Light Metals 2013 *Edited by: Barry Sadler*
TMS (The Minerals, Metals & Materials Society), 2013

DEVELOPMENT OF LOW-VOLTAGE ENERGY-SAVING ALUMINUM REDUCTION TECHNOLOGY

LI Jie, LV Xiao-jun, ZHANG Hong-liang, LIU Ye-xiang
School of Metallurgical Science and Engineering, Central South University, Changsha 410083, P.R. China

Key words: aluminum reduction, low voltage, energy-saving, process control, structure optimization

Abstract

In this study, the representative low-voltage energy-saving techniques for aluminum reduction in recent years in China is reviewed, and two low-voltage energy-saving techniques are described, which include the technique based on innovation of the electrolytic technology and the process control and the one based on comprehensive innovation of cell structure, the electrolytic technology and the process control. The results show that the best energy consumption index can be realized with the application of low-voltage technology and advanced process control technique on the cells designed at the concept of "conventional planar cathode + suitable heat preservation enhancing".

Introduction

China's output of primary aluminum has reached 17.56 million tons in 2011 (the IAI's statistical data), which account for nearly 41% of the global annual production. The energy consumption of aluminum industry is increased consequently, which is as high as 5.2% of the national total power generation last year in China. Therefore, aluminum industry faces great pressure of energy saving and emission reducing. Fortunately, due to the development of new energy-saving technologies and the adjustment of industrial structures, the average DC energy consumption of Chinese primary aluminum industry has been decreased from 14085 kWh/t-Al in 2001 to 13118 kWh/t-Al in 2011（see Fig.1）.

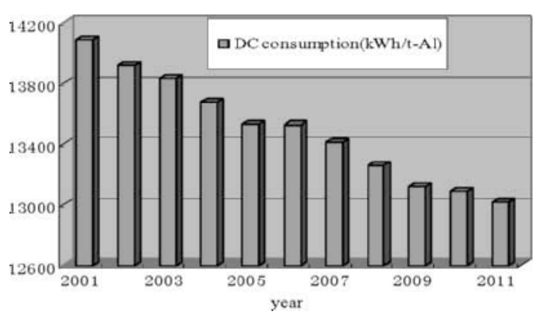

Fig.1: Average DC consumption for aluminum electrolysis from 2001 to 2011 in China

As is well-known, the DC energy consumption (kWh/t-Al) for aluminum reduction depends on two parameters of the current efficiency and the average cell voltage, which equals to "2980 × average cell voltage(V) / current efficiency(%)". So the fundamental ways of reducing energy consumption are to improve the current efficiency and reduce the average cell voltage. In the last a few decades, aluminum smelters achieved energy-saving and increased production efficiency mainly by increasing the current efficiency as high as possible all over the world, which has increased to 93 ~ 95% so far. It is so high that it nearly hits the theoretical limit. Therefore, in recent years, China focuses on the R&D of low-voltage technologies in order to reduce the average voltage as low as possible in the premise of keeping the same current efficiency as before. At present, the application of some low-voltage technologies have reduced the DC energy consumption to below 12500kWh/t-Al and total AC energy consumption to below 13300kWh/t-Al in some industrial potlines. The main low-voltage technologies for energy-saving can roughly divided into the following three categories:

(1) The technique based on innovation of electrolytic technology and the process control.

This technique was originally developed by Central South University (CSU) and its related companies (Hunan CSU Yeshine Science & Technology Ltd. and Hunan CSU Metallurgy Designing Ltd.) established by the aluminum metallurgy researchers at CSU. In the past ten years, based on continuous improvements in the intelligent control technique for aluminum reduction, CSU and its related companies have undertaken some national projects of science and technology, developed this technique under the guideline of "small investment, quick effect, advance and practicality" and achieved remarkable energy saving effect in the application [2-4].

(2) The technique based on innovation of the cathode structure of aluminum reduction cells.

In recent years, after the new cathode structure mentioned in the US patent in 2000[5], some kinds of low-voltage techniques for energy-saving based on "non-planar cathodes" has been developed in China, such as cathodes proposed by Feng et al.[6] and drained cathodes proposed by Gu et al.[7]. In addition, after the slotted cathode collector bar was proposed in the US Patent 4795540[8], some similar designing schemes of cathode collector bar were brought forward in recent years, for example, the patent of "the double-cathode collector bars" proposed by Yang et al[9]. The purpose of such techniques is to decrease the horizontal current component along the cell short axis so as to improve the stability of aluminum liquid bath.

(3) The technique based on comprehensive innovation of cell structure, electrolytic technology and process control.

