AL04 - Application of SAMI Intensive-Current and Energy-Saving Technology in a 240 kA Potline

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Abstract

Due to the proposal and implementation of national dual-carbon strategic goal in China, Shenyang Aluminum and Magnesium Engineering and Research Institute Co., Ltd (SAMI) has carried out a series of technical research and improvement projects at home and abroad since 2015. In 2022, Guangtou Yinhai Aluminum Co., Ltd implemented an upgrading project on their 240 kA potline. This project involved adopting various technical strategies from SAMI such as enhancing magnetohydrodynamic (MHD) stability, utilizing New Conceptual Cathode Technology (NCCT), implementing the "Long Healthy Life" potlining design, and incorporating energy-saving superstructures. The current of this potline was increased to 260 kA, and energy consumption of the potline was reduced to 12.472 kWh/kg Al from 13.350 kWh/kg Al. Statistical data demonstrated that the production capacity increased by approximately 14 000 tonnes per year for the potline. Current efficiency was increased by 4.32 %, achieving the expected goals for the technical upgrade with significant energy saving and production increase. These technologies offer robust support to the aluminum industry in upgrading its current low-amperage reduction cells, leading to lower carbon dioxide emissions.

Keywords: NCCT Technology, "Long Healthy Life" potlining design, MHD stability, Production increase, Carbon emissions.

1. Introduction

China's strategic goal of carbon peaking and carbon neutrality has put forward the requirements of "dual control of both energy and consumption" for the aluminum smelting industry [1]. Especially after the implementation of the "Tiered electricity pricing" policy, energy consumption of aluminum smelters will be directly linked to the price of electricity. High energy consumption and high electricity price will inevitably affect the survival of some aluminum smelters. The entire Chinese electrolytic aluminum industry urgently needs to accelerate technology upgrading for energy saving and carbon reduction.

SAMI is the forerunner and leader in the development of aluminum electrolysis technology in China. Since 2015, SAMI has developed a complete set of deep energy-saving and green low-carbon aluminum electrolysis technology systems, focusing on goals of improving MHD stability of aluminum reduction cell, maintaining good thermal balance and systematically reducing energy consumption, by means of theoretical research based on multi-physical field simulation of aluminum reduction cell, combined with industrial tests, smelter applications and field test verification. The technical route of this technology system is as follows:

- Starting from the essence of aluminum electrolysis process, to optimize the electro-magnetic field and conductive structure design with the aim of improving MHD stability and reducing voltage drop of the cell, establish the foundation for stable cell operation under low anode and cathode distance (ACD), low voltage, and higher current density.
- Research the characteristics of temperature and stress distribution of the lining and potshell under low ACD, low voltage, and higher current density. Optimize the thermal balance design, upgrade the matching lining design and anti-deformation potshell structure, so that the cell can maintain a "Long Healthy Life" under the condition of low energy consumption.
- Develop an energy-efficient and eco-friendly cell superstructure by optimizing the gas flow field. These enhancements aim to achieve an energy-saving and highly efficient fume collection system.
- Develop cell control system with intelligent crust-breaking and alumina feeding system for uniform distribution of alumina concentration, taking into account bath flow.
- Explore production process management technology of aluminum reduction cell under low ACD, low voltage, and higher current density. Integrate production operation control with design concepts to promote a refined, standardized, and intelligent production process management system.

Following the outlined technical path, SAMI has successfully developed numerous sub-technologies. Including:

- MHD stability enhancement technology such as Networked Self-equalizing Busbar Technology (NSBT) and New Conceptual Cathode Technology (NCCT) [2-4],
- "Long Healthy Life" lining technology,
- Energy-saving and eco-friendly superstructure technology,
- Production process management technology of aluminum reduction cell under low ACD, low voltage, and higher current density, etc.

Furthermore, in 2022, the aforementioned energy-saving technology system for aluminum electrolysis was successfully integrated and implemented in the 240 kA potline upgrading project of Guangtou Yinhai Aluminum Co., Ltd. Following the optimization and upgrade provided by this technology system, the operational current of the 240 kA potline has been successfully increased to 260 kA. After being reactivated, the upgraded cells have been operating stably and achieving favorable process technical indicators. They demonstrate clear advantages in terms of energy efficiency and increased productivity.

