Light Metals 2015
Edited by: Margaret Hyland
TMS (The Minerals, Metals & Materials Society), 2015

CHINALCO 600KA HIGH CAPACITY LOW ENERGY CONSUMPTION REDUCTION CELL DEVELOPMENT

Zhou Dongfang, Yang Xiaodong, Liu Ming, Liu Wei

SAMI (Shenyang Aluminium & Magnesium Engineering & Research Institute Co. Ltd.); 184 Hepingbei Street; Shenyang, LN 110001 P.R.CHINA

Keywords: 600kA cell technology, Aluminum reduction cell, Low energy consumption, Horizontal current.

Abstract

High capacity, low energy consumption, SY600 aluminum reduction cell technology has been developed by CHINALCO. Starting with research from 2007, this technology aims at a current intensity of 600kA with a target of low D.C. power consumption. Following the SAMI SY series cell development methodology and using numerical simulation modeling, low ACD energy-saving cell industrial experiments and operation acknowledge, the new design criterion is established for low energy 600kA cell technology. This article presents major technical developments of the SY600 technology with focus on new busbar design, reduction of horizontal current in metal, lining with low voltage heat balance design, and cell bottom shell upward restraint. The startup of a 600kA pilot plant with 12 prototype cells in 2012 and the main performances are also described in this paper.

.

Introduction

Since 2008, the global financial crisis has made a great impact not only on China, but all over the world's aluminum industry. The aluminum electrolysis energy-saving technology and high capacity aluminum reduction cell technology have been developed quickly. In China, a number of energy conservation and emission reduction policies have been issued, the energy consumption index has put forward a definite requirement. Under this background, several energy saving technologies with good energy saving effects have been obtained by CHINALCO, such as metal flow pattern (retarding flow) optimization energy-saving technology[2], horizontal current reduction technology[6] and the new structure energy-saving cell technology[7]. Through deep theoretical research and industrial experiments on the stability of the cell, Shenyang Aluminium &Magnesium Engineering & Research Institute Co. LTD（SAMI）established a new theory system[3] on high capacity energy-saving cell technology development. Based on this theory system, SAMI developed the new generation SY Series technologies and also the SY500 and SY600 cell technologies. There are seven SY500 potlines in operation in China, and the world's biggest cell technology, SY600, was first put into industrial experimentation including 12 prototype cells in the Liancheng Branch of CHALCO. The cells produce steadily with low cell voltage of 3.78V, and D.C. power consumption of 12136 kWh/t.Al.

SY600 development

The SY600 cell technology aims at low D.C. power consumption. As is well-known, the D.C. power consumption (kWh/t-Al) for aluminum reduction depends upon the two parameters of the current efficiency and the average cell voltage. So the fundamental ways of reducing energy consumption are to improve the current efficiency and to reduce the average cell voltage. In the last few decades, the current efficiency has increased as high as possible to 93%~95% all over the world and it nearly hits the theoretical limits. Therefore, the SY600 has focused on reducing the cell voltage as low as possible and keeping relatively high current efficiency.

Analyzing the voltage composition of the cell, we can see that the bath voltage is the biggest factor contributing to heat generation and voltage drops, so the most important and effective way to reduce the non-functional energy consumption and improve the utilization ratio of energy is reduce the cell inter-polar distance (ACD).

It is very difficult to decrease the ACD without losses in current efficiency if the stability of the cell is not further improved. It is well known that the stability of the cell is related to the interaction between the horizontal currents and the magnetic field in the cell, as this produces the electromagnetic force and promotes the fluctuation of the liquid aluminum surface.

Through the analysis above, the first key issue is to deeply research the stability of the cell, find the factors influencing stability and to take effective measures to weaken or eliminate these factors to improve the stability of the cell fundamentally.

Horizontal current reduction and modeling

The relationship between MHD and horizontal current is described in the reference [6], and the new cathode structure described in the reference has proven to further increase the stability of the cell. This technology is also used in the SY600 cell. Figure 1 shows the horizontal current reduction using the new cathode structure compared to the traditional cathode design.

