

Upgrading and Application of Cathode Energy-Saving Technology for 500 kA Aluminium Reduction Pots

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Abstract

The story of upgrading and application of cathode energy-saving technology in Guangxi Hualei New Materials Co., Ltd. was started from 2020. In the numerical simulation part, it showed the cathode energy-saving structure could significantly reduce the horizontal current in the metal pad and its resulting disturbances. The distribution of cathode current could be homogenized, and the cathode voltage drop (CVD) could be reduced as well. In the production management part, low metal level and seven stages method were adopted in the smelting process. Based on three months' KPIs in normal production, an energy saving of 300 kWh/t Al was obtained with the application of this technology. The paper may provide some experience and reference for domestic smelters in the work towards carbon peaking and carbon neutrality.

Keywords: 500 kA aluminium reduction pot, Cathode energy-saving technology, Horizontal currents, Cathode current distribution, Low metal level operation.

1. Introduction

With the Chinese Government “dual carbon policy” of carbon emissions peaking before 2030 and carbon neutrality before 2060, aluminium smelters are facing mounting pressure both in energy consumption and energy intensity [1, 2]. In order to support national policies, Chinese aluminium smelters are keeping on upgrading their technologies in energy saving, green and environmental friendliness. Some mature domestic energy-saving technologies are popular ones, e. g., new cathode collector bars [3–6], variable cross-sectional area collector bars [7], graphitized cathodes [8–9], etc. In new established greenfield lines, large capacity and ultra-large-capacity technology were widely applied due to its advantage in energy efficiency. The potential energy saving has been obtained by the increased magnetohydrodynamic (MHD) stability, which could be optimized both from the direction of magnetic field (B) in busbar design and current density (J) in lining structure design [10].

The new technologies used in greenfield lines also have the ability and potential for industry promotion of brownfield potlines. Particularly the cathode energy-saving technology was developed for the applications on different types of aluminium reduction pots. In order to try to

reduce the energy consumption for existing pots (in short form of G1 pots) in Guangxi Hualei New Materials Co., Ltd., the cathode and lining were redesigned by Shenyang Aluminium & Magnesium Engineering & Research Institute (SAMI). Some new operation parameters and methods were also applied for overhauled pots (in short form of G2 pots). We hope this paper could offer some reference for domestic smelters in the background of carbon peaking and carbon neutrality.

2. Basic Information on G1 Pots

The potline in Hualei was designed with a current capacity of 500 kA and installed with 300 pots. It was put into production in September 2017. The production of G1 pots was always accompanied by some persistent problems, as the following:

- 1) High pot voltage, and there was a considerable possibility for the optimization of KPIs.
- 2) Short service life resulted in high labour intensity for operators and loss in economy.
- 3) It is extremely difficult to control the tap-out risks in lots of pots, and operators were restless and prone to leaving.

In light of the above reasons, the technical upgrading was carried out for G1 pots in September 2020.

3. Technical Upgrade Strategy

Since the aluminium reduction pots are complex systems integrating multiple physical fields such as thermal field, electric field, magnetic field, flow field and stress field. These physical fields are mutually restrictive and influence each other. The ideal economic and technical indicators can only be obtained when a fragile balance is achieved. Slight deviations in the design of these physical fields would seriously affect the safety and KPIs of running pots. The design of MHD stability and thermal balance is particularly important in these physical fields.

Therefore, the strategy of the upgrading was first to evaluate the above-mentioned conditions by numerical method. And to identify problems was the second step. Then implementation of the most reasonable and effective upgrading plan in combination with the actual on-site conditions was the final part.