As the first example, the industrial test on 400kA reduction cells was carried out during 2008~2010 under cooperation of CSU and its related companies with Sichuan Qiya Aluminum Group, with the cell voltage being reduced to about 3.8V. As the second example, the industrial test on 400kA reduction cells of Linzhou Aluminum Company was cooperatively performed by Henan Zhongfu Industrial Co., Ltd., Northeastern University as well as CSU and its related companies during 2009~2011, with the cell voltage being reduced to 3.72~3.80V. The studies of above two examples show that the best cathode structure is still the "conventional planar cathode", but suitable heat preservation enhancing is needed when low-voltage technology is adopted; the best energy consumption index can be realized with the application of low-voltage technology and advanced process control on the cells designed at the concept of "conventional planar cathode + suitable heat preservation enhancing".

In this paper, we mainly introduce the technique (1) and the technique (3) mentioned above.

The technique based on innovation of electrolytic technology and the process control

Our research on Chinese 160-400kA cells showed that with the innovation of electrolytic technology and the process control, normal mass balance and energy balance, outstanding ledge profile and ideal operational stability could be realized at low-voltage (3.8~3.9V), while relatively high current efficiency (92-94%) could be kept simultaneously. Our industrial test was firstly carried out on 300kA cells in 2008, during which the cell voltage dropped from 4.15-4.25V to 3.82-3.88V, and DC energy consumption was reduced to 12200-12400kWh/t-Al. Thereafter, the technique has been spread to more potlines with current amperage of 180-400kA during 2009~2011. The anodic current density of the potlines can be enhanced by more than 10%(i.e. the current density is increased from 0.73～0.75A/cm^2 to 0.80～0.84A/cm^2 and, therefore, the production can be increased by about 10%,)[2-4]. It means that the technique not only saves the energy but also increases the yield significantly for enterprises. The main technical skills include the following:

(1) Low-voltage electrolytic technology.

The characteristics of the electrolytic technology can be concluded as "five-low, three-narrow, and one-high", i.e. low temperature, low superheat, low alumina concentration, low cell voltage, low anode effect coefficient, narrow operational scope for mass balance, narrow operational scope for thermal balance, narrow adjusting scope for cell stability, and relatively high current density (compared with traditional low current density of 0.73～0.75A/cm^2 designed in China). The "five-low" is for the high current efficiency, low power consumption and low emission. The "three-narrow" is for high process stability and long pot life. And the "one-high" is for process enhancement and ideal heat balance at low voltage. Thus, the maximal profit can be achieved ultimately for enterprises. In the new technology, the relationship between current enhancement and low cell voltage is harmonized under support of new control system, which solves the conflict between enhancing line current and reducing cell voltage, and the problem of worse stability and insufficient thermal income resulting from low-voltage process.

(2) Advanced "critical-state stabilizing control" technique

Under the condition of low voltage, the operational state of cells is between "stable" and "unstable", i.e. so-called "critical state". Therefore, the strategy and its calculation method of the "critical-state stabilizing control" have been established in our new control system. The cells based on the new control technique can be in better operation aiming at "as high as possible current efficiency, as low as possible cell voltage, DC energy consumption, and anode-effect coefficient". Meanwhile, the system can automatically monitor the "critical state" and track the state change to make sure that the cells can run durably and stably in the critical state.

(3) Other auxiliary measures.

Other auxiliary measures mainly include enhancement of cell heat preservation and optimization of cell liner structure. For the cells in operation, the heat dissipation of cells can be reduced by increasing thermal insulation materials on some outside surface of the metal shells of the cells so as to help establish normal heat balance at low voltage. For newly-built or overhauled cells, a new liner design scheme we brought forward can be adopted in order to increase thermal insulation in some area of cell liner and adjust the physical field distribution. These auxiliary measures can help realize the goal of maintaining idea heat balance, ledge profile and operational stability of cells at low cell voltage (3.75~3.85V).

Compared with other low-voltage energy-saving technique, this technique has remarkable advantages: firstly, it can be carried out online on all kinds of cells with no need of stopping production; secondly, since more than half of China's aluminum reduction enterprises have employed YESHINE control systems developed by us, the control systems can be easily upgraded to match the low-voltage technology. Benefited from the remarked energy-saving effects as well as the above advantages, the technique is being adopted by more and more Chinese smelters. By April, 2012, our statistics showed that, in about 20 aluminum smelters which had used this technique on their whole potlines, the average cell voltage and energy consumption had been reduced by 200 mV and 640kWh/t-Al, respectively.

The technique based on comprehensive innovation of cell structure, electrolytic technology and process control

To achieve more remarkable energy-saving effects and to develop new aluminum reduction cells with larger capacity (400~520kA), we studied low-voltage energy-saving technique based on comprehensive innovation of cell structure, electrolytic technology and process control in recent years.

