

## Thermal Behavior of Cathode Bottom Lining at CBA

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### Abstract

The heat dissipation at the cell bottom represents 7 - 20 % of the total aluminium smelting cell heat losses, depending on lining design and its condition. The heat transfer at the bottom region is controlled by the thermal insulation of materials. Insulation bricks can be attacked by sodium and bath components, if proper conditions for their diffusion are met, causing deterioration of the material insulation properties. Thermal measurements of the cell bottom insulation evolution with age were made for the existing CBA cell lining, showing progressive increment on heat losses along the lining life. High bottom heat losses not only require more voltage to keep the cell in thermal balance, increasing energy consumption, but also may induce sludge formation on the cathode panel. This increases cathode voltage drop, perturbs horizontal currents in the metal and consequently increases MHD instability. As a solution, a stainless-steel barrier was installed in ten test cells to prevent bath components and sodium migration into the insulation bricks. Heat flow measurement surveys were done to assess the steel barrier efficiency relative to thermal energy saving over time.

**Keywords:** Lining design, cathode sludge, diffusion barrier, lining ageing, cell heat losses.

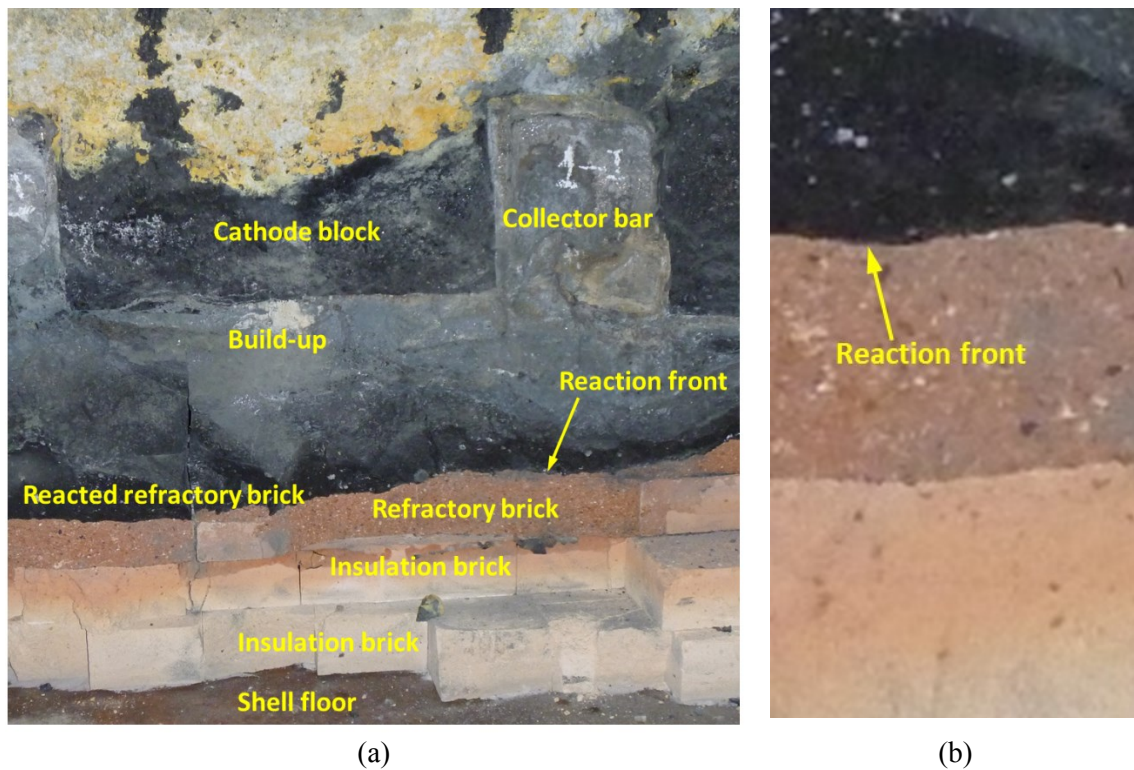
### 1. Introduction

The region below the carbon cathode block is called sub-cathodic and modern designs have layers of refractory and insulation bricks or slabs. The function of the refractory bricks is to protect the insulation underneath. This is because during cell operation sodium and bath percolates through the cathode block towards the shell bottom.

A typical cross section of a used lining, as shown in Figure 1, presents a layer called “build-up” of white grey colour consisting of cryolite, sodium fluoride, aluminium, alumina, silicon,  $Al_4C_3$ , Fe-Si and Fe-Al alloys. Below this layer there is a dense black layer consisting of reacted refractory where nepheline ( $NaAlSiO_4$ ) and a glassy phase close to albite ( $NaAlSi_3O_8$ ) were found [1]. This layer acts as a diffusion barrier slowing down further sodium and bath penetration. The sharp interface between the intact refractory brick and this layer is what is called “reaction front”. The solidus temperature of this front, if albite is present in addition of sodium fluorite and cryolite, is around 865 °C [1]. By design, this isotherm should be located within the refractory brick, not in the insulation layer.

