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INDUSTRY TEST OF PERFORATION ANODE IN ALUMINIUM ELECTROLYSIS TECHNOLOGY

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Abstract

In recent years aluminum industry in China has been developed rapidly. In 2011 China's electrolytic aluminum output reached 18.06 million tons and has topped the list in the world for 11 consecutive years. However, the energy and environmental issues restrain development of aluminum industry. So it is necessary to promote the use of energy saving technology in the aluminum industry. The composition of the cell voltage is analyzed in this paper. It is reasonable that the cell voltage of ordinary flat cathode cell is about 4.05V. The approximate linear relationships between the bubble layer thickness and the anode width is analyzed. Changing the structure of the anode and adding two rows of the vent on the common anode can reduce the gas running distance below carbon anode, anodal bubble voltage and the work voltage of aluminum reduction cells under the same current efficiency of aluminum reduction cells. Perforated anode technology was tested in small-scale and large-scale industrial cells and the experimental results show that average current efficiency of the test cell is 91.447%, the direct current consumption reaches 12337kwh/T-Al. The anode effect coefficient of the test cell with good thermal balance reduces to an average of 0.185 time /cell–day. The results are consistent with the theory and a comprehensive promotion goal is achieved.

Introduction

Since early 1980s the technology and equipment levels of aluminum electrolysis have been greatly improved after decades of development. Due to the challenges from the resources, energy and environment issues, energy saving and environmental protection have become the key factors of sustainable development of Chinese aluminum industry. The special-shaped cathode used in electrolytic cells, which was invented by Naixiang Feng, the professor of Northeastern University[1], has greatly reduced the cell voltage and the power consumption. The technique has made a positive contribution to the development of Chinese aluminum reduction industry.

Composition analysis of aluminum electrolytic voltage

The formula $W_{practical}$ of energy consumption per ton aluminum in the electrolytic production is

$$W_{practical} = \frac{2980 \times V}{\eta} \quad (1)$$

V-----average cell voltage (V);

η-----current efficiency.

In above equation, there are two ways to reduce the energy consumption $W_{practical}$. One is increasing current efficiency η in the cell operation, and another is decreasing the average cell voltage V.

After lots of studies on how to improve the current efficiency, the current efficiency has been effectively improved from 90 percent in 1980s to 95 percent now. It is very difficult to further improve the current efficiency. In recent years reducing the average cell voltage V without loss of current efficiency has become the major research goals for energy-saving in aluminum reduction industry.

The average cell voltage V consists of following sections:

$$V=V_{polarizaqtion}+V_{anode}+V_{cathode}+V_{electolvte}+V_{effect}+V_{bus} \quad (2)$$

V_{anode} and $V_{cathode}$ are constant values when current intensity of cell is steady. The sum of V_{anode} and $V_{cathode}$ is usually 0.7 V. And V_{bus} which is determined by the cell design is usually 0.2V. V_{effect} which is caused by anode effect is less than 0.01V. $V_{polarization}$ which consists of alumina theoretical decomposition voltage is generally 1.2V and the overvoltage of anode and cathode is generally 0.45V. So the $V_{polarization}$ is about 1.65V, which is the voltage drop in the bath between the anode and cathode. When the current density is fixed, $V_{electrolyte}$ is determined by the specific resistivity of the bath and polar distance. The bath specific resistivity is related with the temperature and the composition of the bath. If the bath composition and the electrolysis temperature in electrolysis process are basically stable, the bath specific resistance will be basically stable and $V_{electrolyte}$ will depend on the distance between the anode and the surface of molten aluminum (referred to as ACD). At present, ACD of ordinary large pre-baked cell is about 4.5cm. Relevant information shows that [2]when the alumina content is 2-3% and calcium fluoride content is 5%, the bath molecular ratio is about 2.2-2.3, the bath specific resistance is 0.47Ω/cm at the temperature of 950°; $V_{electrolyte}$ is about 1.5V when the anode current density is $0.72A/cm^2$. Therefore, the ordinary flat cathode cell operating voltage is usually 4.05V.

The relationship between the bubble layer thickness in polar distance and anode width

Based on the ACD model proposed by Yingfu Tian (Figure1) [3], ACD can be divided into three layers: Layer a is molten aluminum fluctuation layer, the height of which is usually 1.5 cm which depends on the magnetic field design and the cell operation. Layer b is the bubble layer at the bottom of anode. According to the simulation result from Professor Hesong Li[4], the bubble Layer b thickness is about 2cm when the anode width is 660mm. Layer c is the isolation layer to prevent the contact of bubbles and aluminum liquid, and it is generally 0.5-1cm. For the ordinary cells, the cell voltage can be actually reduced by reducing the c-layer height, but too much reduction of layer c height will seriously reduce the current efficiency.

