The Development of Energy-Saving and Digital Intelligence Technologies for Primary Aluminium Industry in China

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Abstract

In the past 20 years, the Chinese primary aluminium industry faced new challenges, such as the stricter standards for both carbon emission and energy-saving, the impoverishment of bauxite resources, the deterioration of petroleum coke quality, the complexity of the spatial and temporal distribution characteristics of high/ultra-high amperage cells, and the shortage of labour resources. Therefore, the technical teams of Chinese aluminium industry, represented by experts from Aluminium Corporation of China and Central South University, developed a complete set of energy-saving, low-carbon and digital, intelligent aluminium electrolysis technology. This was a major breakthrough in energy conservation and carbon reduction and played a key role in maintaining the global leading position of energy consumption indicators for Chinese aluminium industry. A new method for online monitoring and regulation of the spatial and temporal distribution characteristics of high/ultra-high amperage aluminium electrolysis cells was proposed, and the key technology of intelligent optimization and manufacturing of aluminium electrolysis was developed. This technology is based on distributed monitoring and digital twin, resulting in "the digital intelligence of distribution parameters" for the control of aluminium electrolysis process, which opened new opportunities for energy saving, carbon emission reduction, and process efficiency improvement. The combination of innovative cathode design, and multi-field optimization improved magnetohydrodynamic stability of the cells. Energy saving technology, based on steady flow and heat preservation, was developed, which enabled the cell voltage reduction for a further energy saving in varying cell operation environment and production conditions of Chinese aluminium industry. The production and application of dust-free prebaked anodes solved technical problems caused by the quality deterioration of both anodes and alumina.

The application of these technologies reduced the cathode voltage drop by about 150 mV, increased the current efficiency by 0.5~1.5 %, reduced the amount of carbon dust by half, increased the labour productivity by more than 30 %, and reduced the energy consumption by 200 to 600 kWh/t Al. In 2023, the average overall AC power consumption of Chinese primary aluminium was 13 324 kWh/t Al, a decrease of 2 155 kWh/t Al compared with that of 20 years ago, which is absolutely a tremendous improvement in energy conservation and emission reduction.

Keywords: Aluminium electrolysis, Prebaked anodes, Magnetohydrodynamic stability, Energy saving, Digital intelligence.

1. Introduction

The aluminium electrolysis process is a high temperature electrochemical metallurgical process under the coupling of multi-fields (six kinds of physical fields, such as electric, magnetic, thermal, force, flow, concentration) and multiphase flow (gas, liquid and solid phase). The process mechanism and reaction characteristics of material and energy balance are complex, and energy saving and carbon footprint reduction has always been a worldwide technical problem.

Since the 1990s, Chinese aluminium electrolysis industry made a remarkable progress in energy conservation and emission reduction. But in the past 20 years, it faced many new challenges, such as stricter energy consumption and carbon emission standards, poor and inferior quality of bauxite and petroleum coke, complex spatial distribution of parameters in high/ultra-high amperage cells, labour shortage, and production and management concentration.

In particular, some of these factors also caused new problems that worsened the operation conditions of the cells, such as great length and high reaction area (> 110 m^2) in 600 kA electrolysis cels., due to increased magnitude of various physical fields and their coupling.

The degrading bauxites in alumina production accelerated the accumulation of impurities which form complex electrolyte in the cell. The inferior quality of petroleum coke for anode production led to the degradation of anode quality and excessive carbon dusting in the complex electrolyte, which worsened the dispersion and dissolution of alumina and increased the non-uniformity of the local distribution of alumina concentration. The joint effect of these factors deteriorated the MHD stability of the cell. The controllable domain of important state parameters was significantly narrowed. The key performance indicators (KPIs) of the cell were seriously affected and started to fluctuate easily in a wider range.

Facing above challenges, Chinese aluminium electrolysis research and development made great progress in energy saving and low-carbon aluminium production, using digital intelligence.

2. The Leap from the "Lumped Parameter Automation" to the "Distributed Parameter Intelligence"

The intelligent control technology of aluminium electrolysis developed and applied in China has contributed to energy-saving and emission reduction. However, with the upsizing of electrolysis cells and the consequently deteriorating operation conditions, the existing control technology, based on the online collection of two lumped parameters (cell voltage and current), is unable to process distributed online sensing and local control of the complex spatial and temporal distribution of high/ultra-high amperage cells. It was difficult to maximize the potential of energy saving, carbon reduction and process efficiency increase. It was also difficult to meet the new demand for more precise production control, let alone to support the construction of intelligent optimization manufacturing technology for aluminium electrolysis industry.

