Technological Innovations and Practices of Carbon Roasting Furnaces for Aluminium Under the Demand of Large-Scale and High-Quality Production

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Abstract

The outdated ring-type baking furnaces for aluminium suffer from issues such as small product sizes, low production capacity, high energy consumption, and significant challenges in retrofitting, making them unable to meet the growing demand for larger-scale and higher-quality products. To address these issues, the team conducted a comprehensive technical upgrade of the baking furnaces. Initially, the operating conditions and baking results of the outdated baking furnaces were assessed through extensive testing. Numerical simulations were then employed to iteratively calculate the temperature, flow, and pressure fields, achieving the development of an optimal upgrade plan. The specific modifications included optimizing the baking furnace structure by adjusting the size and shape of the combustion chamber and altering the flue design, as well as innovatively using new thermal insulation materials. Following the upgrades, systematic testing and process optimization were conducted on the newly modified baking furnace. As a result, the first-grade rate of carbon products increased by 10 %, the baking furnace's energy consumption was reduced to 1.74 GJ per tonne, and the baking furnace now meets the requirements for producing prebaked anodes for 600 kA electrolytic cells. Ultimately, the upgraded baking furnace achieved both energy savings and quality improvement.

Keywords: Ring-type baking furnace, Structural optimization, Numerical simulation, Quality improvement, Energy saving.

1. Background and Current Situation

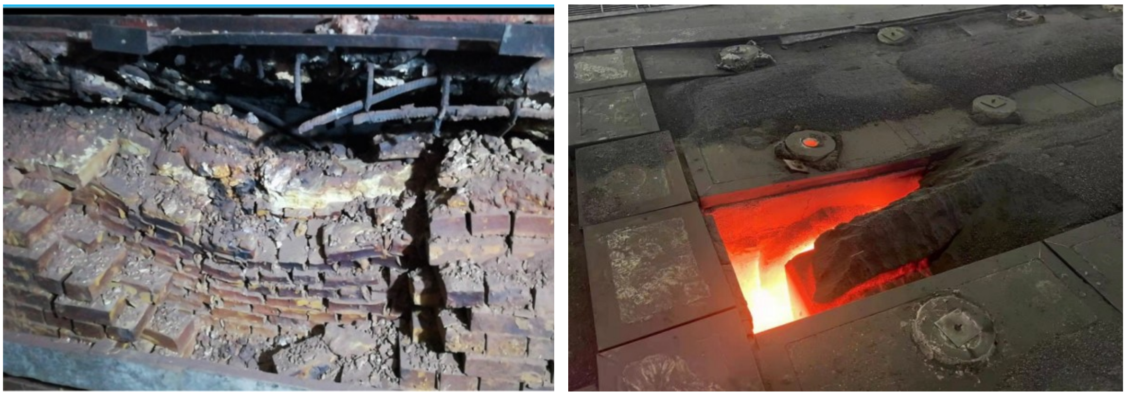
China accounts for over 60 % of global electrolytic aluminium production. With the increasing demand for large-scale and energy-efficient technologies in the aluminium sector, the trend towards larger and higher-quality anodes has become inevitable. Currently, there are over 100 carbon anode producers in China, with a total production capacity of around 30 million tonnes and an actual output of around 23.1 million tonnes. As a critical component in the anode production process, the predominant carbon baking furnaces for aluminium are still in small sizes, only capable of producing small anodes suitable for 300 kA electrolytic cells, making it difficult to meet the increasing demand for larger cells. Some baking furnaces have been in operation for 10 to 20 years, and the aging equipment has resulted in three major issues: limited production capacity, difficulty in improving product quality, and persistently high energy consumption. To address these challenges, systematic upgrades are essential, with a focus on three key areas: optimizing the furnace structure, precisely controlling baking process parameters, and applying new materials while improving maintenance systems. Notably, numerical simulation technology provides innovative solutions for these upgrades. By developing advanced computational models, it not only reduces trial-and-error costs but also allows for accurate prediction and optimized control of the production process. This "digital twin + physical upgrade" approach significantly enhances both the economic viability and efficiency of the upgrades, offering critical technical support for the industry's transformation.

