Overview of the Application of Mathematical Modelling in the Aluminium Production of UC RUSAL

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Abstract

UC RUSAL is one of the world's major producers of aluminum. The continuous analysis, development and design of its own new technologies have allowed the company to maintain its leading position in an environment of fierce competition.

The support and development of the technical and technological components of UC RUSAL fall under the auspices of a specially established business unit, RUSAL ETC (Engineering and Technology Centre), engaged in the research and development of aluminum production technology, the design of new reduction cells, casting technologies and machines, as well as their modernization.

Virtually all studies in various fields for various technical solutions go through a stage of mathematical modelling. Mathematical modelling makes it possible to analyze and evaluate the feasibility of a proposed innovation, and to select the most suitable option at minimal cost.
This article presents examples and opportunities for the main areas of work of the Department of Mathematical Modelling, including calculations of electric, temperature, electromagnetic fields; gas and hydrodynamics; strength calculations, the modelling of casting processes and machines, etc. in order to improve the existing technologies and to enhance product quality.

Keywords: Aluminium reduction cell, mathematical modelling, aluminum cast, thermoelectric field, MHD.

1. Introduction

The Department of Mathematical Modelling is a structural business unit of RUSAL ETC and virtually all technical solutions developed during the implementation of projects go through a stage of mathematical modelling in this department.

Mathematical modelling has been mastered in all of RUSAL ETC's main areas of activity; calculation methods have been developed and improved; many user routines have been written for the world's leading commercial calculation software packages, such as Ansys, Procast, Star-CD, etc., allowing for a more comprehensive consideration of various chemical and physical processes.

Moreover, the department possesses a stock of high-precision measuring equipment which is constantly used by department staff to perform all the necessary measurements of the physical fields of the objects being studied. This makes it possible to significantly improve the accuracy of the calculation models by verifying and adjusting the settings.

As a brief overview of what has been mentioned above, the main areas of mathematical modelling of RUSAL ETC are listed below:

- Modelling of the magnetohydrodynamics (MHD) condition of reduction cells:
    - This is carried out using specialized software, where the electric current distribution in the reduction cell and in its busbars is calculated, followed by the calculation of the magnetic field, and then the magnetohydrodynamics of the molten phases in the reduction cell and an evaluation of its MHD condition, the circulation rates of the melt and the deformation of the metal pad;
- Gas and hydrodynamics:
    - This includes the calculation of the gas flows in the area of the reduction cell superstructure, the various systems of pipelines and gas ducts, the natural and/or forced cooling systems of the various units. Calculations of the velocity and motion patterns of the melt in the reduction cell bath, which are carried out both with and without the MHD and gas emissions. In the case of modelling the process of the gas-flame preheating of the reduction cell or the after-burning of anode gases, the calculation of the combustion of the gas-air mixture is performed together with the calculations of the gas dynamics;
- Thermoelectric calculations for reduction cells:
    - These are performed taking into the account the phase transitions and electrochemical processes taking place in the pot. As a result of this exercise, the total energy balance of the reduction cell can be obtained, and an analysis of the electric field and heat losses can be carried out;
- An integrated model that allows for the simultaneous associated calculation of the temperature, the electric fields and MHD, while factoring in the effect of gas emission on the anodes, as well as taking into the account the phase changes in the bath and the electrochemical processes:
    - This model represents a development of the previous line, and is used as a highly accurate, although much more resource-intensive, verification tool for analyzing the operation of the aluminum reduction cell;
- Mechanical assessments:
    - Calculations of the stress-strain state of any structures of interest, including the cathode assembly and anode superstructure, both as an assembly and as individual elements, in various modes of operation of the reduction cells;
- Casting processes:
    - The modelling of casting ingots and other products, taking into the account temperature conditions, composition and properties, which makes it possible to assess the quality of the products, as well as to predict possible defects and to suggest ways of eliminating them. The modelling of the physical fields of casting machines, the calculation of the flow parameters of molten aluminum along the casting launders and the distribution of the alloying elements.

A more detailed discussion of each of these areas is presented below. The main points taken into the account for each type of calculation are described, and examples of problems that have been solved are presented.

2. Modelling of the MHD Condition of Reduction Cells

At present, the specialized software presented in Table 1 is used for the mathematical modelling of the MHD characteristics of reduction cells at UC RUSAL.

8. Conclusions

The mathematical modelling of physical fields in aluminum electrolysis cells has helped RUSAL to develop new designs for the RA-300, RA-400, RA-500 and to modernize the existing Soderberg cells. This article focuses only on the main areas of modelling and calculations being performed and developed at RUSAL ETC. The company is currently working on the development of a number of new models, such as the dissolution and transport of alumina, the abrasive wear of the bottom of the reduction cell, a model of the formation of ledge and sludge, as well as the improvement of existing models.

9. References

1. Valdis Bojarevics and James W. Evans, Mathematical modelling of Hall-Herault pot instability and verification of measurements of anode current distribution, *Light Metals* 2015, 783-788.
2. Valdis Bojarevics, Time dependent MHD models for aluminium reduction cells, *Light Metals* 2010, 199-206.
3. Valdis Bojarevics and Kulis Pericleous, Solution of the metal-bath interface for aluminium electrolysis cells, *Light Metals* 2009, 569-574.
4. Valdis Bojarevics, E. Radionov and Yuriy Tretiyakov, Anode bottom burnout shape and velocity field investigation in a high amperage electrolysis cell, *Light Metals* 2018, 783-788.
5. Vitaly Pingin et al., Modernization prospects for the bus arrangement of electrolyzer S-8BM (S-8B), *Tsvetnye Metally* 2016(3), 35-41.
6. Gennady V. Arkhipov et al., Simulation of cell thermoelectric field with consideration of electrochemical processes, *Light Metals* 2007. 327-331.
7. Qiang Wang, Baokuan Li, Mario Fafad, Effect of anode change on heat transfer and magnetohydrodynamic flow in aluminium reduction cell, *JOM.* 2016, 610-622.
8. A. D. Brent, V.R. Voller, K. J. Reid Enthalpy-Porosity Technique for Modeling Convection-Diffusion Phase Change: Application to the Melting of a Pure Metal, Numerical Heat Transfer. 1988. No.13:3. 297-318.
9. I. I. Gol'denblat, V. A. Kopnov Criteria of strength and plasticity of structural materials. M. Mashinostroenie. 1968. 192 p.