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ALUMINUM REDUCTION TECHNOLOGY

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SIMULATION AND MEASUREMENTS ON THE FLOW FIELD OF 600KA ALUMINUM REDUCTION POT

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Abstract

The SY600 High Amperage Aluminum Reduction Pot Technology was developed by CHINALCO. The 600 kA pilot pots were started in August 2012 and were operated at 600 kA and 3.777 volts during the testing stage. The technical strategies of 600 kA pot technology were researched by SAMI, which meanwhile completed engineering designs. In this article the flow field of such a 600 kA pot was studied using a simulation and validated by on-site measurements. The results show that the 600 kA pot has a relatively low metal flow and high MHD stability.

Introduction

According to the statistics from the International Aluminum Association, the primary aluminum production in China reached 21.9 million tonnes in 2013 with an annual increase of 11.0%. At the same time the worldwide aluminum production was 48.6 million tonnes with an annual increase of 7.6%[1]. The Chinese aluminum industry has been continuously growing for many years. Meanwhile the energy price in China is quite high and contributes to up to 40% of the total cost per ton of aluminum production. To deal with the conflict between the huge amount of production and the high price of energy, the Chinese government announced a series of policies and regulations. These not only set out the energy saving targets, but also encouraged the industry to be competitive through R&D and utilization of new technologies. The smelting companies, institutes and universities gave an active response and are seeking to reduce the energy consumption as much as possible with new thinking.

A 400 kA pot had just been tested successfully in 2007 when the China aluminum industry was booming. Then development of 600 kA reduction pot technology was put on the agenda by CHINALCO. After intensive research a preliminary design proposal on a 600 kA reduction pot was finalized and awaited approval for testing. During 2008 and 2009 great efforts were made on energy savings and the vision for low pot voltage came into being. The team had been involved in such experiences and activities for small pots. This built the foundation on how to develop a 600 kA pot with very low voltage and energy consumption. The research project related to development and trial of the 600 kA pot was approved and financed by the 863 R&D program of China in October 2009.

As is well known, many issues must be addressed concerning a 600 kA amperage pot, however one of the most import ones is the magneto-hydro-dynamics (MHD). Actually only with high MHD stability can a 600 kA pot be squeezed to significantly reduce the anode-cathode resistance and save substantially on energy consumption. From SAMI's point of view, MHD stability can be ascribed to Horizontal Current Reduction[2] and to the bus bar design. Traditionally to design such bus bars is to control the vertical magnetic field and interface waves. In the SAMI designed 600 kA pot, MHD stability is improved by New Concept Bus Bar Design to control not only the interface waves but metal flow as well. In this paper the modeling, predictions and validation of the flow field of a 600 kA pot are presented. Figure 1 shows the SY600 pilot plant.

Figure 1. 600 kA pot in the pilot plant[3]

Model Development

Recently there have been many papers published on the metal-bath flow calculation such as the shallow layer method[4], three-dimensional models in Ester, CFX and Fluent[5-7]. It is still an interesting topic and any model should be validated by measurements. In this calculation ANSYS/CFX software was used.

<u>Governing Equations</u>

The velocity field and pressure for the incompressible viscous molten fluids are governed by the Navier-Stokes equation.

Continuity equation:

$$\nabla \cdot \boldsymbol{U} = \boldsymbol{0} \qquad (1)$$

Momentum equation:

$$\rho\left(\frac{\partial}{\partial t} + \boldsymbol{U} \cdot \nabla\right)\boldsymbol{U} = -\nabla p + \nu_{eff}\nabla^2\boldsymbol{U} + \boldsymbol{F}_{em} + \rho g \qquad (2)$$

Where:
p——pressure, Pa;
ρ——density, kg/m^3;

F_{em}——electromagnetic force, N/m^3 and $F_{em} = J \times B$ obtained from the electro-magnetic model[8];

v_{eff}——effective viscosity, Pa·s, and it is sum of the dynamic and the turbulent viscosity.

Our strategy for model development uses a zero-equation turbulent model with a wall function, adjustments to the dynamic viscosity to keep the Reynolds number around 2300, or not too high, and setting the turbulent viscosity as a constant.

Interface Tracking Method

The Volume of Fluid (VOF) method is used to track the free interface of the metal-bath. The VOF method is described in CFX User Manual.

Geometry Demonstration

Shown in Figure 2 is the three-dimensional flow domain geometry used to model the 600 kA pot.

Figure 2. The geometry domain for two phase flow of aluminum reduction pot

Boundary Conditions

At the initial time, volume fraction is set for two phases and the velocity is set to zero. The external magnetic forces are imported to the fluid zone. The top surface of the domain is set as a free slip wall and other surfaces are set as no slip walls.

Simulation Results

Metal and Bath Flow Results

As shown in Figure 3(a), two vortexes dominate the metal flow pattern with small recirculation found at the downstream corners. The maximum velocity is 21.2 cm/s and the average velocity is 7.1 cm/s. As shown in Figure 3(b), the bath flow pattern is similar to that of the metal with lower velocity (as assumed without bubble effects). As shown in Figure 3(c), the bath-metal interface heaves by 2.1 cm and depresses by 1.1 cm resulting in an overall 3.2 cm deformation.

