AL03 - The Practice and Effectiveness of Aluminum Reduction 4221-Process Technology in SPIC Nei Mongol Energy Co. Ltd

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Abstract

Since 2016, SPIC Nei Mongol Energy Co. Ltd., the inner Mongolia branch of China State Power Investment Group, has carried out process technology innovation for the existing 300 kA, 350 kA and 400 kA potlines, and gradually developed the aluminum reduction 4221-Process Technology, which consists of a new set of pot operation parameter targets and procedures. This technology has also been applied in all pots of the new 500 kA potline. Seven years of production practice has proved that the 4221-Process Technology improved the operation key performance indicators (KPIs) and significantly simplified pot operation. Compared with the domestic average value, current efficiency is by more than 2 % higher, pot life is by more than 400 days greater, the production of Al99.85 grade aluminum is by more than 30 % greater, and the AC power consumption is by more than 100 kWh/t-Al lower. Employee work intensity was reduced by more than 50 %. The 4221-Process Technology provides a remarkable progress towards more efficient and stable aluminum reduction operation, and greater economic and social benefits.

Keywords: Process management 4221-Process Technology; Reduce power consumption; Reduce labor intensity; Improve production efficiency.

1. Introduction

SY300, SY350 and SY400 technologies, a total of 918 pots, are built in SPIC Nei Mongol Energy Co. Ltd., the Inner Mongolia branch of China State Power Investment Group. The three potlines were put into operation from 2004 to 2011. Since August 2016, in order to solve the common problems of the industry, technical research has been carried out, and after five years of exploration, practice and optimization, the aluminum reduction 4221-Process Technology was formed. In addition to effectively improve the safety and stability of operation, the technology realizes high-current efficiency and low energy consumption, while greatly reducing the manpower and labor intensity. It also significantly improves the efficiency of equipment and the quality of operations. This technology has also been applied in all pots of the new 500 kA potline in 2022 and achieved good operational results.

This technology contains the following what technical features: Requirements for four parameters are low level, for one parameter are intermediate, and for two parameters are high. In addition, two process operations are discontinued. Low, intermediate and high requirements refer to the

control range of data within relatively low, intermediate, or relatively high values. Table 1 shows the requirements.

Table 1. Technical specifics.

Requirements	Quantity	Parameters
Low	4	Metal height, anode cover height, cryolite ratio (CR), bath temperature
Intermediate	1	ACD
High	2	Bath height, superheat
Discontinued	2	Scooping up carbon dust and Scooping up solid bath during anode change

2. Background Conditions

Since 2010, most aluminum smelters in China insisted to increase anode cover height and CR to achieve low voltage and moderate bath temperature [1]. However, reducing the voltage without improving the performance of the pot will inevitably result in too low anode-cathode distance (ACD) and pot voltage instability, so the metal height must be increased to improve stability. Thus, a contradiction arises. Although the power consumption has been reduced to a certain extent, the production operation is unstable. At the same time, the labor intensity and amount are large, and malignant production accidents are prone to occur.

The details are shown in Table 2.

1. The bath has high viscosity and poor fluidity, resulting in low solubility of alumina and difficult separation of carbon dust;
2. There is a lot of sludge and ridge (solidified sludge) on top of cathode carbon blocks and uneven distribution of cathode current, resulting in many early failures and short pot life. The ACD is too small and the anode current distribution is uneven, resulting in large voltage fluctuations and low current efficiency;
3. Production management is very difficult, and pot operators are tired;
4. Employees have high labor intensity and a lot of work, resulting in high manpower turnover rate;
5. The safety risk is too high, and vicious production accidents such as anode burn-offs, metal rolling, metal tap-outs, explosions at the pot bypass shunts, personal injury and potline shutdowns occur from time to time.

Table 2. Technical parameters of the previous process.

Process indicators	**Value**
Metal height, cm	25~30
Bath height, cm	17-19
CR (excess AlF_3, %)	＞2.45 (7.5)
Anode cover thickness, cm	25-35
ACD, cm	~4.1
Superheat, ℃	3-7
Cathode voltage drop (CVD), mV	＞320
Net pot voltage, V	＜4.000

3. Optimization Direction and Measures

The overall optimization process is based on the following ideas, which have been gradually implemented over the last 6 years.

i. By increasing the ACD, the stability of the pot is increased and the intensity and amount of work is reduced.
ii. In order to balance the heat generation of increasing the ACD, anode cover height is reduced.
iii. In order to reduce the sludge and ridge at the bottom of the metal, the metal level and CR are decreased.
iv. In order to improve current efficiency, the ACD is further increased and the CR is further reduced.
v. With further requirements to decrease energy consumption, the ACD and the CR are appropriately slightly corrected.

