Energy Reduction Initiatives to Improve Low Amperage Cell Performance

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Abstract

Incessantly increasing energy prices and low London Metal Exchange (LME) aluminium prices have forced aluminium smelters to reduce energy consumption. HINDALCO Hirakud has four end-to-end prebake potlines with 680 cells altogether, operating at 85 kA, which were converted from Soederberg potlines with GAMI cell technology in 2006 – 2009. Due to end-to-end busbar configuration, magnetohydrodynamic (MHD) stability hinders anode-to-cathode distance (ACD) reduction. MHD stability is adversely affected by the horizontal currents and uncompensated vertical magnetic field in the molten metal. The cells are designed to be heat conservative; therefore, thermal balance of the cells is critical for voltage reduction. As part of the voltage reduction initiatives, copper-insert collector bars (CuCB) have been installed in a few cells. The impact of CuCB in 85 kA cells and required modifications of cell design were calculated with mathematical models. The CuCB reduce the horizontal currents in the molten metal significantly and thereby improve the MHD stability of the cells. The cell lining was modified to compensate reduced heat generation due to voltage reduction. The trial cells have shown significant increase in pot stability. They have been operating since one year at 280 kWh/t Al lower energy consumption and better current efficiency than regular pots.

Keywords: Aluminium reduction cell, copper-insert collector bar, pot stability, thermal balance, low amperage cell.

1. Introduction

Aluminium smelting is an energy intensive process where energy cost contribution is around 40 % of the total cost of production. Unceasingly increasing energy price has affected the smelter operating margins considerably, which lead the smelters to take measures on voltage reduction. Hirakud aluminium smelter has four end-to-end prebake potline operating at 85 kA, which were converted from Soederberg potlines with GAMI cell technology during 2006 – 2009. Due to end-to-end busbar configuration of Hirakud potlines, magnetohydrodynamic (MHD) stability hinders reduction in anode-to-cathode distance (ACD). This contributes to around 35 % of the total voltage requirement, also the maximum heat generation takes place in the ACD. Therefore, it is desirable to maintain ACD as low as possible to operate the cell at lower energy, while satisfying the heat balance requirement. MHD stability of cell is adversely affected by the uncompensated vertical magnetic field and the horizontal currents in the molten metal.

To eradicate the uncompensated magnetic field, busbar configuration can be optimized, however it is capital intensive [1]. Besides improving the magnetic field distribution, reduction in the horizontal current using copper insert collector bar (CuCB) is another way to improve the MHD stability of cells and thereby reduce ACD [2, 3]. Since copper has higher electrical conductivity than steel, it alters the electrical resistance path in cathode assembly, resulting in reduction in the horizontal currents in molten metal along with uniform current distribution in the cathode block. Apart from this, it also reduces the cathode voltage drop (CVD), which is attributed to uniform current distribution in the cathode and lower electrical resistivity of copper. Any voltage reduction in CVD or ACD will also lessen the heat generation and thus deteriorating the thermal balance of cell. Since these cells are designed to be heat conservative, it requires careful evaluation for any design modification.

Earlier the authors have reported, the computational analysis on various designs of CuCB and their impact on the current distribution, cathode voltage drop, cathode temperature, ledge profile and structural integrity of the cell [3]. This paper presents the implemented design of CuCB with modified cell lining in Hirakud 85 kA cells and their impact on cell performance. The thermal-electric, electromagnetic and MHD models were utilized to analyze the impact of CuCB. These models were developed using commercial software ANSYS and PHOENICS-ESTER. The steady state condition was simulated for reference cell with normal steel collector bar and for CuCB cell with modified cell lining. The CuCB with modified cell lining have been implemented in few cells. The performance of these cells with respect to voltage breakdown and key operational parameters was monitored over a year.

2. Mathematical Modeling

A 3D quarter cell, thermo-electric model has been used for analyzing the electrical and thermal impact of CuCB. Also 3D full cell electromagnetic and MHD models have been utilized for fluid flow calculation. The models incorporate boundary conditions based on the cell design and operating parameters. More details regarding the governing equations, model development and its validation with the measurements, have been reported earlier [1, 4].

2.1. Current Distribution

As described in previous section, the CuCB alters the electrical resistance path in the cathode and collector bar assembly thereby improving the current distribution in the cell. Figure 1 and Figure 2 show the current distribution in the reference cell and in the CuCB cell respectively. Figure 1 shows that there are significant amount of horizontal currents being generated in the molten metal region. The magnitude of horizontal current in particular cell design depends on cathode material, and collector bar dimensions [5, 6]. From Figure 2 it is evident that use of CuCB reduces the horizontal currents significantly in the metal region.