4. Evaluation of G1 Pots

4.1 MHD Stability

Through numerical simulation of original G1 pots, the MHD stability had the following characteristics:

- 1) The current out from side A (upstream) accounted for 50.3 % of the pot current, and the current on the side B (downstream) was about 49.7 %. The current on side A was slightly 0.3 % higher than the theoretical value, as shown in Figure 1.
- 2) The maximum value of the horizontal current in the aluminium pad was 5095 A/m², and the cathode voltage drop (CVD) was 287 mV (shown in Figure 2). Compared with the similar pots (SY500 pots) started up in China during the same period, there was a clear space on the optimization both in horizontal current and CVD.
- 3) The average values of the vertical magnetic field (B_z) in the four quadrants of the melt zone were 5.97, 4.64, 5.92 and 5.03 G, respectively. Its distribution is shown in Figure 3. The average value of the four quadrants was 5.38 G. In contrast, the average value of B_z in domestically operated SY500 pots was only 2.94 G. Higher B_z has a significant disadvantage impact on the MHD stability in G1 pots.

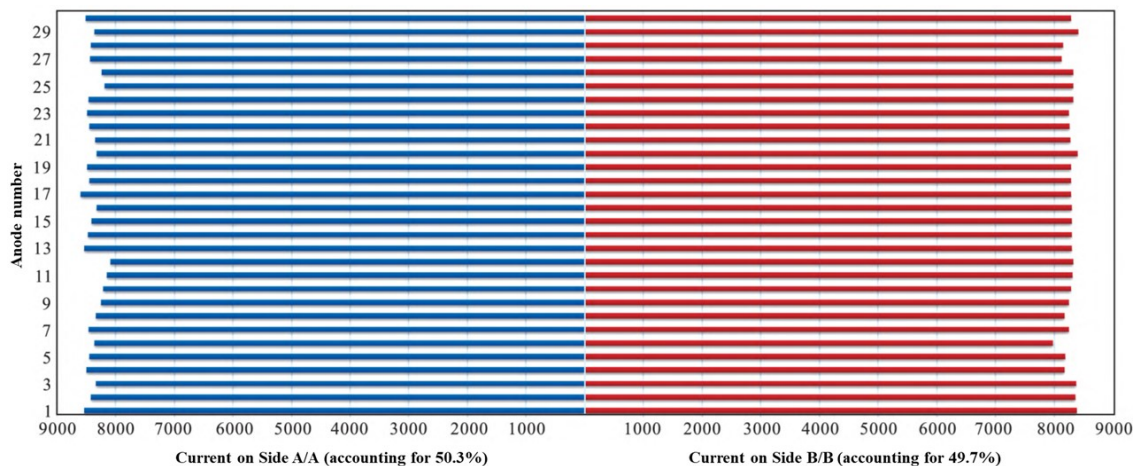


Figure 1. Cathode current distribution in G1 pots.