2. Potline Operation Conditions Before Upgrade

Prior to the upgrade, this 240 kA potline had been in operation for more than 15 years, with the following significant issues:

- The cell suffered from poor MHD stability, failing to meet the requirements for stable production and operation at low ACD. The anode current density was as low as 0.733 A/cm^2, energy utilization rate and unit labor productivity were also low.
- 30 % graphitic cathode carbon block was used, the average cathode voltage drop (CVD) and external busbar voltage of the cell was more than 310 mV and 250 mV respectively. Most cells ran with poor ledge profiles, relatively cold corners, and high potshell bottom temperature.
- The superstructure of the cell utilized a low-type fume collection structure. However, this design led to excessive ash accumulation in the duct, increasing gas collection resistance and decreasing gas collection efficiency. Consequently, the fume collection and scrubbing system exhibited high energy consumption. Most of the time, the traditional pneumatic-controlled crust-breaking and feeding system had a great impact

on the superheat and thermal balance of the cells. The cell experienced a significant distributed gradient in alumina concentration, leading to an increased occurrence of anode effects that were challenging to extinguish.

- The cell operated at high average voltage (4.030 V) and low average current efficiency (89.96 %). As a result, the DC energy consumption of liquid aluminum was approximately 13.35 kWh/kg Al, placing it at a high energy consumption level within China. This consumption level made it challenging to comply with the future policy requirements of the national "Tiered electricity pricing" policy in 2023 and 2025. The technical indicators of the cell were significantly outdated.

3. Technical Upgrading Plan of this Project

The primary goals of this upgrade project are to reduce energy consumption and enhance economic benefits. Through comprehensive evaluation and public bidding, it has been determined that the SAMI deep energy-saving and green low-carbon aluminum electrolysis technology system will be utilized for optimizing and upgrading the busbar, lining, and superstructure of the 240 kA potline. Existing supporting utility and auxiliary facilities will be reused as well. Furthermore, the potline's operating current will be increased from 240 kA to 260 kA following the upgrade.

3.1 High Stability Magnetic Field Upgrade Technology

3.1.1 High Stability Magnetic Field Upgrade Technology

Based on SAMI's latest busbar magnetic field simulation design platform, the electromagnetic field simulation model of 240 kA cell busbar is established to optimize the magnetic field design. The magnetic field calculation results of the 240 kA cell busbar before and after upgrade design are shown in Figure 1 and Figure 2.

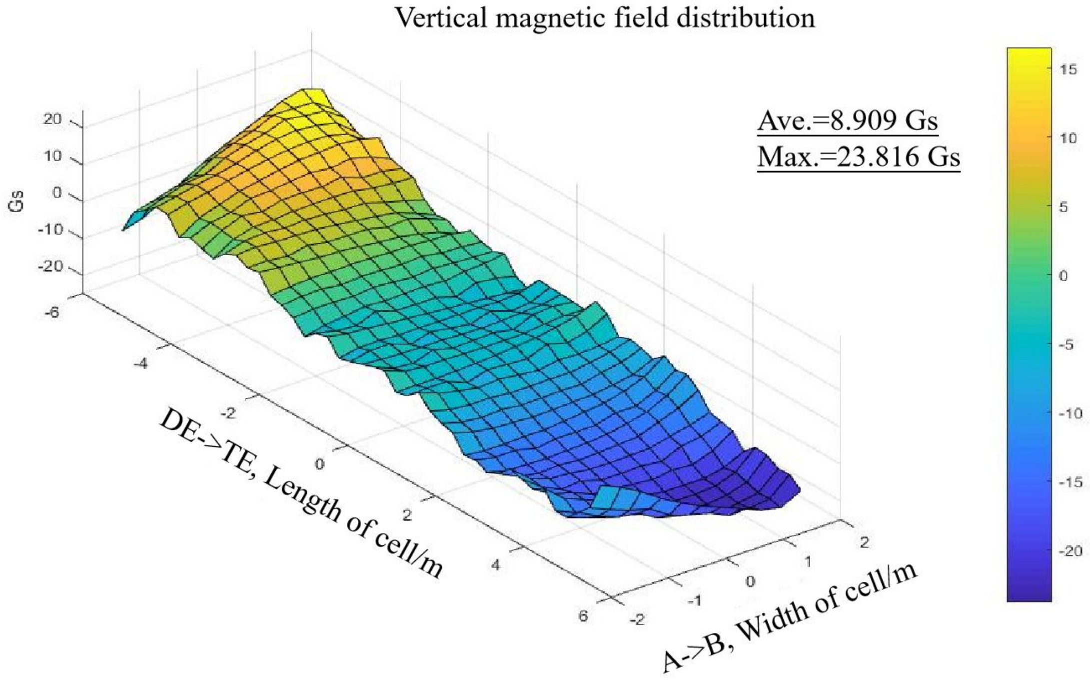


Figure 1. Vertical magnetic field distribution of initial cell busbar design.

