Impact of Metal Pad Heave on Shell Temperature of Aluminum Reduction Cells

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Abstract

The operational window of an aluminum reduction cell is largely determined by magnetohydrodynamics (MHD) and energy balance. While these two fundamental aspects of cell design are usually studied independently, they are in fact coupled. The ledge profile affects the internal electrical current distribution – and, ultimately, Lorentz Forces – while MHD impacts both the metal pad heave and the flow pattern of the liquid phases. These interactions are commonly neglected in numerical modeling and it is usually assumed that the ledge profile and temperature distribution obtained with a quarter cell energy balance computation are representative of the entire cell. However, it is observed in operating cells that the downstream (DS) sidewall of a typical side-by-side, side riser reduction technology is usually hotter than the upstream (US) one. This suggests a significant relationship between the uneven profile of the interface and the spatial distribution of cell heat flux to the ambient. This article presents a tridimensional (3D) thermoelectrical approach for assessing the impact of a distorted metal pad to bath interface on the potshell temperature distribution of a cell using the modernized ANSYS-based model presented earlier [1, 2]. Key conclusions are illustrated by means of numerical results obtained for a fictitious 375 kA reduction technology.

Keywords: Aluminum reduction cells, Energy balance, Metal pad heaving.

1. Introduction

The operational window of an aluminum reduction cell is largely determined by magnetohydrodynamics (MHD) and energy balance. While these two fundamental aspects of cell design are usually studied independently, they are in fact coupled. The ledge profile affects the internal electrical current distribution – and, ultimately, Lorentz Forces – while MHD impacts both the metal pad heave and the flow pattern of the liquid phases. These interactions are commonly neglected in numerical modeling thus enabling the employment of pure, stand-alone thermoelectrical (TE) numerical analyses to study the energy balance of a Hall-Héroult cell.

Such modeling approaches [1–7] often ignore the local effects of metal pad velocity, alumina concentration, and bubble-driven flow (amongst other phenomena) on the heat transfer between the liquid phases and ledge. It also typically considers uniform heat transfer coefficients along the cell perimeter for each of the distinct ledge regions – namely, the lower ledge (facing metal), the upper ledge (facing bath) and, if considered in the calculations, the ledge trench.

This major simplification – *i.e.*, the dissociation between MHD and energy balance – results in considering a uniform metal pad height during energy balance calculations, inherently neglecting the potential influence of its deformed nature on the overall heat losses distribution. In other words, a double symmetry is assumed, and the heat lost to the ambient by a quarter cell geometry necessarily has to be identical to that of the other 3 quadrants of the full cell.

Considerable efforts have been made [8-11] to better account for the effects of the liquid phases flow on the energy balance of a reduction cell. For instance, Langlois *et al*. (2015) [8] introduced a coupled MHD-TE model that considers the MHD-induced flow while ignoring both the bubble-driven effects on the bath as well as the thermal effects caused by alumina dissolution. Moreover, this same work also assumes a flat heave, based on the following statement:

"It has been shown that the metal-bath deformation has no significant impact on the ledge formation in steady-state."

Once the MHD-driven flow for a given reduction technology is known, a relationship between the latter and the heat transfer between the liquids – especially the metal pad – and the ledge can be established. S. Renaudier and coworkers (2018) [9] validated that MHD-TE modeling approach by employing a procedure consisting of 16 distinct experiments generating a set of calibration parameters suitable for the prediction of ledge formation and cell temperature distribution.

This model was then applied [10] to the calculation of an AP44 potshell temperature profile, as shown in Figure 1. The high temperatures seen on both end walls and upstream (US) shell corners seem to correlate well with the high metal pad velocities observed in these areas. It is worth noticing, however, that the downstream (DS) sidewall also presents high temperatures in the vicinity of the cell center, even though exposed to lower liquid velocities that seem similar to the corresponding US sidewall segment. This might indicate that other phenomena are involved in the observed US-to-DS difference in potshell temperature.

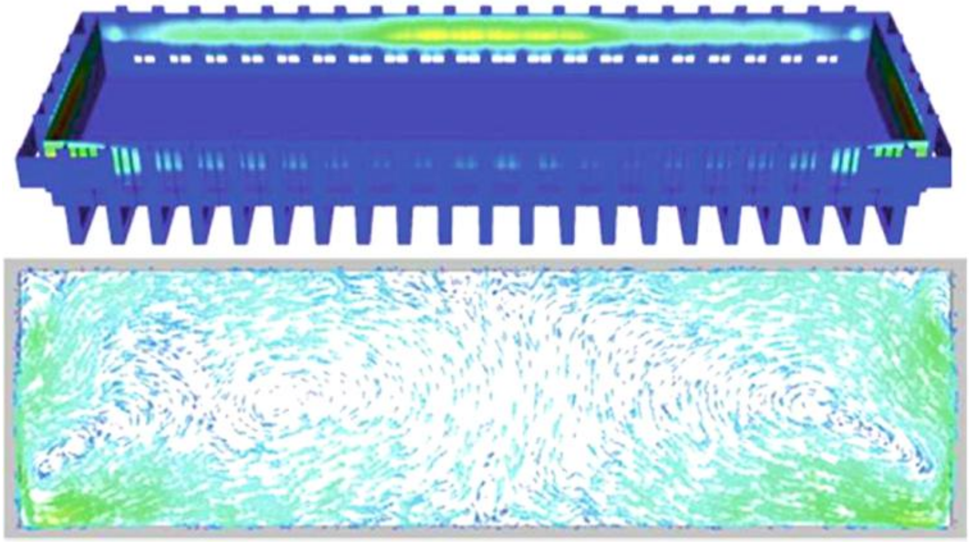

Figure 1. Predicted temperature profile and liquids velocity field for an AP44 cell, where potline current flows from the bottom to the top of the page – reproduced from [10]. Top: potshell temperature (scale not shown), Bottom: velocity field (scale not shown).

One possible explanation may be related to the variation of the metal pad-bath interface elevation on the ledge surface. Metal pad heaving is closely related to the divergence of the Lorentz Forces field such that the interface profile of a typical side-by-side, side risers cell tends to be offset towards the DS sidewall as depicted in Figure 2, with DH being the height difference with respect to the flat interface. It is observed in operating cells that the DS sidewall of such reduction technologies is usually hotter than the US one, similar to that of Figure 1. This suggests the existence of a relationship between the distorted metal pad-bath interface and the spatial distribution of cell heat flux.

It was also found that metal pad heaving slightly modifies the ledge profile at the vicinity of the ledge trench, making it thicker or thinner when moving the metal pad-bath interface up or down, respectively.

Finally, the present modeling approach was also extended to handle different topologies, including slice, half and full cell models, allowing for its potential coupling with a MHD model.

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