

Accurate Bath Height Control in 500 kA Pots

Dailiang Wu¹, Qinglei Wei² and Jiantao Mo³

1. Technical Assistant of Potroom 1, Assistant Engineer
 2. Operating Assistant of Potroom 1, Assistant Engineer
 3. Superintendent of Group D, Potroom 1, Assistant Engineer
- Guangxi Hualei New Materials, Baise, Guangxi
Corresponding author: 2064504301@qq.com
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Abstract

In the production process of high amperage pre-baked pots, the accurate control of bath height is one of the core factors to ensure efficient and stable operations of the pots. With all-graphite 500 kA pots as the object of study, this paper systematically discusses the influence mechanism of bath height on the thermal balance, alumina dissolution, current efficiency and pot life by combining theoretical analysis with production practices. The study shows that an insufficient bath height will lead to increased heat loss in the pots, abnormal ledge development, and aggravated abnormal fluctuations in the molecular ratio; If the bath height is too high, it may cause the frequent occurrence of anode effect, reduce the current efficiency, accelerate the erosion of the pot lining, and easily give rise to stub washing by bath, greatly affecting the quality of primary aluminium. By establishing a dynamic correlation model between bath height and process parameters, an optimization strategy is proposed to control the bath height within a range of 15–18 cm. Combined with industrial production tests, it has been verified that this strategy can significantly improve pot stability, reduce the DC power consumption by about 100 kWh/t Al, extend pot life by more than 10 %, and ensure high quality of primary aluminium. The study gives guidelines for energy consumption reduction and refined control of large high amperage pots.

Keywords: 500 kA aluminium reduction pots, Bath height, Process optimization, Energy saving.

1. Introduction

During aluminium electrolysis, the electrolyte (bath) is the reaction medium that dissolves alumina and electrolytically reduces alumina to aluminium. It is in contact with anode carbon blocks and the cathode, Electrochemical and chemical reactions take place in the bath, making it indispensable for the production of aluminium.

The electrolyte composition determines the temperature of the electrolysis process and is responsible for smooth operation. It greatly affects the energy consumption, product quality and pot life. Variations of process parameters caused by fluctuations of bath height are particularly sensitive in relined pots. This paper discusses the impacts and control of bath height in a 500 kA potline.

2. Impact of Bath Height Changes on the Pots

This paper discusses the influence of bath height on thermal balance, alumina dissolution, current efficiency and pot life at constant metal height. Variations of bath height may greatly affect the thermal balance and material balance, electrolyte temperature, anode effect frequency and current efficiency. The variations of bath height give rise to poor pot operation and increase labour intensity, and reduce the pot life. This was recognized already a long time ago [1].

2.1 Impact of Excessively High Bath Height

(1) Thermal imbalance and increased energy consumption

Excessive heat capacity: If the bath is too high, it is difficult to maintain the thermal balance of the heat input (Joule heat) in the pots.

Increased voltage demand: High bath may lead to higher anode-to-cathode distance (ACD) and pot voltage, which increases DC energy consumption by about 50–100 kWh/t Al.

(2) Increase of anode effect (AE) frequency

Before 2022, the average anode effect frequency of each work area in our plant was about 0.15–0.23 AE/pot-day. After the standardized adjustment of bath height since 2023, the anode effect frequency was reduced to less than 0.02 AE/pot-day, and the pots with high bath level are rarely seen. The cases where the anode effect occurs due to high bath levels are relatively rare, accounting for less than 3 % of all effects.

Low alumina concentration: With high bath, the bath volume is high, and the alumina (Al_2O_3) concentration tends to be low, near the critical value (< 1.5 %) for anode effects.

Difficulty in discharging bubbles: As the anode immersion depth increases, CO_2 bubbles accumulate at the bottom of the anode, forming continuous gas film, which may increase the occurrence of anode effects.

(3) Molecular ratio imbalance and degradation of electrolyte properties

Increased aluminium fluoride (AlF_3) volatilization: High bath level increases bath surface area and increases AlF_3 volatilization, decreases molar ratio (NaF/AlF_3), decreases bath liquidus temperature, and increases bath the viscosity.

Reduced alumina solubility: Lower bath temperature (due to reduced molecular ratio) will inhibit the dissolution of alumina, generate sludge and make alumina concentration distribution less uniform.

(4) Ledge degradation and pot lining erosion

Melting of side ledge: The excessively high bath level increases the side heat flux and melts the ledge, so that the side wall blocks are directly exposed to bath, which accelerates the sidewall erosion.