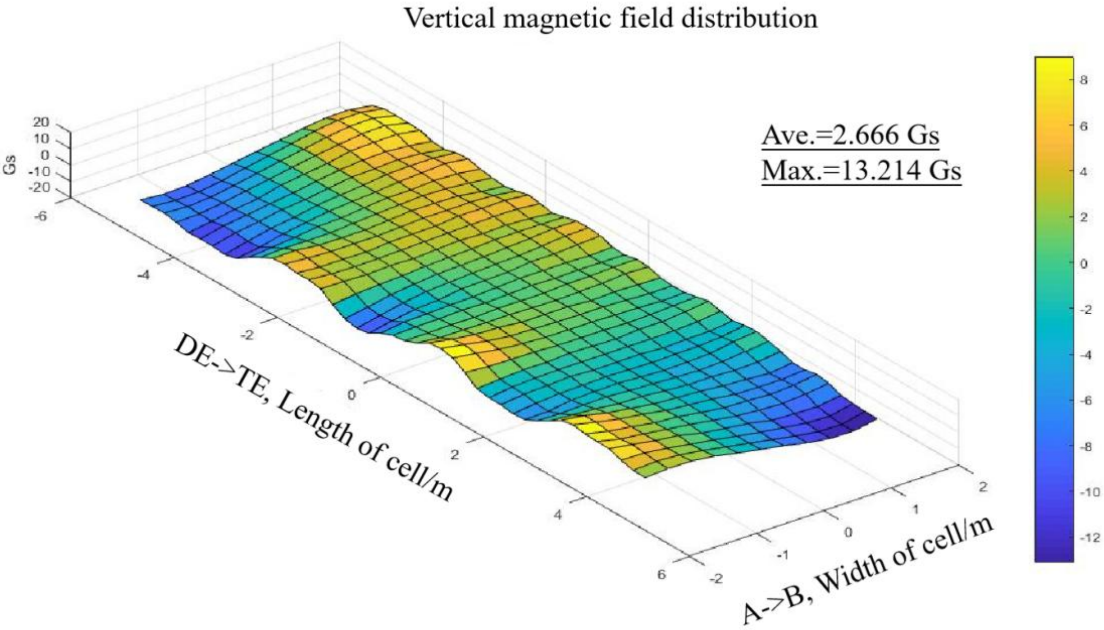


Figure 2. Vertical magnetic field distribution of upgraded cell busbar design.

The results demonstrate a significant improvement in the vertical magnetic field distribution after the upgrade. The absolute average values in the first, second, third, and fourth quadrants have been optimized, reducing from the initial design values of 1.257 mT (12.57 G), 0.643 mT (6.43 G), 0.505 mT (5.05), and 1.158 mT (11.58 G) to 0.332 mT (3.32 G), 0.221 mT (2.21 G), 0.201 mT (2.01 G), and 0.313 mT (3.13 G), respectively. Additionally, the magnetic field distribution is now more uniform, with smaller gradients than before the upgrade. The occurrence of points with a vertical magnetic field exceeding 2.0 mT (20 G) in the cell's melt region has been significantly reduced. The maximum vertical magnetic field value, previously observed in the corner of the cell, has been reduced from 2.382 mT (23.82 G) to 1.321 mT (13.21 G). These optimized magnetic field conditions contribute significantly to increasing the operational stability of the cell.

3.1.2 Networked Self-Equalizing Busbar Technology

The busbar system has been redesigned, incorporating SAMI's innovative networked self-equalizing busbar technology. A new equipotential network is established in the busbar structure. The implementation of this equipotential network enables a reduction in the conduction of uneven cathode and anode current distribution within the potline, particularly under unstable cell conditions such as cell shutdown, anode effects, anode changing, and tapping operations. Consequently, it minimizes current distribution disparities and magnetic field fluctuations in both the unsteady cell and its upstream and downstream cells.

This improvement leads to enhanced MHD stability, operability, and anti-interference capabilities of the cell. Furthermore, the equipotential network effectively suppresses the generation of horizontal currents caused by the deformation of the aluminum liquid/electrolyte interface. As a result, the MHD stability of the cell is significantly improved, creating favorable conditions for reducing ACD. As shown in Figure 3, transient MHD stability simulation shows that the minimum stable ACD of the cell is reduced by 4 mm using this technology while maintaining the same MHD stability characteristics.