3.1 Increasing the ACD and Removing the Insulation Material

From August 2016, the anode cover insulation material was reduced to about 5 cm from 25 cm and the ACD increased to about 4.3 cm in three stages over a period of two years. The production operation is relatively stable, and the labor intensity and quantity are reduced by more than 20 %. Figure 1 shows the condition and the thickness of the covering material on the anode of each potline.

Figure 1. The condition and the thickness of the covering material on the anode of each potline.

3.2 Reducing the Metal Height and CR

From July 2018 to December 2020, the metal height was reduced to 14.5~15 cm from 25~27 cm and the CR was going to be reduced to about 2.35. These changes were carried out in five stages. The sludge and ridge formed at the bottom of the metal for many years have been eliminated. The cathode current distribution is significantly better because of the clean bottom. The operation is

very stable, and the labor intensity and quantity are further reduced, with a cumulative total of more than 50 %.

3.3 Further ACD Increase and CR Reduction

In pursuit of high current efficiency, the ACD was increased to 4.1~ 4.4 cm and the CR ratio was decreased to about 2.25 (excess AlF_3 increased to 10.7 %) in two phases from January 2021 to January 2022. The average current efficiency of the three potlines has gradually increased to more than 95 %. Power rectification efficiency is 98 %.

After the completion of these measures, the technical specifications of the potlines are shown in Table 3.

Table 3. 4221-Process technology of high current efficiency.

Process parameter	300 kA potline	350 kA potline	400 kA potline
Amperage, kA	300	370	400
Anode Current Density, A/cm^2	0.724	0.744	0.799
LiF and KF total content, %	1.5-2.5	1.5-2.5	1.5-2.5
Metal height, cm	14.5-15	14.5-15	14.5-15
Bath height, cm	18-19	18-19	18-19
Excess AlF_3, %	10.2-11.2	10.2-11.2	10.2-11.2
Anode cover thickness, cm	5	5	5
ACD, cm	4.4	4.3	4.1
Bath temperature, ℃	940-945	944-949	942-947
Superheat, ℃	10-15	10-15	8-13
Alumina concentration, %	1.8-2.2	1.8-2.2	1.8-2.2
CVD, mV	290-295	300-305	280-285
Power rectification efficiency, %	98.0	98.0	98.2
Average pot voltage, V	4.120	4.123	4.118
Current efficiency, %	94.8	95.3	95.2
DC power consumption, kWh/t Al	12 951	12 892	12 890
AC power consumption/kWh/t Al	13 215	13 155	13 126
Al99.85, %	45	50	75
Pot life, days	＞2600	＞2600	＞2600

3.4 Reduce the ACD and Increase the CR Appropriately

In 2022, the tiered electricity price policy began to be implemented in China. In order to pursue low AC power consumption, the ACD was gradually reduced to 4.0~4.2 cm and the CR ratio was increased to about 2.30 in two months from January 2022. The average DC power consumption of the three potlines is now 12 820 kWh/t Al or less, and the average AC power consumption is 13 060 kWh/t Al or less, reduced by more than 100 kWh/t Al. Correspondingly, the current efficiency is reduced, but remains greater than 93.5 %. However, the energy consumption of three potlines does meet the Chinese policy requirements by these adjustments.

After these adjustments, the technical specifications of the potlines are shown in Table 4. At this stage, the new 500 kA potline was put into production, and the process technology was also in this range, but due to good MHD stability design of SY500 technology, the current efficiency reached more than 94.5 %.

Table 4. 4221-Process technology of low energy consumption.