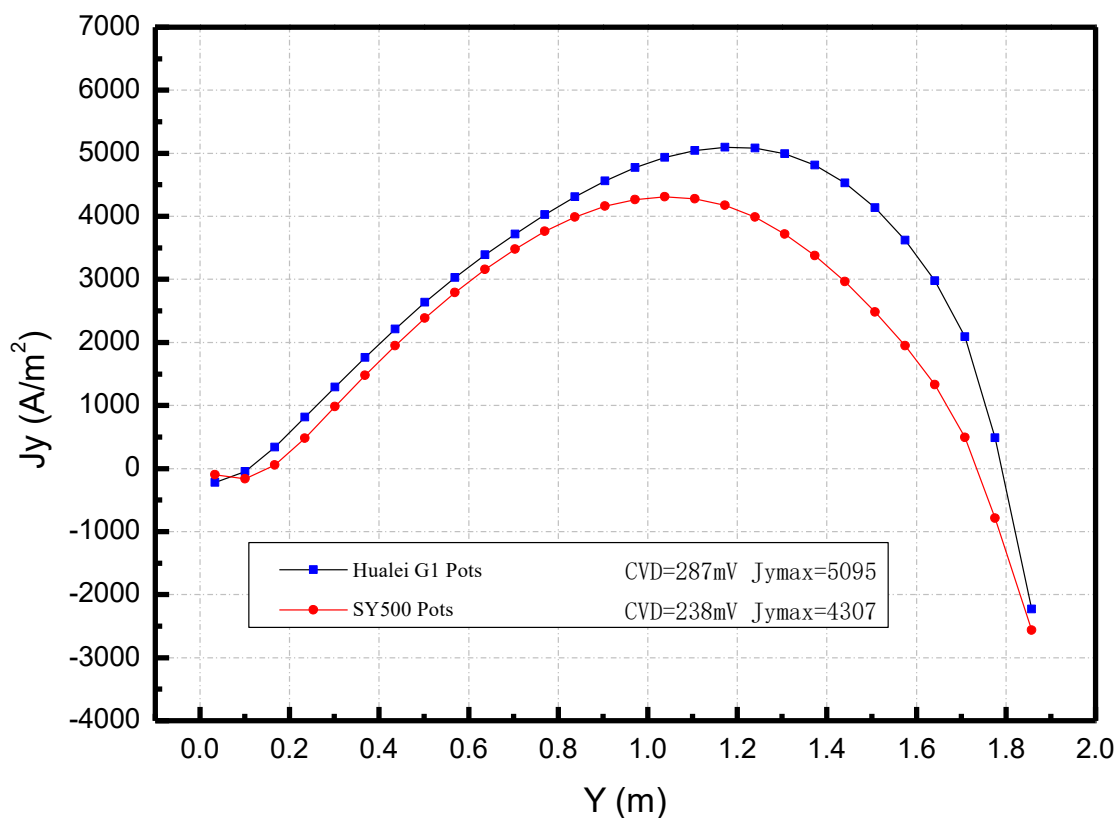


Figure 2. CVD and transverse horizontal current in the metal pad in G1 pots.

- 4) Figure 4 shows the flow pattern of aluminium metal. The maximum and average flow velocities in G1 pots were approximately 30 % higher than those in SY500 pots. The maximum and average flow velocities of the bath layer were both 40 % higher as well. The interface deformation of the bath-metal surface reached 3.8 cm, which was 0.3 cm higher compared to those in domestically built SY500 pots.

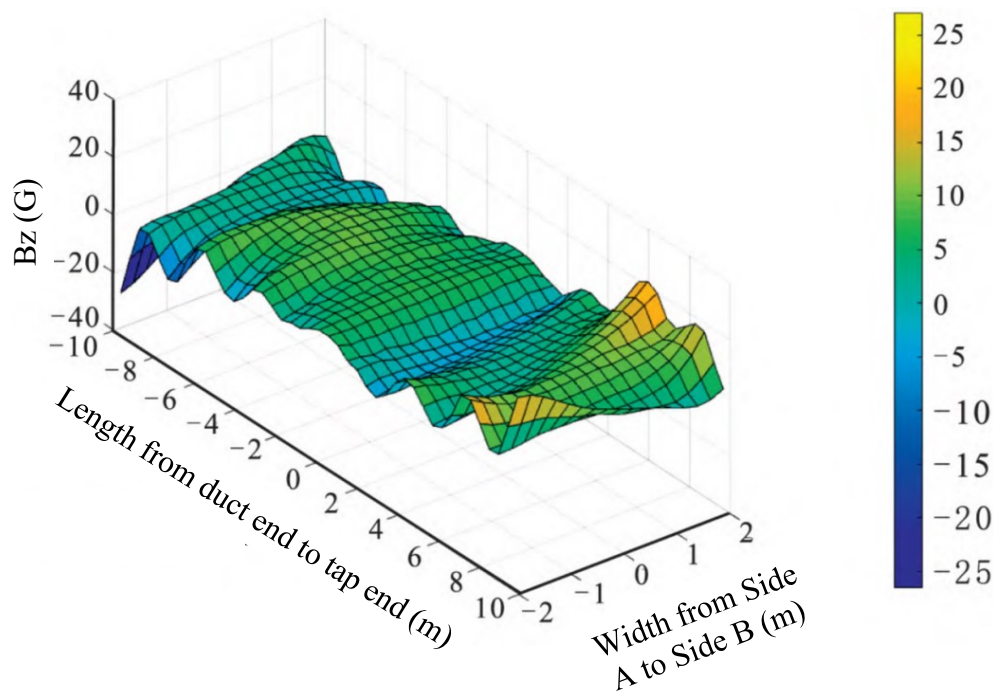


Figure 3. Vertical magnetic field distribution of G1 pots.

