Analysis of New Energy-Saving Technology 2.0 of Different Cathode Materials and Cell Types

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https://doi.org/10.71659/icsoba2025-al003

Abstract

As a high energy consumption industry, aluminium electrolysis has always pursued energy saving and consumption reduction as its goal. Zhengzhou Non-ferrous Metals Research Institute of Chalco has successfully developed the new energy-saving technology for current stabilization and thermal insulation of aluminium electrolysis cells, which effectively addresses technical challenges such as high energy consumption, low efficiency, and short service life of aluminium reduction cells, and achieves the goal of substantial energy saving and emission reduction. This paper provides a detailed analysis of the industrial application of the new energy-saving technology 2.0 across different cathode materials and cell types. Compared with the 1.0 version, this technology can further reduce DC power consumption by approximately 200 kWh/t Al, offering crucial technical support for achieving substantial energy-saving and carbon reduction in the aluminium industry.

Keywords: Aluminium electrolysis, Current stabilization and thermal insulation of cells, Energy consumption, Energy-saving.

1. Introduction

In 2024, China's primary aluminium production reached 43.396 million tonnes (data form International Aluminium Institute), accounting for 59.4 % of global production, maintaining its position as the world's largest producer for many years. To advance industrial structural upgrades and implement the "Dual Carbon Goals", the Chinese government has introduced multiple industrial policies to guide the aluminium industry in accelerating energy-saving and carbon reduction, thereby promoting low-carbon, and high-quality development of the aluminium industry.

Based on the physical field test data and system research of the cells in the past 30 years, through basic theory research, laboratory simulation, pilot and scale-up test verification, Zhengzhou Non-ferrous Metals Research Institute of Chalco has successfully developed the new energy-saving technology for current stabilization and thermal insulation of aluminium reduction cells. This innovative technology effectively addresses the technical challenges of high energy consumption, low efficiency, and short service life in aluminium reduction cells, achieving significant energy-saving and emission reduction. Building upon the accumulated expertise in the new energy-saving technology, the R&D team further integrated key technologies such as structural optimization of fully graphitized and fully graphitic cathode blocks and innovations in cast iron rodding, leading to the development of the new energy-saving technology 2.0 [1–3]. Through compatibility verification in mainstream domestic electrolytic cells ranging 200–500 kA, this technology has achieved large-scale application with diverse cathode material configurations, including fully graphitized cathodes and full graphitic cathodes, demonstrating significant energy-saving effects and providing an innovative solution for the industry's green transition.

2. Application Analysis of New Energy-Saving Technology 2.0

2.1 Performance of Cathode Materials

Chinese aluminium smelters predominantly use traditional carbon-based cathode materials such as GS-3 and GS-5 during cell relining, while fully graphitized or full graphitic cathode materials, despite their significant performance advantages, have not been widely used. This is primarily due to the long processing cycles and high costs associated with their complex forming processes. Table 1gives the physical characteristics of four types of cathode carbon block materials. It is evident that fully graphitized and full graphitic cathodes have significant advantages in three key indicators: electrical resistivity, thermal conductivity, and sodium expansion coefficient. Notably, their room temperature resistivity can be reduced by over 50 % compared to GS-3 and GS-5 carbon-based materials [4]. The simulation data indicate that the cathode voltage drop of fully graphitized and fully graphitic cathodes is the range of 180–220 mV, representing a reduction of 25–30 % compared to traditional cathode materials. This voltage drop advantage creates dual benefits for cell operation: it increases current efficiency while maintaining the same anode-to-cathode distance or enables further reduction in cell voltage while preserving the original current efficiency.

Table 1. Performance indicators of different cathode carbon block materials.

Material	Real density g/cm^3	Room temperature resistivity μΩ·m	Compressive strength, Mpa	Bending strength Mpa	Young's modulus GPa	Sodium expansion %	Thermal conductivity W/m·K
	≥	≤	≥	≥	≤	≤	≥
GS-3	1.95	35	24	7	7	0.8	8–16
GS-5	1.99	30	24	7	7	0.7	12–25
Full graphitic cathode	2.08	21	26	7.5	7.5	0.5	20–35
Fully graphitized cathode	2.18	12	20	7	2.8	0.35	120

2.2 Characteristics of Cell Type

Aluminium electrolysis is a molten salt electrolysis process at 940–960 °C. This temperature range is critical for cell stability and efficiency, but has energy consumption challenges. An effective approach for energy saving is improving the utilization efficiency of electrical energy and reducing reactive power loss. Notably, due to the quadratic relationship between Joule heat and current, the heat generation is nonlinear [5]. As can be seen from Table 2, the unit heat flux density of the 500 kA large-scale cell is reduced by 14.1 % compared with the 200 kA cell type. Therefore, based on the thermo-electric coupling characteristics of the cells with different amperages, the new energy-saving technology 2.0 uses different cathode configurations.

Table 8. Average voltage, current efficiency, and DC power consumption of different cell types.

Item	Units	200 kA	300 kA	Avg.	400 kA	500 kA	Avg.
Average voltage	V	3.864	3.846	3.855	3.848	3.816	3.832
Current efficiency	%	93.64	93.28	93.46	93.53	93.23	93.38
DC power consumption	kWh/t Al	12 297	12 287	12 292	12 260	12 197	12 229

5. Conclusions

The new energy-saving technology 2.0 for current stabilization and thermal insulation aluminium reduction cells, developed by Zhengzhou Non-ferrous Metals Research Institute of Chalco, is well aligned with national energy policies. By fully implementing all graphitic or all graphitized cathodes and cast iron rodding of cathode blocks, the technology enables significant reduction of specific energy consumption. Industrial tests demonstrate that the cathode voltage drop remains below 220 mV, with the overall average DC power consumption of 12 261 kWh/t Al. Compared to the previous version of the technology, this upgraded solution reduced specific energy consumption by more than 200 kWh/t Al, attaining benchmark level within the industry.

6. References

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