Observation of Alumina Dissolution and Bubble Behavior in Molten Salts with High Temperature Transparent Electrolytic Cell

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Abstract

The method of high temperature transparent electrolytic cell, which was developed by Prof. Zhuxian Qiu, was further developed and it played an important role in investigating the physical-chemical phenomena in molten salts. Two topics including dissolution of alumina in molten salts and anodic bubble behavior during aluminum electrolysis are described in this paper. The high temperature transparent cell was used for observing the dissolution behavior of alumina, including comparison of dissolution behavior between the secondary alumina and the primary alumina, physical-chemical properties of alumina on dissolution rate and crust dissolution dynamics. Another type of laboratory scale transparent aluminum electrolytic cell was used to observe the bubble dynamics beneath the anode in an electrolytic environment like that of an industrial cell. Some factors, such as anode design, anode current density, and bath composition on anodic bubble behavior are discussed.

Keywords: Aluminum electrolysis, transparent electrolytic cell, alumina dissolution, bubble behavior, molten salts.

3. Introduction

At present, the electrolysis of cryolite-alumina molten salts, also known as Hall-Héroult process, is the only industrial process for the primary aluminum production. The temperature of electrolysis is usually in the range of 940 to 970 °C. The cathodic product is liquid aluminum and the anodic product is a mixture of CO/CO_2 gas. The energy consumption is about 13.5 kWh/kg Al.

In 2018, the global primary aluminum production is estimated to be around 64.34 million tonnes. China produced 36.49 million tonnes accounting for 56.7 % of global production [1]. Currently, the largest prebake cell operating at 600 kA was started in China in 2014 [2]. Such great achievements were based on the development of fundamentals on aluminum electrolysis, including bath chemistry, cell magnetohydrodynamic (MHD) stability of the aluminum metal, energy balance and mass balance, electrochemical process of super large anode, materials selection and engineering.

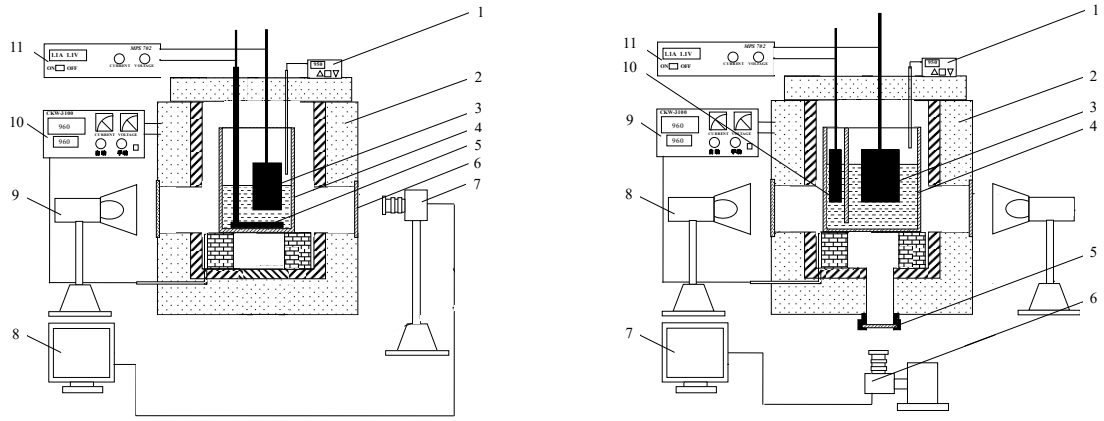
In this paper, some fundamental developments in understanding physical and chemical phenomena in the cryolitic melt are presented, such as dissolution of aluminum oxide in molten salts and anodic bubble behavior during aluminum electrolysis. A special instrument, called high temperature transparent cell was used to investigate these phenomena.

4. Introduction of the High Temperature Transparent Cell

Restricted by the high temperature and heavily corrosive environment of the molten salt, studies of industrial aluminum electrolytic cells are very difficult and expensive, particularly for detailed bubble dynamics and alumina dissolution process.

Haupin invented the first generation of transparent cell used for observation of molten salt electrolysis [3]. He employed sapphire windows held in a graphite crucible to 'see' the electrolysis process. This kind of transparent cell was limited due to high cost and small viewing window. For better viewing, Zhuxian Qiu [4 - 5] applied square-shaped quartz crucibles to study the metal fog, anode effect and other electrolysis phenomena, e.g., alumina dissolution. The cell enables us to observe experimental phenomena through side window, therefore it is called side-view transparent cell, as shown in Figure 1(a). This design of cell was limited in time and current density as metal fog rapidly arose and led to an opaque electrolyte. Qiu [5] improved the transparent cell design using double-chamber crucibles by positioning a square-shaped quartz tube inside the quartz crucible. Gao [6] further improved the cell design by implementing two chambers in one quartz crucible with a slot at the bottom of the middle wall connecting the two chambers. The cell can be operated more conveniently.

