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.

Table 1. Types of computer software used for modelling MHD processes in reduction cells for the production of aluminum at UC RUSAL.

Software	Author(s)	Advantages
"Smelter"	A.V. Kalimov (Polifem LLC, St. Petersburg, Russia)	• The adequacy of the calculation of the magnetic field verified by the results of in-situ measurements; • Visualisation of the model in online mode and, as a result, simplicity and comfort in work; • Equipped with an additional module which makes it possible to build maps of MHD-stability.
"Blums"		
"ArcRUSAL"	P.N. Vabishevich A.V. Kalimov	• Has a difference in the settings and a more convenient interface compared to "Blums".
"MHD-Valdis"	V. Bojarevics (University of Greenwich, England)	• Makes it possible to calculate the circulation rate and deformation of the metal surface; • Performs the Fourier transform and analyses the type of MHD instability.

The "Blums" and "ArcRUSAL" softwares, both based on the "shallow water" theory, are intended to determine the electrical and MHD parameters of Søderberg (including horizontal-stud type) cells, as well as pots with baked anodes.

The "MHD - Valdis" software [1, 2, 3] may be regarded as an international multi-user product. The software is intended to calculate the electrical characteristics, magnetic field, patterns and directions of movement of the metal pad, its deformation, as well as to analyze the MHD instability of baked anode reduction cells.

The solution of the MHD problem is reduced to the step-by-step solution of the following tasks:

1. The solution of the thermoelectric problem, with the subsequent determination of the current distribution, current density, as well as the temperatures of the main conductive elements of the reduction cells and in the inter-electrode space;
2. The solution of the problem associated with the determination of the magnetic field in the reduction cell melt, taking into account the influence of ferromagnetic masses, as well as the magnetic field from the currents in the molten phases;
3. The determination of the Lorentz forces and the subsequent interrelated calculations of the directions and velocities of the metal pad, its deformation, as well as of the MHD stock of the reduction cell.

Figures 1 – 5 show examples of models created in different software applications, as well as results of the calculations made with them.

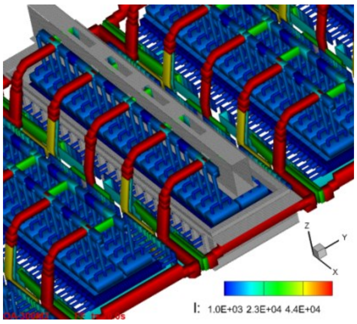


Figure 1. Model OA-300M2 built with "MHD – Valdis", [4].

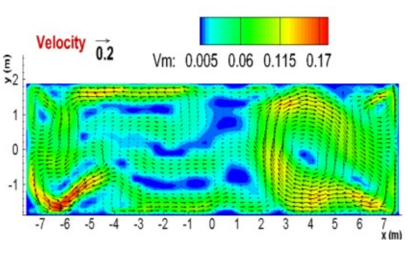


Figure 2. Metal pad velocity profile for the OA-300M2 reduction cell, [4].

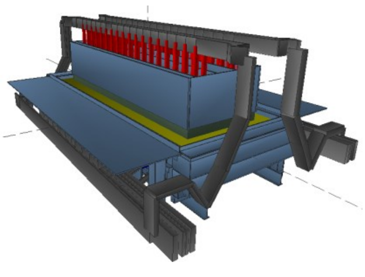


Figure 3. Model of a Søderberg reduction cell buit with "Blums V5.07".

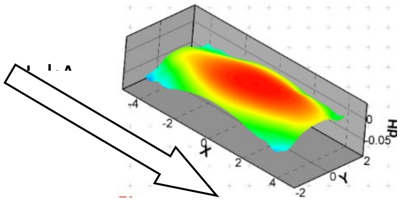


Figure 4. Predicted metal pad heave for the C-8BM Søderberg reduction cell.

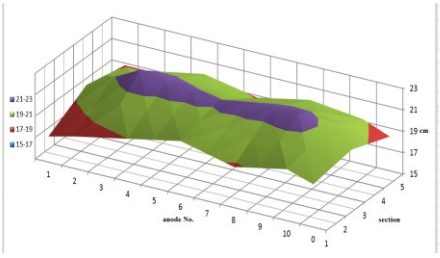


Figure 5. Metal pad heave measurements for the C-8BM Søderberg reduction cell.

During our work in solving MHD tasks, it was possible to implement the following projects:

1. Designing and upgrading busbars for high-ampere reduction cells in the 300 – 550 kA range;
2. Upgrading the busbar of Søderberg reduction cells with the aim retrofitting it to operate with prebaked anodes;
3. Developing methods for the start-up of reduction cells with fuse shunts start-up (without shutdown of the current load).

Another software product currently being employed at RUSAL ETC is ANSYS Maxwell (Figure 6), which, in our opinion, has the following advantages:

- The possibility of calculating the magnetic field at any point in space;
- Calculation of the magnetic field from all the currents flowing through the volume of the melt;
- The possibility of setting more accurate material properties;
- The possibility of parameterization of the model, with its subsequent optimization.