Shortened pot life: The lining erosion may lead to the cathode collector bar attack, pot shell deformation and other problems, significantly shortening the pot life (approximately by 20–30 %). Table 1 shows the pot life of 500 kA potline with long-term excessively high bath level, long-term excessively low bath level and stable bath level.

The metal height in the above selected test pots was 22–25 cm for a long time (the smelter target is 23–26 cm). The metal height in the pot 0010 is greater for protective maintenance after the pot was damaged.

As can be seen from Table 1, the pot life may be shortened due to the excessively high or low bath. Excluding the individual cases of pots 0005 and 0010, pots 0001–0003 in group I (extremely high bath level) had an average pot life of about 1428 days. Pots 0004, 0006 and 0007 in group II

(stable bath level) had an average pot life of about 1894 days. Pots 0008 and 0009 in group III (low bath level) have an average pot life of 1555 days. Therefore:

- Compared with the pots in group I, the pot life of the pots in group II is extended by: $[(1894 - 1428) / 1428] \times 100 \% = 32.6 \%$.
- Compared with the pots in group III, the pot life of the pots in group II is extended by: $[(1894 - 1555) / 1555] \times 100 \% = 21.8 \%$.

Table 1. Statistics of pot life of 500 kA potline with different bath heights.

Pot No.	Metal height (cm)	Bath height (cm)	Age before initial damage (days)	Age at pot shutdown, days)
0001	23–24	17–20 (high)	910	1562
0002	23–24	17–20 (high)	964	1688
0003	22–23	18–21 (high)	863	1033
0004	24–25	15–17 (stable)	1124	1963
0005	23–25	16–18	1008	2231
0006	23–24	15–19 (stable)	1139	1768
0007	24–25	15–17 (stable)	1366	1950
0008	22–24	13–16 (low)	968	1688
0009	23–24	13–15 (low)	1011	1422
0010	26–30	12–14	688	863

(5) Reduced current efficiency

Increased pot instability (noise): High bath increases pot noise and decreases current efficiency (usually by 1–3 %). For example, in May to July in 2021, due to the hot weather, many pots had high bath; the monthly average current efficiency decreased from 92.5 % to 90.6 % in May, 91.3 % in June, and 91.5 % in July.

Uneven ACD distribution: Increased bath viscosity leads to the uneven distribution of anode current. More anodes are adjusted, which leads to uneven anode bottom (uneven ACD).

(6) Increased operational difficulty and cost

Increased risk of sludge: When the fluidity of the electrolyte decreases, alumina particles tend to settle at the bottom of the pot cavity and form sludge and hard ridge, which need to be frequently treated, increasing the manual intervention and material consumption.

Complex process control: The AlF_3 dosage, feeding frequency and voltage settings need to be frequently adjusted to maintain the thermal balance, thereby increasing the operational complexity and production costs.

2.2 Impact of Low Bath Height

(1) Risk of potline open circuit

Low bath gives very little anode immersion and the control system may create an open circuit when anodes are moving up. E.g., 12 cm of bath and 4 cm ACD gives anode immersion of 8 cm only.

(2) Disrupted thermal balance and aggravated heat loss

Reduced thermal stability: When the bath is too thin (e.g., less than 12 cm), its heat capacity and thermal buffering capacity will be significantly reduced, resulting in an imbalance between the heat input (Joule heat) and heat loss and severe fluctuation of the pot temperature.

Melting of ledge: The side ledge is unstable and may melt, which directly exposes the sidewall blocks to the bath, and accelerates the chemical corrosion and mechanical wear of the carbon lining.

Shortened pot life: Lining erosion can cause early damage to the pots (such as cathode collector bar attack, aluminium infiltration, etc.), significantly shortening the pot life.

(3) Uncontrolled alumina dissolution and concentration

Reduced alumina dissolution rate: When the amount of electrolyte is low, the alumina dissolution volume is reduced, resulting in high local concentration and settling as sludge. The risk of anode effects increases.

(4) Molar ratio fluctuation and degradation of electrolyte properties

Difficult process control: Fluctuations in molecular ratio require the frequent addition of fluoride salts for compensation, which can easily lead to unstable electrolyte composition and increase the complexity of process control.

Table 2 shows the statistical curve of molar ratio control in 500 kA pot 0011 with low bath height (the bath height is maintained at 12–14 cm for a long time, and the metal height is 25–27 cm). As can be seen from the table, when the bath is low, it is difficult to reduce the molar ratio and adjust the process parameters.

Table 2. Process data of pot 0011.