Process parameter	300 kA potline	350 kA potline	400 kA potline
Amperage, kA	300	370	400
Anode Current Density, A/cm^2	0.724	0.744	0.799
Li+ & K+ total content, %	1.5-2.5	1.5-2.5	1.5-2.5
Metal height, cm	14.5-15	14.5-15	14.5-15
Bath height, cm	18-19	18-19	18-19
Excess AlF_3, %	9.6-10.6	9.6-10.6	9.6-10.6
Anode cover thickness, cm	5	5	5
ACD, cm	4.2	4.2	4.0
Bath temperature, ℃	948-953	948-953	948-953
Superheat, ℃	7-12	7-12	6-11
Alumina concentration, %	1.8-2.2	1.8-2.2	1.8-2.2
CVD, mV	290-295	300-305	280-285
Power rectification efficiency, %	98.0	98.0	98.2
Average pot voltage, V	4.040	4.040	4.040
Current efficiency, %	93.8	94	94
DC power consumption, kWh/t Al	12835	12807	12807
AC power consumption, kWh/t Al	13097	13068	13041
Al99.85, %	50	55	80
Pot life, days	＞2600	＞2600	＞2600

3.5 Cancel Some Regular Jobs

Due to the reduction of metal height, the freeze profile shape in the pot is better, and the top of carbon blocks is clean, free of sludge and ridge. Therefore, 4221-Process Technology eliminates some operations, such as skimming carbon dust, manual scooping of crust during anode changing, and also reduces the frequency of anode cover redressing.

3.6 Uniform Technical Standards

In March 2022, the process parameters of 918 pots in the 3 potlines tended to be consistent in metal height, bath height, Excess AlF_3, bath temperature, superheat, pot voltage and other process parameters. The differences between pots are gradually eliminated, so the conditions are ripe for fixing these technical conditions to technical standards.

A comparison of main process technical standards before and after 4221-Process Technology is given in Table 5.

Taking the 400 kA potline as an example, monthly data of various process parameters before the transition, transition and after transition up to now is shown in Figures 2 to 7.

Table 5. Comparison of main process parameters before and after 4221-process technology implementation.

Process data	300 kA potline		350 kA potline		400 kA potline	
	Before	After	Before	After	Before	After
Metal height, cm	22-23	14.5-15	23-24	14.5-15	26-27	14.5-15
Bath height, cm	16.5-17.5	18-19	16.5-17.5	18-19	16.5-17.5	18-19
Excess AlF_3, %	6.8-8.3	9.6-10.6	6.8-8.3	9.6-10.6	6.8-8.3	9.6-10.6
Anode cover thickness, cm	25-35	5	25-35	5	25-35	5
ACD, cm	4.1	4.2	4.0	4.2	3.9	4.0
Bath temperature, ℃	952-957	948-953	955-960	948-953	958-963	948-953
Net carbon cons., kg C/t Al	414	414	414*	414*	414	414
Net pot voltage	3.976	4.039		4.038		4.033
Superheat, ℃	3-7	7-12	3-7	7-12	3-7	6-11
CVD, mV	315-335	290-295	315-335	300-305	300-325	280-285

*The anode sizes of the 300 kA and 350 kA potline are the same and share the same anode assembly Rodding shop.

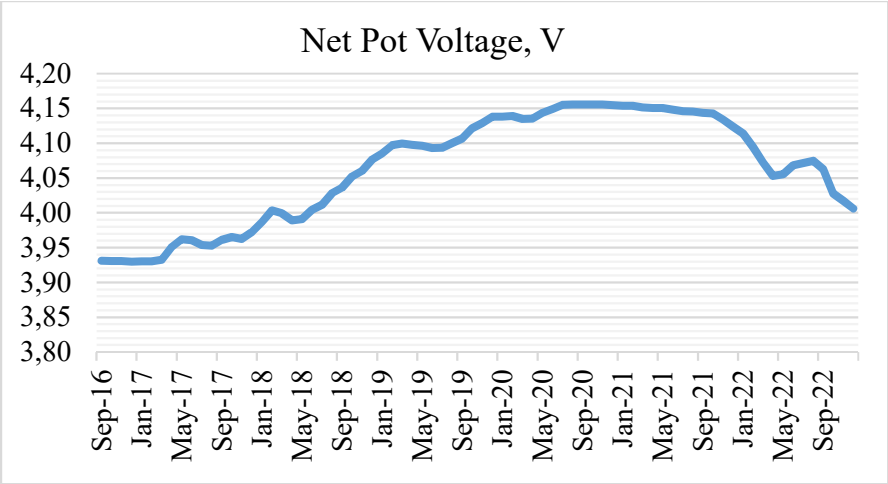

Figure 2. Net pot voltage.

