Production Practice of Reducing Anode Effect Frequency

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Abstract

This paper presents a series of technical and managerial measures adopted in the production process of a foreign high anode current density aluminium reduction cell to reduce the anode effect frequency, as well as their practical results. Through appropriate adjustment of cell process parameters, enhanced production management, and improved operation quality, the anode effect frequency was effectively reduced, the stability and current efficiency of the reduction cell were improved. Also, energy-consumption was reduced, and negative environmental impacts were mitigated.

Keywords: Aluminium reduction cell, High anode current density, Anode effect frequency, Energy-consumption reducing

1. Introduction

During aluminium electrolysis, the occurrence of anode effects is unavoidable. An excessively high anode effect frequency exerts numerous adverse impacts on aluminium electrolysis, not only causing a significant increase in power consumption but also leading to the emission of pollutants such as fluorides, harming the environment, reducing current efficiency, and undermining the stability of the reduction cell. Therefore, reducing the anode effect frequency has become an important research topic for production efficiency and sustainable development.

1.1 Characteristics and Challenges of High Anode Current Density Cells

1.1.1 Impact of High Anode Current Density on the Cells

High anode current density significantly alters the electrochemical processes on the anode surface. The anode overvoltage increases, resulting in higher power consumption. Meanwhile, the uneven distribution of current in the bath intensifies, making local overheating and alumina concentration gradients more likely to occur, which further affects the dissolution and diffusion of alumina and increases the probability of anode effects.

1.1.2 Production Problems Related to the Anode Effect Frequency

Under high anode current density, an increase in the anode effect frequency leads to unstable operation of the reduction cell. Frequent anode effects cause drastic fluctuations in cell voltage, resulting in substantial energy waste. In addition, the high-temperature and strongly oxidative environment generated during anode effects accelerates the anode consumption, affects potlining, shortens its service life, and raises production costs. Moreover, the emissions of pollutants such as fluorides generated during the anode effect may fail to meet environmental protection standards.

2. Principle of Occurrence and Hazards of the Anode Effect

2.1 Principle of Occurrence

The occurrence of an anode effect is caused by excessively low alumina concentration in the bath, which alters the gas evolution process at the anode surface [1]. When alumina concentration drops below a certain critical level, a high-resistance fluorocarbon film forms on the anode surface, leading to a sharp rise in cell voltage and triggering the anode effect [2]. At the same time, a series of complex electrochemical reactions take place on the anode surface, generating large amounts of heat.

2.2 Hazards to Production

The anode effect causes a sharp increase in energy consumption of the reduction cell because cell voltage rises during the anode effect. An excessively high anode effect frequency disrupts the thermal balance of the cell, impairing its stability and service life. Frequent anode effects also reduce the quality of molten aluminium, increase impurity content, and release substantial quantities of fluorine-containing harmful gases during the process, leading to severe environmental pollution [3].

3. Technical and Managerial Measures to Reduce the Anode Effect Frequency

3.1 Strict Implementation of Process Specifications

Strictly control cell voltage to avoid excessively high or low levels. Excessively high cell voltage increases energy consumption, while excessively low voltage increases cell noise and decreases current efficiency. Maintain the bath temperature within an appropriate and stable range. Excessively low temperature slows alumina dissolution and makes anode effects more likely. Therefore, precise control of bath temperature is crucial for reducing the anode effect frequency. Maintain alumina concentration within a relatively stable and narrow range, avoiding sludge creation at high range and anode effects at low range. Keep the excess aluminium fluoride within a controlled and stable fluctuation range to avoid sharp rises and drops.

3.2 Anode Change Management

Establish strict anode change cycles and operating procedures. Determine the replacement timing reasonably based on the anode consumption rate and the operating condition of the cell. During the anode change, ensure accurate installation of new anodes, good contact with the bath, and strictly control replacement speed to prevent bath fluctuations and alumina concentration imbalance caused by improper operations, thereby reducing the anode effect frequency.