Date	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11	3.12	3.13	3.14	3.15	3.16
Bath height	13	13	13	12	14	13	12	10	13	15	13	14	12	13	13	14
AlF ₃ target (kg/day)	55	55	60	60	55	55	60	70	70	70	60	60	60	55	70	60
Actual AlF ₃ feed	55	55	63	63	58	55	59	75	104	72	63	63	60	98	90	63
Molar ratio	2.58			2.58			2.58			2.60			2.59			2.59
Alumina (%)	1.23			1.56			1.48			3.2			2.36			1.56

(5) Reduced current efficiency and increased energy consumption

Increased noise: Low bath increases pot noise and reduced current efficiency.

Increased voltage: Low bath leads to pot voltage increase to maintain the thermal balance, resulting in the increased DC power consumption. Typically, for every 1 cm decrease in bath height, the power consumption increases by about 50–80 kWh/t Al.

Table 3 shows the process report of 6 pots with different bath heights in our smelter on a certain day. The 6 pots have all-graphite cathodes, similar ages (within a two-month range) and the metal height of 22–24 cm.

Table 3. Process data of 6 pots with different bath heights.

Pot No.	Bath height (cm)	Set voltage (V)	Operating voltage (V)	Average voltage (V)	Noise (mV)	Noise time (min)
001	12	3.92	4.03	4.01	33	18
002	13	3.92	3.991	3.973	28	7
003	15	3.92	3.948	3.93	25	0
004	17	3.92	3.924	3.922	21	0
005	17	3.92	3.931	3.931	22	3
006	16	3.92	3.94	3.94	20	0

2.3 Bath Height Control Range and Measures

According to the analysis results in 2.1, targeted measures were taken to adjust the process and operation under different circumstances, so as to achieve effective bath height control.

2.3.1 Bath Height Control Range

In the all-graphite 500 kA potline, if the aluminium level is 23–26 cm, the optimal bath height range during the steady-state shall be 15–18 cm. Under such bath height, the pot condition is relatively stable, so that it can easily match the existing material balance and the thermal balance, and can also ensure the stable operation under the test with the minimum possible power consumption and gross anode consumption.

2.3.2 Bath Control Measures

Bath control is the core technology to ensure the efficient and stable pot operation. The control comprises: bath height, composition (molecular ratio), temperature, alumina concentration and impurity management. The following are specific control methods and strategies:

(1) Daily bath height control

It is necessary to keep the daily bath height at 15–18 cm with a small fluctuation range. If the bath is too low, liquid or solid bath it has to be added. Liquid bath is transferred from pots with high bath. Solid bath is added in chunks. If bath is too high it has to be tapped.

(2) Bath height control by the molar ratio (NaF/AlF₃) adjustment

Target range: The molecular ratio is generally controlled to the range 2.3–2.5 (due to differences in bath systems in northern China and southern China, specific bath analysis is required) to maintain the liquidus temperature in the range 940–960 °C.

The control measures are: AlF₃ addition determined by bath sample analysis or online measurements with Fiberlab or StarProbe or bath conductivity sensor. Cryolite (Na₃AlF₆) can also be added in exceptional cases.

(3) Bath height control by the alumina concentration management

The proper control of alumina concentration is essential. On one hand, maintaining an appropriate concentration helps prevent frequent anode effects caused by too low concentration. On the other hand, it avoids excessive sludge, which may lead to pot instability and melting of the ledge.

Target range: The concentration of alumina should be maintained at 1.5–3.0 %, avoiding values below 1.5 % which may trigger anode effect or exceeding 4 % which may generate sludge).

Control measures:

Intelligent alumina feeding system: Use adaptive feeding algorithm to adjust the feeding frequency and amount in real time based on the pot resistance change. Individual crust breaker and feeder control is essential.

Currently, the point feeding system has been adopted in our smelter to precisely control the feeding of alumina and AlF_3 in the pots, so as to effectively maintain the stable alumina concentration.

Sludge control: Prolonged low-voltage operation or excessive feeding shall be avoided to reduce the sludge formation. The alumina sludge shall be regularly cleaned.

Pot MHD design: The busbar design has to provide sufficient bath circulation for good alumina dispersion from breakers.

(4) Bath height control by regulating bath temperature

Target range: Bath temperature is generally controlled at 950–960 °C (with superheat of 5–10 °C). The excessively high bath temperature can easily lead to a significant rise in the bath height. The excessively low bath temperature results in bath shrinkage.