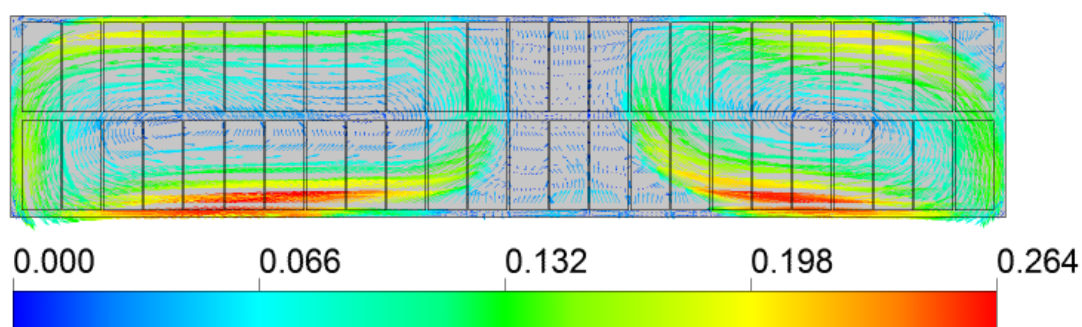


Figure 4. Flow pattern of the metal pad in G1 pots.

4.2 Thermal Balance

Through numerical simulation of G1 pots the thermal balance presented the following characteristics:

- 1) At the current of 500 kA and the pot voltage of 3.96 V, the anode voltage drop was 0.348 V, the bath voltage drop was 1.201 V, and the cathode voltage drop (CVD) was 0.291 V. The bath temperature was 957.7 °C. Figure 5 shows the contour of the temperature. It could be seen that the 900 °C isothermal line was located in the refractory layer, while the 800 °C isothermal line was placed in the insulation layer. These results indicated the thermal insulation was excessively strong in the bottom part of the pot.
- 2) Figure 6 shows the predicted ledge profile in G1 pots. Under the same operating conditions, the minimum thickness of the side ledge was only 3.5 cm. There was almost no frozen ledge toe. This indicated that the design of the thermal balance was not suitable for the operating voltage of 3.96 V. Meanwhile, some distribution problems in heat losses also could be seen from the figure.

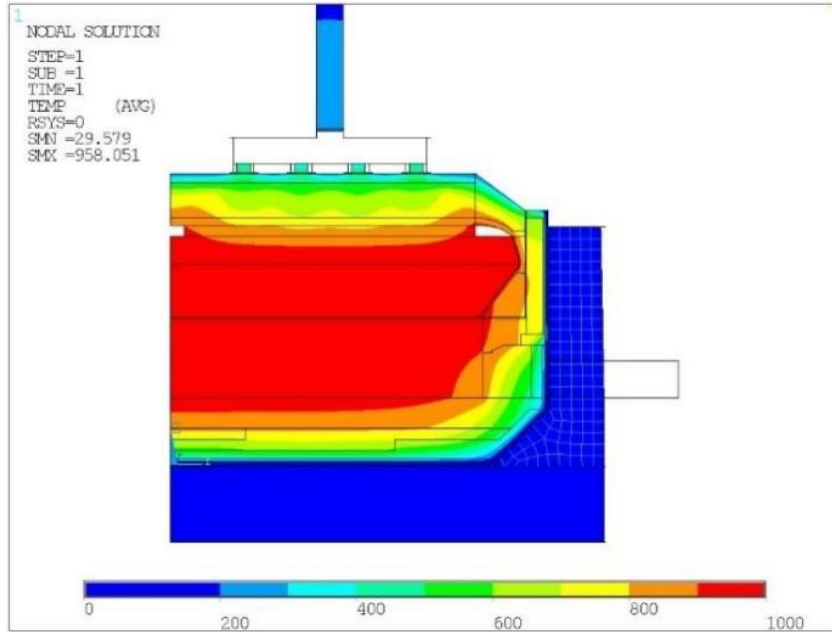


Figure 5. Temperature distribution in G1 pots.