3.3 Strengthening Production Management and Monitoring Systems

Provide training and skill enhancement for on-site operators, reinforce professional training for cell operators, and improve their operational skills and understanding of cell operating principles. The training covers anode replacement, troubleshooting cell abnormalities during inspection, extinguishing anode effects, and diagnosis and handling of cell faults. Through regular training and strict assessments, ensure operators master the required skills, accurately judge the operating state of cells, and take timely and effective measures to prevent and handle anode effects, thereby reducing the anode effect frequency.

Implement monitoring and analysis of production data by establishing a comprehensive system to collect, store, and analyse in real time various operational parameters of the cells. These include current, voltage, temperature, alumina concentration, and anode current distribution. Through in-depth analysis of extensive production data, identify key factors and potential patterns affecting the anode effect frequency, providing a scientific basis for optimizing production processes and adjusting operating parameters. At the same time, utilize the data analysis system to achieve real-time early warnings of cell operating conditions, promptly detect abnormalities, and take corresponding measures to prevent the occurrence or escalation of anode effects.

3.4 Equipment Maintenance and Management

Strengthen the daily maintenance and management of the cells and their auxiliary equipment. Regularly inspect, maintain, and service equipment such as anode lifting devices, feeding systems, and cooling systems to ensure proper operation and avoid cell instability and increased anode effects caused by equipment failures. For example, ensure smooth operation of the alumina feeding system to prevent alumina concentration fluctuations and anode effects caused by uneven alumina feeding or alumina blockage.

4. Case Study of Production Practice

4.1 Overview of Cell Production in a Foreign Aluminium Smelter

During work at a foreign aluminium smelter, long-term management was carried out on 33 assessment demonstration cells. Before amperage increase, the anode current density was 0.75 A/cm^2. After upgrades, the anode current density reached 0.9 A/cm^2, higher than the domestic level of around 0.75 A/cm^2. Under high anode current density, compared to low current density, sudden anode effects occurred more frequently [4]. In the early production stage, due to insufficient technical and managerial experience, many abnormalities occurred, such as inadequate inspection and handling of the cells, insufficient maintenance of alumina conveying and feeding systems, and untimely bath replenishment. These led to high anode effect frequency, with monthly average > 0.65 per day per cell, resulting in high power consumption, low current efficiency, passive on-site operations, and certain environmental pollution. The production indicators of the reduction cells all failed to meet the expected targets.

4.2 Measures to Reduce the Anode Effect Frequency

4.2.1 Reasonable Matching of Process Parameters with Strict Standard Execution

Based on the actual situation of the cells, reasonable process parameters were matched to achieve multiparameter balance. A temperature-control-centred technical route was established, reasonably coordinating electrolysis parameters (see Table 1) to improve cell stability. In actual production, the excess AlF_3 was controlled within 8–12 %, and alumina concentration was maintained between 1.5–3.0 %, effectively reducing the occurrence of anode effects. Through precise adjustment and control of voltage and excess AlF_3, the bath temperature was controlled within 950–965 °C to ensure adequate electrolysis quality. The bath depth was increased from 18 to 20 cm, maintaining reasonable superheat and improving alumina dissolution, thereby stabilizing the electrolysis process and reducing anode effects triggered by temperature fluctuations.

Table 1. Control standards for cell process parameters.

Cell set voltage, V	4.10–4.15	
Metal height, cm	26–28	Before metal tapping
	24–26	After metal tapping
Bath height, cm	20–24	Before metal tapping
	16–20	After metal tapping
Excess AlF_3, %	8–12	Adjusted according to operational quality and pot condition
Bath Temperature, °C	950-965	

4.2.2 Improving On-Site Operation Management

The quality of operations is the foundation for stable and efficient operation of the cells. At the foreign site, there were discrepancies in operation quality, with various operational tasks being imprecise and far from the required standards. For example: anode change without scraping the material, poor edge quality during anode replacement, insufficient insulation material, frequent instances of the cover plate remaining open for long periods, failure to seal the anode edges or block the inner end of the anode during replacement, and material blockages caused by misplacement of the crane during feed operations. Additionally, bath replenishment was often not timely or complete, all of which contributed to an increase in the anode effect frequency. To address these issues, strict operating procedures were established to standardize the operator workflow, ensuring the accuracy and timeliness of feeding, anode replacement, and aluminium tapping operations. Enhanced training for operators was conducted to improve their operational skills and sense of responsibility, enabling them to promptly identify and resolve abnormalities, thus preventing anode effects caused by improper operations. Personnel management was strengthened through strict assessments, gradually reducing the anode effect frequency. Specific requirements are as follows:

