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NUMERICAL SIMULATION ELECTRIC DISTRIBUTION IN ALUMINUM REDUCTION CELL WITH VERTICAL COLLECTOR BARS

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The electric current distributions in cathode were calculated using a 3D thermal-electric model. The results show that the cell with vertical collector bars has a uniform voltage (electric current density) in the cathode carbon across the entire cell width than that of a conventional cell. Furthermore, the horizontal density in the metal pad with vertical collector bars is far less than that in the conventional cell, which indicates that the cell with vertical collectors will generate the minor metal turbulence and the polar distance can be control in a minor and uniform value.

Key word: Aluminum reduction cell; Numerical simulation; ANSYS; Vertical collector bar

INTRODUCTION

Aluminum is produced by an electrolytic reduction of alumina in an electrolyte. The typical aluminum reduction cell is shown as in Figure 1. The current enters the reduction cell through the anode and then passes through the electrolyte bath, down through the molten aluminum pad where it then enters the cathode carbon blocks and is carried out of the cell by the cathode collector bars (steel bar).

As the bath is traversed by electric current, alumina is reduced electrolytically to aluminum at the cathode. The aluminum accumulates in a molten aluminum pad. The aluminum reduction cells are operated by maintaining a minimum depth of liquid aluminum in the cell, the surface of which serves as the actual cathode. The cells operate at low voltages and very high currents. The current flowing through the cell and in the conductors gives rise to a substantial magnetic field in and around the cell. The horizontal components of the flow of electric current interact with the vertical component of the magnetic field, adversely affecting efficient cell operation [1]. The force caused by the combined effect of magnetic fields and current distribution cause movement of the molten metal pad and deformation of the bath/metal interface. The motion of the metal sometimes violently stirs the metal pad and causes localized electrical shorting. Furthermore metal pad turbulence can increase the "back reaction" or reoxidation, thereby lowering cell efficiency. The depth variations also restrict the reduction of the anode to cathode gap and produce a loss in current efficiency since power is lost to the bath between the anode and cathode.

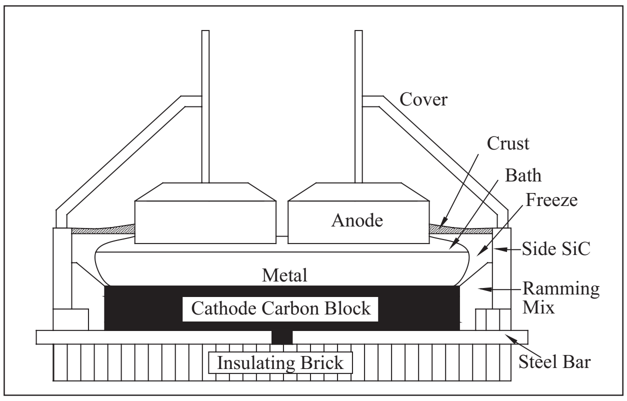

Figure 1 Schematic of an aluminum reduction cell

In recognition of the adverse effects that horizontal current components have effect on cell efficiency, great efforts were made on research the horizontal in conventional cell. Tarapore [2] determined the horizontal current in the metal by measuring the current in steel collector bars. Furman [3] noted the horizontal electric currents are not "pathological" but a logical result of the cell circuit topology. Aritaet al [4] and Robl [5] studied the effects of side ledges on horizontal current in metal pad. It was observed that longer ledges cause larger inward flowing currents in metal pad. Fraser et al [6] and El-Demerdash et al [7] calculated the current density of different metal layers under different ledge lengths. Moreover, cells designs have been proposed which attempt to reduce the horizontal components of current by changing the basic design of the cathode collector bars [8-9]. One example of design, with "vertical collector bars", was proposed by liang in 2011, which the current flow out of cathode vertically instead of horizontally. It is report that the cell voltage is in the range of 3,7-3,9 V and the energy consumption is only 12 000 kWh per ton Al [10]. However, little attention has been paid to the current distribution in this type cell. Compared with the comprehensive studies on electric field of the currently used conventional cell, studies reported on the relative

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problems of the vertical cells were few. So in this paper, We use ANSYS calculating the electric distribution in the new style cell, especially the electric distribution in the cathode carbon and horizontal electric current (HEC) in the metal pad. All the calculations are on 300 kA aluminum reduction cell.