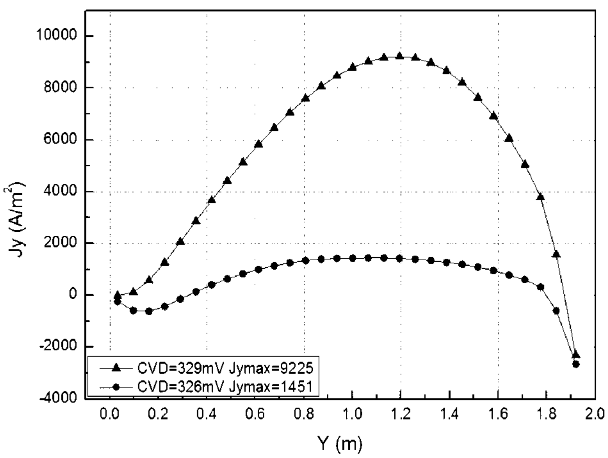

Figure 1: Horizontal current reduction modeling, the line with triangle is the horizontal current distribution in the metal of the SY600 using new cathode structure; the line with solid circle is the horizontal current distribution in the metal with traditional cathode.

As shown in Figure 1, the maximum horizontal current is reduced from $9225 A/m^2$ to $1451 A/m^2$ by using the new cathode structure. The cathode voltage drop stays almost the same as the traditional one (new cathode 326mV vs. traditional one 329mV).

Busbar design and modeling

In the metal pad and molten bath, without considering the effect of bubbles, the main driving force is the electromagnetic force $\vec{F} = \vec{J} \times \vec{B}$ and the main movements will be rotating flow and interface fluctuation.

Based on the Navier–Stokes equation, and considering the characteristics of the cell, the main factor contributing to the rotation is the magnitude and distribution of vertical magnetic field and the horizontal currents in the metal. The horizontal current reduction is already talked about and measures have been taken to realize an optimization of the magnetic field. The vertical magnetic field will be another key issue to solve and improve the stability of the cell, which is also the design criterion widely adopted for busbar arrangement. This concept is proven correct in practice.

Besides the rotation, another important factor that affects the stability of the cell is the interface wave. The interface wave equation proposed by M. Segatz and C. Droste[1] as the following.

In molten metal and bath:

$$\left(\frac{\rho_a}{h_a} + \frac{\rho_b}{h_b}\right)\frac{\partial^2 \zeta}{\partial t_2} - g\Delta\rho\nabla^2\zeta = \left(j_y \frac{\partial B_Z}{\partial x} - j_x \frac{\partial B_Z}{\partial y}\right) \quad (1)$$

On the boundary wall:

$$\left(\frac{\rho_a}{h_a} + \frac{\rho_b}{h_b}\right)\frac{\partial^2 \xi}{\partial t^2} - g\Delta\rho\nabla^2\xi = B_Z\left(\vec{n}_y j_X - \vec{n}_x j_Y\right) \quad (2)$$

According to the above formulas, the reason for the interfacial fluctuation in the molten metal and bath is also the disturbance of the horizontal current and vertical magnetic field magnitude and distribution.

Horizontal current reduction for SY600 is just one factor that is optimized to improve the stability. In order to get further stability improvement on this biggest cell, SAMI established a new criterion for busbar arrangement design. The busbar arrangement is designed based on this new criterion. Compared to the old criterion, the modeling result of velocity of molten metal is reduced by 40%, and the interface deformation is also decreased, although the unit quantity of busbar is less than the lower amperage SY cells. The modeling results are shown as the following in Figures 2 through 5 and in Tables 1 & 2.

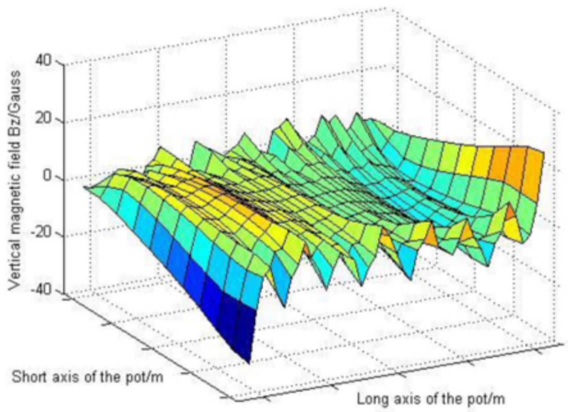

Figure 2: Vertical magnetic field Bz distribution

Table 1: Distribution of the Bz component in four quadrants

SY600	First quadrant Gs	Second quadrant Gs	Third quadrant GS	Fourth quadrant Gs	Max. Gs
Bz Modeling	3.374	4.114	5.565	4.604	28.633

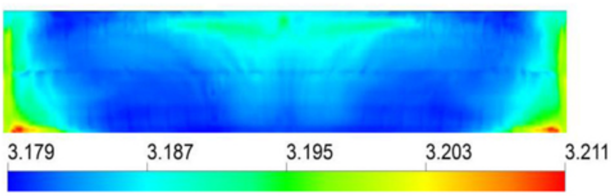

Figure 3: Interface deformation (m)

