The Development of Aluminum Industry and Technology in China

Since the 1980s, the aluminum industry in China has made the most significant progress in two aspects. One is the annual output of primary aluminum that has continuously risen from roughly 400,000 tons in 1983 to 40.21 million tons in 2022, accounting for 58.8% of the total annual global output. Another aspect is the average total energy intensity (*i.e.* the average comprehensive AC power per tonne of aluminum), which has consistently decreased from 17,560 kWh/t-Al in 1983 to 13448kWh/t-Al in 2022, a reduction of 4112kWh/t-Al over the past 40 years. Meanwhile, China has continuously been the world's best indicator of energy consumption for aluminum electrolysis in the last decade. The above trends can be clearly seen from the data of global primary aluminum output (Fig. 1) and total energy intensity (Fig. 2) (Note: data sourced from the International Aluminium Institute (IAI), and Chinese data before 1998 sourced from China Nonferrous Metals Industry Association).

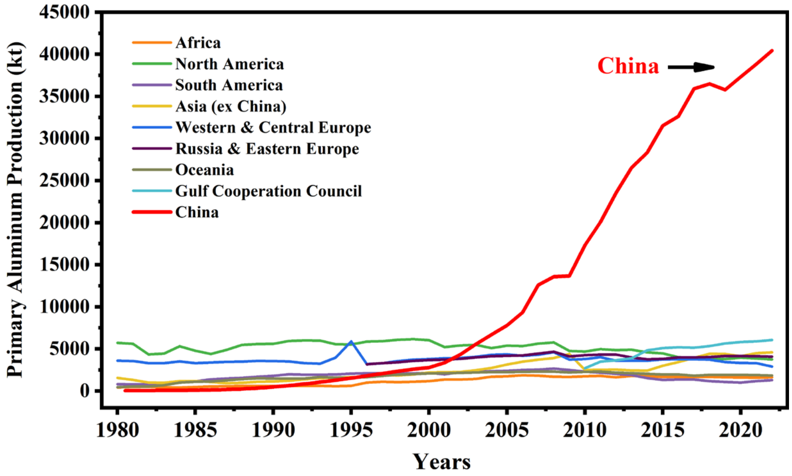

Fig 1. Global primary aluminum output (by regions)

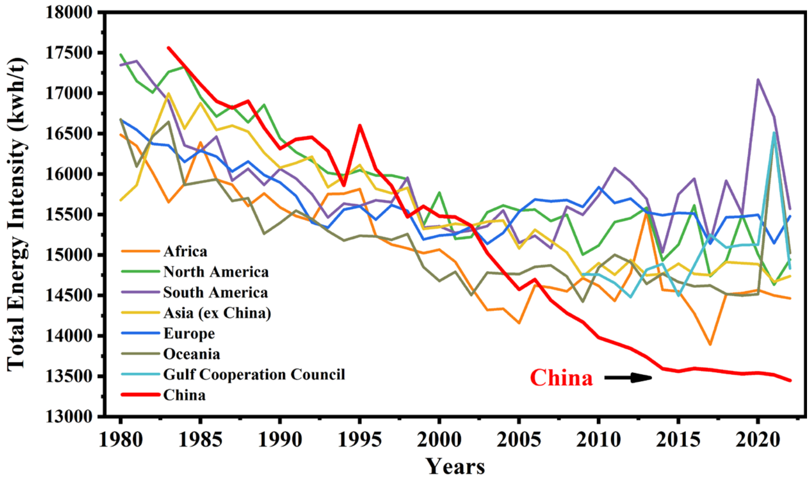

Fig 2. Total energy intensity of aluminum (by regions)

In China, the progress in aluminum industry and its energy-saving technologies can be divided into three stages.

