Numerical Simulation of the Voltage Drop with Different Bubbles under the Anode

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Abstract

During the operation of the aluminum reduction cell, bubbles are continuously generated under the anodes. As a result, they combine as a gas layer which isolates the anode from the electrolyte and current path from the anode is prolonged and an extra voltage drop is needed for the normal operation of the cell. In the present work, a numerical model was developed to address the additional voltage drop caused by these bubbles. Other than presented by numerical approximation, the real bubbles were created in the model. The influence of bubble size, bubble area coverage and bubble gap on the voltage drop is comprehensively discussed.

Keywords: Bubble, Voltage drop, Bubble shape, Finite element model, Aluminum reduction cell.

1. Introduction

Carbon dioxide bubble behavior has become one of the hot issues in recent years in the aluminum industry. Carbon dioxide is generated under the anode working surface during the electrolysis process. Due to its big electrical resistance, the bubbles have influence on the local current distribution during its generation, growth and coalescence. When the bubbles gather in the bottom of the anode to form a large bubble layer, this bubble layer blocks the transmission of current, which results in a significantly increased cell voltage, and the increased energy consumption. Moreover, the bubble movement is one of the main driving forces that promote the circulating flow of the electrolyte, which greatly affects the alumina concentration equilibrium and heat transfer in the electrolysis cell. Hence, it is significant to carry out the research on the bubble behavior in aluminum reduction cell. Though the industry also has great interest in directly measuring the bubble behavior in industrial cell, due to the extreme corrosiveness of the high temperature molten salt, direct observation of anode bubble behavior is difficult to achieve. Haupin [1] measured the contribution of bubbles to voltage drop to be in the range of 0.15-0.35 V in industrial cell at an anodic current density of 0.8 A/cm^2. And the bubble layer was about 5 mm thick with a maximum value of 2 cm. Hyde and Welch [2] studied the influence of accumulated gas under the anode on the bubble resistance by putting ceramic objects as the bubbles in a lead smelting cell. The results showed that the resistance increase caused by the presence of the ceramic objects primarily depends on the bubble volume, and it increases linearly with the accumulated gas. With a lab-scale see-through cell, Youjian Yang [3] found that bubbles tended to generate and adhere to certain regions on the anode surface due to the heterogeneity of the carbon material, and the adhering regions moved when current density was increased. Nikolina Stanic [4] found that an anode slot lowered the actual current density on the anode significantly by reducing the anode bubble coverage.

In order to give an insight into the bubble behavior, as a powerful tool, the numerical simulation has been applied in the industry. The detailed current flow around individual bubbles can be addressed in the numerical modeling, and it provides an excellent opportunity to quantitatively assess the effect of bubbles on induced voltage drop. There are a few numerical works that investigate the electrical resistance within the presence of bubbles under the anode. Zoric [5] developed a two-dimensional (2D) model to calculate the current distribution and voltage drop induced by bubbles. When the bubbles were treated as a homogeneous layer (thickness of 5 mm) with constant resistivity, an extra voltage drop of 0.4 V was measured at average current density of 0.75 A/cm^2. Using a 2D geometry of part of a real cell as the testing bed in a computational fluid dynamics model, Kaiyu Zhang [6] predicted bubble-induced voltage drop for a current density of 0.7 A/cm^2 of about 0.11 V for bubble coverage of 37 % and 0.29 V for bubble coverage of 50 %.

The 2D study may not fully represent the real case which is indeed three dimensional (3D). The aim of this work was to construct a 3D model to investigate the contribution of bubbles to voltage drop.

2. Modeling

2.1 Geometry of the Model

The bubbles were generated under the anode bottom surface. And the current passed from the anode bottom to the aluminum pad. In the physical model, the interested domain of this work was the region between the anode bottom and the top surface of the aluminum pad. And the distance from the anode bottom surface to the aluminum pad top surface was 0.04 m. For simplification, the rectangular slice in this region was selected for the numerical simulation. Therefore there were electrolyte and bubbles in the physical model without the anode carbon and cathode carbon.

2.1.1 Single Bubble Model

Under the vertical projection of the carbon anode in the single bubble model, the electrolyte layer was sliced into a block as shown in Figure 1. One bubble was placed under the anode bottom surface. In order to improve the simulation accuracy, the real entity of the bubble was created in the model.

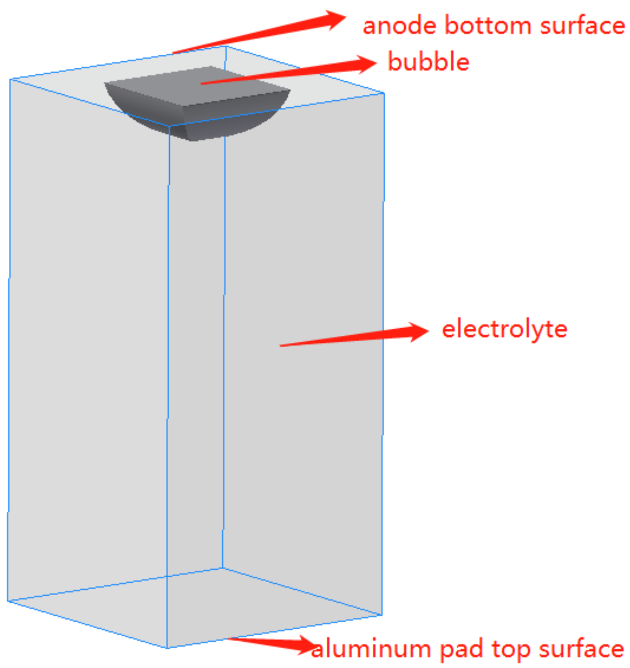

Figure 1. Physical model of a single bubble.

5. Reference

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