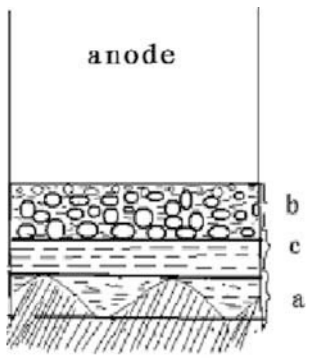

Figure 1.Polar distance model

Hesong Li , professor of Central South University, establishes the physical and mathematical models of the relationship between anode width and anode bubble layer. According to usual electrolyte composition, the bubble layer thickness with six different anode width of 660mm, 600mm, 550mm, 500mm, 450mm and 400mm is simulated. The results show that: the bubble layer thickness under the anode decreases with the decrease of the anode width and presents an approximate linear relationship (Figure 2).

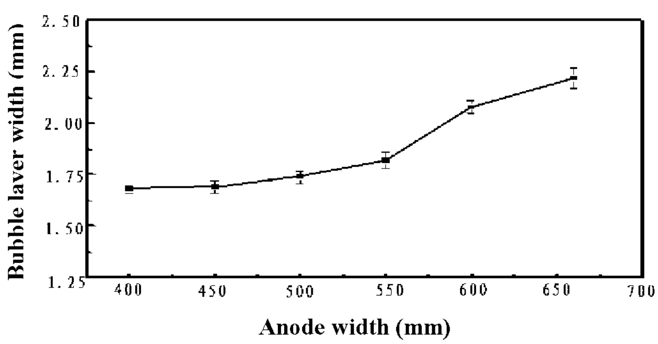

Figure 2.The curve of anode width and bubble layer thickness

When the anode width is 400mm, the bubble layer thickness is 1.4cm, which is decreased by 0.6cm compared with the ordinary anode (660mm). In theory, the anodic overvoltage should be lowered after decreased the thickness of anode bubble layer. So when the anode width reduces to 400mm, the cell voltage can be reduced to 3.8V compared with normal operation.

Perforated anode production and small-scale test on cells

Perforated anode production

According to the model mentioned above, thinning the anode bubble layer can reduce the ACD without lowering the value of c (that is without affecting the current efficiency). So the cell voltage can be reduced and ultimately the purpose of energy saving can be achieved.

Based on this idea, Chongqing Tiantai Aluminum Industry Co., Ltd. has cooperated with Central South University, Chongqing University of Science and Technology and Chongqing Carbon Co., Ltd. for the study and tests. The majoe goal is to study how to reduce the cell operating voltage through reducing the thickness of the anode bubble layer. If the anodes are narrowed, the upper structure and a series of ancillary equipments of existing electrolytic cells as well as the anode current density and three physical fields will be changed with the great difficulties to operate the cells. Yingfu Tian et al. from Chongqing Tiantai Aluminum Industry Co., Ltd. proposed that, perforating a number of guiding holes in the anode can accelerate the discharge of gas and reduce the thickness of anode bubble layer, which would shorten ACD and reduce the cell voltage and finally reach the goal of reducing power consumption.

According to the simulation of pre-baked anode cell bubble behavior with aqueous solution model which was established by S. Fortin [5], it is known that the anode with a certain Angle is beneficial to bubble emissions. Professor Hesong Li from Central South University simulated bubble layer thickness of perforated anode designed by Chongqing Tiantai aluminum company. The results show that the bottom bubble layer thickness is 1.33 cm, which is decreased over 0.6 cm than the ordinary anodes (width 660 mm). Therefore, the ordinary cell voltage can be reduced by more than 200 mV by reducing ACD and considering the anode overvoltage reduction. Based on this point, Chongqing Carbon co., LTD. successfully applied the qualified perforated anode in December 2009 according to the perforated anodes designed by the research team for the small-scale industrial tests on 3 of 168 kA cells in the Tiantai aluminium company.

The small scale industrial trials on perforated anodes

According to the calculation results the test cell voltage will be reduced by more than 200 mV and ACD will be reduced by 0.6 cm. The test results showed that the cell voltage was 3.75 V and 230 mV lower than contrast cell. Since the cell heat income is reduced with reducing of the cell voltage it is necessary to reduce heat expenditure. Therefore, the level of liquid aluminum will be decreased with other technical conditions basically unchanged. Specific technical conditions are reported in Table 1. At the end of February 2010, 3 test cells were all changed into the perforated anode. At the end of May adjustment of technical conditions were achieved basically. Independent assessment started in this August. Installation of anode in the cells is shown in Figure 3 and the operation curves of the test cells are shown in Figure 4, Figure 5 and Figure 6 respectively.