We have systematically upgraded traditional, outdated baking furnaces using a comprehensive approach that combines performance diagnostics, design optimization, and numerical simulations. By innovatively optimizing the geometry of the combustion chamber, improving the flue structure, and adopting new high-performance thermal insulation materials, we significantly enhanced the operational performance of the outdated baking furnaces, confirming the effectiveness of the upgrade plan. This paper provides a reliable technical pathway and practical reference for the modernization of similar baking furnaces.

2. Operations and Baking Results of Outdated Small-scale Baking Furnaces

2.1 Operations

Take a 36-chamber baking furnace from a carbon plant as an example: with dimensions of 5246 × 773 × 5340 mm (L × W × H) for each pit, this baking furnace is capable of producing small-sized carbon anodes with specifications of 1560 × 660 × 620 mm. The baking furnace has been in operation for 17 years, but it is no longer compatible with the production needs for larger anodes required by modern electrolytic cell process.



(a) (b)

Figure 1. (a) Deformation and sagging of the flue. (b) Oxidation of baked products.

On-site inspection of the baking system revealed several issues, including sagging and deformation of the flue. Due to the extended operation time of the baking furnace, some areas experience rapid temperature increases in the carbon blocks during critical periods. Additionally, abnormal cooling at certain points in the flue and localized overheating have led to the sagging and deformation of the flue, as shown in Figure 1(a). Moreover, significant oxidation was observed in products from certain areas of the baking furnace, as shown in Figure 1(b). The oxidized products are no longer suitable for aluminium electrolysis.

2.2 Baking Results

A comprehensive analysis was conducted on the dynamic temperature and baking results within the baking furnace's pit and flue. The results are presented below. Table 1 shows the final temperature at the side cross-section of the flue inside the pit. The measurements were taken at the upstream, midstream, and downstream sections across the upper, middle, and lower layers. The results indicate a temperature deviation of 47.8 ℃ at the cross-section, with significantly lower temperatures at the bottom layer and relatively higher temperatures in the middle section

In terms of energy consumption, the comparison focused on natural gas usage during the same production cycle before and after the retrofit. After the retrofit, the average natural gas consumption per tonne of anodes was 50 m^3, which represents a saving of 18 m^3 per tonne compared to pre-retrofit levels.

5. Conclusions and Application Prospects

To address the limitations of traditional ring-type baking furnaces, such as constraints on product specifications, low production capacity, high energy consumption, and the technical challenges of retrofitting, this study integrates diagnostic testing, structural optimization, and numerical simulation to develop an efficient upgrade solution for aging baking furnaces. After applying this solution, the baking furnace of a carbon enterprise was able to meet the conditions for large-scale anode baking. The average natural gas consumption per tonne of anodes was reduced by 18 m^3, and the anode resistivity was lowered by 2.80 μΩ·m.

1. In line with the demand for high-efficiency, low-carbon, and intelligent industrial upgrades, the airflow distribution within the baking furnace was significantly improved by redesigning the structure size of combustion chamber and flue shape. The innovative use of new insulating materials reduced both renovation and operational costs while improving the quality of carbon anodes. These upgrades offer a practical solution for revamping small-sized baking furnaces and for replacing or repairing flue systems in aging serving equipment, both domestically and internationally.

2. A coordinated optimization model integrating process, design, and simulation was established. Based on dynamic alignment between fuel characteristics and product quality requirements, CFD simulations guided the optimization of key structural parameters. This approach resulted in a comprehensive energy-saving and quality improvement solution that covers the entire cycle of design, operation, and retrofit of baking furnaces.

3. Energy-saving diagnostic and optimization techniques were implemented on both existing and upgraded baking systems. The furnace structure was optimized to better align with the baking process, resulting in a 10 % increase in the yield of first-grade anode blocks and a reduction in energy consumption to 1.74 GJ/t, successfully achieving the goals of quality improvement and energy efficiency.

Through the above measures, large-scale and high-quality products were produced while reducing both energy consumption and investments. During the implementation, challenges emerged due to the limitations of the flue gas purification system and the reused combustion control system. Although the technical team successfully addressed the issues, the experience highlights the importance of thoroughly evaluating the process coordination and the compatibility with existing facilities in such upgrading projects.

6. References

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