The erosion of cathode top surface is a function of current density in the cathode block, resulting in non-uniform cathode surface over its life. Apart from reducing the horizontal current in molten metal, CuCB also improves the current density distribution in the cathode block. This would also reduce the non-uniform erosion of cathode surface thereby enhancing the cathode and cell life.

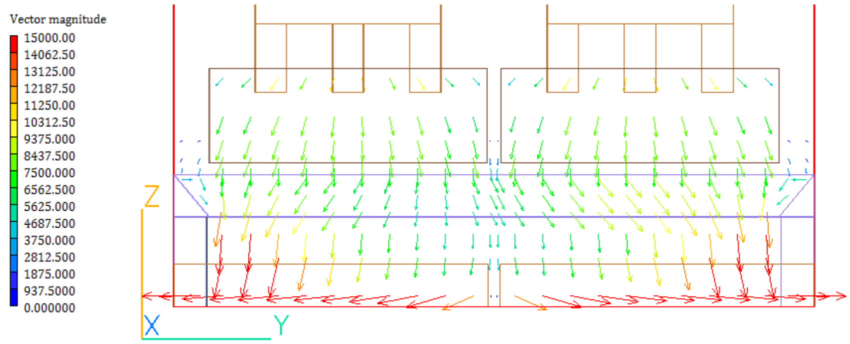

Figure 1. Simulated current distribution in reference cell.

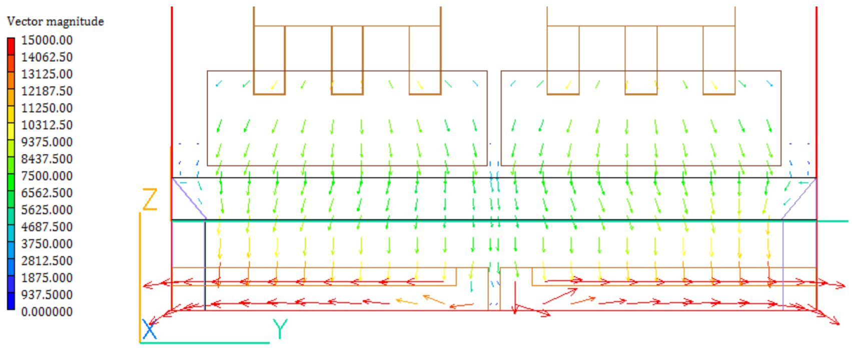

Figure 2. Simulated current distribution in CuCB cell.

2.2. Cathode Voltage Drop

The reduction in horizontal current in molten metal is accompanied by reduction in CVD due to the presence of copper which has higher electrical conductivity than steel. CVD has been computed by calculating the voltage drop from the cathode top surface to collector bar exit as shown in Figure 3.

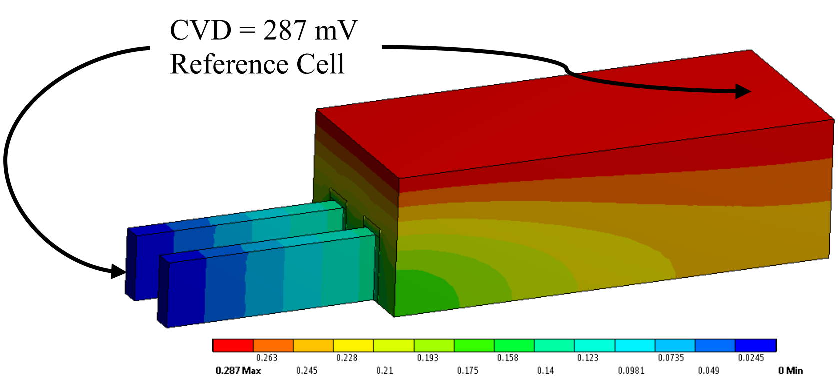

Figure 3. Simulated CVD for reference cell.

Table 1 shows that there is reduction of cathode voltage drop for reference cell and copper insert collector bar. Measured data was found to have good agreement with model predicted CVD.

Table 1. Simulated and measured cathode voltage drop.

	Cathode Voltage Drop (mV)	
	Reference cell	CuCB Cell
Computed	287	249
Measured	~ 286	~ 251

The electrical impact of CuCB on reducing the horizontal current and CVD may vary depending on the cell design, copper insert design and cathode material [3, 5, 6].