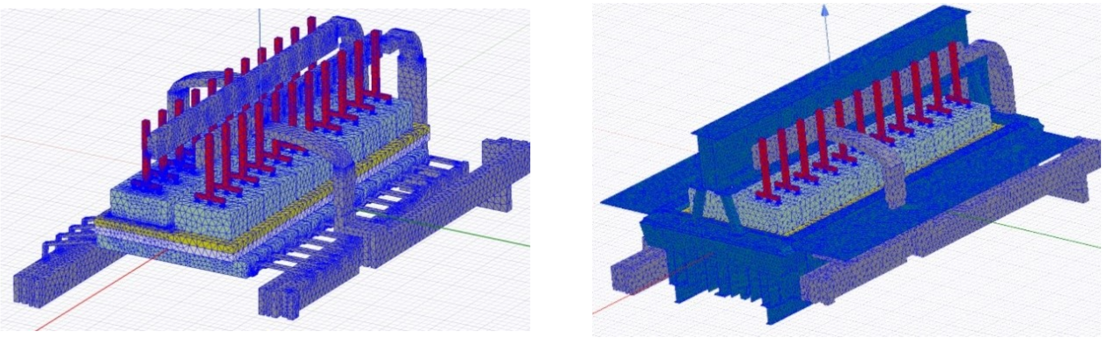


Figure 6. Finite element mesh of a standard OA-160 aluminium reduction cell (JSC "RUSAL Krasnoyarsk"), built with ANSYS Maxwell.

3. Gas Dynamics and Hydrodynamics

3.1. Potroom Ventilation

The aim of these calculations was to assess the efficiency of the potroom ventilation based on an analysis of air temperature distribution and concentration of harmful pot emissions. The maximum permissible values of temperature and harmful emissions (HF, Fs, SO2) in the working area were proposed as criteria for evaluating the efficiency of ventilation in the potroom.

The mathematical model for describing the physical processes occurring during the ventilation of the potroom consists of a system of equations describing the standard turbulent motion of a viscous heat-conducting incompressible gas. In this case, one may neglect the conjugated heat transfer between gases and solids. Air extracts heat from the potshell, therefore increasing its own temperature, and rises (natural convection problem). Harmful chemicals penetrate the working area through the gaps in the covers.

The results of the calculations make it possible to assess the compliance with the established Health, Safety and Environmental requirements, to select the most efficient design of the roof, to determine the size and location of the ventilation gratings and openings, and to assess the feasibility of lowering the height of the potrooms.

During verification of the model, potshell temperature measurements were performed using contact thermocouples, optical pyrometry and thermal imaging. Furthermore, heat fluxes from the potshell and the superstructure as well as the parameters of the gaseous medium near the shell, the ventilation gratings and above the covers were measured. The concentrations of harmful gases in the working area and at the superstructure were determined. Smoke visualisations of the actual flow pattern around the reduction cells and in the vicinity of the potroom aisle were performed (Figure 7).

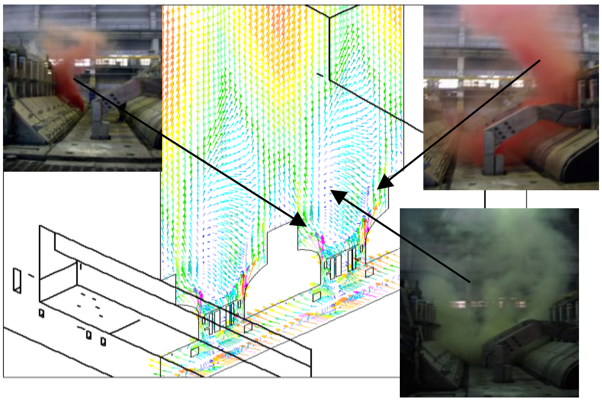


Figure 7. Comparison between predicted and experimental flow patterns.

A comparative analysis of the calculated and measured data showed a good qualitative and quantitative agreement.

Based on the use of the developed models, technical decisions were made during the construction of the Khakas Aluminium Smelter and documentation was prepared for the Taishet Aluminium Smelter.

3.2. Prebake Pot Ventilation System

The developed mathematical model makes it possible to evaluate the efficiency of both an existing prebake anode pot ventilation system as well as another one, currently under design. Calculations were performed for both standard operation and the anode-changing mode (where partial depressurisation of the reduction cell occurs). As a rule, several options for the design of a pot ventilation system are considered. The performance of such a system is estimated by the following parameters:

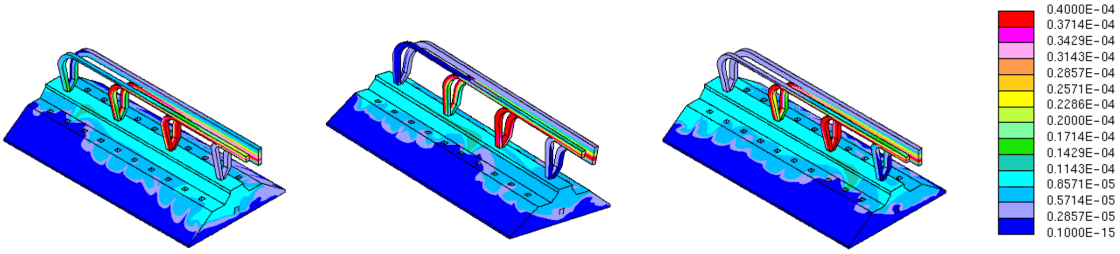
- Efficiency of HF emission into potroom;
- Gas velocity in ventilation system horizontal ducts;

- Vacuum at the outlet of the pot exhaust system.

The computational area of each reduction cell under study comprises the superstructure, pot hoods with anodes and alumina point feeders. The process gas in the model enters the under-hood space through the holes from the point crust breakersand the cracks in the anode cover; the air enters through gaps in the hoods. For the computational area, a system of equations is solved, describing the standard turbulent motion of gases, as well as the motion of dust in a multiphase flow. When modelling turbulent transfer processes, the standard two-parameter high Reynolds number k-ε model is used.

An example of the calculation results is shown in Figure 8. In the calculations, zones with positive pressure and zones of HF concentration under the cover are determined. In the figure 8 ratio of the total HF mass flow, that is captured by the gas cleaning system, to the total process gas HF mass evolution is shown.

