test calculations were carried out, which confirmed the model adequacy and the presence of the proposed numerical solutions to the problem with sufficient accuracy. The suggestion that the Soderberg electrolyzer is less MHD-stable than the multi-anode electrolyzer was confirmed. The impact on the MHD stability of various initial configurations forms has been assessed. The influence of a potential change on the MHD-stable form of the bath working space is investigated.

1. Introduction
This work is devoted to mathematical modeling of the industrial aluminum electrolysis process and the influence of heat and mass transfer processes on its MHD stability. Adequate mathematical modeling gives a more complete picture of the processes that take place inside the bath and are in close interaction, such as: distribution of velocity fields, electromagnetic fields, thermal regime, determination of the surface shape of liquid aluminum and the zone of reverse oxidation, change in the dynamics of the shape of the working space, finding the release rate gases arising during chemical reactions that are difficult to control due to a chemically aggressive environment, high current strength supplied to the bath and temperature exceeding 900°C.

The work uses a three-dimensional three-phase mathematical model to describe the four main processes: hydrodynamic, electromagnetic, thermal and chemical, occurring in an aluminum electrolyzer. The conducted numerical experiments proved the influence of the working space shape on the MHD stability of the electrolysis bath, and made it possible to substantiate the higher MHD stability of multi-anode electrolyzers compared to Soderberg electrolyzers. Taking into account the interrelation of magnetohydrodynamic processes with thermal and chemical processes allows us to study the MHD instability of an industrial electrolysis bath under various disturbances introduced into the process technology.

2. Mathematical model
To describe the hydrodynamic processes in an electrolysis bath, the Navier-Stokes system of equations written in a 3-phase medium of the bath’s working space (liquid metal, electrolyte and gas phase) is used. When modeling electromagnetic fields and electric current density, the Maxwell system of equations written in the SI system of units was taken as the basis. The chemical kinetics of aluminum
Electrolysis is described by the Nernst-Planck-Poisson equations for the main ions involved in the process.

In a heterogeneous mixture, each phase occupies only a part of the elementary volume; in this regard, volume fractions \( m = 1,2,3 \) for each phase are introduced, which characterize the fractions occupied by each phase of the mixture in the elementary volume [1]. In this case, it is natural to assume that the volume balance equation of the mixture is satisfied in an elementary volume

\[
\alpha_1 + \alpha_2 + \alpha_3 = 1
\]

To simulate thermal processes in the bath volume, a simplified model is used, in which the temperature is considered the scalar characteristic of the mixture and varies due to convection of diffusion and the Joule heat source.

3. Changes in the shape of the bath space

The bath working space shape, as well as the aluminum-electrolyte interface and the surface of the reverse oxidation zone, is a dynamic object and depends on the process parameters. The melting or growth of the skull and the accretion of the electrolysis bath, which form the working space shape, occurs when the temperature changes above or below the critical value \( (945^\circ C) \), respectively. The temperature of the working space of the bath, in turn, changes due to the loss of heat through the sides of the bath and heat from the electric current that flows through the melting. Thus, changing of the potential distribution over the anode and thereby changing the electric current density, it is possible to influence the working space shape of the electrolyzer [2]. The calculation results for various initial forms of accretion, corresponding to practical observations during the commercial operation of the bath, showed that when accretion is brought under the protrusion of the anode, the electrolysis process is more is more MHD-stable.

In the work, studies were conducted on the possibility of a dynamic influence on the working space shape of an electrolysis bath by distributing the potential across the anodes to maintain the geometry corresponding to the most MHD-stable operation of the electrolyzer. Moreover, at the initial moment of time, the linear slant was brought under the projection of the anodes onto the bottom of the bath, and the regions of the highest modulus of the current density are in the corners of the anodes and in the corners of the hearth (bath region, where the potential is assumed to be zero) [1, 4].

It was shown that the regions of elevated temperature correspond to the regions with the highest modulus of the current density, which indicates a direct relationship between the current density and the temperature in the electrolysis bath.

With the same potential distribution over the anodes, the current density (Figure 1) and the temperature distribution qualitatively remain unchanged.

![Figure 1. Initial current density distribution](image-url)
With a reduced potential at the fifth pair of anodes by 15%, the current density in the electrolysis bath is redistributed (Figure 2) and the temperature changes. The resulting working space of the electrolysis bath is deformed due to the increase in the skull and the accretion, the change is about 12 - 16 cm.

![Figure 2](image1)

With a reduced potential at the extreme pair of anodes by 15%, a change in the shape of the bath occurs from one edge of the bath symmetrically with respect to the OY axis. Since the pair of anodes is extreme, the redistribution of heat differs from the redistribution of heat for the case with the fifth pair of anodes, because of this the working area of the bath cools more strongly, which makes the growth of the skull more intense (on average by 6 cm).

![Figure 3](image2)

With a 15% increase in potential, the density of the current flowing through the bath (Figure 4) increases on the fifth pair of anodes and, as a result, increases the heat generated. The increase in the bath working space shape is about 10 - 13 cm. Relative to the initial form. There is a significant
increase in the current density flowing in the electrolysis bath. An increase in current leads to an increase in the generated heat and subsequent blur of the accretion and the skull.

![Current density distribution](image)

**Figure 4.** The resulting current density distribution, $t = 20$ s

Thus, a change in the potential on any pair of anodes, both positive and negative, leads to a change in the shape of the bath working space: a decrease in potential leads to an increase in accretion, an increase in potential leads to melting of the accretion. This increases the amplitude of the vibrations of the liquid metal and the lower boundary of the reverse oxidation zone, leaving, however, their changes in the range acceptable for MHD stability.

**Conclusion**

In the work it is shown that changing of the working space shape can be controlled by varying the distribution of potential at the anodes. The developed mathematical model allows modeling various technological features of industrial aluminum electrolysis. Prospects for development are the improvement of the mathematical model, the numerical solution algorithm and the computing complex for mathematical modeling of the main technological cycles, that is, the processes that occur during the day of the electrolyzer operation.

**References**

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