However, the percolation of bath through the cathode block will not stop during the cell life. The consequence will be accumulation of material below the cathode, the “build-up”. This may result in lift of the cathode panel, the “heave”, and/or compression of insulation material that will move the solidification isotherm downwards, thus progressing the contamination.

The refractories used are aluminosilicate chamotte bricks with high silica content since it was found to have a better cryolite resistance [2], most likely because it results in a more viscous glass diffusion barrier.



**Figure 1. Cell cross section bottom lining (a) and reaction front in detail (b).**

There is a fine balance in a well-designed bottom lining for aluminium reduction cells. The thermal resistance of the bottom should be high enough to provide good energy efficiency but at the same time, it should not be too high to favour the sodium and bath contamination which deteriorates the insulation over time.

In the case of an over-insulated bottom design, in the beginning of the cell life a too high temperature at the hot face of the insulation layer would be present, reacting with percolating bath components and being destroyed completely too early in the pot life. When the insulation is destroyed, its thermal conductivity increases reducing the bottom thermal resistance which will in turn increase heat losses, thus reducing process energy efficiency. Also, sludge and bottom freeze may become an issue, requiring more heat generation.

In a bottom with a thermal resistance designed to have the solidification isotherm inside the refractory bricks, the heat flux is a little higher but stable over time and it is not necessary to increase cell voltage to compensate extra heat losses. Figure 2 shows the heat flux measurements for two different lining designs of the same technology that relies only on high silica refractories as diffusion barrier. Lining A is the old design with theoretical thermal resistance of  $1.24 \text{ m}^2\text{K/W}$ , which results in an initial heat flux of  $680 \text{ W/m}^2$ . However, the insulation hot face temperature is  $877 \text{ }^\circ\text{C}$  leading to its deterioration over time. Lining B was designed to have a thermal resistance of  $0.84 \text{ m}^2\text{K/W}$ , having an initial heat flux of  $980 \text{ W/m}^2$ , but in this case the insulation hot face temperature is  $810 \text{ }^\circ\text{C}$ . The heat flux remains stable over the period of 600 days when the Lining A was already having more than twice the designed heat flux.

## 7. Conclusion

Numerical model, autopsies and internal thermocouple measurements confirm the hypotheses of an over insulated bottom lining by design at CBA cells. Due to this over insulated bottom and the use of low silica refractory bricks, a diffusion barrier did not form in the bottom of the CBA cells. This leads to a contamination of the insulation thus increasing the heat loss from the cells over time. The cells were not equally affected, as the measurements of heat flux showed. Also, variations were found in the same cell. Even though the cell materials and start-up are the same, it is not known why the cells have different behaviour. It is possible that differences in preheat temperature distribution lead to cracks making the infiltration rate non-uniform [10].

When the sub-cathodic insulation is destroyed it is necessary to operate the cell with a higher voltage to compensate the extra heat losses. The cell is kept in thermal balance adjusting the ACD to generate the proper heat to compensate the heat losses. Although no correlation was found, one of the reasons for the dispersion of the voltage necessary to maintain the thermal balance must be related to the degree of contamination of the lining, which is not uniform even in the same cell.

The hard muck usually found in the CBA cells is directly related to the sludge at the cathode top. CBA cells are prone to form sludge due to their side-break feeding, high  $\text{AlF}_3$  and deteriorated sub-cathodic lining. Then the sludge becomes hard muck when the cathode top reaches the eutectic temperature for alumina.

The non-uniform distribution of hard muck, liquid and solid sludge over the cathode top generates electrical perturbation leading to magnetic instabilities which results in energy consumption increase. The accumulation of hard muck reduces the cell cavity resulting in sidewall bath infiltration and tap-out.

So far, the test cells using the stainless-steel barrier seem to be preventing bath components and sodium migration into the insulation bricks. Heat flow measurement done on three occasions did not show significant increase of heat loss over cell life. The use of steel plates as a diffusion barrier in an over-insulated bottom will only postpone the destruction of the bottom insulation [10]. However, we expect that the stainless-steel plates will last longer than the low carbon steel due to their better corrosion resistance.

Regarding the cost, when steel plates are used as a diffusion barrier approximately 100 kg of low carbon steel per  $\text{m}^2$  of cell bottom area are used. The test cells used only around 25 kg of stainless steel per  $\text{m}^2$ . So, although the stainless steel (AISI 304) cost is 3.5 times higher than the cost of low carbon steel, the cost of this design is below the one using carbon steel. In the test cells around 850 kg of stainless steel were used which cost around USD 4 500 per cell in 2015.

If we consider the average gain of cell voltage being 100 mV over a 3 000 days cell life, the total energy saving will be around 920 MWh at 128 kA of cell current. If the energy cost is 30 USD/MWh the total savings will be around 27 000 USD. This is only the direct gain not considering gains in cell stability, reduction of sidewall tap-outs, etc.

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