Distribution of HF concentration in pot cavity, in wt%.



Pot ventilation system efficiency, %

98.46 97.86 97.9

Figure 8. Computed HF concentration and pot ventilation system efficiency.

The results of the calculations were used for the development of new designs of pot ventilation systems for RA-300, RA-400 and RA-500 reduction cells, as well as upgrading existing ventilation systems for various reduction cells of the company.

3.3. Pot Ventilation Systems for Søderberg Cells

Mathematical modelling was employed to evaluate technical solutions for a pot ventilation system for Søderberg reduction cells while increasing the efficiency of exhaust gases after-burning and increasing the efficiency of the cover to capture process gasses.

The efficiency of the proposed technical solutions is based on an evaluation of:

- The possibility of anode gase emissions into the potroom;
- The degree of the after-burning of the anode gases;
- The impact on the operation of the de-clogging system and the increased wear of the system elements.

To assess the possibility of anode gases puffing out from under the gas manifold into the atmosphere of the shell, the vacuum under the cone is determined. The magnitude of the vacuum should ensure drawing of the gases from the cryolite-alumina crust into the gas manifold space, both during the interoperative period and during the depressurization of the reduction shell when carrying out technological operations (Figure 9).

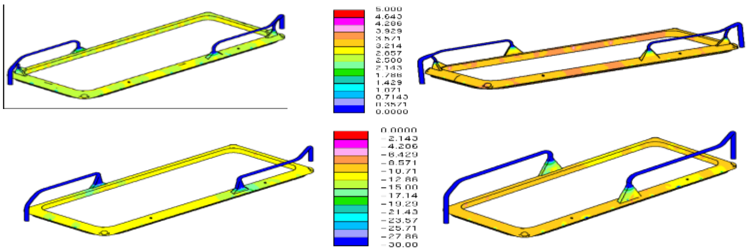


Figure 9. Vacuum under the gas manifold cone for various designs in Pa.

The degree of after-burning in this model is estimated by computing a multistage chemical reaction of burning anode gases with drawn-in air, and taking into account the temperature and kinetics. Thanks to this model, it was possible to develop a pot ventilation system for a Søderberg reduction cell with high environmental efficiency.

3.4. Distribution of Air Flow Through the Gas Duct System using Specialized Software

The distribution of air flow through the pots is calculated in the Sigma Flow software using the hydraulic resistance method (Figure 10).

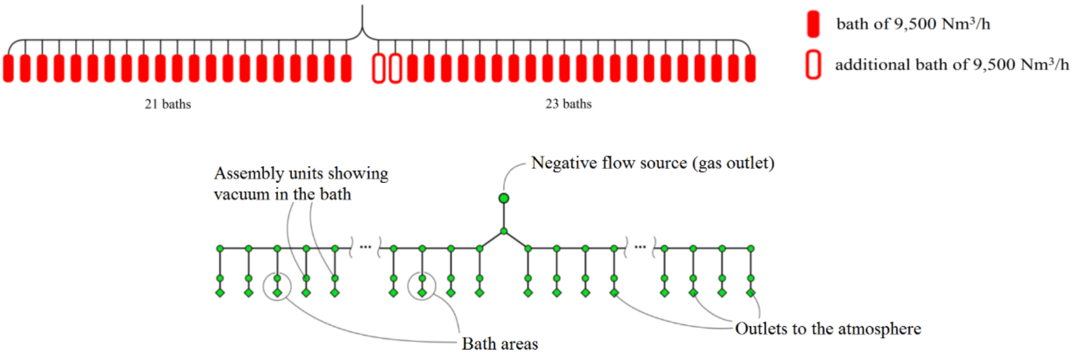


Figure 10. Considered hydraulic resistance network.

Using Computation Fluid Dynamics (Ansys Fluent software), we obtained the dependence of the hydraulic resistance for various parts of the gas duct on their respective dimensions. The obtained coefficients are used to calculate the distribution of gas flow through the ducts. Appropriate orifice diameters are automatically selected using a subroutine that updates the considered hydraulic resistance network. As a result, a large number of calculations are performed automatically, and the hydraulic resistance network ensuring the most uniform flow rate between pots is identified (Figure 11).

In this case, the gas flow problem was coupled with a thermal calculation and took into the account the chemical reactions of anode gas burning and CO after-burning in the pot ventilation system (Figures 12 – 13). More than forty intermediate chemical reactions were considered.

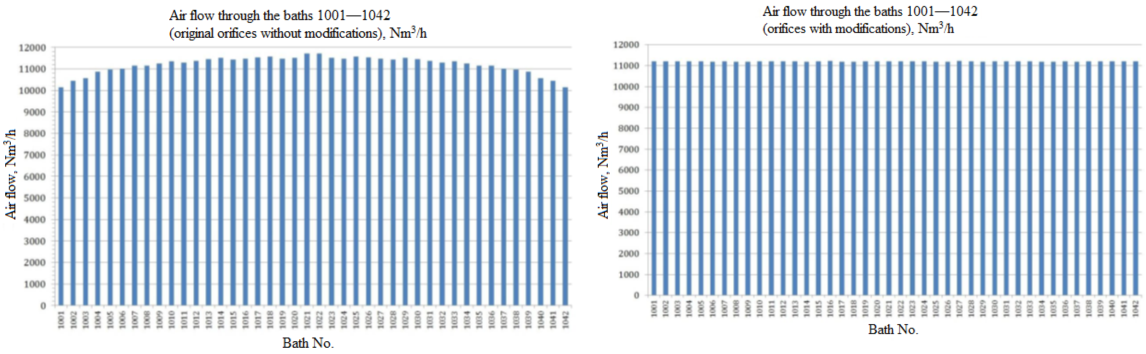


Figure 11. Flow through pots: left – initial configuration; right – final configuration (selected using the software).