2.3. Velocity Profile

Figure 4 and Figure 5 show the velocity field in the plane located at mid-height of molten metal region for the reference cell and the cell with copper insert collector bar respectively. The average and maximum velocity for reference cell was calculated to be 2.85 cm/s and 7.30 cm/s respectively. Cell with CuCB shows reduction in metal velocity along with change in flow profile. In this case the average and maximum velocity was calculated to be 1.88 cm/s and 6.83 cm/s respectively.

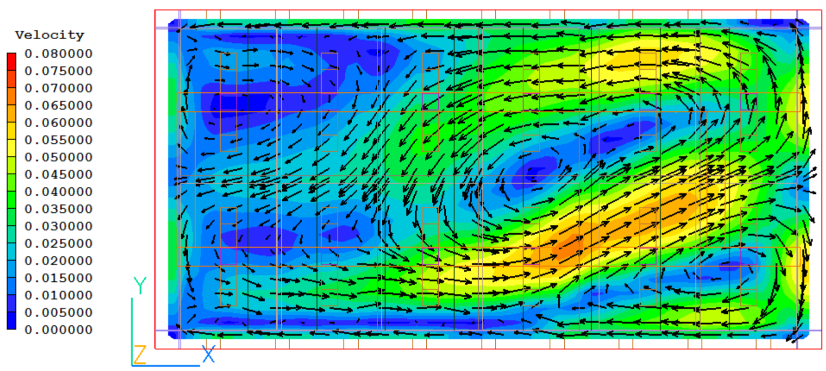

Figure 4. Simulated metal flow profile in reference cell.

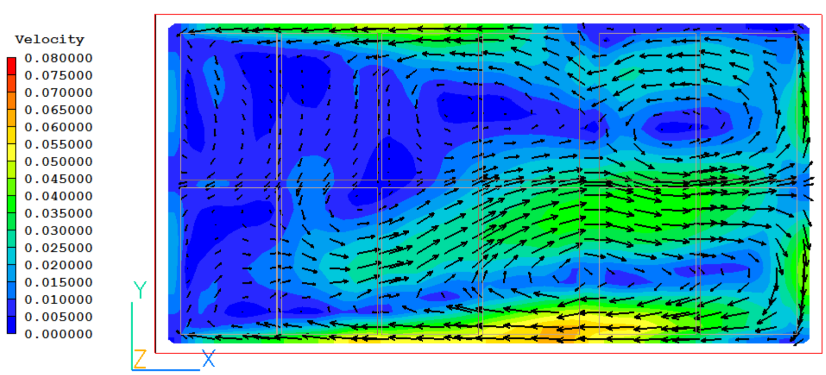

Figure 5. Simulated metal flow profile in CuCB cell.

The reduction in average velocity improves the cell stability which was also reflected as low voltage noise during the operation of these cell as compared to reference cell. Reduction in velocity adversely affects the alumina dissolution and may lead to the problem of sludge formation, however during the operation of these cells over a year, this problem was not observed.

2.4. Metal-Electrolyte Interface

Figure 6 and Figure 7 show the metal-electrolyte interface deformation (metal upheaval) for the reference cell and the cell with copper insert collector bar respectively. Model prediction shows that for CuCB cell, metal-electrolyte interface deformation was reduced by 1.2 cm in comparison to the reference cell.

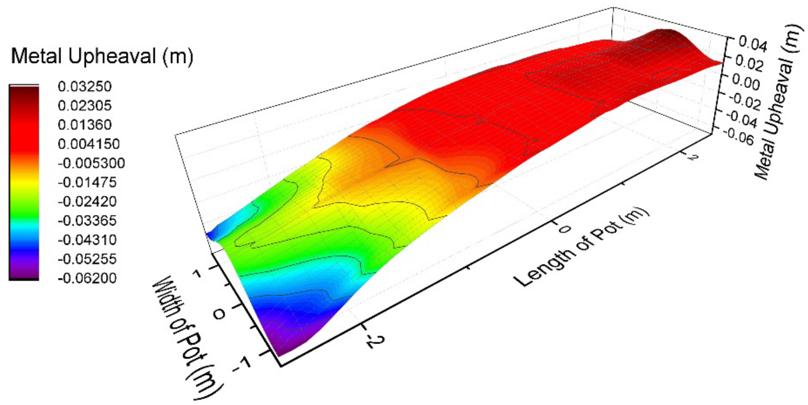

Figure 6. Simulated metal-electrolyte interface for reference cell.