Table 1.The comparisons of each technical parameter between test cells and the contrast cells

Item	Cell voltage (V)	Aluminium level (cm)	Electrolysis level (cm)	Cell temperature (°)	Molecular ratio
Test cell	3.75	14-16	18-20	945-955	2.3-2.4
Contrast cell	3.98	19-21	18-20	945-955	2.3-2.4

Figure 3.The use of perforated anode in cell

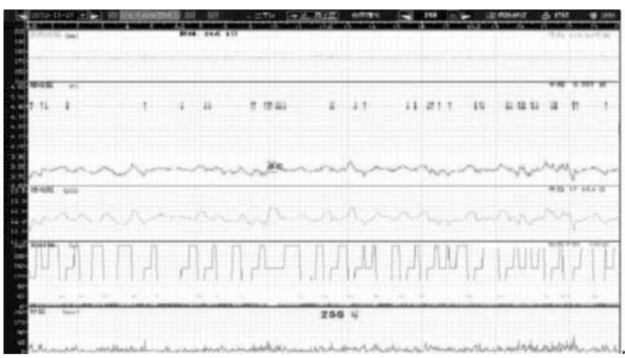

Figure 4.The operation curve of 256 # cell

Figure 5.The operation curve of 257 # cell

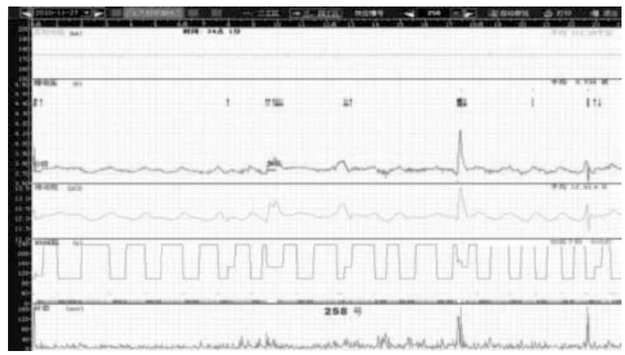

Figure 6.The operation curve of 258 # cell

The 5 months of technical conditions of control situation from August to December in 2010 are showed in Table 2 and the economic index statistics are showed in Table 3.

Table 2.The cell voltage contrast between 3 test cells and 25 contrast cells from August to December

month	3 test cells				25 contrast cells				Difference value between test cells and contrast cells			
	Set voltage	Working voltage	Average voltage	Effect coefficient	Set voltage	Working voltage	Average voltage	Effect coefficient	Set voltage	Working voltage	Average voltage	Effect coefficient
August	3.763	3.769	3.784	0.313	3.975	3.978	3.983	0.101	0.212	0.209	0.199	0.212
September	3.755	3.759	3.780	0.300	3.979	3.982	3.985	0.096	-0.224	-0.223	-0.202	0.204
October	3.749	3.754	3.778	0.462	3.981	3.984	3.987	0.104	-0.232	-0.230	-0.209	0.358
November	3.745	3.750	3.776	0.622	3.982	3.984	3.988	0.102	-0.237	-0.234	-0.212	0.520

December	3.741	3.744	3.765	0.419	3.981	3.984	3.989	0.105	-0.240	-0.240	-0.224	0.314
Average	3.751	3.755	3.777	0.423	3.980	3.982	3.986	0.102	-0.229	-0.227	-0.209	0.321

Table 3.The current efficiency and dc power consumption contrast between 3 test cells and 25 contrast cells from August to December

Month	Current (KA)	day	3 test cells			25 contrast cells			Difference value between test cells and contrast cells		
			Daily production (T)	Current efficiency (%)	DC power consumption (KWh/t-Al)	Daily production (T)	Current efficiency (%)	DC power consumption (KWh/t-Al)	Daily production (T)	Current efficiency (%)	DC power consumption (KWh/t-Al)
August	168.1	31	1.228	90.71	12431	1.229	90.78	13075	-0.001	-0.07	644
September	168.	30	1.240	91.66	12287	1.229	90.81	13077	0.011	0.85	790
October	168.58	31	1.245	91.68	12279	1.242	91.39	13001	0.003	0.29	722
November	168.87	30	1.262	92.78	12122	1.249	91.83	12942	0.013	0.95	820
December	169.68	31	1.263	92.42	12140	1.243	90.95	13070	0.020	1.47	930
Average	168.74		1.248	91.85	12252	1.239	91.15	13033	0.009	0.70	781

The test cells run stably for five months after the test assessment. The average voltage was 3.777V and the average anode effect coefficient was 0.423 time/cell-day. The DC consumption reached to 12252 kWh/ t-Al. The test cells were identified by the China Nonferrous Metals Industry Association on January 29 in 2011.

