Experience and Learnings with Inclined Anode Slots in High Amperage Aluminium Reduction Cell

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Abstract

Rio Tinto is known for its high amperage operation and its main primary aluminium production hub in the Saguenay Lac Saint-Jean region (Québec, Canada), with five aluminium smelters and a research centre. Over the last decades, cell designs have continuously evolved to allow higher heat dissipation and support successive amperage increases. Recently, a recurring problem threatening cell life duration, expressed by repetitive shell sidewall temperature peaks, was encountered in one of the regional smelters. The situation was addressed by mobilizing R&D teams to understand the provenance of the phenomenon taking place and to propose a solution to mitigate it. The results of the investigations pointed to a solution lowering the solicitation of the inner sidewalls of the cell by modifying the anode slot design. Industrial tests were carried out using different anode slot designs to better assess the behaviour of the proposed solution. The retained inclined anode slot design has been in operation for more than two years now.

This paper presents the sequence of events that unfolded from the apparition of the problem to its solution. It summarizes the experience gathered through key learnings in both technical and operational fields. It also addresses the thermal impact that needs to be compensated in the operation of the cells with the new anode slot design.

Keywords: Aluminium reduction cell, Anode slots, Cell sidewall, Cell ledge.

1. Introduction

Rio Tinto is a large aluminium producer operating different aluminium reduction technological platforms, with most of its production located in the Saguenay region (Québec, Canada). Rio Tinto also benefits from two private R&D centres which support the continuous improvement of technologies. Thanks to sustained developments over the last two decades, a growth of 1 % per year on amperage has been achieved, bringing local production to more than 1.2 million tonnes of aluminium per year.

The AAR-AP60 smelter (Aluminerie Arvida, Centre Technologique AP60) started in 2013 as a highly productive technology, maximizing the size of the shell and anodes, to produce more than 20.5 tonnes of aluminium per year per cell square meter. This technology is currently in the validation phase, with a cell configuration that defines new limits, exacerbating certain phenomena detrimental to performance. During the test phase, the repeated appearance of hot spots on the long sidewalls of the cells was observed. The R&D teams followed an exhaustive approach to understand and resolve the problem on a group of pilot cells before generalization. The use of inclined anode slots, increasingly found throughout the aluminium industry, is the main solution. The various tests carried out provided a better understanding of how they work and their advantages and disadvantages.

1.1 Anode Slots in Aluminium Production: A Brief Review

The Hall-Héroult process uses a reactor, or aluminium reduction cell, to feed alumina (aluminium oxide) into a high temperature melted cryolite bath, where it is transformed into aluminium by the passage of direct electric current following reaction (1).

$$2\,Al_2O_3 + 3\,C = 4\,Al + 3\,CO_2 \quad (1)$$

The electrical power fed to the cell (voltage times amperage) is used to preheat raw materials and to carry out the alumina reduction while the rest (roughly 50 %) is dissipated as heat through exchanges with the cell surroundings. There exists an operating power range for each cell design within which a sufficient layer of frozen bath forms inside the cell, protecting the lining from the corrosive bath to ensure the long-term operation of the cell (cathode blocks erosion as the expected failure mode). The reduction of aluminium oxide, equation (1), also produces carbon dioxide bubbles, combining oxygen from the alumina with carbon from the anodes. The continuous generation of this gas phase creates movements in the liquid bath, which enhances alumina dissolution and heat transfer in the cell. Buoyancy keeps the bubbles at the anode bottom surface, where they form an electrically insulative layer, referred to as "bubble voltage" in operating terms. The longer the gas bubbles stay under the anodes, the more likely they are to coalesce, forming larger bubbles which can insulate parts of the anode surface, increasing the cell electrical resistance.

To better understand and ultimately predict the "bubble voltage", studies were carried out on the behaviour of the bubbles themselves, from physical air-water models to computational fluid dynamics modelling [1, 2]. To shorten the residence time of the bubbles under the anodes, by reducing their mean free path, the anode bottom surface was slit with perpendicular grooves, or slots. Many slot designs have been studied [1, 3, 4, 5], but the ones running along the long side of the anode block offer better results in terms of reducing gas coverage and voltage [1, 2, 5, 6]. Such longitudinal slots are thus common within the aluminium industry nowadays, as they reduce the noise of the cell (or cell resistance variation) by reducing the current variation of individual anodes compared to non-slotted anodes [7].

The discharge of the gases collected in the slots occurs differently if the slot height reaches above the bath level (slot partly immersed in the bath) or if the slot is completely immersed in the bath. When a new anode is set, part of its slots is outside the bath, provided that they are higher than a certain height (i.e., slot height greater than "bath height minus ACD", where ACD is anode-to-cathode distance). As the carbon anode is consumed, the slots become fully immersed in the bath, drastically changing the behaviour of the generated gases and their impact on the cell, as shown on Figure 1, until the slots disappear. In the former case, the gas bubbles escape through the free bath surface, causing smaller bath displacements. In the latter case, the captured gases are ejected along the channel formed by the slots, causing bath displacement at both ends (lateral and central channels of the cell). In the central channel, these movements are linked with stirring and improved dissolution [2, 7], while in the lateral channel, they foster advection effects onto the inner sidewall [5, 8, 9].

5. References

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