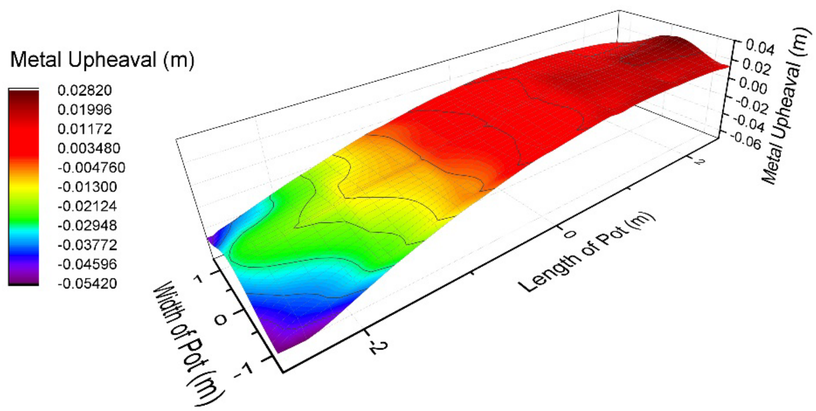

Figure 7. Simulated metal-electrolyte interface for CuCB cell.

2.5. Thermal Balance

Thermal-electric simulations were performed for the reference cell and for CuCB cell. Lower electrical resistivity of CuCB reduces the joule heat generation in the cathode assembly. Also, presence of copper insert, increases the effective thermal conductivity of CuCB. These changes contribute towards shifting the temperature isotherm location in the cathode block, resulting in reduced temperature gradient in the cathode block. Because of improvement in current distribution, flow profile and metal-bath interface deformation, ACD was anticipated to reduce by 2 mm. Such reduction in ACD will further reduce the heat generation in the ACD. Therefore, thermal insulating material was used at appropriate locations to improve the cathode temperature and positioning of isotherm at anticipated lining material.

These modifications also affect the ledge profile and ledge thickness which play vital role in cell performance. Figure 8 shows the simulated ledge profile for reference cell and CuCB cell with modified cell lining. It can be seen that for reference cell, the lower ledge extends slightly under the shadow of the anode, whereas for CuCB with modified cell lining ledge thickness and profile was found to improve without ledge getting extended underneath the anode shadow.

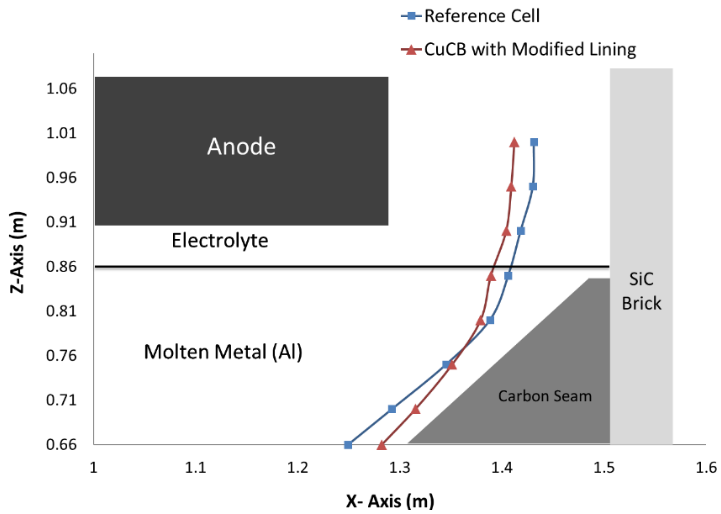

Figure 8. Ledge profile for reference cell vs CuCB cell with modified lining.

3. Cell Measurements

The voltage drops of all the components, temperatures, electrolyte chemistry and cell stability measurements were performed to have good understanding of the cell performance. Table 2 shows the comparison of measurement data for reference cell and for CuCB cell with modified lining. Measurement shows that steel shell temperature was reduced in case of CuCB cell affirming the model prediction of increase in ledge thickness. Also there was slight increase in collector bar exit temperature.

Table 2. Temperature measurement at the cell boundaries.

	Reference Cell	CuCB Cell
Avg. temperature at mid length of steel shell and at metal-electrolyte interface (°C)	356	337
Avg. temperature at quarter length of steel shell and at metal-electrolyte interface (°C)	336	321
Avg. temperature at collector bar exit (°C)	219	226

Model prediction shows noteworthy impact of hydrodynamics of molten fluids, this was assessed by pot stability test. During pot stability test, ACD was lowered in steps of 2 mm and kept for 15 minutes to analyze the growth in voltage fluctuation. Figure 9 and Figure 10 show the cell voltage as a function of time during pot stability test performed in reference cell and CuCB cell with modified lining respectively.