The first industrial test was carried out on 400kA reduction cells under cooperation of CSU and its related companies with Sichuan Qiya Aluminum Group. Designed in 2008 and put into operation in 2009~2010, several types of testing cells with new structure we developed were set up in the 400 kA potline of Sichuan Qiya Aluminum Group. The testing cells are divided into three types according to their structural features:

Type one: Testing cells with drained cathode. The parallel grooves or channels are slotted on the surface of carbon block cathode, and coated with TiB_2. The test began in December, 2009.

Type two: Testing cells with suitable heat preservation enhancing. The heat preservation of the side, the bottle and the four corners of the testing cells was enhanced. Among them, the conventional planar cathode was used in half of the testing cells, and the drained cathode for the other half. The test began in March, 2010.

Type three: Testing cells with vertical current collector bars, i.e.

the cathode collector bars traverse through the bottom of the cell vertically. The conventional planar cathode was used in half of the testing cells, and the drained cathode for the other half. The test began in April, 2010.

Apart from the above mentioned differences in the structure of the three types of testing cells, the structure of the rest part of the cells, the outside conditions and the control system were kept the same with each other. The testing results showed that the testing cells of "type two" with conventional planar cathode achieved best operational stability and best technical and economic indexes under low-voltage technology.

The 400kA industrial test cooperatively performed by Henan Zhongfu Industrial Co., Ltd., Northeastern University as well as CSU and its related companies during 2009~2011 also gave similar results: among three types of testing cells—"type one" with non-planar cathode, "type two" with conventional planar cathode but with proper heat preservation enhancing and "type three" with vertical-collector bar cathode, the cells of "type two" maintained the most stable operation and the lowest energy consumption. The testing results also showed that the main innovation is still based on the comprehensive improvement of the physical fields of cells, the technological conditions, the process control techniques and operation management.

We used this new technique in the development and the design of up to date 520kA potline for Xinjiang Qiya aluminum Co., Ltd. The newly-built potline is located in Xinjiang, China, possessing the annual production capability of 450 kiloton. The start-up of the first 44 cells in the potline was successfully accomplished from August 15 to October 26, 2012. By the end of October, 2012, the work voltage of the 44 cells had been reduced to 3.87~3.88V and the working status showed that the designing target should be realized: (1) the average voltage <3.87V; (2) The DC power consumption<12400 kWh/t-Al; (3) the anode effect coefficient<0.02; (4) the current efficiency >93%

Conclusion

(1) The low-voltage energy-saving technique based on innovation of electrolytic technology and the process control is an energy-saving method with the merits of small investment and quick returns. It can be extensively applied in not only operational cells but also newly-built cells. The cell voltage and DC consumption can be decreased to 3.82-3.88V and 12200-12400kWh/t-Al, respectively. In addition, about 10% of the yield can be increased. Hence, this technique has the largest coverage of application in China now.

(2) The studies based on comprehensive innovation of cell structure, electrolytic technology and process control show that the best cathode structure is still the "conventional planar cathode", but suitable heat preservation enhancing is needed; the best energy consumption index can be realized with the application of low-voltage technology and advanced "critical-state stabilizing control" technique on the cells designed at the concept of "conventional planar cathode + suitable heat preservation enhancing".

References

1.General Office of the State Council. The non-ferrous metals industrial restructuring and revitalization[EB/OL]. http://www.gov.cn/zwgk/2009-05/11/content 1310436.htm, 2009.

2.Li Jie, Xiao Shenghua, Lv Xiaojun, *et al*. A method of current-intensifying and high-efficiency energy-saving for the pre-baking aluminum reduction cell: China, 201010297450.3, 2011-01-05.

3. Li Jie, Ding Fengqi, Zou Zhong, *et al*. Development and application of integrated technology of current-intensifying and high-efficiency energy-saving for aluminium reduction[J]. *Light Metals* (in China), 2011, 2: 25-30.

4. Zhang Hongliang, Zhang Hehui, Li Jie, *et al*. Numerical calculation of heat balance adjustment of 160kA pre-baked aluminium reduction pot after current strengthen[J]. *Light Metals* (in China), 2011, 11: 33-36.

5.Vittorio de Nora, Nassau, Bahamas. Cell for aluminium electrowinning: US 006093304A, 2000-7-25.

6.Feng Naixiang. A aluminum reduction cell with abnormal cathode carbon block: China, 200710010523.4. 2007-10-17.

7.Gu Songqing, Liu Fengqin, Yang Hongjie, *et al*. A cathode structure of aluminum reduction cells: China, 200920109237.8, 2010-03-17.

8.TOWNSEND DOUGLAS W. Slotted cathode collector bar for electrolyte reduction cell: US4795540A, 1989-01-03.

9.Yang Xiaodong, Zhou Dongfang, Liu Yafeng, *et al*. A structure of significantly decreasing aluminum liquid horizontal current in the aluminum reduction cell: China, 201020566373.2, 2011-06-15.