3.5. Optimization of the Design of a Pot Ventilation System for a Søderberg Reduction cell to Increase the Degree of CO After-Burning

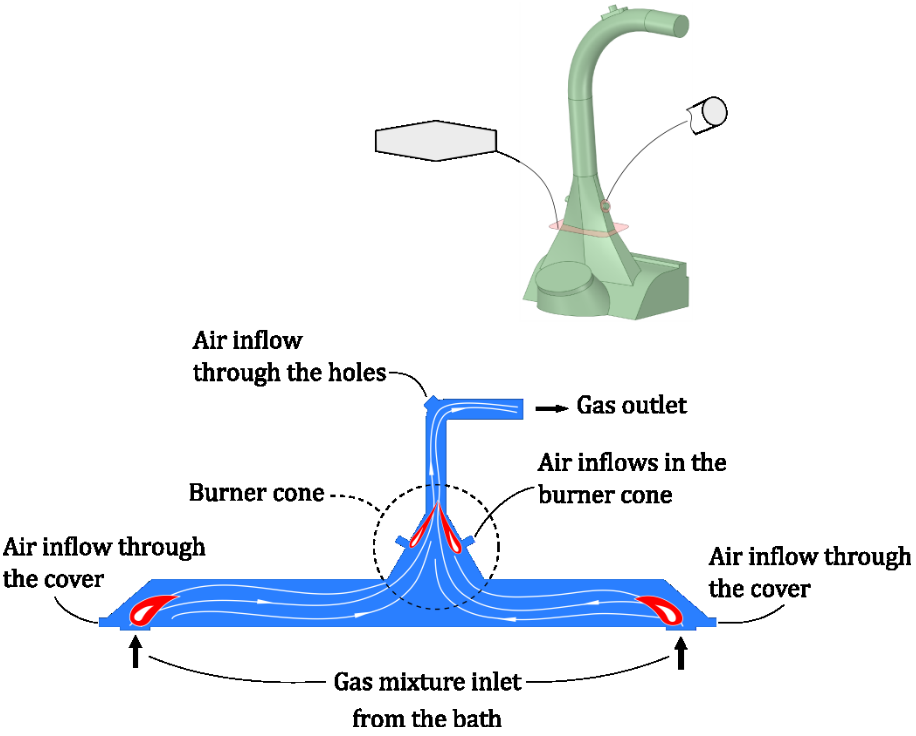


Figure 12. The geometry of the task and the scheme of its calculation.

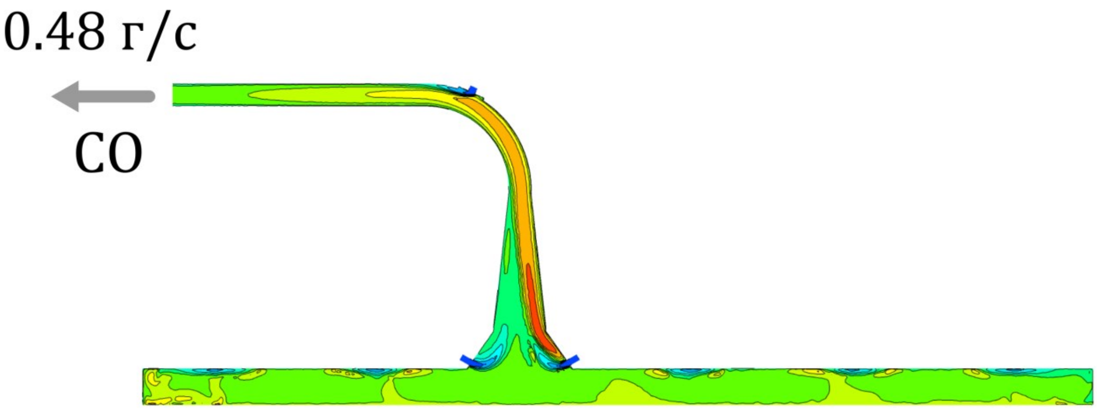


Figure 13. Temperature distribution in the plane of the burner.

This model made it possible to determine which of the designs provides the greatest efficiency of CO after-burning.

3.6. Velocities and Pressure Distributions in a Gas Treatment System

To optimise the gas treatment system, RUSAL employees created models of this system, both as an assembly, as well as of its individual elements. With the help of these models, the tasks related to the modification of gas ducts were solved in order to optimise the design. The zones with parasitic air circulation were eliminated, and guides were sized and designed to optimise the distribution of the air flow over the cross-section of the gas duct in places of any significant changes in the cross-sectional area. Moreover, the effect of the filter design on the efficiency of the gas treatment system was analysed. Examples of geometries and calculation results are given in Figure 14.