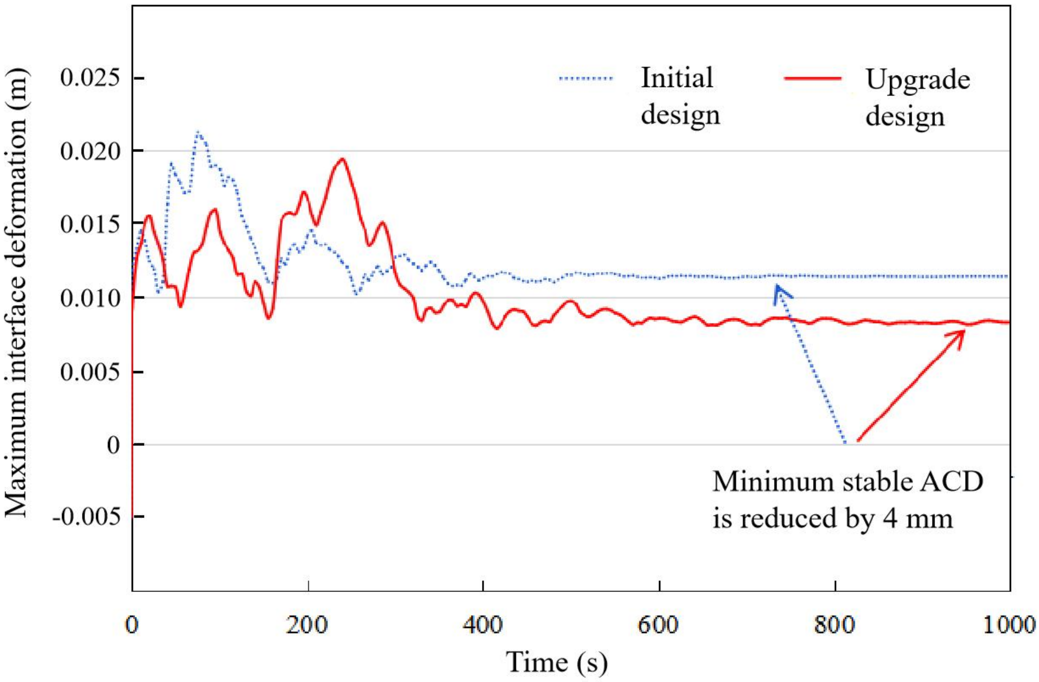


Figure 3. Maximum interface deformation before and after upgraded design.

3.2 Upgrade Design of Cathode Assembly Based on NCCT

3.2.1 Reduction of Horizontal Current and CVD

SAMI has developed an advanced thermoelectric coupling model to calculate the horizontal current in the metal pad and CVD. To reduce the horizontal current in the metal pad, SAMI has integrated the design concept into the structural design of the cathode assembly. By optimizing the conductive structure of the cathode through changes in the connection mode and assembly form of the collector bar and cathode carbon block, significant reductions in horizontal current in the metal pad and CVD of the cell can be achieved. This optimization approach offers several advantages. Firstly, the utilization of graphitized cathode material with lower resistivity, lower sodium expansion coefficient, and more uniform physical and chemical properties effectively decreases the physical voltage drop in the cathode carbon block. Additionally, it mitigates the increase in cathode expansion and voltage drop caused by sodium absorption during production [2, 5]. Secondly, through structural design and optimization of the casting process, the contact voltage drop between different materials is minimized. This is achieved by connecting the collector bar and cathode carbon blocks using pig iron, which has a lower resistivity than the traditional carbon paste.

As shown in Figure 4, before upgrading, the horizontal current in the metal pad of the 240 kA cell assembled with 30 % graphitic cathode carbon block and carbon paste was 9361 A/m^2, and the CVD was 309 mV. Through the implementation of graphitized cathode carbon blocks and optimization with NCCT Technology, significant reduction of the horizontal current in the metal pad was achieved, with a maximum of 4849 A/m^2, and of the CVD at 187 mV. Furthermore, following the technology upgrade, even with an increased operational current of 260 kA, the horizontal current in the metal pad and CVD can still maintain low values at 5087 A/m^2 and 202 mV, respectively. The MHD stability of the cell is significantly improved.

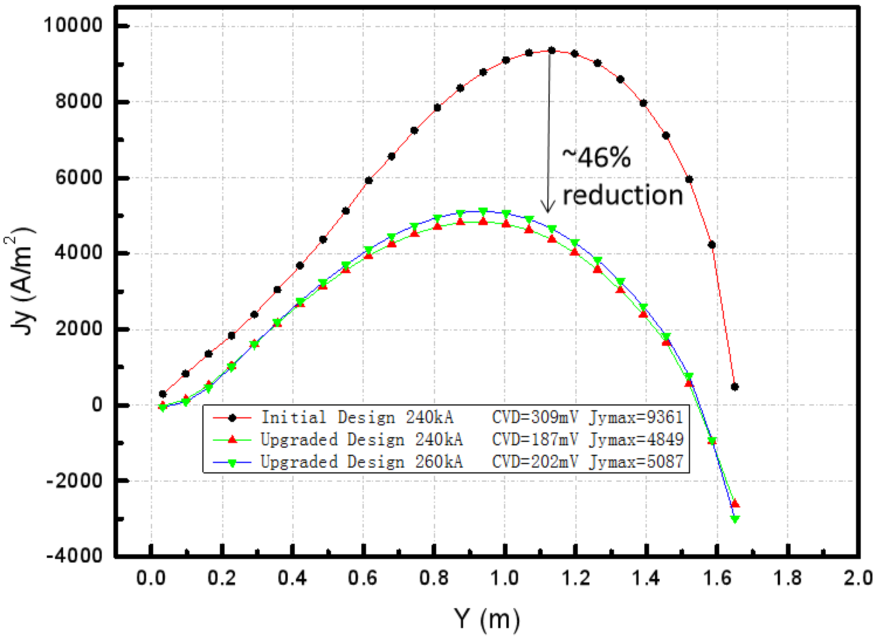


Figure 4. The CVD and horizontal current in the metal pad before and after design upgrade.