The expanding application test of perforated anode technology

The industry expanding test of perforated anode was initiated on 30 cells of 168kA in Chongqing Tiantai aluminum Industry company in May 2011. During three cells testing, there were many problems including the insufficient heat income, reduced bath levels and an increasing anode effect. The averaged effect coefficient of the three cells reached to 0.423 times/cell-day in the period of half year assessment. In order to eliminate the problems above, we decided to appropriately adjust the technical conditions. One is warm for the cell sidewall, and the other is the set voltage transferred from 3.75V to 3.77V for running. The specific adjustment process of technical parameters is shown in Table 4. When the perforated anode has swapped 10 groups, the cell set voltages began to decline. After about 2 months or so, the set voltage value gradually dropped from 3.95V to 3.77V. The sidewall insulation should be completed before lowering voltage. And with the process of lowering the cell voltage, the thickness of the insulation material needed to increase. The liquid aluminum level needed to be correspondingly reduced to decline the conduction heat loss of molten aluminum when other conditions remaining unchanged. By taking these measures, the thermal dissipation had been reduced and a new thermal equilibrium system was established in the cells.

Table 4.The cell voltage and effect coefficient of test cells

month	Set voltage (V)	Working voltage (V)	Average voltage (V)	Effect coefficient (time)	Effect coefficient (time/cell-day)
7	3.762	3.765	3.792	322	0.347
8	3.768	3.769	3.788	242	0.26
9	3.773	3.775	3.793	234	0.26
10	3.778	3.779	3.791	105	0.116
11	3.775	3.773	3.778	49	0.065
12	3.772	3.770	3.775	34	0.059
average	3.771	3.772	3.786	164.3	0.185

The actual technical conditions and economic indicators of the perforated anode expanding industrial pilot production each month

We carried out the independent assessment of 30 test cells from July 2011 to December 2011, the control of technical conditions in six months are shown in Table 4, the economic indicators are in Table 5.

Table 5.The economic indicators of the test cells

month	Current intensity (KA)	Test cells using days (day)	Production (Kg)	Daily production (Kg)	Current efficiency (%)	DC power consumption (Kwh/t-Al)
7	168.073	930	1141668	1227.6	90.71	12455
8	168.152	930	1152782	1239.55	91.55	12328
9	168.103	900	1119778	1244.2	91.92	12295
10	168.08	905	1124742	1242.81	91.83	12300
11	168.025	758	938049	1237.53	91.47	12305
12	168.011	583	718819	1232.96	91.14	12341
average	168.074	834.33	1032640	1237.58	91.447	12337

Conclusion

In summary, the industrial expanding tests have been carried out in 30 reduction cells. During the industrial tests in six months the current efficiency reached 91.447%, and the process DC consumption was 12337kwh/T-Al. The test cell DC consumption reached an domestic advanced level. By insulating the sidewall and properly enhancing the cell voltage, a good thermal balance was established in the cells. The anode effect coefficient dropped to an average of 0.185time/cell-day, which is 0.238 time/cell-day lower than the first three test cells, and even down to about 0.06 time/cell-day from November 2011. Therefore, the industrial expanding experiment on perforated anode has been successful.

With comprehensive promotion of the technology, China's electrolytic aluminum industry will obtain enormous energy-saving benefits. The perforated anode industrial tests was evaluated by China Nonferrous Metals Association on February 11, 2012.

References:

[1] Jianping Peng, Yingfu Tian, and Naixiang Feng, Test of novel energy-saving cell for aluminum electrolysis, *Journal of Materials and Metallurgy*, 3(2009), 165-167.

[2] Mingjie Zhang and Zuxian Qiu, *The new technology of the modern aluminum metallurgical industry*, ShengYang, Light Metals, 2001.

[3] Yingfu Tian,"Anode-cathode-distance model for aluminium reduction cell and its energy consumption", *Light Metals*, 2(2011), 31-33.

[4] Hesong Li, Xi Cao, Yingfu Tian, Aluminum reduction cell anode width optimization under low-carbon, Nanjing, *National Nonferrous Metals Industry low-carbon economy and smelting emissions reduction Symposium*, 2010.

[5] Zhigang Wang, Yanqing Lai and Wei Liu, Research Progress of Anode Bubble Behavior in Aluminum Electrolysis, *Light Metals*, 5(2007), 27-31.