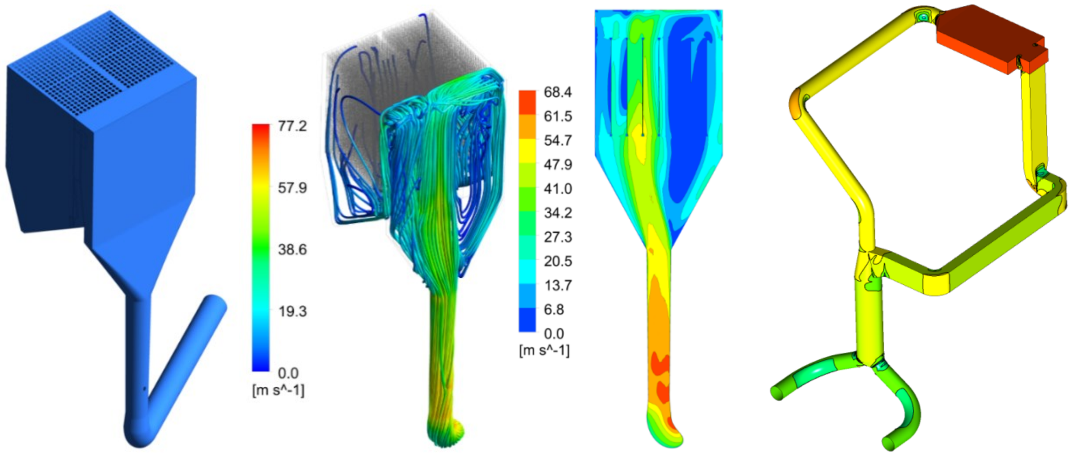


Figure 14. Model geometry and the gas velocity fields in both the reactor and the crude gas chamber.

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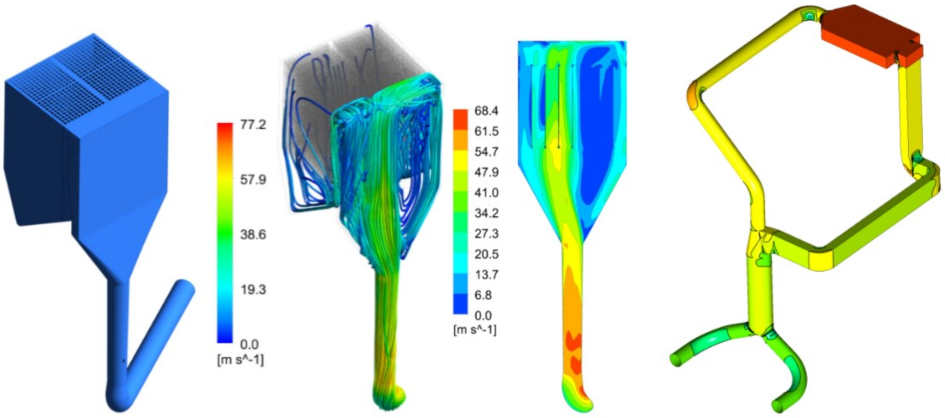

Figure 14. Model geometry and the gas velocity fields in both the reactor and the crude gas chamber.

4. Thermoelectric Calculations for the Reduction Cells

Thermoelectric models are widely used to improve the design and to optimise the process parameters of aluminium reduction cells of various types and amperages. They are used to analyse thermal and electric fields during preheating and start-up, in standard and emergency modes of operation. One of the main advantages of thermoelectric models is the possibility of calculating, in a relatively short time, the thermal and electric fields with sufficient accuracy for engineering calculations.

The specialists at UC RUSAL use ANSYS Mechanical APDL and ANSYS Mechanical software packages for thermoelectric modelling. These software packages make it possible to perform very "flexible" model setting and, if necessary, to quickly rebuild the finite element grid. The main advantage is the possibility of editing the finite element grid, both in manual mode and with the use of automatic meshing and user programming is also implemented to a fair degree, making it possible to check a large number of options in a short time, with a sufficient engineering accuracy.

Thanks to the user macros written in the APDL language (ANSYS Parametric Design Language), in addition to Joule heat generation, the thermoelectric models also take into the account the thermal effects of chemical reactions, the heat of phase transitions and the energy consumed to heat the raw material loaded into the reduction cell. Moreover, the developed code makes it possible, when solving thermoelectric tasks, to save the intermediate results in the form of electrical and energy balances recorded in text files, which significantly simplifies the post-processing of the calculations as they are being performed. A detailed description of the model and the developed code is given in [6].

Thermoelectric modelling is performed in three stages. At the first stage, measurements of the thermal and electric fields, as well as the shape of the working space in an existing cell, are carried out. Then, the measured values are used to verify the developed mathematical model of an existing reduction cell. After a thorough verification, changes made to the reduction cell design and technological parameters are introduced into the model in order to analyse the possibilities of its operation under these conditions. Thus, by using multi-parameter calculations on various designs, the optimisation of the process parameters and the upgrade of the design of the reduction cell assembly units are achieved.

As an example, Figure 15 shows the both temperature and electric fields as well as the ledge profile of the RA-300 reduction cell operating at the KhAZ and BoAZ smelters of UC RUSAL.

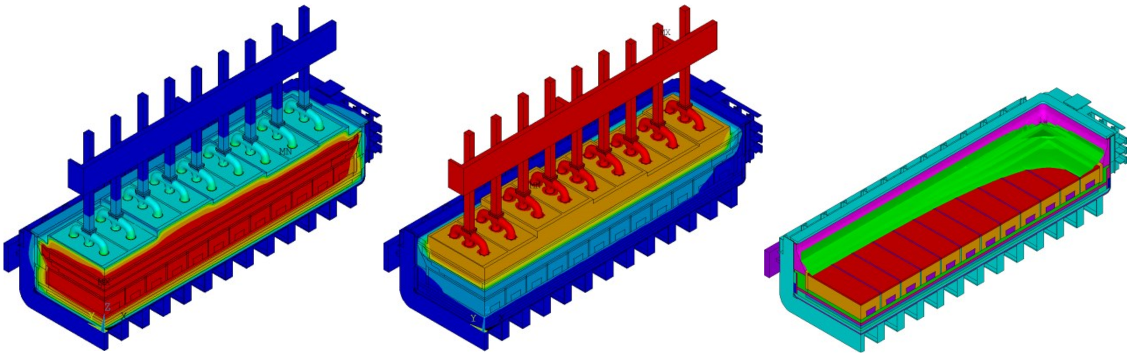

Figure 15. Temperature field (left), electric potential (centre) and ledge profile (right) of the RA-300 reduction cell.