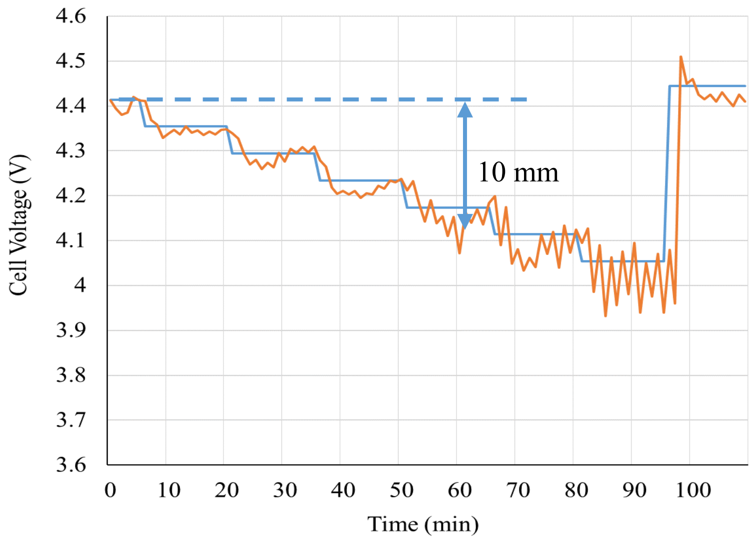

Figure 9: Pot Stability test in reference cell.

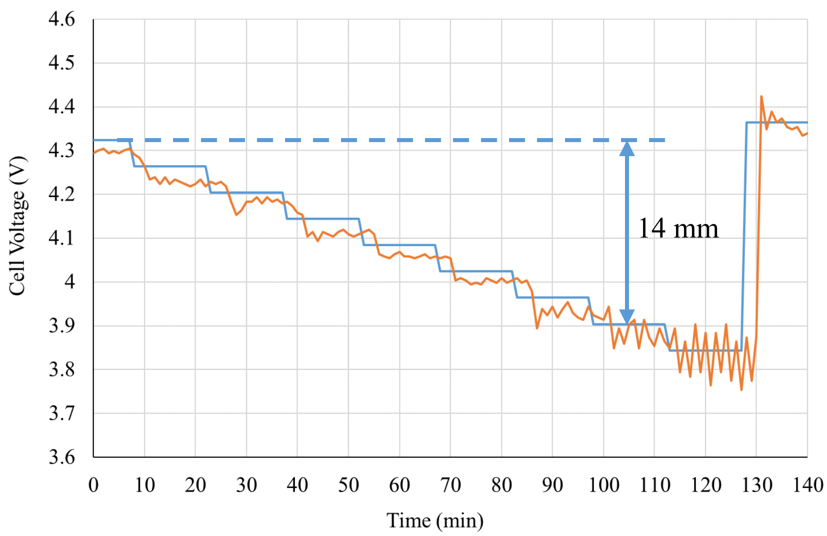

Figure 10. Pot stability test in CuCB cell with modified lining.

CuCB cells with modified lining are running around 90 mV lower than reference cell, because of voltage reduction in CVD and ACD. It can be seen that reference cell was able decrease voltage down to 4.12 volts before the voltage instability kicked in, whereas in case of CuCB cell it could go down to 3.92 volts. This shows a total potential of ACD reduction by around 6 mm in CuCB cell however thermal balance needs to be ensured either by increased amperage or by increased insulation in the cell lining. In present case, 2 mm of ACD reduction was achieved by modifying the cell lining insulation, without increasing the cell amperage. Cells have been running for more than a year with good performance with respect to reduced voltage noise, lower energy consumption and improved current efficiency.

4. Conclusions

As part of the voltage reduction initiatives, the copper insert collector bar (CuCB) was evaluated using mathematical models. Modeling and measurement shows that CuCB provide significant voltage saving potential in low amperage cell, provided the thermal balance is maintained. The cell lining was modified to compensate the reduced heat generation due to voltage reduction. CuCB was installed in few cells of 85 kA potline at Hirakud. Modeling results show significant improvement in current distribution in the metal pad, molten metal velocity and metal-electrolyte interface deformation by using CuCB. Test performed on running cells for pot stability, highlighted the potential of operating the cell with 5 - 6 mm lower ACD than in the reference cells. In spite of higher pot stability attained by CuCB cell, the voltage reduction was limited by thermal balance constraint, as these cells were originally designed to be heat conservative. These cells have been operating for a year at approximately 280 kWh/t Al, lower energy consumption and better current efficiency than reference cells. Cell design is being explored to further reduce the energy at same amperage, by putting more insulation in the cell lining. The optimal design of copper inserts and the cell lining, for a particular cell technology, are the key to achieve low CVD, optimum current distribution and thermal balance.

5. Acknowledgement

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