3.2.2 Optimization of Long-life and Anti-Permeation Cathode Structure

SAMI conducted extensive simulation research on the multi-dimensional coupling model of the cathode structure. By optimizing the dovetail groove structure of the cathode carbon block, the local thermal stress concentration during the casting and assembly process is effectively eliminated. This optimized design also enhances the cathode assembly's ability to withstand the thermal shocks associated with high-temperature cast iron. The electro-thermal-stress model of the cathode assembly and the cathode assembly post-casting are illustrated in Figure 5.

The cathode is the first line of defense against electrolyte penetration [6], and the impervious layer is the key line of defense. To enhance the permeability resistance of the cathode assembly, SAMI has implemented an improvement by adding a new impermeable layer beneath the cathode carbon block. This new layer is positioned above the traditional impermeable layer to prevent the downward leakage of electrolyte. This optimization ensures not only high MHD stability and low CVD but also contributes to the prolonged lifespan of the cathode assembly and lining.

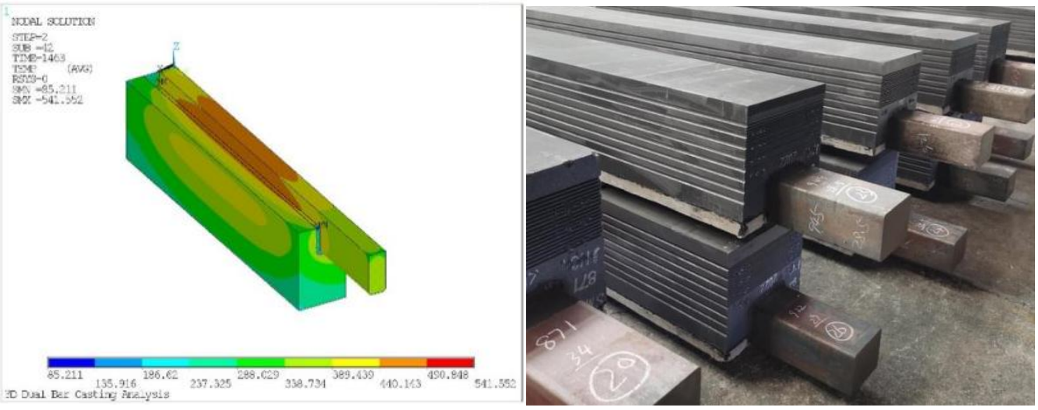


Figure 5. Electro-thermal-stress simulation model of cathode assembly and cathode assembly after casting.

3.3 Positive Thermal Balance Control

The application of the above busbar optimization technology and NCCT provide a basis for reducing ACD and operational voltage of cell. However, matching of the thermal balance of the lining is also a key factor for long term efficient and stable operation of cell under low ACD and low voltage. After optimization, the CVD value is lower, and the heat production in the cathode region is relatively low with low ACD operation. On the other hand, objective conditions for the greater heat dissipation of the cathode region are formed due to the higher thermal conductivity of the fully graphitized cathode carbon block. In this case, the supporting lining design must minimize the heat dissipation at the side and bottom of the cathode region to ensure a good thermal balance under low ACD and low voltage and create conditions for extending the "Healthy Life" of the lining.

SAMI has employed a precise thermal balance simulation calculation model to optimize the thermal balance of the lining. Through systematic upgrades in materials, structural forms, and lining processes, each functional area at the side, corner, and bottom of the lining has been enhanced. This optimization effort has resulted in achieving a good isotherm distribution and ledge profile shape, ensuring improved thermal balance within the lining.

The thermal balance simulation calculation results of the lining structure after optimization are shown in Figure 6, Figure 7 and Table 1. From Figure 6 and Figure 7, we can see that when the upgraded cell running under 260 kA current and at the target voltage of 3.942 V, a good isotherm distribution and ledge profile shape can be obtained by adjusting the appropriate process conditions. The thinnest ledge profile at the metal/bath interface is 6.1 cm, and the shortest distance from the ledge surface to the sidewall is 14.8 cm. The ledge profile is relatively uniform and there is no long ledge toe, just 3.4 cm. The cathode lining is well protected.