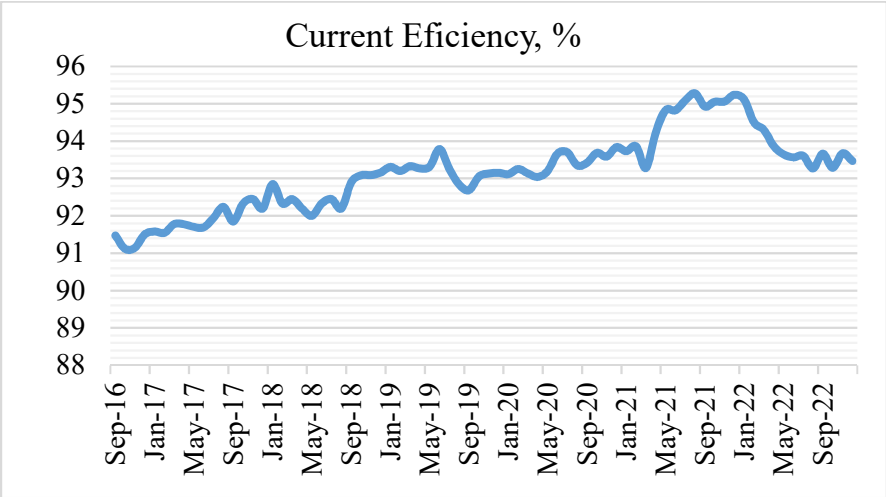

Figure 3. Current efficiency.

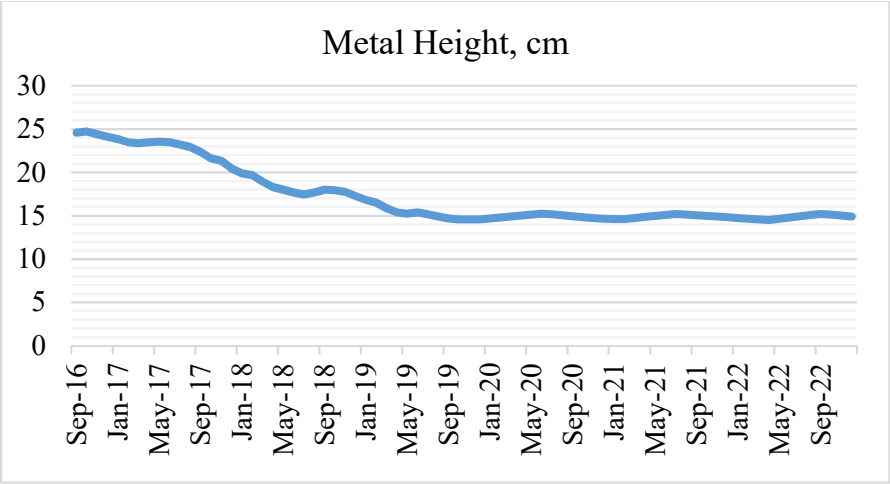

Figure 4. Metal height.

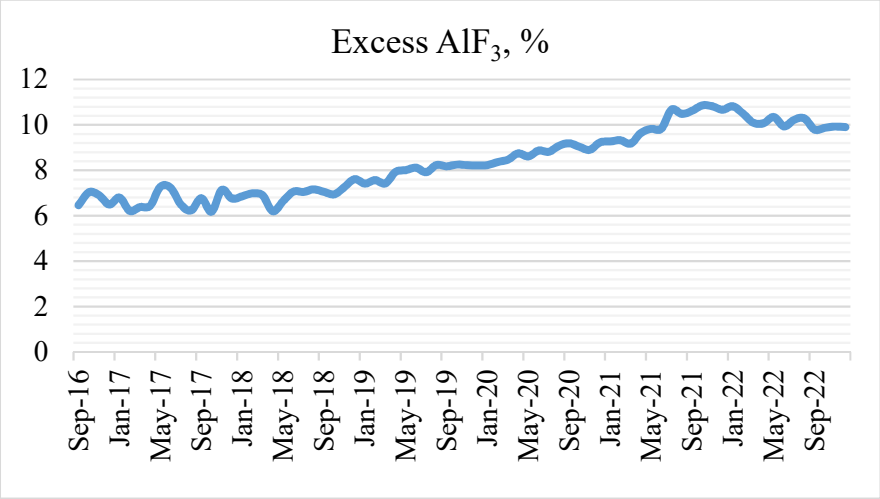

Figure 5. Excess AlF_3.

