Impact of Anode Change on MHD in Aluminum Reduction Cell

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Abstract

Anode change is one of the most important operations in modern aluminum electrolysis industry. The impact of new anodes on the pot primarily focuses on two aspects: the thermal component and the magnetohydrodynamic (MHD) component. Our previous [1] paper discussed the thermal impact by anode changing. This study now shifts our focus to explore the MHD impact of the anode change.

It is found that the anode-cathode distance (ACD) would be squeezed if the total voltage of the cell remained unchanged during anode change. An increase of pot voltage is required to maintain its original ACD. We delved into the consequences of anode change on various aspects through numerical simulations and industrial measurements. This paper also delves deeper into understanding the underlying mechanism behind “sensitive anodes”, by exploring horizontal current redistribution, metal flow pattern and magnitude, and interface deformation after anode change.

Some potential methods to mitigate the impact of anode change are explored here. Optimizing the operations of anode change and implementing the "customized technology for anode set modifier" are short-term endeavors, while selecting a suitable anode set modifier may require a longer-term effort.

Keywords: Aluminum reduction cell, Anode change, MHD stability.

1. Introduction

Since its invention, the technology and design of the Hall-Héroult reduction cell have undergone significant advancements, with cell capacity increasing from 4 kA to 600 kA and current efficiency increasing from 75 % to 96 %. Despite these substantial developments, the Hall-Héroult reduction cell remains the sole primary aluminum smelting process utilized commercially.

Anode change or anode replacement is the most important routine practice in modern aluminum electrolysis industry. The anode is consumed at a rate of about 1.5-1.8 cm per day, proportional to current density. When the anode reaches the end of its service life, the anode butt is replaced by a new anode. The impact of new anodes on the pot primarily focuses on two aspects: the thermal component and the MHD component.

The first aspect concerns the thermal balance. Introducing cold anodes could have a significant impact on the thermal equilibrium of aluminum reduction pots. In our previous paper [1], we examined the thermal effects resulting from anode changes. The theoretical calculations of heat absorption and generation revealed that the commonly used anode set modifier in most aluminum smelters is insufficient to maintain its own thermal balance after an anode change.

Another crucial aspect to consider is the MHD balance. In the process of aluminum reduction, direct current is supplied to the electrical layers of the bath and metal, both of which exist within a magnetic field environment. The magnetic field is also generated inside and outside of the pot by its high electric current. The effect of magnetic field and direct current in an electrical fluid conductor can lead to MHD-related issues. During the practice of anode change, the just set new anodes are wrapped by a layer of insulating solidified electrolyte, which impedes the current flow in the anode and generates large horizontal current in the aluminum pad. It is well-known that a significant horizontal current can have adverse effects on the MHD balance.

This paper serves as a continuation of our previous discussion regarding the thermal impact of anode change in aluminum reduction cells. However, this study will now shift its focus to explore the MHD impact of anode change. We conducted theoretical calculations and analyses concerning the changes in ACD after anode replacement.

Through numerical simulations (ANSYS and CFX) and industrial measurements, we delved into the consequences of anode change on various aspects. These included the influence on the horizontal current in the metal pad, alterations in the flow pattern and magnitude of metal velocity, as well as the deformation of the bath-metal interface. Our findings provide insights into the MHD effects resulting from anode replacement in aluminum reduction cells.

2. Theoretical Analysis

We selected a 500 kA cell with 48 anodes as our physical geometry. The anodes size and other physical parameters were used to analyze the theoretical calculations of ACD change during anode changing.

2.1 Geometry, Simplifications or Assumptions

Figure 1 illustrates the schematic diagram of a modern Hall-Héroult reduction cell. For better understanding of the problem discussed here, only the anode assembly and bath in the blue box are considered.

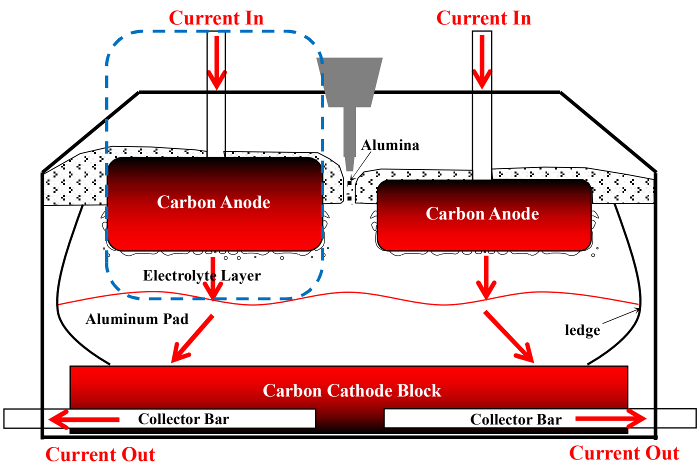

Figure 1. Schematic diagram of a typical Hall-Héroult reduction cell.

shutting down alumina feeding in the region of newly changed anodes. Simultaneously, the deficiency of alumina can be compensated for by adjusting the feeding points nearby. For instance, the first feeding point of total 6 feeders could be shut down during 3 hours after A1A2 change, and feeding point 2 and 3 compensate alumina at a rate of 1.4 or 1.5 times of their original feeding. This approach not only reduces energy absorption in the new anode area, but also accelerates the consumption of alumina in the covering material that falls into the bath during anode change.