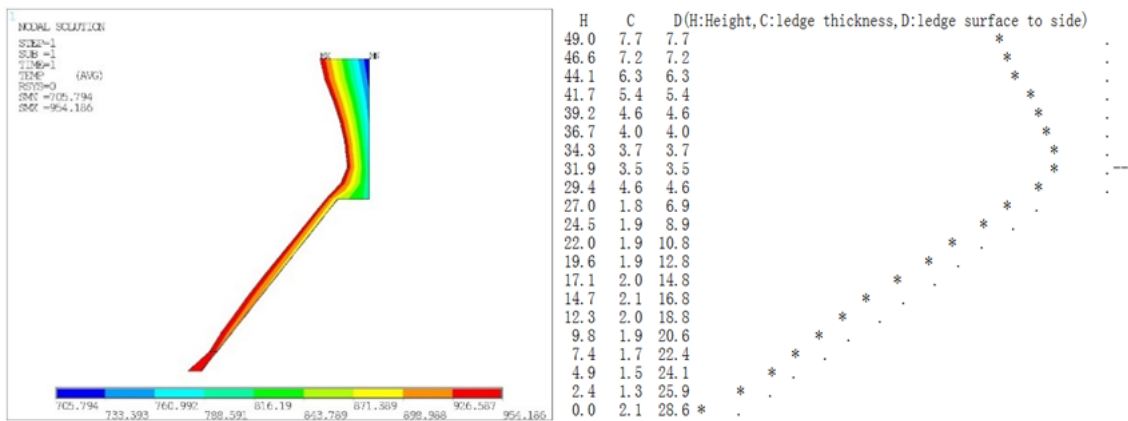


Figure 6. Ledge profile in G1 pots.

5. Upgrading and Optimization of G1 Pots

Considering the market and the objective conditions required for technological upgrading, the economic loss would be too great to afford if it was decided to shut down the potline to optimize physical fields (particularly magnetic and flow fields). We focused on two critical issues of early pot damage and operational stability improvement. The optimization and upgrading were concentrated on the following two parts:

- 1) Utilizing the opportunity of pot overhaul, adopting a new cathode energy-saving structure to eliminate safety problem in cathode carbon blocks, and improving the MHD stability by reducing the horizontal current in the metal pad;
- 2) Through the upgrading of pot lining, optimizing and upgrading the lining structure, thermal balance and the distribution of heat losses.

5.1 Cathode Assembly

The electromagnetic force generated by the interaction between horizontal currents and vertical magnetic field is the root cause for bath/metal flow and interface deformation. Therefore, reducing

and homogenizing horizontal current during optimization and upgrading is critical for improving the MHD stability. The new cathode assembly for G2 pots was designed with careful consideration of its original magnetic field. This was done by changing the structure and assembly method of the cathode carbons, adjusting the conductive properties of various materials in the cathode assembly. The resistance distribution in the cathode assembly could be effectively adjusted and controlled. This technology significantly reduced and homogenized the horizontal current in the molten aluminium. Thereby a substantial improvement in MHD stability would be achieved. The design of cathode assembly created a solid foundation for energy saving in the following production.

Figure 7 shows the horizontal current was dropped to 4114 A/m² after upgrading G1 to G2 pots. Meanwhile the CVD was reduced by 35 mV to 252 mV. The improved MHD stability made the operation of G2 pots more economical.

