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MHD Analysis to Improve the Flow Profile in High Amperage Cells

Amit Gupta[1], Bhavya Narang[2], Mahesh Sahoo[3] and J. P. Nayak[4]
1. Senior Scientist
2. Scientist
Aditya Birla Science & Technology Company Pvt. Ltd., MIDC Taloja, Maharashtra, India
3. General Manager
4. President
Hindalco Industries Ltd, Hirakud, Sambalpur, Odisha, India
Corresponding author: amit.gupta@adityabirla.com

Abstract

Busbar configuration of large-scale aluminium reduction cells has become more complex with amperage increase in order to achieve the desired magnetic field distribution inside the cell. Magnetohydrodynamics (MHD) plays imperative role in the cell performance in terms of molten liquids flow profile and metal-bath interface stability. This paper outlines a case study to improve the molten liquids flow profile of a high amperage side-by-side cell through magnetic compensation. The molten liquids flow profile is governed by electromagnetic forces, which in turn depend on the magnetic field. To analyse this, 3-dimensional models were developed in commercial software packages: Magnetic field model using ANSYS, EMAG module, and MHD model using PHOENICS/ESTER. The metal flow profile was measured using iron rod method in a live cell of Hindalco Hirakud smelter to verify the model predictions. The models have been used to evaluate different magnetic compensation busbar designs with varying busbar positions and amperages to correct the force field and thereby improve the flow profile inside the cell.

Keywords: Magnetic compensation of cells, metal and bath flow profile, MHD models, busbar configuration.

1. Introduction

Aluminium reduction cells operate at very high current, resulting in strong magnetic field in and around the cell. The major component of electrical energy losses consists of the anode-to-cathode distance (ACD), contributing to approximately 1.5 V, which is about 35 % of the total cell voltage. The minimum ACD is governed by two important factors: (i) the heat generated in the ACD to maintain the electrolyte and aluminum in molten state and (ii) to avoid the molten metal short circuit with anode which leads to loss in the current efficiency.

Within a cell, the current flows vertically downwards through anodes, molten electrolyte, molten aluminium and cathodes before being collected by collector bars for feeding into another cell. The interaction of magnetic field with current flowing through the molten electrolyte and metal produces electromagnetic forces, which are responsible for the motion in the molten liquids as well as the deformation of the interface between the electrolyte and the metal. Electrolyte is immiscible in molten metal and floats on top of it, leading to formation of molten metal-electrolyte interface. The movement of interface and its control has been an active area of scientific research, also referred as magnetohydrodynamic (MHD) stability of cell. Over the years, research is being carried out to improve the MHD stability of the cell for increasing the energy efficiency. MHD stability of the cell is adversely affected by the waves generated due the unbalanced magnetic field resulting from poor busbar design. As per cell MHD design criteria, electromagnetic force in each quadrant of cell should be equal and balancing; indeed, it would be best to have point-wise balance of forces over the molten liquid zone of the cell [1]. A symmetrical magnetic field distribution helps in attaining the right balance of forces. The latest improved aluminium reduction cell technology is the result of an advanced design aided by computational modeling and computer controlled electrolysis process. Over the years, improvement in the MHD stability of the cell has been achieved with efficient design of busbar configuration.

For higher energy efficiency of the cell, ACD needs to be maintained as low as possible subject to satisfying the cell thermal balance. The unstable interface at lower ACD may cause shorting of the molten metal with the anode, leading to loss of current efficiency. The minimum ACD at which the cell remains MHD stable depends on two factors - current distribution and magnetic field in the molten liquids. To improve the current distribution copper-insert collector bar has been a proven choice for the aluminium smelters, which decreases the horizontal currents significantly in the molten aluminium [2, 3]. Whereas magnetic field correction requires modification in the existing busbar network or additional compensation busbar [4]. It has been reported that the interaction of vertical magnetic field and horizontal current components are known to adversely affect the MHD stability of the cell [5, 6]. Hence, thorough understanding of the cell MHD state for correct design and control is a key to achieve high energy efficiency. The present study focuses on magnetic compensation busbar for compensation of vertical magnetic field to achieve a balanced force field for improved molten metal flow profile and stability of metal-electrolyte interface.

2. Computational Analysis

To improve the MHD flow profile and stability of the metal-electrolyte interface in a side-by-side Hirakud 235 kA smelter, 3-dimensional computational models were used. The electromagnetic and the steady state MHD model was developed using commercial software packages ANSYS EMAG module and PHOENICS/ESTER. Electrical and magnetic calculations were performed using ANSYS EMAG, assuming that interface between the metal and electrolyte is flat. For electromagnetic model development two cells on either side of the analyzed cell are considered and rest of the potline is modelled as line elements. Center of analyzed cell is taken as origin for all the calculations. Effect of neighbouring line is also modeled using the line element. The governing equation and modeling setup for electromagnetic and MHD model had been reported earlier [7]. Figure 1 shows the electromagnetic model of existing design of 235 kA smelter, referred as Base-case subsequently.

5. Conclusion

MHD stability could be improved either by reducing the vertical magnetic field or by reducing the horizontal currents in the metal pad. Tweaking the magnetic field requires modification in the busbar configuration. However, magnetic field compensation becomes extremely important where the pot performance is inferior because of the faulty busbar design. In the existing side-by-side 235-kA potline, the magnetic compensation is achieved by deliberately shifting under the cell compensation busbar towards the neighbouring potroom of the potline. In Case-2, the internal magnetic compensation has altered the vertical magnetic field distribution in such a way that the opposing force field is diminished, thus improving the molten metal flow profile.

The compensated busbar design improves the overall molten metal flow profile inside the pot, hence it would impact the pot performance positively. The longitudinal force field of compensation design, i.e. Case-2, is similar to the force field of Case-1 whose B_z equals to zero, thus Case-2 would have comparatively higher MHD stability than Base-case. It would also provide an opportunity to squeeze the inter-electrode gap and thus reduce the specific energy consumption.

6. References

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