It should be noted that dozens of reduction cells of various types and their components have been improved and upgraded using thermoelectric models at UC RUSAL. Various process parameters for different operation modes have been selected and optimised. New designs and advanced technologies have been developed, such as: RA-300, RA-400, RA-500, etc., which highlights the undoubtedly high importance of these models when upgrading existing reduction cells and designing new ones.

5. Integrated Thermoelectric and MHD Model

The company is carrying out continuous research to improve the mathematical models which take into the account the interrelationship of different physical fields in a reduction cell. Integrated mathematical modelling includes the coupled calculation of magnetohydrodynamics and heat transfer, taking into the account the formation of both ledge and sludge, as well as the dynamics of gas bubbles in the bath volume. The energy equation takes into the account the heat sources responsible for heating the materials charged into the bath and the phase transitions: the heating of alumina, the heat of moisture evaporation, the heat of dissolution, the heat of phase transition of Al2O3 ($\gamma \rightarrow \alpha$), the heating of aluminium fluoride. The model also takes into the account the nonlinear relation of thermal conductivity and electrical conductivity as a function of temperature.

During the operation of the aluminum reduction cell, the heat-insulating and refractory materials are impregnated with electrolyte. The coefficients of thermal conductivity and electrical conductivity were determined in laboratory experimentally at different times of the operation of the reduction cell. In the model, this is taken into the account by the correction factors for thermal conductivity and electrical conductivity. Moreover, this model allows for the calculation of the deformation of the metal-bath interface, which makes it possible to estimate the MHD stability of the bath.

The formation of ledge and sludge was taken into the account by including an additional retarding body force into the Navier-Stokes equation. The retarding body force was assumed to be zero for the temperature above the liquidus temperature, while at temperatures below the liquidus temperature, the magnitude of the body force was sufficient to bring the velocity to zero within the local control volume. This method is used in particular in [7]. For the first time, to simulate crystallization, such a method was proposed in [8].

Integrated modelling is performed using software intended to solve the tasks of computational fluid dynamics - Ansys CFX and Blums 5.07 specialised software intended to calculate magnetic fields. It should be noted that the standard tools of Ansys CFX do not allow for the modelling of bath solidification in order to simulate both ledge and sludge formation. Moreover, using standard Ansys CFX tools, it is impossible to apply the boundary condition for the formation of a gas phase at the bottom of the anode as a function of the current density. To tackle these issues, user-defined subroutines were written in Fortran (User Routines). In addition, subroutines in the CEL language (CFX Expressions Language) were written to take into the account the additional heat sources of chemical reactions, and a subroutine in the Perl language was written to form a report containing the energy and electrical balances.

Integrated modelling is carried out as follows: First, the magnetic fields are calculated with the Blums 5.07 software. The calculated magnetic fields are imported into the Ansys CFX software, where the coupled calculation of the magnetic hydrodynamics, heat exchange with phase transitions and the movement of gas bubbles released at the bottom of the anode is performed. Below, examples are given of the calculation results of the circulation patterns, cavity profile and temperature field of the OA-120 reduction cell obtained using this model (Figure 16).

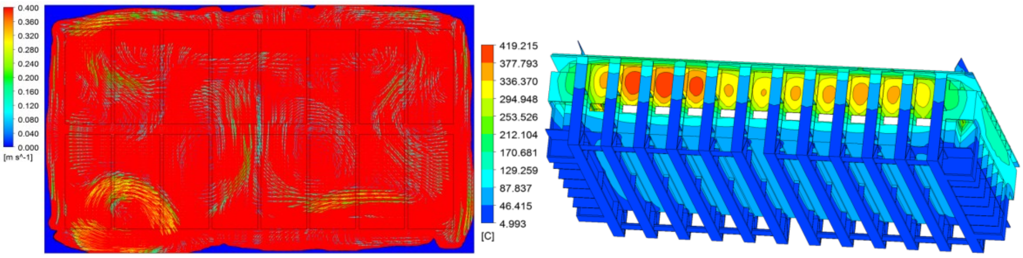

Figure 16. Results of the calculations of the circulation patterns, cavity profile and temperature field of the OA-120 reduction cell.

Thus, the integrated modelling of physical fields makes it possible to analyse the interrelationship of magnetic hydrodynamics, the movement of gas bubbles released on the anode surface, and the heat exchange with phase transitions. With the help of the developed model, it is possible to determine the cavity profile as a function of the circulation pattern and the velocity values of the bath and metal.

6. Mechanical Assessments

Models of deformable solid mechanics are used to develop new designs of metallurgical machines and their assembly units, as well as to improve and optimise already existing ones. To analyse the designed structures for strength, rigidity, stability, fatigue strength, the determination of the stress-strain state (SSS) of structures caused by heating or cooling while taking into account the non-linear behaviour of the materials, the specialists at UC RUSAL use models for calculating the mechanics of static and non-stationary low-velocity processes. The main advantages of these models is that they make it possible to determine the stress-strain state (SSS) of a structure, taking into account the temperature fluctuations and non-linear behaviour of materials, with an accuracy sufficient for engineering calculations.