The anode current online monitoring system should be installed on the reduction cells. The operators should pay close attention to the current pick up rate of new anodes. When it is detected that the recovery rate of the new anode current is abnormal, some adjustments should be made accordingly.

Anode change is a manual operation and is subject to human influence. Strengthening the training of workers is a rapid way to enhance the quality of anode change. This includes effectively cleaning impurities, crust pieces, and cover material pieces that may fall into the bath. Additionally, setting the appropriate height of new anodes, improving anode quality, and reducing carbon dust are all essential measures to be implemented.

4.3 Customized Technology for Anode Set Modifier

Both thermal and MHD impacts of anode change in aluminum reduction cell show that anode change in a pot has an individual characteristic. There are some "sensitive anodes" with larger possibility of abnormal voltage fluctuation, more obvious upward metal deformation trend, and smaller anode current pick up rate.

To address the issue of "sensitive anodes," a "customized technology for anode set modifier" was proposed [1], specifically tailored for various anode change scenarios. Both numerical and industrial work has proven that this technology played a positive role in improving thermal and electrical behavior of "sensitive anodes" without any thermal and MHD issues.

5. Conclusions

This paper combines theoretical calculations, numerical simulations, and statistical results from industrial measurements to analyze the MHD impact of anode change in aluminum reduction cells.

Theoretical calculation and analysis of ACD change after anode change were conducted. With the total voltage drop of the cell (represented by anode assembly and bath) remaining unchanged during anode change, the ACD is squeezed from 45 to 42 mm. To maintain its original ACD, an increase of pot voltage by 0.113 V is required.

Our previous work [1] identified certain “sensitive anodes” characterized by a lower anode current pick up rate. This paper delves deeper into understanding the underlying mechanism behind this phenomenon, exploring horizontal current redistribution, metal flow pattern and magnitude, and interface deformation after anode change.

This paper also explores potential methods to mitigate the impact of anode change. Optimizing the operations of anode change and implementing the "customized technology for anode set modifier" are short-term endeavors, while selecting a suitable anode set modifier may require a longer-term effort.

6. References

1. Zhibin Zhao, Wei Liu, Yafeng Liu, Michael Ren, and Zhaowen Wang, A discussion on

thermal impact of anode change in aluminum reduction cell [J]. *Light Metals* 2023, 128-136.

2. Fuqiang Wang, Xi Cao, Qinsong Zhang, Yafeng Liu, Xiaodong Yang, and Dongfang Zhou, Numerical simulation research and application of electric-thermo-stress coupled field for anode assembly [J]. *Light Metals* 2019 (5), 22-25 (In Chinese).
3. SAMI. Physical field measurements of aluminum reduction cell - electric field part [R]. *Internal Report* 2019 (In Chinese).
4. Tuofu Li. Numerical simulation study on optimization of anode structure of aluminum reduction cell for energy saving [D]. *Northeastern University,* Shenyang, China 2020.
5. Zhibin Zhao, Zhaowen Wang, Bingliang Gao, Yuqing Feng, Zhongning Shi, and Xianwei Hu, Anodic bubble behavior and voltage drop in a laboratory transparent aluminium electrolysis cell [J], *Metallurgical and Materials Transactions B* 2016 47(3), 1962-1975.
6. Warren E. Haupin, A scanning reference electrode for voltage contours in aluminum smelting cells [J], *Journal of Metals* 1971 (10), 46-49.
7. Xiaodong Yang, and Wei Liu, Discussion on designing high amperage energy saving aluminum reduction pot - busbar, cathode structure and MHD stability [J], *Light Metals* 2016 (10), 27-32. (In Chinese)
8. Wei Liu, Dongfang Zhou, Yafeng Liu, Ming Liu, and Xiaodong Yang. Simulation and measurements of the flow filed of 600 kA aluminum reduction pot [J], *Light Metals* 2015, 497-482.
9. Xi Cao, Qinsong Zhang, Zhibin Zhao, Yafeng Liu, Hongwu Hu, Zhe Dong, and Haigang Wu, Study on the rule of interfacial deformation and anode current distribution evolution of aluminium reduction cell during anode changing [J]. *Light Metals* 2021 (06), 20-28 (In Chinese).
10. Fuqiang Wang, Zhaowen Wang, Qinsong Zhang, Zhibin Zhao, Shaohu Tao, Wei Liu, and Xiaodong Yang. Computation and validation of ACD for aluminum reduction cell [J]. *Light Metals* 2022 (02), 23-25 (In Chinese).
11. Qiang Wang, Baokuan Li, and Mario Fafard, Effect of anode change on heat transfer and magneto-hydrodynamic flow in aluminum reduction cell, *JOM* 2016 (68), 610-622.
12. Zhibin Zhao, Wei Liu, and Yafeng Liu. Numerical study and industrial testing on optimizing new anode behavior by changing additional voltage strategies [C], *Proceedings of 38th International ICSOBA Conference*, Virtual, 16-18 November, 2020, Papre AL13, Travaux 49, 679-689.
13. Hongliang Zhang, Qiyu Wang, Shuai Yang, Jie Li, Jinding Liang, and Ling Ran, Numerical investigation of flow field effect on ledge shape in aluminum reduction cell by coupled thermo-flow model [J], *Light Metals* 2020, 517-526.