Stage 1: the "catching up" stage from the 1990s to the mid-2000s

In the 1980s, Soderberg cells with line current of about 60kA were widely used in China, yet their production environment and operating indicators were far from satisfactory. In the 1980s, China introduced a Japanese 160kA prebaked-anode aluminum reduction potline, indicating the start of the modern aluminum smelting with large-scale reduction cells in China. However, the introduced process used an outdated fixed-time feeding control model, high molecular ratio (around 2.8) and high anode effect coefficient (1.0~1.2), resulting in less-advanced technical and economic indexes with current efficiency of about 87% and DC power consumption at about 13800kWh/t-Al. Starting from the late 1980s, the former China National Nonferrous Metals Industry Corporation (later known as Aluminum Corporation of China, or Chalco) organized its affiliated enterprises, Central South University and other research institutes to jointly work on upgrading the imported potline. One of the most valuable innovations was an intelligent fuzzy control technology developed in the mid-to-late 1990s. This technology upgraded fixed-time feeding to point-feeding and converted the "high molecular ratio (around 2.8)-low current efficiency (above 87%) process to a "low molecular ratio (around 2.3)–high current efficiency (above 93%)" process, thus leading to a reduction of DC power consumption of large-scale prebaked-anode cell to around 13200kWh/t-Al, reaching global advanced level during the same period. In addition, based on the developed technologies of process, control and physical field simulation, a series of 180~280kA aluminum electrolytic cells have been further developed. Within a few years of this century, such large-scale cells, as well as their process and control technologies, were widely promoted and applied in China, and all Soderberg potlines were shut down or transformed into prebaked-anode potlines, propelling China's average energy intensity indicator into the global advanced rankings in the mid-2000s.

Stage 2: the "leading" stage from the mid-2000s to the mid-2010s

At this stage, Chalco took the lead in increasing the capacity of China's large-scale prebaked-anode aluminum electrolysis to more than 500kA, as well as developing new energy-saving and emission-reduction technologies in collaboration with universities such as Central South University and Northeastern University. Because electricity prices in China are much higher than those in other countries or regions around the world, energy saving in aluminum electrolysis has been high-prioritized. By the mid-2000s, advanced enterprises had already raised the current efficiency indexes to 93~95% by improving current efficiency to achieve energy savings, approaching the theoretical limit value of industrial reduction cells, and China had thus turned its attention to how to achieve energy savings by reducing the cell voltage on the premise of maintaining high current efficiency. Based on this, a novel low-voltage and high-efficiency energy-saving process with critical-stability control technology, which was first developed by Central South University, represented a significant advance. This technology was able to reduce the cell voltage from 4.1~4.3 V in the past to below 3.75~3.95V with the current efficiency being unchanged, resulting in significant energy savings and thus being widely used and promoted. At this point, the design concept of China's aluminum reduction cell has also realized a transition to low-voltage energy-saving types, which play an important part in making China's energy intensity indicator into the global top rankings in the mid-2010s.

Stage 3: the stage of expanding the lead since the mid-2010s.

Since the mid-2010s, China has upgraded the maximum capacity of aluminum potline over 600kA and consistently developed and applied new technologies related to energy savings and emission reduction. Among them, the key technology of green, low-carbon, digitized and intelligent aluminum electrolysis, developed by Chalco in conjunction with Central South University etc., is a representative new technology, which is of great significance in promoting the aluminum electrolysis industry to achieve further energy savings and carbon emission reduction as well as sustainable development. Its main innovations are as follows:

(1) Key Technology for Intelligent Optimized Manufacturing of Aluminum Electrolysis Based on Distributed Sensing and Digital Twin.

