New ESTER/PHOENICS – An Upgraded 3D MHD Modelling Software for Aluminium Reduction Cells

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Abstract

ESTER/PHOENICS is the first 3D MHD commercial software package, developed in the 1980s, that included steady state calculations of the metal and bath velocities, metal heaving and transient calculation of MHD waves of the bath-metal interface. ESTER (Electrolytic SmelTER) is a special purpose adaptation of the general-purpose fluid flow and heat transfer code PHOENICS, dedicated to the MHD of the aluminium electrolysis cells. The original ESTER was limited in geometry to metal pad, bath and anodes to the top of carbon. Electrical boundary conditions required vertical current density distribution at the bottom of metal pad. Magnetic field was also given as an input file or an analytical equation in ESTER, and this remains the same now. The new ESTER upgrade extended the geometry from the end of collector bars to the anode beam (Model 1), so that the calculation of the current distribution in the metal pad does not require external input file. This requires a detailed computational grid to represent the geometry of collector bars correctly, but such a detailed grid cannot be used for transient calculations. Therefore, two submodels for the calculation of waves were built: Model 2 from the bottom of the metal pad to the top of the anode beam and Model 3 from the bottom of the metal pad to the top of anodes, allowing a much coarser grid in order to reduce the transient computation time. In these two submodels, at the bottom boundary, the vertical current density distribution is obtained from the detailed model by automatic interpolation between the fine and the coarse grid. The paper describes the new ESTER structure and some test applications.

Keywords: MHD of aluminium electrolysis cells, Computational fluid dynamics (CFD), ESTER/PHOENICS software package, 3D MHD wave calculations.

1. Introduction

ESTER (Electrolytic SmelTER) is a special purpose adaptation for MHD of aluminium electrolysis cells of the general-purpose fluid flow and heat transfer code PHOENICS. It is attached to PHOENICS as an additional user accessible GROUND station. It makes use of the standard PHOENICS pre- and post-processors for data input and graphical display, ESTER VR-Editor. ESTER can be set-up and run easily by anybody, it does not require any programming skills but, of course, it requires understanding of MHD and busbar design principles to effectively use it for cell design.

ESTER was the first 3D MHD commercial software package, developed in the 1980s, that included steady state calculations of the metal and bath velocities, metal heaving and 3D transient calculation of MHD waves of the bath-metal interface [1]. The capability of wave calculations with application to magnetic compensation loop design of potlines has been recently demonstrated again [2].

The main features of ESTER are:

- It is a 3D code, steady state and transient.
- Turbulence models are included (constant viscosity, k-ε, k-ω and other models).
- Its analysis domain has 3 options with specific electrical boundary conditions for each of these:
    - Model 1: Full model from the end of cathode blocks and collector bars to the top of the anode beam busbar;
    - Model 2: From the top of cathode carbon to the top of the anodes below stubs and;
    - Model 3: From the top of cathode carbon blocks to the top of anode beam busbar.

  For Model 2 and Model 3, the electric current density on the top of cathode block can be imported from Model 1.
- Magnetic field has to be calculated by another program. It can be imported as an external data file represented in analytical form at ESTER input. The default analytical expression is available to all users.
- Anode bottom can be flat or shaped to the metal pad heave, keeping the anode-cathode distance constant for steady-state calculations.
- Individual anodes can be active (carrying current) or inactive (after anode change). Anodes can be raised or lowered.
- Flow induced current density is also calculated, $\mathbf{j}_i = \sigma\, \mathbf{v} \times \mathbf{B}$). This is a toggle (off or on) in ESTER, so that its effects can be easily explored.
- Electric current density is calculated within the conductive parts of the cell. In the liquid metal and bath, the current density is combined with the magnetic field to get the electromagnetic (Lorenz) force $\mathbf{j} \times \mathbf{B}$.
- For transient calculations, initial metal-bath interface can be uniformly inclined in the longitudinal direction or specified in a table.
- ESTER uses floating grid, where the grid plane at the bath-metal interface deforms with the metal heave and keeps the interface always sharply defined. This simplifies the tracking of the interface tremendously and eliminates the need for fine grid and remeshing near the interface, which is required in the volume of fluid (VOF) models used in other models. The gain is much reduced computation time for steady-state, and particularly for wave calculations.

The results are:

- Current densities in the whole domain. Of specific interest are current densities in the liquid metal pad and in the bath;
- Velocities in bath and metal;
- Metal bath interface deformation;
- Flow induced current density;
- Currents in anode rods, anode busbars and collector bars;
- Turbulence parameters and viscosity;
- For transient calculations:
    - Waves, on the metal-bath interface;
    - Oscillations of anode rod currents and
    - Oscillations of cell voltage (cell MHD instability).

9. Conclusions

The upgraded ESTER/PHOENICS is a user-friendly software package for the calculation of 3D MHD of aluminium electrolysis cells. It is designed so that no programming skill is required to run it. It calculates steady-state circulation of the bath and metal, metal heave and 3D waves of metal-bath interface. The calculation of metal velocities, interface heave and waves has been validated with measurements in various cell designs. During more than 30 years, ESTER has proven to be a valuable tool in cell MHD design.

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10. References

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