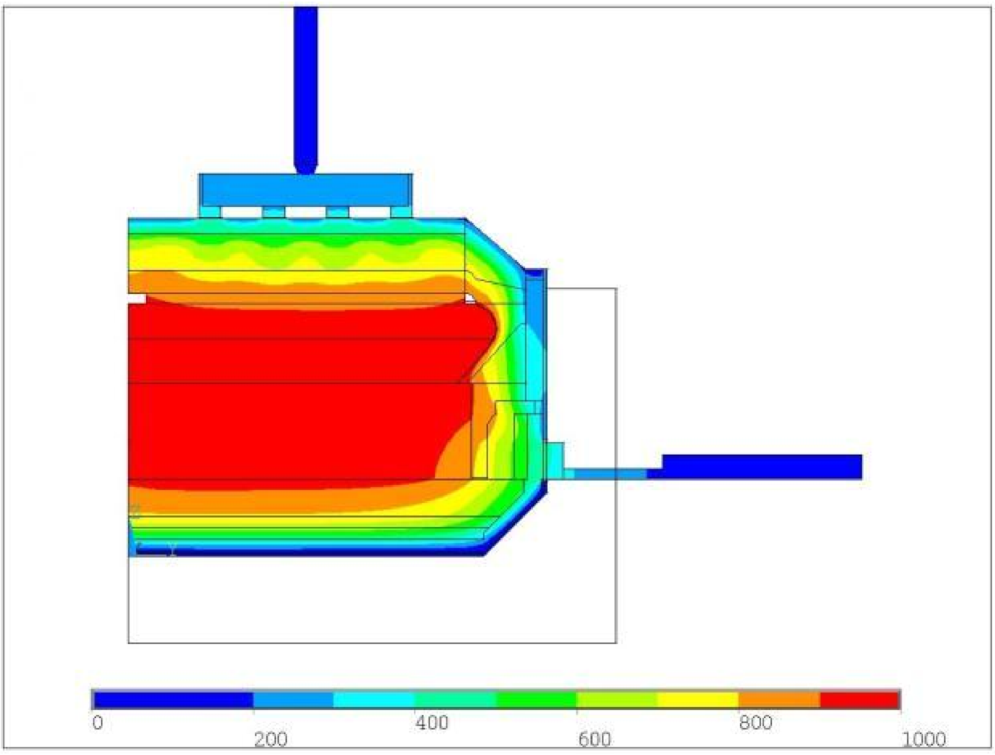
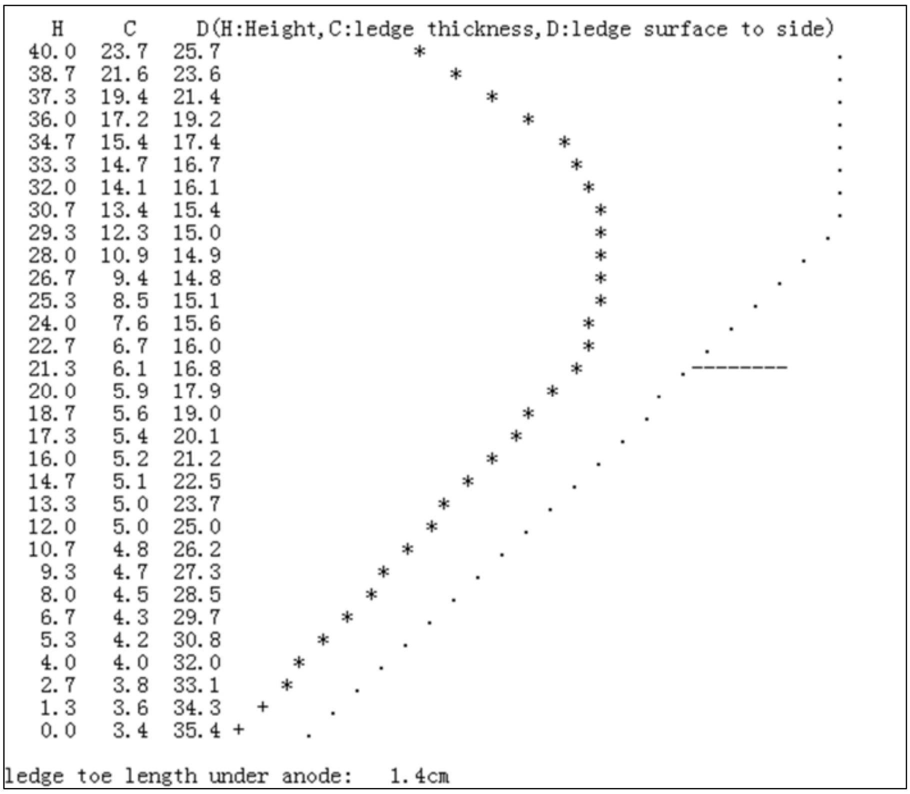


Figure 6. The lining isotherm distribution of the upgraded 260 kA cell.



