Experimental Study of Multi-Bubble Dynamics Below a Small Anode Using an Air-Water Model

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Abstract

This research investigates several characteristics of multi-bubble motion under the bottom surface of a reduced-scale carbon anode sample in a physical air-water model of the Hall-Héroult cell. Applying the principles of similarity to our experimental setup, we used low-temperature water and air to represent the bath and CO_2 molecules in the real cell. Ultra-speed camera imaging and videography technique was implemented to track the bubble evolution under the anode from initial generation to detachment from the anode bottom surface. After post-processing the laboratory data using ImageJ, GIMP, and MATLAB, we determined interesting information on the bubble size, residence time, and velocity under the anode. Considering the effect of anode tilt in the longitudinal direction, we demonstrated that increasing the anode tilt reduced the bubble size, residence time, collision, and coalescence under the anode, while bubble velocity was enhanced. Moreover, the threshold initial volume for bubbles to detach from the anode bottom surface at nucleation sites was decreased by increasing the anode tilt. On top of this, the similarity between the bubble size and velocity data that we have determined in our setup and those reported in existing literature, confirms the success of the current configuration in the prediction of the two-phase bubbly layer features beneath the anode. Consequently, we can provide valuable insights for aluminum smelters by optimizing the bubbly layer resistance of our model cell through modification of the geometrical features.

Keywords: Multi-bubble dynamics, Air-water model of the Hall-Héroult cell, Tilted anode, Bubble size, Bubble collision and coalescence.

1. Introduction

In the high-temperature aluminum reduction cell, a reaction between the carbon in the anode and dissolved alumina during the Hall-Héroult process produces CO_2 bubbles beneath the anode. Bubble behavior is illustrated in Figure 1. Small bubbles begin to form under the anode, grow, and eventually merge into larger ones. As they move towards the anode edges, bubbles will detach from the bottom of the anode. The released bubble has the ability to induce circulation in the surrounding liquid (Figure 1(d)). This complex phenomenon plays a significant role in magnetohydrodynamic (MHD) instability and current efficiency [1]. However, due to the harsh operating conditions and high temperatures within the aluminum reduction cells, studying bubble behavior below the anode surface in the aluminum cell is challenging.

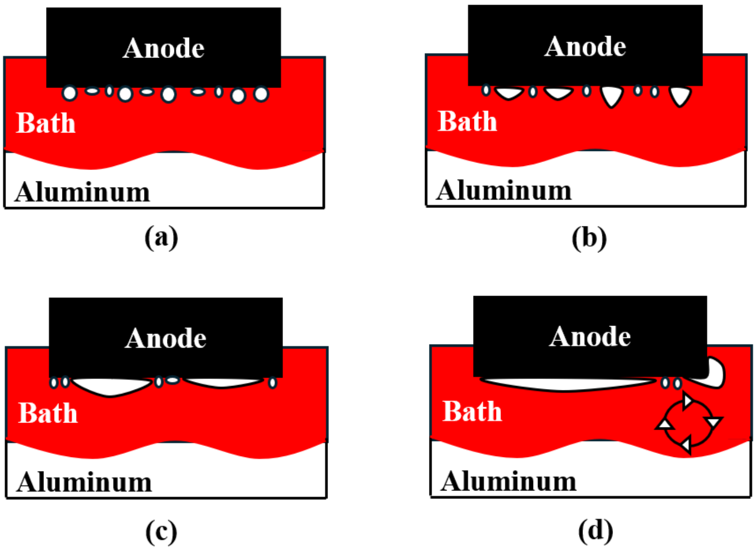

Figure 1. Schematic representing the motion of bubbles under the anode bottom surface: (a) microbubble nucleation, (b) bubble coalescence, (c) bubble swallowing, and (d) bubble detachment.

In recent years, several studies have been conducted on various aspects of bubble transient motion under the anode in the Hall-Héroult process. In an experimental study, Maneri and Zuber [2] conducted the first investigation on the formation of gas bubbles under a tilted anode. Vekony et al. [3] used a full-sized air-water electrolysis cell model to examine the formation of the bubbly layer under the anode. They reported that the larger bubbles tend to absorb the smaller and slower ones, with a maximum height of 2 cm. Additionally, they found that gas bubbles under the anode increases the ohmic resistance of the cell, resulting in higher energy consumption. Alam et al. [4] utilized a one-fourth size aqueous $CuSO_4$ model of the Hall-Héroult cell to study bubble behavior under a flat anode. Their findings indicated that as the anode tilt increased from 0° to 3°, the thickness and size of the bubble layer decreased, along with reduced bubble coverage under the anode. Aaberg et al. [5] measured gas production under the anode by monitoring liquid levels during the electrolysis process. They observed that the bubble thickness ranged from 0.4 cm to 0.6 cm, occasionally reaching 0.71 cm before release from the anode edge. Fortin et al. [6] used a full-scale air-water model of a 150 kA prebaked anode sample to study the morphology of the bubbly layer under the anode. They found that the coverage factor of the bubbles under the anode is influenced by the anode tilt angle, ranging from 24 % to 90 %. Further research by various authors [5, 7-9] supports the idea that the bubble coverage value can vary from 30 % to 90 %, resulting in an additional voltage drop in the cell. Haupin [10] inserted a probe-type reference electrode between the anode and cathode to directly measure the voltage drop of the industrial cell, noting a minimum bubbly layer thickness of 0.5 cm. Das et al. [11] observed that bubble size decreases as the anode tilt increases, while Shekhar and Evans [12] found that a tilted anode leads to a narrower bubble layer beneath the anode. The thickness of the bubble layer estimated to be around 0.4 cm by Xue and Oye [13].

Apart from the mentioned features, many studies have investigated other aspects of bubble motion under the anode, such as bubble velocity and volume. Perron et al. [14] conducted a

This, in turn, could provide valuable insights to aluminum producers seeking novel geometries to decrease power consumption in industrial cells.

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6. References

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