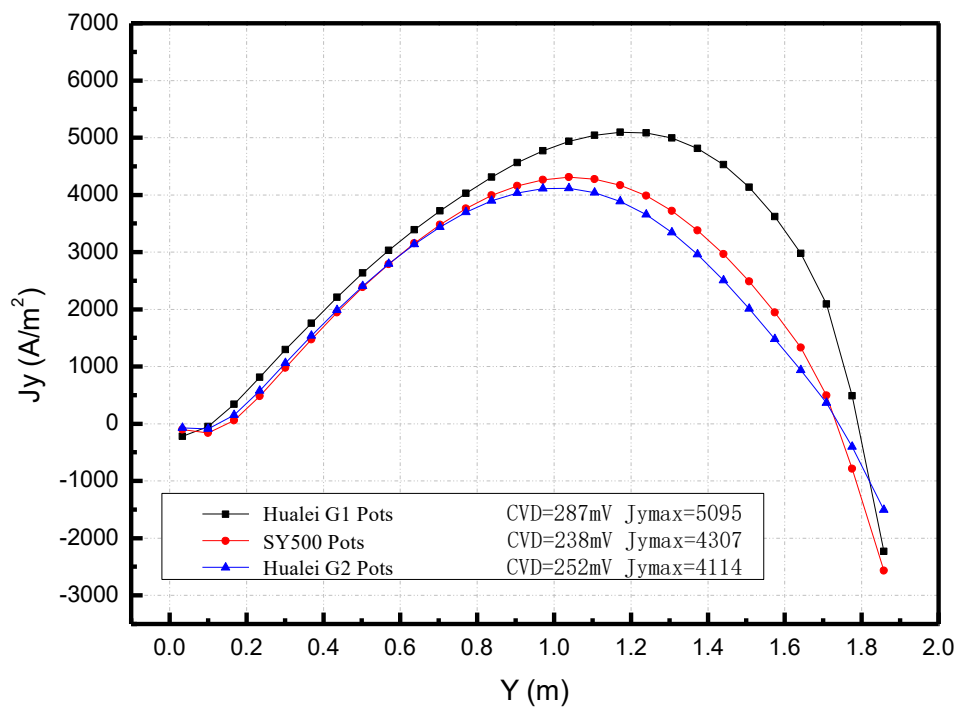


Figure 7. The CVD and transverse horizontal current in the metal pad in G2 pots.

5.2 Lining Designs

The optimization and upgrading were concentrated in the following parts:

- 1) Use SiC-Si₃N₄ and prebaked carbon as side blocks, to enhance heat loss from sidewall.
- 2) Optimize the material, structural design and construction processes in cathode collector bar windows, improve heat loss from the side part, and maintaining seepage prevention capability.
- 3) Set rational compaction space, qualified and sufficient refractory layer and physical barrier to achieve structural optimization of the pot lining, effectively extending the service life of G2 pots.
- 4) Implement comprehensive and stringent requirements in raw material selection, performance metrics, manufacturing processes and quality inspection protocols to ensure all lining materials comply with technical specifications.

Figure 8 shows the lining isotherm distribution in G2 pots. The pot voltage was 3.90 V, where the anode voltage drop was 0.344 V, the bath voltage drop was 1.201 V, and the CVD was 0.252 V. The bath temperature was 958.5 °C with a superheat of 8.5 °C. It can be seen that the 800 and 900 °C isothermal lines were located in the refractory material layer. The isothermal lines distributed in a reasonable profile with horizontal at the bottom and vertical on the side. The minimum part of side ledge is presented at the upper part with a value of 14.8 cm (shown in Figure 9). The width of the ledge toe was 5.3 cm. The ledge profile was in good condition.

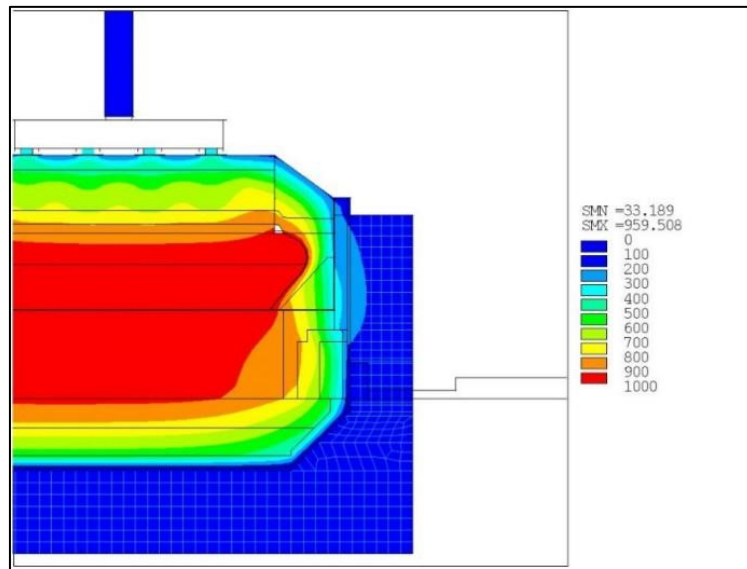


Figure 8. Temperature distribution in G2 pots.