1) Inspection Work: The responsible person should inspect the cell once every hour. The inspection items include but are not limited to: abnormal voltage, material feeding issues, crust-breaking cylinder head blockage or elephant foot formation, crust holes, anode oxidation, carbon dust at tapping holes, abnormal anodes, and equipment abnormalities. Any abnormality should be reported and handled promptly according to the established procedure, to ensure no carbon dust at the tapping hole, no crust holes on the edges, no anode oxidation, no material accumulation at the feeding port, and the cover plate must be properly sealed.

2) Tracking Bath and Metal Heights: The responsible person should measure bath height once per shift, performing bath tapping and addition according to standards. In addition, metal height should be measured twice per day. Instruction values must be issued, and bath levels should be maintained in accordance with standards.

3) Anode Replacement Operations: The responsible person should follow anode replacement procedures, paying special attention to anode positioning, crust handling, and edge quality. Voltage should be checked after anode replacement, and any abnormalities should be handled promptly (if noise exceeds 100 mV, immediate action should be taken, and failure to handle within 2 hours is prohibited).

4) Aluminium Tapping Operations: The responsible person should conduct aluminium tapping operations according to standard procedure. Tapping precision should be controlled within 50 kg.

5) Anode Redressing: The responsible person should perform Anode redressing according to operating requirements. Each test cell must undergo anode redressing once every 7 days.

6) Voltage Curve Management: Any abnormal voltage should be addressed without delay. If noise exceeds 100 mV, anode current distribution should be measured, analysed, and anodes adjusted accordingly. Issues must not remain unresolved for more than 2 hours. In the event of abnormal voltage rise, alumina feeding conditions should be checked. It is the responsible person's responsibility to properly handle blockages and anode effects. Anode effects must be attended to within 5 minutes of occurrence. Equipment failures must be promptly corrected. Inspections shall be strengthened, and any issues discovered must be addressed immediately, including but not limited to: feeding malfunctions, air/material leaks of crust breaking cylinder and feeding devices, and cell control system failures.

7) Other Operations: After anode beam raising and anode replacement, anode clamp voltage drop shall be controlled within 20 mV, and the average single-cell clamp voltage drop shall be controlled within 15 mV. During the shift, operators must strictly prevent extended anode effects. In addition, skills training on the standardized procedures for extinguishing effects shall be reinforced.

4.2.3 Data Collection, Analysis, and Equipment Maintenance

Production data were continuously monitored and analysed, with real-time tracking of various cell operation parameters. Through this system, abnormal operating conditions of the cells could be promptly identified, and potential anode effects could be predicted and addressed in advance. Furthermore, equipment maintenance management was strengthened by developing and implementing detailed maintenance plans. Key components of the cells were inspected and serviced regularly to ensure stable operation, preventing cell instability and increased anode effects caused by equipment failures.

4.3 Production Practice Results

4.3.1 Changes in the Anode Effect Frequency

By implementing the above measures to reduce the anode effect frequency, monitoring began in April, tracking the frequency on a monthly basis. Results indicated a consistent decrease in the anode effect frequency, significantly dropping from 0.65 per day per cell before implementation to 0.22 per day per cell after implementation, achieving a 66 % reduction (see Figure 1).

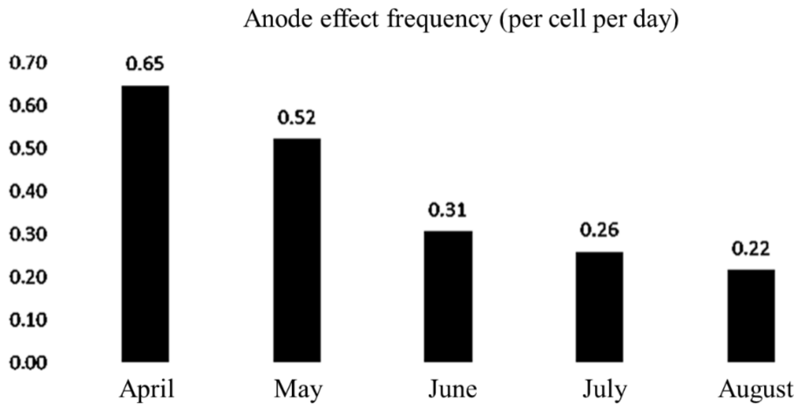

Figure 1. Monthly trend of the anode effect frequency.