Control measures:

Anode-to-cathode distance adjustment: Change the anode-to-cathode distance by raising or lowering the anode (for every 1 mm increase in the anode-to-cathode distance, the pot temperature rises by about 2–3 °C).

Thermal balance optimization: Keep current efficiency constant, control anode current distribution and control pot hood sealing to reduce the heat loss.

Potshell cooling assistance: Install forced-air cooling devices or heat sinks on the sides to control the local overheating.

In the daily production, for cold pots, the anode effect can be used to supplement heat as required, and the electrolytes can be replenished in time to ensure the immediate reverse of the cooling trend in the pots. For hot pots, it is necessary to identify other reasons, such as increased carbon dust in the bath, anode spikes or cracking, etc. Eliminate abnormalities in time, and adjust other process conditions. High-temperature pots can be cooled with cryolite additions.

(5) Control of physiochemical properties of the electrolyte by managing impurities and additives

Key impurities:

- Sodium (Na): Coming as Na_2O in alumina, is neutralized by AlF_3 additions.
- Calcium (Ca) and magnesium (Mg): Coming as CaO and MgO in alumina, is neutralized by AlF_3 additions. In extreme cases, it is necessary to employ electrolyte replacement to adjust the level.
- LiF: In China, it is coming as Li_2O in alumina with concentration up to 5 %.
- KF: In China, it is coming as K_2O in alumina with concentration up to 5 %.
- MgF_2 : In China, it is coming as MgO in alumina in smaller concentrations.

(6) Collaborative optimization of processes and equipment to ensure stable pot conditions

- Pot control: Use the pot control system to monitor the voltage, temperature, resistance and other parameters in real time, and automatically adjust the feeding, anode-to-cathode distance and AlF_3 addition.
- Pot superstructure design: Optimize the thickness of anode covering, the position of the crust breaker and the gas collection system to reduce heat loss and alumina flying.

(7) Countermeasures for electrolyte changes caused by abnormal operating conditions

The following measures should be used:

- Anode effect handling: Ultra-fast feeding of alumina, effective anode effect quenching logic. Optimize the feeding logic to prevent anode effect due to low alumina concentration .
- Hot/cold pot adjustment: Hot pots (temperature > 970 °C)—Reduce the anode-to-cathode distance, increase the AlF_3 dosage, and enhance the heat dissipation.
- Cold pots (temperature < 930 °C): Increase the anode-to-cathode distance, add cryolite, and reduce the alumina feeding rate.

2.4 Impact of Good Bath Height Control on Pot Performance

Actual industrial production shows that by stable control of the bath height to 15–18 cm, the pot conditions remain relatively stable. Gross anode consumption is reduced. Taking the 500 kA potline of an aluminium smelter as an example, the average annual anode gross carbon consumption decreased from 484 kg/t Al to 472 kg/t A in 2023. Based on the statistics, the average annual carbon consumption reduction resulting from the implementation of precise bath height control is 12 kg/t Al. The anode effect frequency and pot instability also significantly decreased. In this potline, after the implementation of precise bath height control, the production of the 300 pots has been 400 kt/a, and the average operating voltage has reduced from 3.986 V to 3.952 V, thus reducing the DC power consumption by 110 kWh/t Al.

3. Conclusions

To ensure the stable and efficient operation of the 500 kA pots, it is essential to maintain the bath height within the range of 15–18 cm. This contributes to increased current efficiency, reduced operational complexity, and prolonged pot life. Bath height control should be achieved through comprehensive and coordinated adjustments across multiple aspects, including daily regulation of bath height, adjustment of the molecular ratio, alumina concentration management, pot temperature control, and the optimization of supporting facilities and processes. Only through such an integrated approach can a consistently optimal bath height be sustained over the long term.

By establishing a dynamic correlation model between bath height and process parameters, an optimization strategy was developed to maintain the bath height within a specified range (15–18 cm). This strategy was validated through industrial-scale production trials, which revealed notable improvements in pot stability, a reduction in energy consumption by 110 kWh/t Al, an extension of pot life by more than 20 %, and the consistent production of high-quality primary aluminium.

The advancement of aluminium electrolysis technology has been rapid, with continuous improvements in both process efficiency and equipment and facilities. Looking ahead, digitalization and intelligent automation are expected to become dominant trends, driving the aluminium electrolysis industry toward safer, more stable, and more efficient production practices.

4. References

1. Zhenglin Zhang, How to maintain bath height in electrolytic aluminium production, *Proceedings of the 2005 Annual Meeting and Academic Exchange Conference of the Fifth Aluminium Electrolysis Professional Committee*. 2005: 145–149 (in Chinese).