To solve the problems of deformable solid mechanics, the specialists at UC RUSAL use the ANSYS Mechanical APDL, ANSYS Mechanical and ANSYS nCode DesignLife software packages. These software packages make it possible to perform an SSS assessment of a structure of almost any complexity, taking into account the non-linear behaviour of materials caused by heating or cooling. Another advantage of this software is that it allows for the editing of the finite element grid in manual mode and with the use of automatic meshing, thereby making it possible to analyse a large number of options within a short time, with a sufficient engineering accuracy.

Thanks to the mathematical apparatus, the built-in functions, and the user code written in APDL language (ANSYS Parametric Design Language), the specialists at UC RUSAL are able to analyse the strength of the cathode bottom, the "compression" of the peripheral and interblock joints, the strength of the lining materials according to the Goldenblat-Kopnov criterion [9], the SSS of metal structures of the anode and cathode of all types of reduction cells.

Analysis of the compression of the peripheral and interblock joints, the strength of the lining materials and the SSS of the structures is carried out depending on the temperature and impregnation with the bath components. The database of properties of the lining materials, depending on the temperature and impregnation with the bath components, is constantly verified and updated. Thus, by using multi-parameter calculations on various designs, the optimisation of the process parameters and the modernisation of the design of the reduction cell assembly units are carried out.

As an example, Figure 17 shows equivalent stress according to the von Mises criterion occurring in the anode superstructure and cathode of the RA-167 reduction cell, in standard operation mode, of the NkAZ smelter of UC RUSAL.

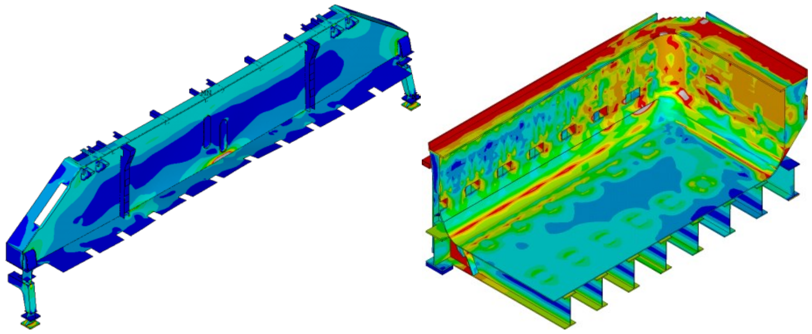

Figure 17. Equivalent stress according to the von Mises criterion occurring in the anode superstructure and cathode of the RA-167 reduction cell.

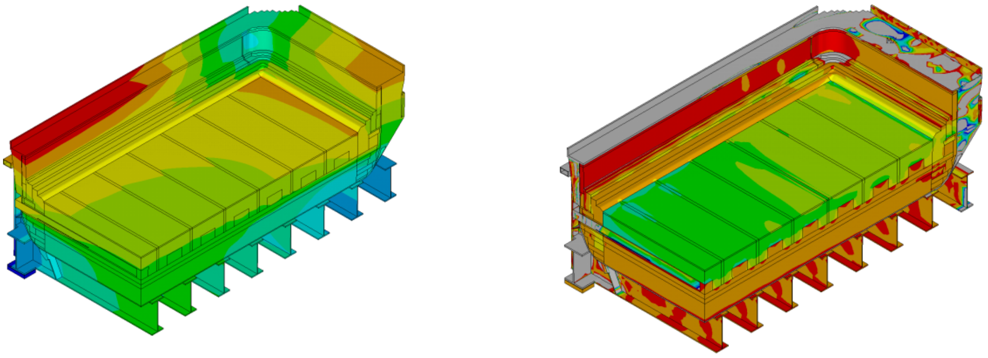

Figure 18. Total displacements (left) and normal stresses acting in the longitudinal direction (right) of the cathode of the RA-167 reduction cell.

An analysis of the rigidity of the structure of the cathode lining of the reduction cell in the steady-state mode of operation is carried out on the basis of displacements. Based on normal stresses, an analysis of the "compression" of the peripheral and inter-block joints is performed, as shown in Figure 18.

It should be noted that, using models of deformable solid mechanics, the specialists at UC RUSAL repeatedly test all new design solutions before actually trying them out at the experimental sites. With the help of these models, dozens of various aluminium reduction cells and their components have been developed, improved and upgraded.

7. Modelling of the Casting Processes

At present, the production of aluminium products with high added value is a promising area. Mathematical modelling of casting processes makes it possible to improve casting technology, and, as a consequence, to reduce the cost of producing commercial products.

Currently, RUSAL ETC has a wide range of software for modelling casting processes. ProCast, Ansys Fluent and Ansys CFX software is used for calculations. This software packages are invaluable in modelling furnaces and casting launders, the optimisation of casting molds, the continuous casting of ingots, the low-pressure casting of automobile wheels, and calculating the micro-structure of the casting.

One of the urgent tasks for modelling the casting processes is the optimisation of the lining design, as well as the choice of the power and location of the holding furnace heaters. Thus, when using mathematical modelling, the optimum thickness of the lining materials was determined, and the total heating power was reduced by selecting the location of the heating elements (Figure 19).

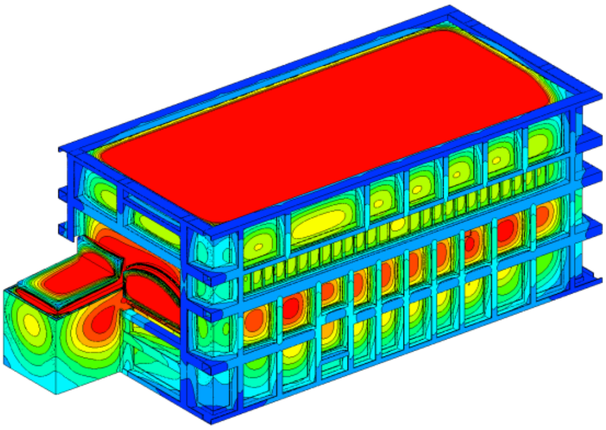

Figure 19. Holding furnace temperature field.