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   H     C     D(H:Height,C:ledge thickness,D:ledge surface to side)
 40.0  23.7  25.7                *                                  .
 38.7  21.6  23.6                   *                               .
 37.3  19.4  21.4                      *                            .
 36.0  17.2  19.2                         *                         .
 34.7  15.4  17.4                            *                      .
 33.3  14.7  16.7                             *                     .
 32.0  14.1  16.1                              *                    .
 30.7  13.4  15.4                               *                   .
 29.3  12.3  15.0                               *                  .
 28.0  10.9  14.9                               *                .
 26.7   9.4  14.8                               *              .
 25.3   8.5  15.1                               *            .
 24.0   7.6  15.6                              *           .
 22.7   6.7  16.0                              *         .
 21.3   6.1  16.8                             *        .--------
 20.0   5.9  17.9                           *        .
 18.7   5.6  19.0                         *         .
 17.3   5.4  20.1                        *        .
 16.0   5.2  21.2                      *        .
 14.7   5.1  22.5                    *        .
 13.3   5.0  23.7                  *        .
 12.0   5.0  25.0                 *       .
 10.7   4.8  26.2               *       .
  9.3   4.7  27.3             *       .
  8.0   4.5  28.5            *      .
  6.7   4.3  29.7          *      .
  5.3   4.2  30.8        *      .
  4.0   4.0  32.0      *      .
  2.7   3.8  33.1     *     .
  1.3   3.6  34.3   +     .
  0.0   3.4  35.4 +     .

ledge toe length under anode:   1.4cm
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Figure 7. The ledge profile shape of the upgraded 260 kA cell.

Voltage distribution and heat losses of upgraded design 260 kA cell are listed in Table 1. The simulation calculation results show that the upgraded design effectively reduces the CVD and external busbar voltage. The average net voltage of the cell is significantly reduced from 4.030 V to 3.942 V, and good voltage distribution and heat losses are obtained.

Table 1. Voltage distribution and heat losses of upgraded design 260 kA cell.

Voltage distribution / V		**Heat losses (voltage equivalent)/ V**	
Reversible and overvoltage	1.844	Top heat loss	0.824
Anode voltage drop	0.357	Side heat loss	0.505
Bath voltage drop	1.291	Heat loss of steel collector bar	0.162
Cathode voltage drop	0.199	Bottom heat loss	0.111
Anode effect average voltage	0.005	End heat loss	0.103
External busbar voltage	0.223	Busbar and contact surface voltage drop heat loss	0.226
Anode rod to anode beam contact voltage drop	0.008	Material heating	0.219
Noise voltage	0.015	Al production	1.792
Average net voltage of the cell	3.942	Total heat loss	3.942

3.4 Energy-Saving and Eco-Friendly Superstructure Design

After careful evaluation, it was decided to reduce renovation costs by reusing the original anode lifting devices, anode busbar, main structure of the girder, and posts. However, some partial upgrade designs were necessary to minimize gas exhaust resistance and enhance fume collection efficiency.

Using simulation software, SAMI performed modeling and calculations for the newly designed upper-type fume exhaust system. Through this process, the relative distance of each upper fume collection hood was optimized, resulting in a more uniform distribution of fume flow along the length of the cell. The simulation and circulation optimization of fume pressure and flow field were conducted to significantly reduce the pressure loss of the fume collection and the air volume of the system. This reduction effectively lowers the energy consumption of the gas scrubbing system. Furthermore, careful control of the fume flow rates was implemented. The fume flow rate in the duct was maintained at 13-15 m/s, while the fume flow rate at the outlet of the duct was controlled at 17-18m/s. This control strategy helps prevent dust deposition and ensures smooth operation of the system.

The optimized design of the cell flue model and the simulation calculation results of fume pressure and flow field are shown in Figure 8 and Figure 9 respectively.