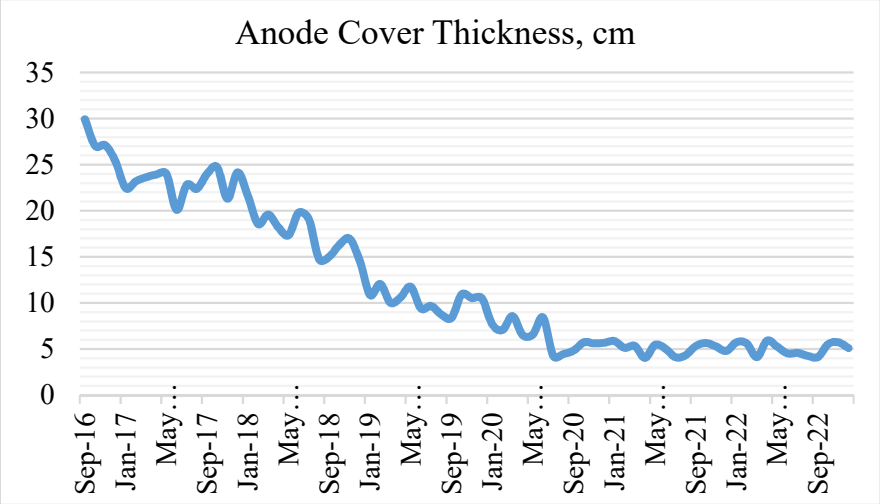

Figure 6. Anode cover thickness.

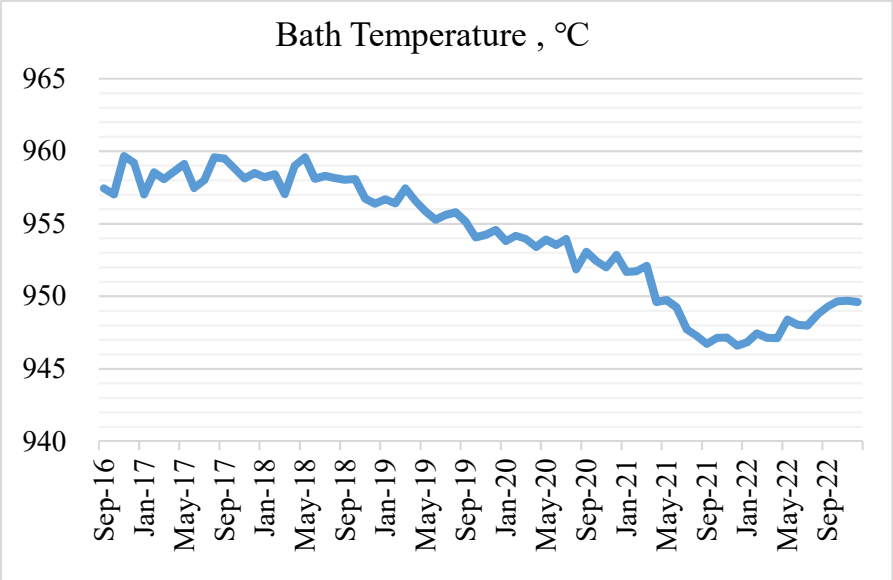

Figure 7. Bath temperature.

4. Technology Upgrade Achievements

4.1 Easier Pot Operation

Under the 4221-Process Technology application, the top of the carbon blocs is clean, and the cathode current distribution is uniform. The shape of the pot freeze profile is more regular, so the pot operation is very stable. The pot operation is simpler, and the labor intensity is greatly reduced.

4.1.1 Reduce Work Intensity

The anode crust surface is loose and easy to break, and the single group anode change time is 12 minutes. At the same time, the following operations have been greatly reduced: Bath taping and additions, handling bath accumulation on crust breakers and feeding blockages, and measuring anode current distribution.

4.1.2 Basically, Eliminate Abnormal Production

Abnormal production conditions such as anode current unevenness, voltage fluctuations, hot pots, cold pots, anode burn-offs, metal rolling, lining failure, pot tap-outs are basically eliminated. The Al 99.85 metal purity has been increased by more than 30 % for long time. To a large extent, it also reduces the manpower and labor intensity of auxiliary production processes such as power supply rectification, casting, gas treatment center (GTC), anode assembly production, maintenance, transportation and so on.

