Alucell Latest Development: Modelling Impact of CO_2 Bubbles and Anode Slot Configuration on Liquid Flows in Hall-Héroult Pot

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Abstract

During the aluminum electrolysis process, CO_2 bubbles are generated under the anodes and released through anode slots. To study the impact of these bubbles on bath flows and therefore to help understand related phenomena observed in an aluminum reduction pot, a mixture model of CO_2 bubbles diluted in a liquid bath was developed and integrated into Alucell software. Alucell is a suite of numerical simulation models which calculates magnetohydrodynamics (MHD), alumina dissolution as well as the coupling between thermo-electric balance and MHD flow.

This article explains how equations are modified in Alucell in relation with the latest mixture model developed. The effect of the gas on bath velocity, and metal pad upheaval is demonstrated. Furthermore, the impact of anode slot configurations on bubbles and liquid flow behavior is also investigated. Modeling results were analyzed and compared to some observed phenomena in the aluminum reduction pots.

Keywords: Alucell, mixture model, liquid flows, bubbles, slotted anodes

1. Introduction

Industrial aluminum production is based on the Hall-Héroult electrolysis process. The electrochemical reduction occurs in molten electrolyte (bath) maintained at 970 °C in a pot where high quantities of electrical energy are needed. The latest generation of pots is very large with current greater than 600 kA. Direct electric current passes continuously from the anode to the cathode allowing electrolysis of alumina (Al_2O_3) with carbon anodes to produce molten aluminum, as shown in Equation (1)

$$2Al_2O_3 + 3C = 4Al + 3CO_2 \tag{1}$$

Since carbon anodes takes part in the chemical reaction, carbon dioxide (CO_2) is generated under the anodes by the reaction of carbon with oxygen leading to the consumption of anodes, which have to be replaced regularly. CO_2 bubbles influence electrical and hydrodynamic behavior of the pot in both positive and negative ways. Gas bubbles induce bath flow and play a significant role in the alumina mass transfer, resulting in better alumina dissolution and alumina transport in the bath. On the other hand, since most of the bath is covered by the anodes, a nearly continuous layer of gas could be generated underneath the anodes through bubble collision and coalescence. Such a gas layer can cover a large part of the anode surface up to 90 percent of its surface, according to modelling [1]; this increases electrical resistance between the anode and the bath and can significantly raise the pot voltage and eventually decreases the performance of the pot.

Several ways are used by the aluminum industry to optimize its production and reduce energy consumption. In recent years, some solutions were based on the optimization of electrical and geometrical configurations of the pot. Among others, slotted anodes have been used by aluminum smelters to reduce gas coverage and gas bubble layer resistance [2, 3]. Indeed, the slots encourage a quick evacuation of the bubbles from the bottom of the anodes, and slot effectiveness depends on their dimensions, positions, and orientation. For a good control of the electrolysis process, understanding the movement as well as the behavior of the gas bubbles is essential. Due to the complexity of the flow field measurements in the extreme pot operating conditions, numerical simulation is often used to understand and describe the complex flows inside the pot. Such flows involve multiphase coupling between liquid, bubbles, and alumina dissolution.

In the past years, some studies have been carried out where only gas driven flow has been considered [4, 5]. Other studies were done without considering the impact of magnetohydrodynamic effects and/or metal-bath interface fluctuations. We can quote the work of Wang et al. [6] who developed a multiphase flow model to study the gas driven flow without considering the effect of magnetic forces. Their model was validated with measurements in a full-scale water model. Yang et al. [7] also ignored the influence of the magnetic forces in their numerical simulation modeling. Wang et al. [8] studied the behavior of the gas bubbles in a water model to define the optimum slotted anode design without considering bath metal interface movement. Recently, Meijia et al. [9] developed a two-phase model coupled with magnetohydrodynamic aspects to investigate the effect of slotted anodes on the gas bubble movement with the consideration of the bubble coalescence. The model was developed on a pair of anodes only.

Indirectly, the impact of the bubble release from the slots during the anode cycle is observed experimentally on the increase of the sidewall temperatures and a local decrease of ledge thickness.

To consider these complex coupling phenomena, in this work we focused on the modeling of the gas-bath mixture flow at the level of the whole aluminum reduction pot. This paper presents the Alucell's latest development where the equations of the steady state model are modified to include the presence and the movement of the CO_2 bubbles.

2. Model Description

The global effect of the CO_2 bubbles on the bath flow is studied without considering bubble nucleation and coalescence. Since the typical size of the whole pot is several meters whereas the size of a gas bubble is a few millimeters, we adopted a statistical averaged model, namely a dilute dispersion of gas bubbles in liquid bath, described by Soutter [10]. Our model is coupled with magnetohydrodynamics and free surface calculations, and is incorporated in Alucell for industrial simulations.

Alucell is a unique suite of numerical simulation models which has been developed over thirty years in partnership between Rio Tinto, Ecole Polytechnique Fédérale de Lausanne (EPFL) and Ycoor Systems. The software comprises five different physics-based models as described by Renaudier et al. [11]. In these coupled models, magnetohydrodynamic stability (MHD) of the pots, alumina dissolution and thermal balance with ledge calculation are performed.

Investigations should be done to study the impact of the modified velocity on alumina dissolution in the pot, using alumina dissolution model [16]. Furthermore, further R&D efforts will more precisely investigate the impact of the gas bubbles on the ledge profile, using the MHD-TE Alucell model [16].

However, when the whole pot is modeled with all anodes slotted, a large number of mesh elements is required, which makes the calculations impossible. Work is currently underway as part of a recent PhD. thesis in collaboration with EPFL, to develop a methodology to optimize and adapt the mesh in order to obtain more precise results. This ongoing work reduces the number of mesh elements, and the computational time of the calculations.

5. References

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