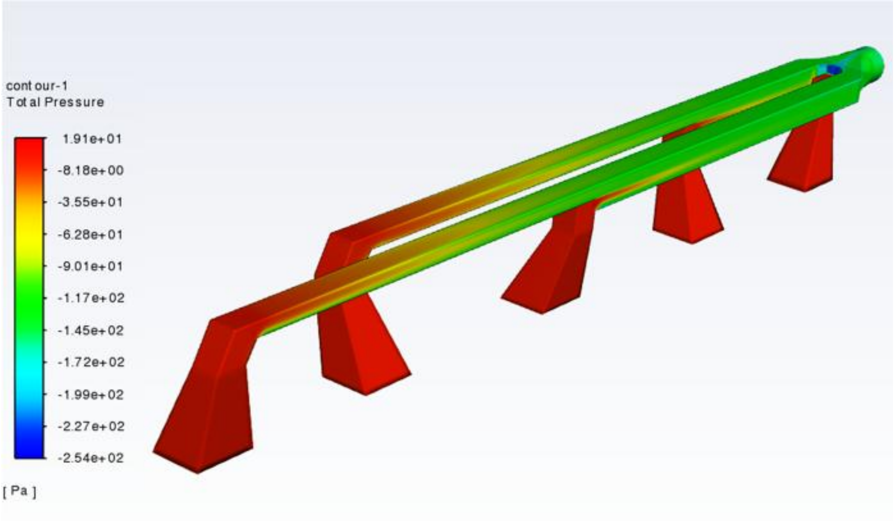

Figure 8. Optimized negative pressure distribution of the flue.

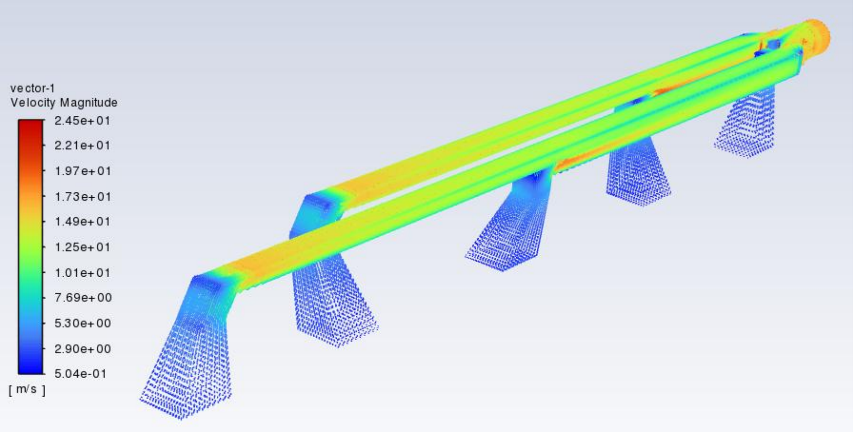

Figure 9. Optimized flow field distribution of the flue.

4. Technical Application Effect

The upgraded design 260 kA potline has been commissioned since August 2022. To date, the upgraded cells have been stable for over 240 days. During the investigation period of nearly 3 months, the main process technical indicators of the cells have been recorded and are presented in Table 2.

Table 2. Summary of key performance indicators.

KPI	Unit	Initial design	Upgraded design
Number of cells	/	164	164
Cell current	kA	240	260
Cell voltage	V	4.030	3.945
Current efficiency	%	89.96	94.28
DC power consumption	kWh/kg Al	13.350	12.472
Bath temperature	℃	954	953
Bath height	cm	18.2	18.9
Metal height	cm	28.0	20.5
Cell Noise	mV	25	16
Cathode voltage drop (CVD)	mV	315	199
Cyolite ratio	/	2.45	2.35
Potline Production Capacity	Tonnes/y	104064	118150

Throughout the investigation period, the upgraded 260 kA cell demonstrated promising results. The average CVD during normal operation was 199 mV, with an average current efficiency of 94.28 %. The DC power consumption of liquid aluminum was 12.472 kWh/kg Al, showcasing notable energy-saving advantages.

Compared to the previous figures, the average DC power consumption of liquid aluminum witnessed a substantial reduction of 0.878 kWh/kg Al. This achievement marks a record-breaking milestone for the largest energy-saving and consumption reduction in technology upgrades among China's aluminium smelters.

5. Conclusions

By implementing SAMI's Networked Self-equalising Busbar Technology (NSBT), high-stability magnetic field upgrading technology, New Conceptual Cathode Technology (NCCT), and precise lining thermal balance technology, notable improvements are achieved in the MHD stability of the cell. Furthermore, significant reductions in horizontal current within the metal pad and CVD are accomplished. These technological advancements create favorable conditions for the stable operation of cells at low ACD, low voltage, and higher current density. Such conditions are instrumental in achieving low energy consumption and ensuring the longevity of cells with a "Long Healthy Life."

SAMI's deep energy-saving and green low-carbon aluminum electrolysis technology system is capable of meeting the technical upgrade needs of existing aluminium smelters. Remarkable improvements can be achieved by focusing on upgrading the lining, busbar system, and auxiliary metal structure of the cell, while keeping the primary layout of the aluminium smelters unchanged.

The successful implementation of this technical upgrade project has set a record for the most significant energy-saving and consumption reduction in the technology upgrading of China's aluminium smelters. This achievement holds significant reference value for the technology upgrade, energy-saving, and efficiency improvement of other aging aluminium smelters.

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