Velocity Trend With the Amperage

Figure 4 shows the velocity trend with the amperage of the pot. All results were obtained with the same flow model and different magnetic forces depending on the specific pot. In Figure 4 two fitting curves for maximum velocity and average velocity respectively are plotted for the conventional bus bar design. It can be seen that velocity increases linearly with the amperage. If still using the conventional bus bar design, then the metal velocity of 600 kA pot will become very high. That is to say, the maximum velocity is over 30 cm/s and the average velocity is over 10 cm/s, rising along the fitting lines' slopes. It is believed that high speed metal flow, which is a consequence of the internal magnetic forces will cause negative effects on stable operation such as anode change and metal tapping and regular ledge formation. As a new technical measure a New Concept Bus Bar Design was made to improve 600 kA pot stability. The simulated results show that the metal flow of a 600 kA pot is comparable to that of a 400 kA pot.

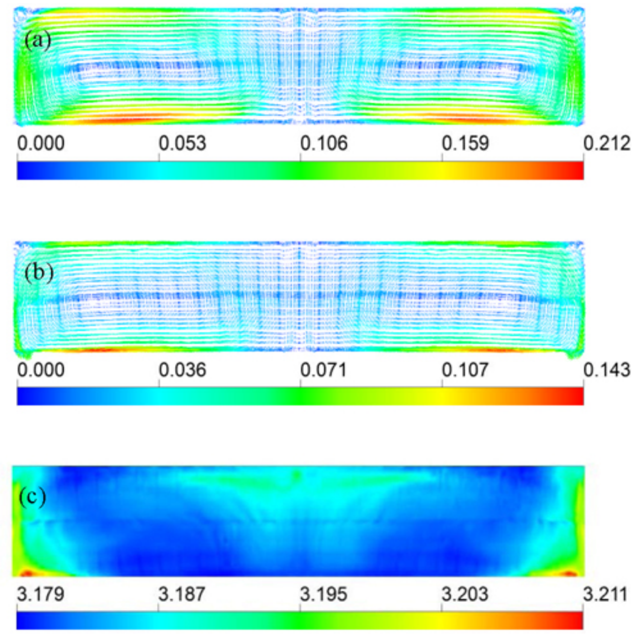

Figure 3. Simulated flow results of 600kA pot: (a) Metal flow in the middle of the metal pad (metres/second), (b) Bath flow in the middle of the ACD (metres/second) and (c) Relative Metal-bath interface deformation (metres)

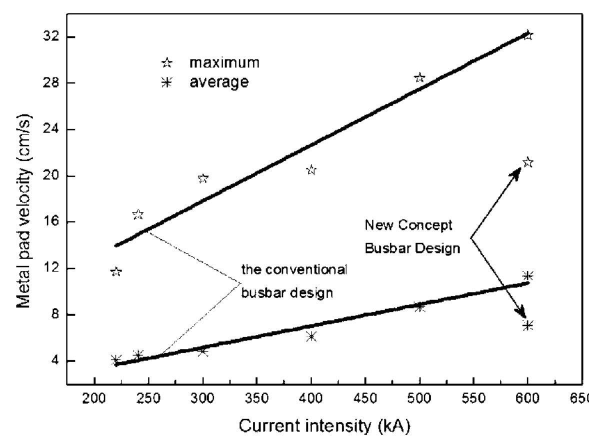

Figure 4: Calculated metal velocity under the conventional bus bar for 220~600kA pot vs. New Concept Bus Bar Design for a 600 kA pot

Measurements

Method and Measurements

The iron rod method was used to measure metal pad velocity. The general approach is as follows: rapidly insert calibrated iron rods into the broken holes as shown in Figure 5. Keep rods vertical with their reference points parallel to the pot side for about eight minutes. Remove them from the pot simultaneously and clean them with a caustic solution. Finally determine the metal pad velocity according to the diameter change and the metal temperature. The metal pad velocity measurement was conducted by an independent contractor under the coordination of SAMI.

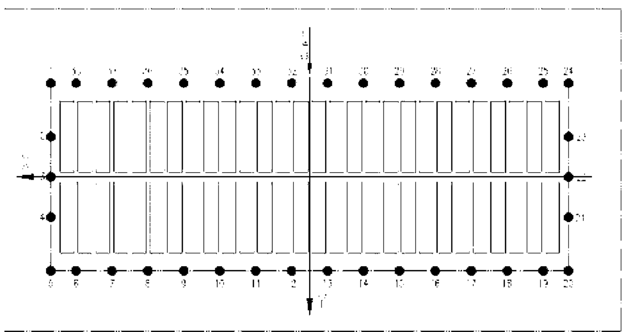

Figure 5. Definition of measuring locations and coordinates

A self-made piece of equipment was used to measure the metal-bath interface profile. It consists of two stands fixed to one side of the pot shell, one positioning tool and one fastening tool per stand, one leveler and some fine steel wire as shown in Figure 6. The iron rod is used without requirements upon its chemistry but it should be long enough, no less than 130 mm, and thick enough to prevent high erosion after 12 minutes of insertion into the metal. The equipment is easy to set a horizontal line above the deck plate. This is the upper baseline to measure the interface profile downward.

