Modeling of the Distribution of Alumina Aggregates in an Electrolysis Cell based on a Multi-Slice Method

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Abstract

Uneven alumina distribution is one of the factors that may disrupts the stability of electrolysis cells. Consequently, an improved understanding of the mechanisms leading from the alumina injection to its complete dissolution will reduce environmental impact (lower greenhouse gas (GHG) emissions) and improve the lifespan of the cells (improved stability with fewer thermal excursions). When alumina is injected, a layer of bath solidifies around the powder due to the decrease in temperature, forming an agglomerate, or a raft. This raft will undergo fragmentation that forms additional aggregates and each of these will contribute to alumina dissolution in different regions of the electrolytic cells until completely dissolved. It is considered that each alumina-bath agglomerate can only be in one of three specific states: 1) it can float on the surface of the bath, 2) sink in the bath and relocate at the bath-metal interface, or 3) settle on the cathode surface and contribute to the formation of alumina sludge.

This article presents a model for tracking the movement of aggregates in the electrolysis cell. The objective is to highlight the most likely alumina distribution patterns and to identify areas with low alumina feed and areas more prone to sludge formation. The model is based on three independents layers: the free surface of the bath, the bath-metal interface (BMI), and the cathode surface. Each layer has their own respective flow and agglomerates population along with specific behavior and criteria which allow the passage of one state to another. By comparing different simulations, the article highlights the main factors that contribute to atypical alumina dissolution pattern, uneven alumina distribution and increased sludge formation. Consequently, this study pinpoints areas of improvements for primary aluminum production to mitigate the effect of these drawbacks.

Keywords: Alumina distribution; Raft formation; Mathematical model; Sludge formation; Alumina dissolution.

1. Introduction

Aluminum is a highly valued material in various fields due to its mechanical, thermal, and electrical properties. The production of aluminum is achieved through electrolysis in a cell filled with an electrolyte, generally referred to as bath. The metal produced is then accumulating at the bottom of the cell as molten aluminum. Under such circumstances, three interfaces can be distinguished: the surface of the bath in contact with free-air, bath-metal interface (BMI), and the surface of the carbon cathode in contact with the metal. Alumina is injected into the cells in the form of a granular material. Since the injected alumina temperature is much lower than the solidification temperature of the bath, bath infiltrates through the particles and solidifies around and within the alumina powder to form an agglomerate called a raft. This entity generally floats on the free surface of the bath until it disintegrates or dissolves completely. In the case of disintegration, the aggregates sink to the bath-metal interface. Depending on their geometry, the aggregates will either float on the BMI or perforate it and migrate to the surface of the cathode to

form sludge. The presence of this sludge on the cathode surface affects the flow of current and the stability of the cell. The distribution of dissolved alumina is also influenced by the movement of rafts at the free surface of the bath and the bath-metal interface due to their dissolution process. This article presents the development of a model created to track the position and behavior of rafts and agglomerates in the electrolysis cell.

The present model consists of simulating three parallel plane surfaces. One simulates the bath flow at the free surface of the bath, the second simulates the different mechanisms at the bath-metal interface, and the third plane simulates the liquid aluminum a few centimeters above the cathode surface. The flows are based on results from computational fluid dynamics (CFD) simulations and the resulting flow profile is implemented directly in the mathematical model.

Dissolution and disintegration of the rafts and agglomerates are based on a heuristic model developed through a collaborative research [1]. This work was developed using the main elements from the fundamental thermodynamics of the dissolution process coupled with observations and measurements conducted under industrial and laboratory conditions. Hence, with known cell conditions, it is possible to predict the total length of the dissolution process for each individual raft or agglomerate.

By reproducing the physics associated to these alumina-bath agglomerates with a known lifetime which are immerged into different liquids flows with known properties and velocity; the proposed model allows for the precise tracking of the position of each raft and agglomerate until their complete dissolution. The choice of importing results from external numerical model was selected to reduce computation time and to enhance the potential of the model to simulate a wide variety of cell conditions rapidly.

2. Methodology

2.1 Presentation of the Multi-Slice Model

Homogeneity of alumina concentration in electrolysis cells is crucial to maintain the proper balance that assures stability in current distribution (limiting the formation of perfluorocarbons (PFC)), while mitigating the risk formation of sludge on the cathode surface. As described in the introduction, the multi-slice model's main goal is to represent the different interfaces in aluminum electrolysis cells in order to track the movement of alumina rafts and aggregates. By understanding the behavior of the undissolved alumina, this tool can target areas of the bath where undissolved alumina is more likely to be present; leading to a significant contribution to the local alumina concentration of these regions while also determining areas prone to sludge accumulation on the cathode surface.

Several models [2-8] simulate the movement of the rafts in the cell using the CFD method to determine the flow related to magnetohydrodynamic (MHD) forces. Bojarevics et al. [4] presented a follow-up of aggregates of different sizes at the bath-metal interface with the transport being exclusively controlled by the MHD flow. Bojarevics et al. [4] show that the deformation of the interface has a significant impact on the movement of the rafts. Liu et al. [3] considered that the injection of alumina would create small agglomerates with a diameter of approximately five centimeters. These two papers don't consider the displacement of the raft at the free surface of the bath, which can be significant as reported by some authors [9-11]. Rakotondramanana et al. and Richer et al. presented an novel approach by studying the tranport of agglomerates specifically at the BMI interface. These papers inspired the work presented in this paper.

exact final position of these agglomerates is most probably dependent on a wide variety of factors such as the return flow velocity, the size of the agglomerates, the deformation curvature, their kinetic energy, and others. Although, the most likely scenarios are that these agglomerates remain either caught in the cell curvature until they are completely dissolved, or they pierce the BMI and move to the cathode surface. In both cases, the contribution of these agglomerates to the global alumina distribution in the cell will be strong and negative. Therefore, efforts to mitigate these occurrences should be preserved.

4. Conclusions

A new approach has been developed to simulate the transport of rafts and aggregates by simplifying the aluminum electrolysis cells into three parallel planes representing the free surface of the bath, the bath-metal interface, and the cathode surface.

This model simulates the interaction of the raft and the flow at the bath surface via drag force. The flow at the bath-metal interface is based on a simulation of magnetohydrodynamic forces coupled with permanent deformation and waves. This flow acts on the raft with drag force and buoyancy force. The flow at the cathode surface is identical to the flow related to the magnetohydrodynamic forces present at the bath-metal interface.

The model also uses the results from a heuristic model that determines the evolution of a raft's mass after alumina injection. It also determines the specific timeline for the disintegration of the raft into aggregates that will sink to the bath-metal interface.

The obtained results show that the time between raft formation and the start of disintegration impacts the drop-off point of aggregates at the bath-metal interface. They will move differently, and the formation of sludge on the cathode can be influenced.

The results obtained from the study on the impact of the injected mass on the movement of rafts show that as the injected mass increases, the individual masses of the aggregates become larger. Consequently, waves have a greater influence on their movement, and their dissolution is less pronounced. The results indicate an increase in the mass of produced sludge and also illustrates that the commonly injected mass of 1000 g is above an optimal threshold.

Permanent deformation is the studied factor that promotes raft movement towards the corners of the cells, which in turn is very likely a strong contribution to sludge formation.

This model is still under development, but it already highlights key behaviors that can pinpoint potential solutions with significant gains in the process. Additional tools such as this one are critical to achieve the proper understanding related to alumina distribution, which is required for optimal operation in the present era of low energy consumption. Such knowledge is key to maintain optimal operational standards and also to maintain anode effects frequency and sludge formation at minimal possible levels.

5. References

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