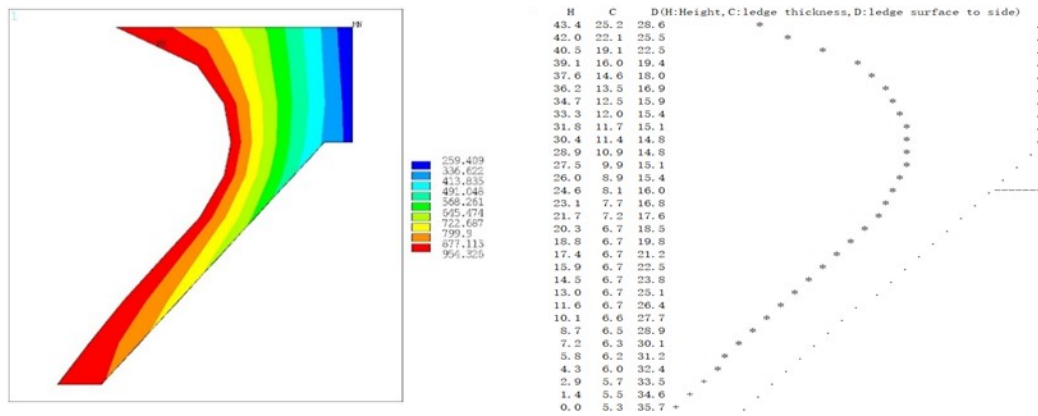


Figure 9. Ledge profile in G2 pots.

5.3 Comparison of Heat Losses

Table 1 shows the proportions comparison of heat losses of the aluminium reduction pots before and after optimization in terms of thermal balance. After optimization, the heat loss at the bottom and side part both increased, while the heat loss from the collector bars decreased. The above designs eliminated the unbalanced heat loss due to the strong insulation at the bottom and side of G1 pots. The distribution of heat losses was more reasonable in G2 pots.

Table 1. Comparison of heat losses in aluminium reduction pots.

Heat losses	G1 pots (%)	G2 pots (%)
Top heat loss	56.66	49.98
Side heat loss	20.52	30.78
Bottom heat loss	5.46	7.35
Heat loss of collector bars	12.76	7.63
End heat loss	4.67	4.26

6. Operation Management of G2 Pots

6.1 Operation Management in the Initial Period

In the initial period, the operation parameters were slightly adjusted from pot startup to normal production period. Special attention was paid on three key tasks:

- 1) The initial period lasted for three months.
- 2) Formulate scientific technical standards for the initial period, the principles of "Two Lows and One High" (low pot voltage, low energy consumption and high current efficiency), and "Three Matches and One Limit" (match cryolite ratio and temperature with ACD, match aluminium level with energy balance and limit anode effect coefficient).
- 3) Implement differentiated process standards for six stages in the initial period, the key point was the management of bath temperature, and the decrease in pot voltage also should be defined with pot age.

Table 2 presents the process parameters in the initial period. Figure 10 shows the voltage management in the period.

Table 2. The management of process parameters in the initial period.

Parameters	Pot Startup	Days 1-20	Days 20-30	Month 2	Month 3	Normal period
Aluminium Level (mm)	0	180–200	180–200	190–210	200–220	210–230
Bath level (mm)	≥ 500	230–320	210–320	180–250	180–230	180–200
Bath temperature (°C)	970–990	965–985	965–985	960–980	960–975	950–965
Excess AlF ₃ (%)	≤ 3.0	≤ 3.0	≤ 3.0	≤ 3.0	3.0–7.0	7.0–9.0
CVD (mV)	≤ 245	≤ 250	≤ 250	≤ 255	≤ 260	≤ 280