The location and coordination was the same as shown in Figure 5.

Figure 6: Stand of Interface profile measuring equipment fixed to the pot shell

Comparison of Measurements and Simulations

On Metal Pad Velocity. Table 1 shows the detailed comparison of calculated values versus measured values at each location. Measured values in the middle and at the corners are much higher than calculated values. The other measured values well match those calculated at the high speed zone near the upstream side and downstream side. The maximum measured value is close but average value is almost double. The average is not modeled well. The calculated velocity of the metal flow is lower at middle points where two dominating vortexes encounter each other. Authors believe that bubbles may drive bath and metal flow by stirring effects at such areas. However bubble effects are not considered here.

Measured data in 400 kA pots show that the maximum velocity is around 25 cm/s, the average velocity is 15 cm/s shown in Table 2. Therefore we came to a conclusion that a 600 kA pot that attains low metal velocity is comparable to a 400 kA pot. This demonstrates that the 600 kA pot bus bar design was successful.

Table 1. Comparison of Calculated and Measured velocity of the metal pad[9] (units in cm s^{-1})

No.	Calculated	Measured Avg	No.	Calculated	Measured Avg
1	2.9	14.5	5	4.2	15.8
38	11.3	15.9	6	4.3	11.4
37	19.3	19.8	7	16.4	17.8
36	20.6	18.6	8	15.4	14.6
35	16.7	18.7	9	13.3	13.0
34	12.0	18.2	10	9.4	16.0
33	4.5	15.8	11	5.1	15.3
32	1.8	13.3	12	1.2	16.2
31	2.2	12.4	13	1.8	13.9
30	5.6	16.9	14	5.5	16.5
29	13.0	15.2	15	9.8	17.8
28	17.4	20.0	16	13.6	14.0
27	21.0	21.3	17	15.9	14.5
26	19.6	21.7	18	16.9	17.9
25	11.5	12.6	19	4.4	15.9
24	3.0	13.8	20	4.2	17.0
Max	16.9	17.9			
Avg	8.8	15.5			

Table 2. Measured velocity of one 400kA pot for reference[9] (units in cm s^{-1})

Pot No.	Measured Avg.	Measured Max.
707#	15.15	22.62
117#	16.37	31.39
136#	14.99	24.21
129#	15.23	21.59

On Metal-bath Interface. Figure 7 shows the height variation of the interface for Pot 3037. At the upstream and downstream side similar variation trends were observed along the long- or short-axis of the pot and furthermore the difference of the deformation is relatively small. The overall interface distortion is 4.77 cm for pot 3037. This value may be seen as acceptable considering severe industrial conditions and it roughly agrees with the calculated value 3.2 cm The self-made equipment is good for interface profile measurement.

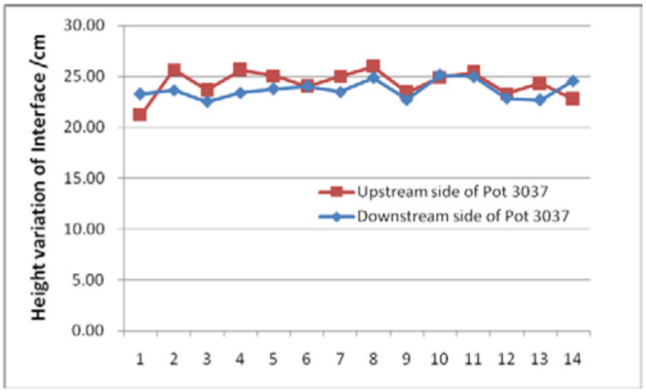

Figure 7. Height variation of the interface for Pot 3037

Cell Performance

With crucial contributions from many innovations such as New Conception Bus Bar Design, Horizontal Current Reduction and other techniques, 600 kA pilot pots were operated smoothly since start-up. Average results obtained during the testing and evaluation period were the voltage of 3.777 V, CE of 92.77%, AE coefficient of 0.02 and DC power consumption of 12136 kWh/t-Al.

Conclusions

A 600 kA High Amperage Aluminum Reduction Pot Technology was developed by CHINALCO. The effect of New Concept Bus Bar Design on the metal flow of 600 kA pots was evaluated with aid of the constant viscosity turbulent model built in ANSYS/CFX. Simulation results show that the metal pad flow of the SY600 pot is at the equivalent level of a 400 kA pot with a traditional bus bar design. The metal-bath interface on each side shows a similar deformation trend and the difference of the deformation is small. These two results were verified with on-site measurements conducted on pilot pots. The MHD stability brought by the new bus bar design has also been confirmed by smooth operation since start-up and outstanding key performance index values. Average performance indices obtained during the testing and evaluation period include voltage of 3.777 V, CE of 92.77%, AE coefficient of 0.02 and DC power consumption of 12136 kWh/t-Al.

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