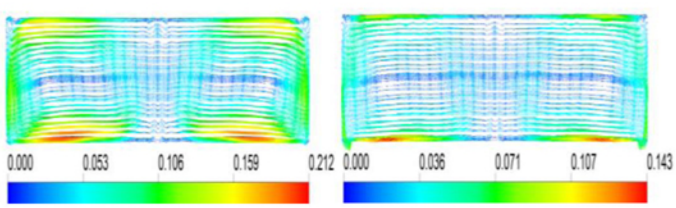

Figure 4: Velocity in molten metal (left) and bath (right) (m/s)

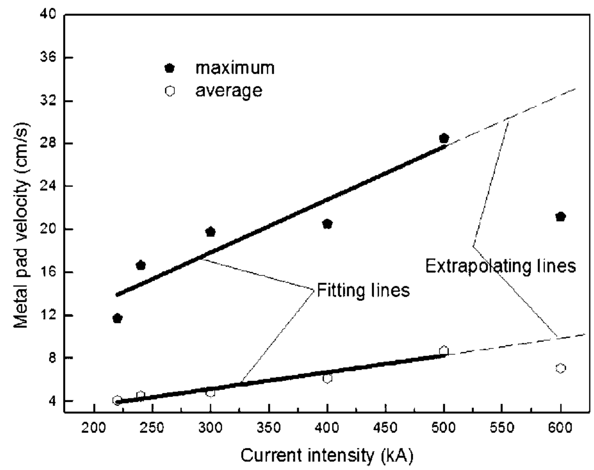

Figure 5: Molten metal velocity increasing with current intensity

Table 2: Velocity and interface deformation

SY600	Velocity in metal /cm s^{-1}		Velocity in bath /cm s^{-1}		Interface deformation /cm
	Max.	Ave.	Max.	Ave.	—
modeling	21.2	7.1	14.3	3.04	3.2

From the modeling above, we can see that with the busbar arrangement design based on the new criterion, the value of vertical magnetic field Bz is small and even, the molten metal velocity is much reduced and is equivalent to 400kA cell with traditional busbar design.

Heat balance design and modeling

The stability improvement creates the condition for the cell to further decrease the ACD without loss the current efficiency, but whether the cell can be operated stably at such low ACD will be related to the heat balance.

There is a big change for the large low voltage energy-saving cell on heat generation and dissipation distribution, so another key issue to be solved for SY600 is to redesign the lining to achieve reasonable temperature field in the lining and heat loss proportion in different parts of the cell. Figure6 shows the SY600 cell modeled temperature field distribution and the ledge profile with the newly designed lining. This modeling result was obtained with the cell average voltage of 3.78V. The related voltage distribution and key heat balance parameters are listed in Tables 3 & 4.

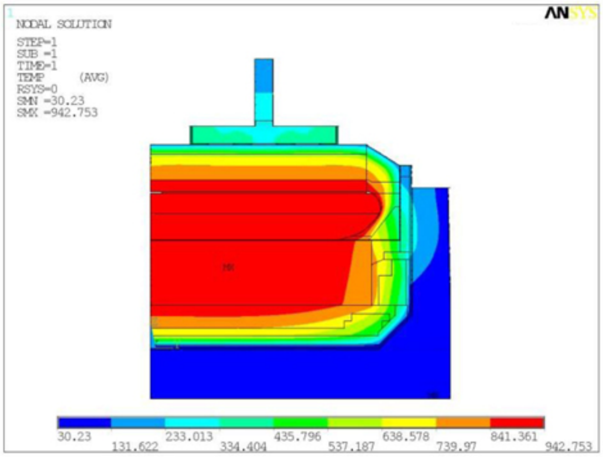

Figure 6: Modeling temperature field and ledge profile

Table 3:SY600 Cell voltage

Item	Units	Modeled	Measured
Anode	V	0.365	-
EMF	V	1.650	-
Bath	V	1.185	-
Cathode	V	0.326	0.316
External	V	0.254	0.241
Cell	V	3.780	3.777

Table 4: Heat balance

Items	Modeled	Measured
Bath temperature (℃)	941.5	941
Superheat (℃)	6.5	6.9
Cell voltage (V)	3.782	3.777
Shell temperature Ave. (℃)	264	285
Ledge thickness (cm)	18.3	19.6

The heat balance designed for SY600 permits the cell to operate at low cell voltage, which is proven practical and reasonable through the experiment.