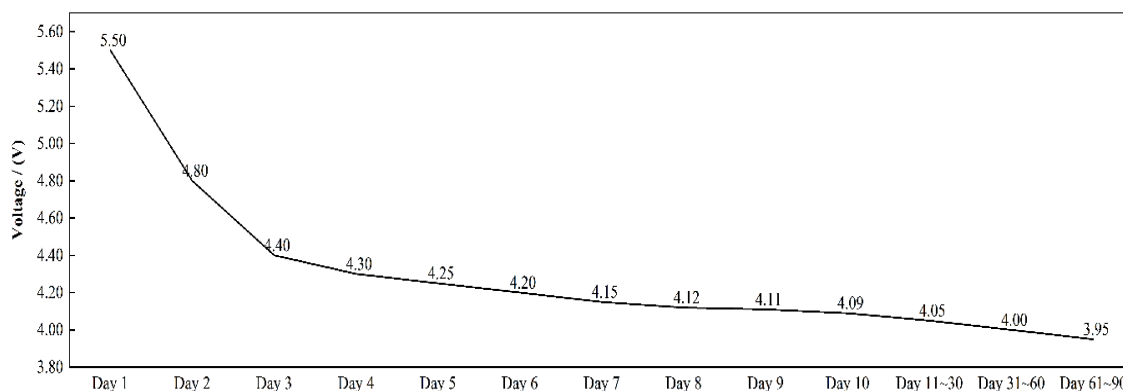


Figure 10. The management of pot voltage in the initial period.

6.2 Operation Management in the Normal Period

Following the criteria of "Two Lows and One High" and "Three Matches and One Limit", the normal period was divided into seven stages according to pot age. Different process standards were set for each stage based on varying production conditions. This was good for enabling the long-term stable operation. Table 3 shows the detailed information.

Table 3. Seven stages in the normal period of G2 pots.

Pot age	Bath level (mm)	Aluminium level (mm)	Excess AlF ₃ (%)	Bath temperature (°C)
91–120 days	180–200	210–230	5.0–6.0	960–980
121–150 days	180–200	210–230	6.0–7.0	955–975
151 days–1 year	180–200	210–230	7.0–9.0	955–975
1–2 years	180–200	210–230	7.0–9.0	953–963
3–4 years	180–200	220–240	7.0–9.0	953–963
5–8 years	180–200	230–250	7.0–9.0	953–963
Over 8 years	180–200	250–270	7.0–8.0	953–963

7. KPIs of G2 Pots

As to June 2021, the G2 pots entered into normal period production. Three months of data were collected for KPIs analysis. The average pot voltage was 3.912 V, the average DC power consumption was 12 706 kWh/t Al, and the average anode effect frequency was 0.019 anode effects/pot·day. A reduction of approximate 300 kWh/t Al was obtained compared to G1 pots. The problems mentioned in section 2 were essentially resolved. The production stability and economic indicators were significantly improved. Some other KPIs are also listed in Table 4.

Table 4. Some KPIs of G1 and G2 pots (one-year averages).

KPIs	G1	G2
Average pot voltage (V)	3.972	3.912
Current efficiency (%)	91.01	91.75
DC power consumption (kWh/t Al)	13 006	12 706
Anode effect frequency (AE/pot·day)	0.032	0.019
Anode effect duration (s)	243	213
Net carbon consumption (kg/t Al)	399	393
Gross carbon consumption (kg/t Al)	482	475
Alumina consumption (kg/t Al)	1918	1910

8. Conclusions

- 1) The cathode energy-saving technology and lining designs applied in domestic greenfield potlines were also suitable to apply in brownfield potlines. The technical upgrading and optimization were carried out in Guangxi Hualei New Materials Co., Ltd. 500 kA pots. The original problems in MHD stability and thermal balance were eliminated. The problem with early failure was solved.

- 2) Through dual upgrading in design and process management, the upgraded pots achieved exceptional performance: the average pot voltage stabilized at 3.912 V, and the DC power consumption dropped 300 kWh/t Al. The problems in production were eliminated with significant improvements in production and economic directions.
- 3) In the background of China's "Dual Carbon Policy", reducing energy consumption through low-carbon optimization and upgrading is an important technical route to support national policies. This paper could offer some reference for domestic smelters.

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