4.2 Achieve Excellent Key Performance Indicators (KPIs)

4.2.1 Small Dispersion of Operating Parameters

After the application of 4221-Pprocess Technology, the operating parameters of 918 pots in the 3 potlines have small deviations or fluctuation range, such as metal height within ± 0.5 cm, bath height within ±1 cm, CR within ±0.03, bath temperature within ±5 °C, CVD within ±20 mV, voltage within ±10 mV, current efficiency within ±0.25 %.

4.2.2 KPIs Significantly Improved

After the application of 4221-Process Technology, the current efficiency is greatly improved under the condition of low AC power consumption. When the voltage of the 3 potlines is 4.12 V or higher, current efficiency is above 95 %. When the voltage is 4.04 V or less, current efficiency is above 93.5%. The CVD of the three potlines is below 295 mV, and the pot life is increased to more than 2600 days at present. Judging from years of production practice and pot condition and trends, the pot life will reach more than 2800 days, or even more than 3000 days.

4.2.3 Large Reduction of Production Costs

After 4221-process technology, the company's current efficiency is increased by more than 2 %. The production is increased by more than 18 000 tonnes per year, and the fixed cost is reduced by more than 36 million yuan per year. The life of the pot is increased by 400 days, and the variable cost is reduced by more than 40 million yuan per year. When the aluminum market is better, the effect is even greater.

4.3 Working Environment Obviously Improved

After 4221-process technology, the frequency and intensity of routine operation are greatly reduced, so the operating time and failure rate of major equipment such as pot tending machine (PTM) have been greatly reduced. Production management is simple and easy, and the labor intensity and labor amount of an employee are greatly reduced, by more than 50 %.

5. Practical Conclusions

5.1 Low Metal Height, the Core Parameter to Keep the Pot Clean

Whether the top of the cathode blocks is clean and whether the cathode current distribution is uniform, depends mainly on the metal height. When the metal height is reduced to 15 cm, and the sludge formed briefly on top of the cathode carbon blocks is easily dissolved and cannot freeze into a ridge, is the core parameter of keeping the bottom of the furnace clean and the cathode evenly conductive. The CVD of 50 % graphitic cathode blocks is stable below 295 mV for a long time. With graphitized cathode and cast-iron rodding, the CVD is below 190 mV.

5.2 ACD, the Core Parameter to Maintain Efficient Operation

Current efficiency can reach more than 95 % in China. The current efficiency is very sensitive to ACD, and in many smelters in China that keep ACD below 4 cm, it is difficult to achieve the current efficiency greater than 92 %.

Our 3 potlines data show that the ACD is maintained at 4.5-4.7 cm when the pot voltage is higher than 4.12 V, the current efficiency is more than 95 %; The ACD is 4.2-4.5 cm when the pot voltage is above 4.04 V, and the current efficiency is 93.5-94 %.

5.3 Labor Intensity and Manpower Reduced

The main reason for the high turnover rate of employees is abnormal production operation, too high labor intensity, too much work, and overwhelming work. The labor intensity and labor amount have been reduced by more than 50% by applied the 4221-Process Technology at present, and the employee turnover rate has been zero.

5.4 Technology Adapted to High Current Efficiency and Low Energy Consumption

Production practice has proved that this process technology can not only adapt to the production mode of high current efficiency but is also suitable for the Chinese policy requirements of low energy consumption.

6. Conclusions

(1) The 4221-Process Technology of aluminum reduction has significant advantages in high-current-efficiency and low-energy-consumption production, and the technology is mature; it is a reference to be promoted in the industry.
(2) The 4221-Process Technology solves the problem of high labor intensity and large manpower requirement. To a large extent, the problem of high worker turnover rate has been solved. It can be used as a reference for other smelters.
(3) The process technology solves the problems of poor operational stability, short pot life and high production safety risk of earlier technology, and greatly reduces the potline shutdown risk caused by anode burn-offs, metal rolling, pot tap-out and explosion of the pot bypass shunts.
(4) The tiered electricity price policy requires the smelters to adopt graphitized cathodes. The high thermal conductivity of graphitized cathodes requires process technology with low metal height and higher superheat. Therefore, 422-Process Technology is also suitable for graphitized cathode carbon blocks.
(5) Aluminum reduction 4221-Process Technology provides a solution for efficient and stable operation of aluminum reduction smelters. The economic and social benefits are remarkable.

7. References

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