4.3.2 Impact on Production Indicators

As the anode effect frequency decreased, the energy consumption of the cells significantly dropped, decreasing by 300 kWh/t Al (see Figure 2), effectively reducing production costs. The stability of the cells improved, and current efficiency increased from 91.5 % to over 94.5 % (see Figure 3). Simultaneously, with fewer anode effects, the emission of fluoride-containing harmful gases was significantly reduced, alleviating environmental pollution. The on-site working environment was improved, and the stability of the cells was improved.

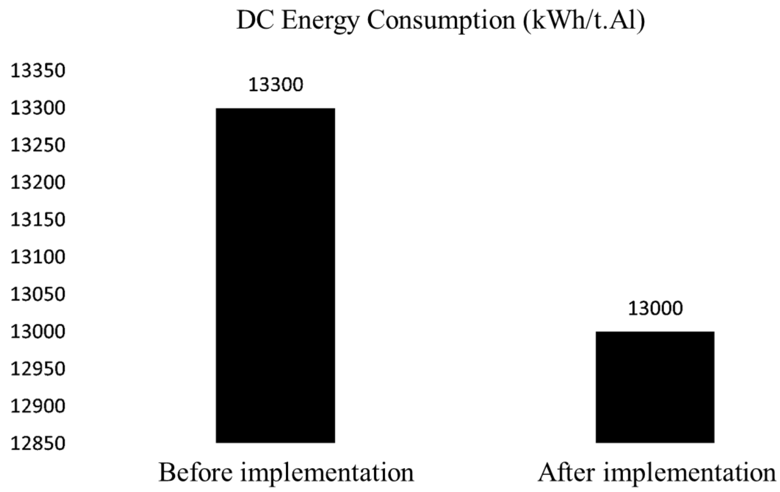

Figure 2. Comparison of DC energy consumption (kWh/t Al).

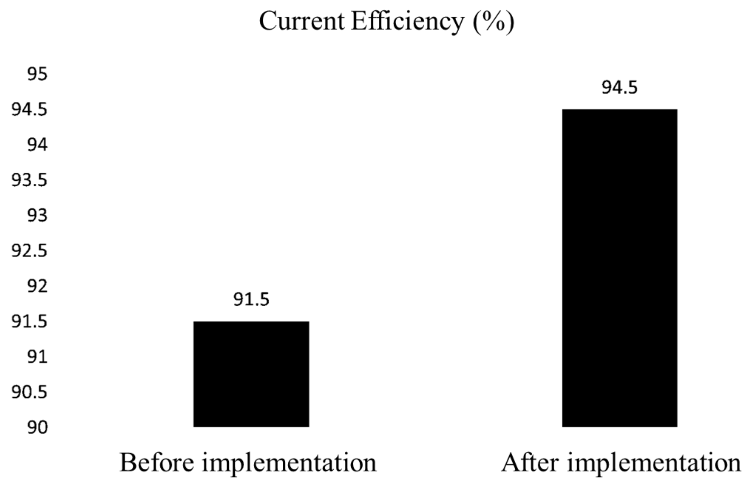

Figure 3. Comparison of current efficiency (%).

5. Conclusions

By adopting a series of technical and management measures to reduce the anode effect frequency, including some adjustments to process parameters, improving production management and on-site operations and monitoring systems, the anode effect frequency was effectively reduced, the cell stability and current efficiency improved, and both energy consumption and pollutant emissions were lowered. Production practice cases demonstrated the feasibility and effectiveness of these measures. Although the anode effect frequency in the reported smelter is still higher than in the domestic smelters, valuable experience was gained for future improvements.

6. References

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