Modelling Study of Bath Agitation by Bubbles and its Effect on Bath-Metal Interface Stability

Samuel Théberge[1], Lukas Dion[2], László Kiss[3], Thomas Roger[4], Simon-Olivier Tremblay[5], Sébastien Guérard[6] and Jean-François Bilodeau[7]

1. Master student

University Research Centre on Aluminum (CURAL) – Aluminum Research Centre (REGAL) - Université du Québec à Chicoutimi (UQAC), Chicoutimi, Canada

2. Professor

3. Professor emeritus

4. Post-doctorat

5. Research professional

Université du Québec à Chicoutimi (UQAC), Chicoutimi, Canada

6. Research scientist

7. Research scientist

Arvida Research and Development Center, Arvida, Canada

Corresponding author: stheberge2@etu.uqac.ca

Abstract

Two dimensional simulations of the carbon dioxide production and its bubble flow under an aluminum electrolysis anode were performed using a CFD model on ANSYS FLUENT. This model calculates the local current density to determine the local gas production rate. Building on previous research from the group, the bubble behavior underneath the anodes is replicated along with their escape from electrolytic bath towards the central and side channels.

The simulations investigate the system's response to the bubble behavior as a function of the turbulence it generates and its effect on the bath-metal interface stability. The results are consistent with previous publications regarding the frequency of bubble generation and evacuation along with the corresponding response on the voltage variations under the anode as a function of time. Further analysis has allowed a better understanding of the mixing in the center channel and the side channels as well as a perturbation indicator for the bath-metal interface (BMI) caused by the bubbles escaping from under the anode.

Finally, a sensitivity analysis of different key parameters such as anode geometry, anode-cathode distance, and central channel size, was performed to pinpoint the conditions in favor of an increased mixing index (better alumina dissolution), while also highlighting the conditions that minimize the BMI perturbation (increased current efficiency). A discussion on the effect of these parameters and recommendations leading to potential improvements for the Hall-Héroult process are presented.

Keywords: Computational fluid dynamics, Aluminum reduction cell, CO_2 production, Bubble flow.

1. Introduction

1.1 Generality

The Hall-Héroult process is a process invented simultaneously by Charles Hall and Paul Héroult in 1886. With this process, aluminum is produced by electrolyzing alumina (Al_2O_3). A cryolite mixture is used to dissolve the alumina and allow the electrolysis reactions at a much lower

temperature (950-970 °C) then its melting temperature (2072 °C) [1, 2]. Aluminum is produced in industrial cells where the main components are illustrated in Figure 1.

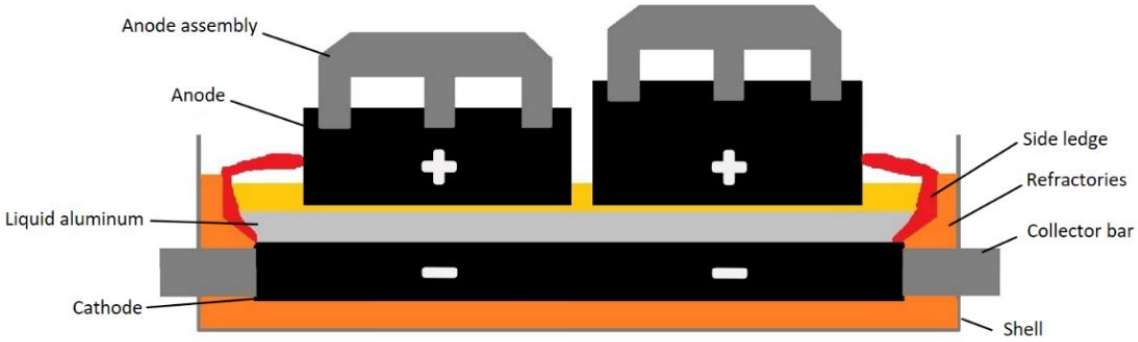

Figure 1. Electrolysis cell main components.

In the electrolytic cell, a current circulates from the anode to the cathode, producing the following generalized reduction reaction in the cell:

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

While the reactions occurring are much more complex, the main products of this reaction are aluminum and carbon dioxide (CO_2) gas. The aluminum produced joins the liquid aluminum already present at the bottom of the cell due to gravity forces. On the other hand, CO_2 is formed on the lower surface of the anode and tends to rise to the surface.

1.2 Gas Production and Bubble Flow

During aluminum electrolysis using the Hall-Héroult process, various gases are produced in addition to CO_2. The resulting gas flow has the advantage of stirring the electrolytic bath, particularly in the cell's central channel, which promotes alumina dissolution and distribution [3]. However, they also produce significant disadvantages, such as voltage fluctuation due to electrical insulation between anode and cathode [4-7], along with a significant greenhouse gas contribution [1, 2]. It is therefore important to understand the behavior of bubbles to promote optimal mixing conditions while avoiding excessive electrical insulation.

Among the gases found in an electrolytic cell, the most commons are CO_2, CO, HF, SO_2, CF_4 and C_2F_6. The most concentrated gas generated is CO_2, directly proportional to the mass of metal produced as shown in equation 1. This reaction is the only one considered for the initial step of the work presented in this paper. On the other hand, a better understanding of the flow of CO_2 bubbles may help to improve the dissolution of alumina in the smelting cell and thus reducing the generation of perfluorocarbons.

The layer of bubbles is around 5 mm thick [5, 8-10]. While bubble nucleation occurs at various sites under the anode. Initially small in size, they grow as gas is generated, and coalescence between the bubbles takes place, leading to even larger bubbles. At some point, they escape from the bottom surface of the anode, leading to continuous variations in potential (between 0.05 and 0.2 V) [4].

To facilitate the bubble removal, anode slots are usually cut into the bottom of the anodes for a significant part of their life. However, since the model presented in this work is two-dimensional, the effect of the slots has not been represented, discussion on the impact of this hypothesis is presented further in the analysis.

The last analysis in this study showed that chamfers reduce bubble coverage by an average of 9.1 %, but this effect remains to be verified under 3D simulations as it may be amplified by the absence of anode slots in the 2D simulations. Also, it was seen that a 20 mm increase in ACD had the effect of reducing anode bubble coverage by 10.6 %.

Since the generated model is 2D and not 3D, it is important to consider that the absolute values obtained when analyzing these results are unrepresentative in magnitude to the reality. Bubbles modeled in 2D have a much greater effect than bubbles modeled in 3D especially on BMI deformation, since they occupy the entire width of the anode. The mass of bath displaced by the evacuation of a 2D bubble is therefore more important than the mass displaced by a 3D bubble. Also, the absence of anode slots has a significant effect on the results. In the 2D model, the bubble escape locations are limited to the two corners, while in a real cell, a large portion of the bubbles escape through the slots. This effect will be important for each of the output parameters studied in this work. The deformation of the BMI, the turbulence in the central and lateral channels, as well as the bubble coverage of the anode, may be lower.

However, the likeliness that the dominant factors highlighted remain of interest as we move towards a 3D simulation is elevated. Thus, these results mainly serve to understand trends and to identify which variables are the most relevant to properly design and investigate the same effects using a three-dimensional model.

Therefore, the next step is to use the knowledge acquired in this study to create a 3D model of bubble flow beneath the anodes. By transitioning to a 3D model, the effects of anode slots, which are of great interest to the industry, will be considered in the analysis. Similarly, the numerical values obtained with the 3D model can be considered more reliable than those obtained in 2D.

6. References

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