Ingot heat treatment furnaces are an integral part of the process of manufacturing aluminium semi-finished products; the creation and development of mathematical models in this area makes it possible to select the modes of heat treatment of products, and also to assess the uniformity of ingot heating (Figure 20).

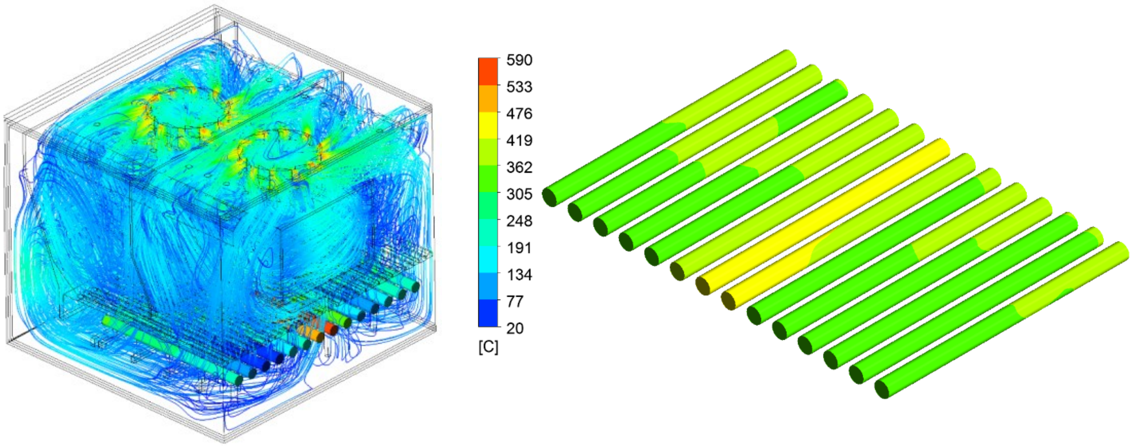

Figure 20. Patterns of air circulation in the soaking pit furnace and the temperature field of the billets.

Literary sources suggest that the feathery structure defect is a kind of columnar crystal and results from the growth of crystals in the form of lamellar twins, which is facilitated by a high temperature gradient in the mould and the calm state of the melt in the sump; therefore, the "feathery structure" defect usually forms in the peripheral zone of the ingot. Mathematical modelling of continuous casting made it possible to assess the uniformity of the temperature field, to select the optimal design of the combo bag for casting, the temperature of the metal, the level of the melt in the mould and the conditions of nozzle cooling in the secondary zone (Figure 21).

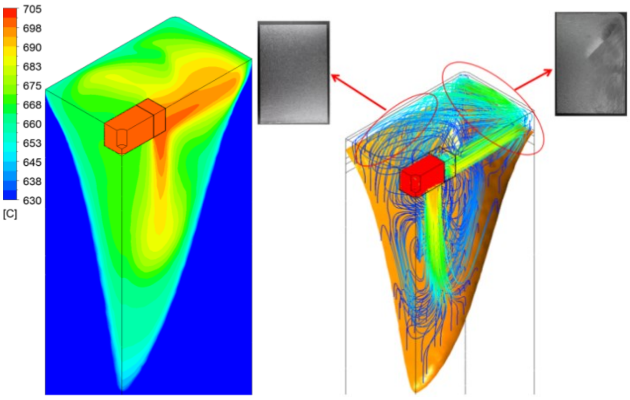

Figure 21. The temperature field of the ingot during casting and the pattern of circulation in the sump.

In addition, as part of the research work, a large number of calculations are performed with the ProCAST software package (Figure 22). This software makes it possible to perform calculations of various casting processes used in the company, such as gravity casting into moulds, calculations for low-pressure casting of automobile wheels to identify shrinkage defects and die casting at high pressure. These calculations make it possible to significantly decrease the number of defects in the finished product and to reduce the cost of casting.

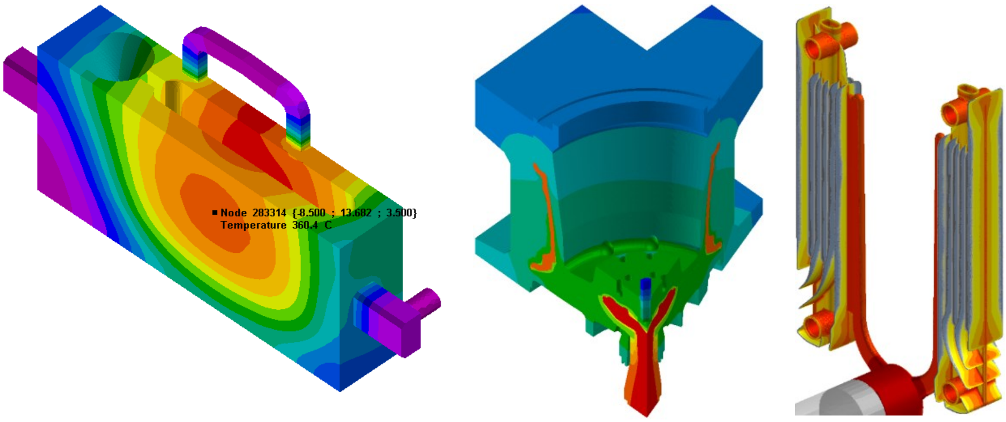

Figure 22. Examples of calculations performed in ProCAST.

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.

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