Cell shell design and modeling

The cell shell, as a carrier of the cathode lining, is one of the most important parts of an aluminum cell. It bears the entire load of the cell including its own weight, lining, metal, bath, superstructure, thermal stress and expansion force of the lining structure. The most important function of the shell is that it has enough strength to restrain the deformation of the side and ends of the shell and also the upward deformation of the bottom of the shell. The shell for the SY600 cell is longer and wider, so it is becoming more difficult to design. A new shell structure has been developed and applied to the SY600 cell. Figure 7 shows the modeling result of deformation the shell. The comparison between modeling result and the measurement in operation cell is listed in Table5.

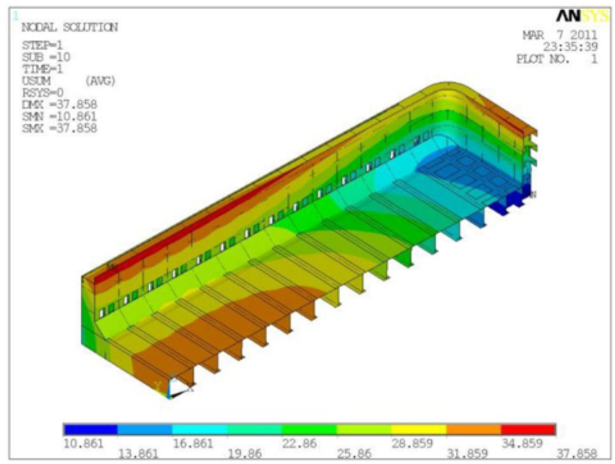

Figure 7: Modeling deformation of cell shell

Table 5: Deformation of pot shell

SY600	Uz Max. /mm	Ux Max. /mm	Uy Max. /mm
Modeled	34	35	21
Measured	20	-	24

The new cell shell designed for SY600 has shown very good performance in the practical application which can be seen clearly in Figure 7 and Table5.

Industrial experiment of SY600

The industrial experiment of the SY600 has been organized by CHINALCO. One pilot plant is established which installed 12 600kA pilot cells, the first cell was baked on 28th July 2012 and the total 12 cells finished start-up smoothly on 28th August 2012.

Dry start up method was used for starting up the pilot 600kA cell, which involved a pre-heat procedure using resistor coke for 48~72hours followed by liquid bath and metal additions.

Through nearly two years of experimentation, the 12 pilot cells have operated very stably at a current intensity of 600kA and achieved very good performance, as shown in Table 6.

Table 6: Key technical and economic indices

Current intensity (kA)	Average voltage (V)	D.C. Power consumption (kWh/t-Al)	Anode effect /cell.day
600	3.78	12136	0.02

Conclusions

The world's biggest cell technology, SY600, has been successfully developed from conception, through modeling and design, to the industrial experimentation phase, which achieved world-class operational performance as a result of considerable analysis and optimization activities. Besides the world's lowest specific power consumption 12,136kWh/t-Al, SY600 technology also gives the advantage of higher productivity and lower capital cost per installed tonne of capacity.

Acknowledgements

The authors wish to thank the financial support provided by the National High Technology Research and Development Program ("863"Program) of China (2009AA064501).

References

1. M. Segatz and C. Droste, Analysis of magnetohydrodynamics instabilities in aluminum reduction cells. Light Metals, (1994) 313-322.
2. Zhou Dongfang, Yang Xiaodong, Liu Wei, Zhao Hongsheng, Development and Application on the Metal Flow Pattern (Retarding Flow) Optimization Energy-saving Technology, [J]. Light Metals, 3(2011) 27-33.
3. Yang Xiaodong, Zhou Dongfang, Liu Wei, SAMI's Research and Advances on Energy-saving Technology [J]. Light Metals, (2011supplement) 165-169.
4. Liu Wei, Yang Xiaodong, Zhou Dongfang, Zou Zhiyong, Liu Ming, Development of 3D Steady-State Magneto-Hydro-Dynamics Model of Aluminium Electrolysis Cells [J].Light Metals, (2011Supplement) 173-177.
5. Liu Ming, Zhou Dongfang, Zhang Qinsong, Research of Thermal-electric Balance for SY200 Energy Saving Cell [J]. Light Metals, (2011supplement) 178-180.
6. Zhou Dongfang, Yang Xiaodong, Liu Wei, Development and Application of SAMI's Low Voltage Energy-Saving Technology, Light Metals 2012, 607-612.
7. Liu Fengqin, GuSongqing et al. Application of New Structure Reduction Cell Technology in Chalco's Smelters, Light Metals 2011, 509-512.