Modelling Study of the Impact of Copper Insert Design on Aluminium Reduction Cell Heat Balance and Voltage

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Abstract

The rapid development of the aluminium industry and tightening environmental regulations require engineers to look for ways to increase reduction cell productivity while reducing their carbon footprint. One universal remedy are copper inserts in a steel collector bars. This paper describes the impact of the copper insert design on aluminium reduction cell performance parameters. A detailed modelling study was conducted to understand the influence of different copper insert designs on various cell KPIs such as cathode voltage drop, cathode current distribution, heat balance, and cell life.

Keywords: Copper insert, Energy saving, Cathode voltage drop, Cell numerical modelling, Cell life, MHD stability.

1. Introduction

Due to its high electrical conductivity, cathode collector bar copper inserts are a common design innovation in modern aluminum electrolysis cells. It is primarily used to reduce cathode voltage drop. However, copper insert design requires an intelligent approach as it can both positively or negatively affect other key performance parameters such as cell heat balance, cathode current density distribution, and cell stability. At the same time, copper is relatively expensive, therefore, any potential improvement it brings has to be evaluated against its cost. Copper inserts in the collector bars are a simple design improvement, and almost all smelters have adopted it.

According to Wiedemann–Franz law, high electrical conductivity in copper is associated with proportionally high thermal conductivity. Because collector bars are major heat sinks in the electrolysis cell, the addition of copper noticeably increases cell heat losses. This is beneficial for amperage increase in existing technologies because it can withdraw additional heat which is generated by increased heat generation in the cell. However, for the heat-deficient cells, there should be an optimal insert size and position for the best electrical gains and minimal heat loss increase, which should allow for higher total energy efficiency.

The introduction of copper not only decreases overall collector bar resistance but also redistributes the current more uniformly on the surface of the cathode carbon blocks. This is advantageous for the magnetohydrodynamic (MHD) stability of the cell and for cell life expectancy due to reduced cathode erosion.

Non-uniform current on the cathode block creates horizontal currents in the metal pad, which interact with a vertical magnetic field (B_Z) to create unfavorable Lorentz forces for metal-bath interface stability. A good copper insert design decreases horizontal currents in the metal pad. Typically, a copper insert can be defined using three major parameters: cross-sectional area, length, and position within the cathode carbon blocks. It is expected that each of these parameters will have a different influence on cell performance, so it is important to understand how they affect it individually as well as in conjunction with each other.

This unique combination of costs, benefits, and restrictions requires a sophisticated multi-parameter optimization of the topology and geometry of the cathode. In this paper, we used the COMSOL Multiphysics software package which uses finite-element modelling. We focus on understanding copper insert design parameters and their effect on cell heat and voltage balance.

Several studies of copper insert designs have been published, including modelling and cell performance [1-3].

2. Model Description

For this study, a steady-state thermo-electrical model was created using the COMSOL Multiphysics software package. The model represents a 3D cell slice of half-cathode block width, including everything below the anode: bath, liquid metal, cathode block and collector bars, lining, potshell, and part of a cathode ring busbar (Figure 1).

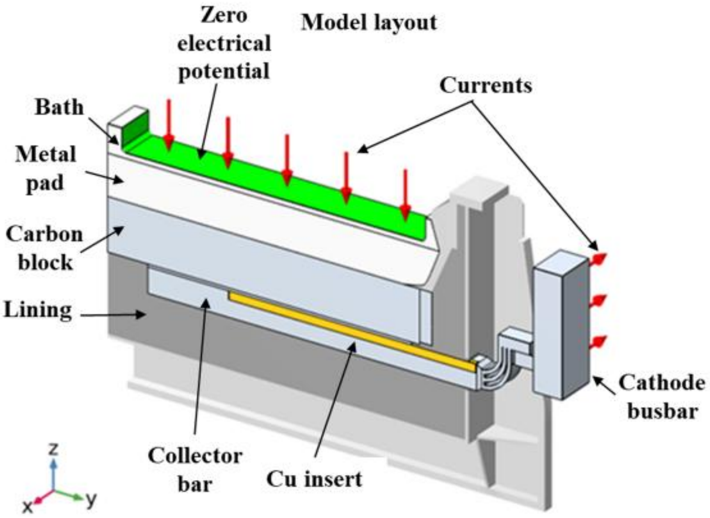

Figure 1. Model layout.

Electrical currents are simulated within the conductive domains using generalized Ohm’s law. This is achieved by defining a zero potential boundary at the electrolyte-anode interface and a negative current density on the cross-section of the exit cathode busbar. The interface between cast iron and cathode carbon block, which does not provide perfect contact, is represented by contact resistances on the top and the sides of the collector bar. All models were calculated with the same cell current of 465 kA.

The model simulates heat transfer within all solid components using a steady-state conductive heat transfer equation. This equation uses joule heat sources in electrically conductive materials, coupled with a radiative heat loss model on the outside boundaries, which explicitly evaluates view factors of such shell elements as shell wall, fins, cradles, as well as radiative heat flux between the potshell and the cathode busbar. The heat fluxes from liquid aluminum and electrolyte are approximated as convective heat transfer on cathode and ledge boundaries with homogeneous bath and metal temperature distribution. Heat transfer coefficients from liquids to solids (from liquid aluminium to cathode block, toe, freeze, trench, and bath to the freeze) are fitted to the measured thermal distribution in an industrial cell.

7. Conclusions

Copper inserts play a substantial role in the modern aluminum industry. As excellent conductors of both electricity and heat, they serve dual purposes: CVD reduction and thermal balance control, thus improving reduction cell key performance indicators (KPIs).

The copper insert cross-section is a crucial parameter affecting CVD, heat loss, cathode surface current density, horizontal current in the metal, etc. Its size can be increased provided that compensatory measures, like enhanced thermal insulation through lining or anode cover material (ACRM) are taken to offset the accompanying heat losses and reduction of internal heat generation. Failure to do so can lead to operational issues related to low bath temperature, such as slower alumina dissolution, and formation of anode spikes.

The copper insert length and shape inside the cathode block primarily affect the cathode surface current density and horizontal current in the metal, and to a smaller extent, the CVD. These parameters do not have a significant impact on heat loss and collector bar temperature. On the other hand, the copper insert length and shape outside the cathode block do affect CVD, heat loss, and collector bar temperature.

For the cell design, essentially two approaches can be considered. The first approach is tailored for high-productivity cells and involves maximizing the copper cross-section provided the solidus isotherm remains outside the cathode block. The second approach is used for low specific energy or “cold” cells and involves careful selection of the copper insert cross-section, length, and position to achieve the highest operational efficiency. However, the copper insert has to be utilized with care, because modification of the cell thermal balance might cause an increase in collector bar temperature which could be associated with accelerated corrosion by sodium ooze.

While copper inserts offer a range of benefits in optimizing cathode performance, their design and placement must be carefully considered to maximize advantages. The complexity and interconnection of thermal and electrical effects in such design studies make them difficult to carry out without a comprehensive 3D finite element modelling. Copper inserts also affect cell magnetohydrodynamics (MHD), which was part of this sudy but is not presented in this paper for the lack of space.

8. References

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