In response to the long-standing problem that the online signals collected by the control system were only two (cell voltage and line current), which makes it impossible to realize online sensing and fine regulation of the spatio-temporal distribution characteristics of large cell, the developed technology advanced the online distributed detection and sensing method of reduction cell. This technology solved the long-term issues plagued by the aluminum industry of accurate, reliable and low-cost on-line detection of distributed signals of anode current distribution, and innovatively extended the online detected signals from the traditional 2 kinds (2 detecting points) to 7 kinds (nearly 300 detecting points). On this basis, digital twin, fine and zoned control of reduction cell as well as intelligent decision-making for smelting process were realized, leading to an increase in the uniformity of the alumina concentration in the whole cell by more than 80% and a reduction of the abnormal cell by more than 50%. This technology had a great impact on further reducing energy intensity and increasing labor productivity, while also providing technical support for the construction of digital and intelligent factory of aluminum electrolysis, leading the transition of the digitalization and intellectualization of aluminum reduction cells and the production process control from the era of “aggregate parameters” to the era of “distributed parameters”.

(2) Energy-Saving Technology for Aluminum Electrolysis Based on Steady Flow and Heat Preservation.

Aiming at the problem that existing technologies for improving magnetohydrodynamic stability (MHD) in aluminum reduction cells are approaching their "limit", new technology featured with highly conductive collecting bar (including steel conductivity enhancement + size optimization), regional current conduction strengthening, thermal regulation and energy balance optimization was developed. This technology has not only achieved great breakthroughs in improving MHD, but also in optimizing flow field of aluminum liquid and thermal field of the cell, as well as reducing the cathode voltage drop, which provide new technical supports for efficiency promoting and energy saving at low voltage in aluminum reduction cells.

(3) Technology for the Preparation and Application of Carbon Dusting-Free Prebaked Anodes.

In the past ten years, China has faced the environment and conditions that are unfavorable to the production of high-quality anodes and the stable operation of reduction cells. On the one hand, the supply of petroleum coke was gradually deteriorating, which has adversely affected on the quality of anodes. On the other hand, about half of the alumina used for the aluminum production in China was produced from gradually-deteriorating bauxite, which results in the increase of content of impurities in alumina, and, thus, impurities like lithium and potassium were prone to accumulating in the cell to form a complex electrolyte composition that was very unfavorable to the running stability of reduction cells. More worse, the overlap of the above two unfavorable factors makes it difficult to separate carbon particles detached from the anode from the electrolyte, which seriously affects the cell operation. Thus, the developed technology can not only solve the problem of producing high-quality anode from low-quality and complicated petroleum coke, but also realize dusting-free operation for aluminum electrolysis.

(4) Green and Safe Disposal Technology for Aluminum Electrolysis Pollutants.

This technology solves a number of technical problems in the green, safe disposal and resourceful use of aluminum electrolysis overhaul slag and secondary aluminum ash, through which the contained toxic substances have realized safe and rapid leaching from slags and have been rendered completely harmless, allowing the tailing to be turned into building materials. The products and tailings after disposal meet the requirements of the national mandatory standard GB-5085.3 “Identification standards for hazardous wastes-Identification for extraction toxicity”, in which the leaching concentration of fluoride and cyanide is less than 9.0mg/L and 0.03mg/L, respectively. For the secondary aluminum ash, the enhanced hydrolysis leaching and graded gas released and recycling technology has been developed, with the decomposition rate of AlN being greater than 95%, and the recovery rate of soluble salt, combustible gas and ammonia being greater than 98%. The alumina content of the leaching tailings was greater than 70%, with the reactivity and leaching toxicity meeting the requirements of national mandatory standards. After directional transformation, it can be used for the production of refractory materials, refining agent for steel-making, calcium aluminate powder and other aluminum-based products. Most of all, zero waste discharge is realized during the disposal and utilization process, and all environmental and quality indicators meet the requirements of relevant standards.

The development and deployment of energy-saving, carbon-reducing, and digital-intelligent technologies in China's aluminum electrolysis industry plays an essential role in demonstrating and promoting the technological and industrial development of the worldwide aluminum industry. According to the latest statistics of the International Aluminium Institute (IAI), the average total energy intensity in China's electrolytic aluminum industry was 13,448kWh/t-Al in 2022, which was significantly lower than the global (ex China) average of 15,008kWh/t-Al, with a difference of 1,560kWh/t-Al.