A new transparent cell with a bottom viewing window was developed at Northeastern University, as is shown in Figure 1(b) [7]. To observe the bubble behavior in the anode-cathode distance (ACD), a new viewing window at the bottom of furnace was opened. The experimental situations are recorded by an Industrial Camera (MV-VS078FC) with 15 frames per second (FPS) from bottom viewing window.



a) Side-view transparent cell

b) Bottom-view transparent cell

Figure 1. The schematic diagram of side-view transparent cell and bottom-view transparent cell [7].

5. Dissolution of Alumina in Molten Salts

Industrial aluminum smelters use alumina as the raw material for electrolysis. The dissolution of alumina in molten cryolite bath has been a long and challenging topic. The high temperature transparent cell was used for observing the dissolution behavior of alumina, including comparison of dissolution behavior between the secondary alumina and the primary alumina, physical-chemical properties of alumina on dissolution rate as well as crust dissolution dynamics [8 - 11].

9. References

1. The website of the International Aluminum Institute, http://www.world-aluminum.org/statistics/ (retrieved on 6 July 2019).
2. Alton Tabereaux. Super-high amperage prebake cell technologies in operation at worldwide alumiunum smelters. *Light Metal Age*, Vol. 75, 2017 (1):26-29.
3. Warren E. Haupin and W. C. McGrew, See-through Hall-Heroult Cell. *Aluminium*, 51, 273 (1975).
4. Qiu Zhuxian, Fan Liman, Kai Grjotheim, Halvor Kvande, Formation of metal fog during molten salt electrolysis observed in a See-Through cell. *Journal of Applied Electrochemistry*, Vol. 17, 1987(4):707-714.
5. Kai Grjotheim, Halvor Kvande, Qiu Zhuxian, Fan Liman, Influence on the carbon wettability of electrolyte composition. *Aluminum*, 1989(2), 157-162.
6. Bingliang Gao, Xianwei Hu, Junli Xu, Zhongning Shi, Zhaowen Wang and Zhuxian Qiu. Study on bubble behavior on anode in aluminum electrolysis - Part II. *Light Metals* 2006, 467-470.
7. Zhibin Zhao, Zhaowen Wang, Bingliang Gao, Youjian Feng, Zhongning Shi and Xianwei Hu. Observation of anodic bubble behaviors using laboratory scale transparent aluminum electrolysis cell. *Light Metals* 2015, 801-806.
8. Yangjian Yang, Bingliang Gao, Zhaowen Wang, Zhongning Shi, Xianwei Hu, Mechanism of Dissolution Behavior of the Secondary Alumina. *Metall. Mater. Trans. B*, 2013, 44(5), 1296-1303.
9. Youjian Yang, Bingliang Gao, Zhaowen Wang, Zhongning Shi, Xianwei Hu, Jiangyu Yu, Dispersion Caused by Carbon Dioxide during Secondary Alumina Dissolution – A Lab-scale Research. *Metall. Mater. Trans. B*, 2014, 45(3), 1150-1156.
10. Youjian Yang, Bingliang Gao, Zhaowen Wang, Zhongning Shi, Xianwei Hu, Effect of physiochemical properties and bath chemistry on alumina dissolution rate in cryolite electrolyte. *JOM*, 2015, 67(5), 973-983.
11. Youjian Yang, Bingliang Gao, Zhaowen Wang, Zhongning Shi, Xianwei Hu. The Formation and Dissolution of Crust upon Alumina Addition into Cryolite Electrolyte. *JOM*, 2015, 67(9), 2170-2180.
12. Zhibin Zhao, Zhaowen Wang, Bingliang Gao, Yuqing Feng, Zhongning Shi, Xianwei Hu, Anodic bubble behavior and voltage drop in a laboratory transparent aluminium electrolysis cell. *Metall. Mater. Trans. B*, 2016, 47(3), 1962-1975.
13. Zhibin Zhao, Bingliang Gao, Yuqing Feng, Yipeng Huang, Zhaowen Wang, Zhongning Shi, Xianwei Hu. Effects of Anode Wettability and Slots on Anodic Bubble Behavior using Transparent Aluminium Electrolytic Cells. *JOM*, 2016, 69(2), 281-291.
14. Youjian Yang, Bingliang Gao, Zhaowen Wang, Zhongning Shi, Xianwei Hu, Study on the Inter-electrode Process of Aluminum Electrolysis. *Metall. Mater. Trans. B*, 2016, 47(1), 621-629.