Chinese researchers developed a distributed-parameter accurate online monitoring, based on online distributed measurements and physical field modelling, and expanded the collection points of aluminium electrolysis cell online parameters from the traditional 2 types and 2 points to a maximum of 7 types and 297 points, with low-cost monitoring of individual anode current distribution and other distributed parameters, which had eluded the aluminium industry for a long time. A "dual-simulation" method was developed to extract the dynamic distribution of key parameters, such as local alumina concentration in the cell from the online monitoring of anode current distribution, and digital twin construction of aluminium electrolysis [1].

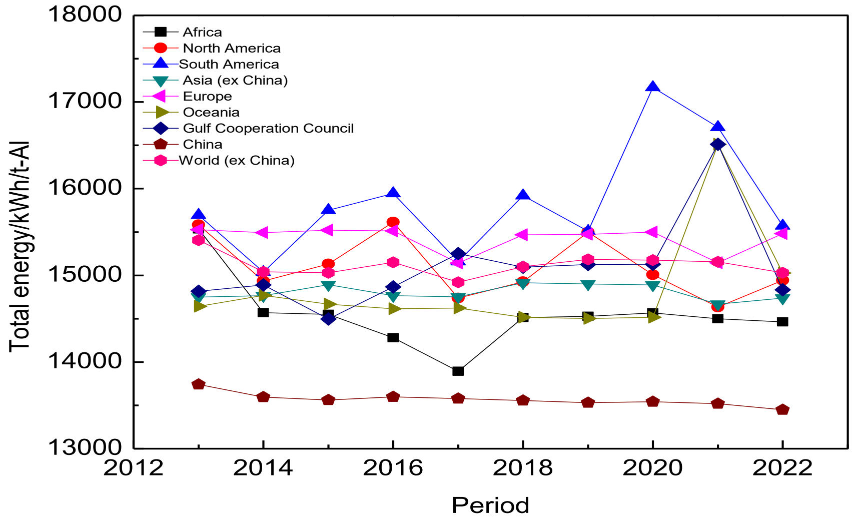

Figure 9. Specific energy consumption in China compared to the rest of the world.

6. References

1. Li Jie et al., A twice simulation method, system, and storage medium for alumina concentration, Patent of the People's Republic of China, ZL 202110471902.3, 2023-4-28.
2. Li GuoWei et al., A method for adjusting aluminium electrolysis process, Patent of the People's Republic of China, ZL 202111545171.8, 2023-3-21.
3. Chen Xiaofang et al., Method and devices for detecting abnormal alumina concentration and for monitoring electrolyte temperature in aluminium electrolysis driven by process mechnaism knowledge, Patent of the People's Republic of Australia, 2020200691, 2020-1-30.
4. Zhang Hongliang et al., A fully digital electrolysis cell and its integrated intelligent control system, Patent of the People's Republic of China, 202810762764.2, 2019-12-24.
5. Zhirong Shi et al., Technology research on decreasing the aluminium surface waves and reducing the cathode voltage drop in aluminium electrolysis cell, Light Metals 2016, 613-616.
6. Jiao Qingguo et al., A directional magnetic cathode collector bar for aluminium electrolysis, Patent of the People's Republic of China, ZL 201910386896.4. 2020-11-6.
7. Wang Yanfang et al., A gas heated cathode carbon block preheating device, Patent of the People's Republic of China, ZL 201510809669.X.
8. State Administration for Market Regulation & National Standardization Management Committee, Energy consumption limit per unit product of carbon for aluminium use, National Standards of the People's Republic of China, GB25324-2022, 2022-12-29.
9. Luo Yingtao et al., A method for preparing less slagging pre-baked anodes and less slagging pre-baked anodes, Patent of the People's Republic of China, ZL 202211584967.X, 2023-9-19.
10. Li Changlin et al., A less dust carbon anode for aluminium electrolysis and a preparation method thereof, Patent of the People's Republic of China, ZL 202110702386.0, 2022-8-16.