PHYSICAL, MATHEMATICAL MODEL AND BOUNDARY CONDITIONS

Due to quite large volume and the symmetry of the cell structure, the sketch of the chosen part of the cell and a coordinate system are shown in Figure 2. Two cathode structures is plot in Figure 3.

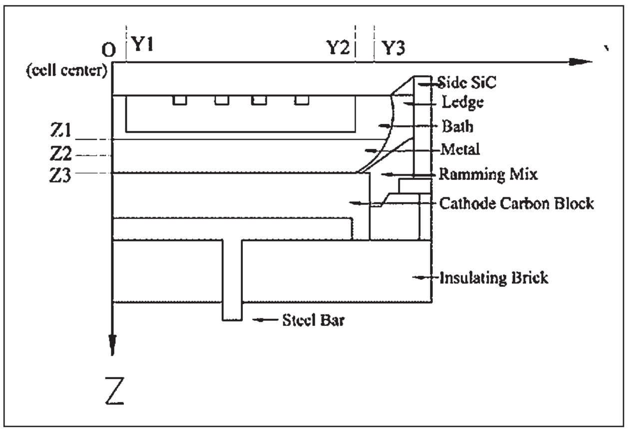

Figure 2 Physical model

The origin point (O) of the calculation system is located at the center of the cell, *Y* is the longitudinal axis and *Z* is the vertical axis directed downwards.

Where Y1-the anode side in the intermediate channel;

Y2 - the ledge on the cathode carbon block;

Y3 - the cathode carbon block;

Z1 - the electrolyte/metal interface;

Z3 - the metal/carbon interface;

Z2 = (Z1+Z3)/2;

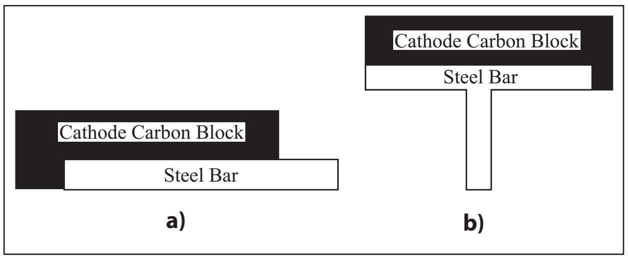

Figure 3 Two cathode structures
a) Conventional collector bar b) Vertical collector bar

The governing equations for thermal and electric field are described by the following equations, respectively.

$$\frac{\partial}{\partial x}(\lambda_x \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(\lambda_y \frac{\partial T}{\partial y}) + \frac{\partial}{\partial z}(\lambda_z \frac{\partial T}{\partial z}) + q(x,y,z) = 0 \quad (1)$$

Where T is the temperature, q is heat source, λ_x, λ_y and λ_z are the thermal conductivity in X, Y and Z directions.

$$\frac{\partial}{\partial x}(\frac{1}{\rho_x}\frac{\partial V}{\partial x}) + \frac{\partial}{\partial y}(\frac{1}{\rho_y}\frac{\partial V}{\partial y}) + \frac{\partial}{\partial z}(\frac{1}{\rho_z}\frac{\partial V}{\partial z}) = 0 \quad (2)$$

Where V is the voltage, ρ_x, ρ_y and ρ_z are the electrical resistivity in X, Y and Z directions.

A fully coupled thermo-electrical model was run to obtain the electrical potential and the temperature fields. Thermo-electrical solid elements SOLID69 were used to transmit heat and current as well as to generate Joule heat, and SOLID70 thermal-only elements were used to simulate the heat transfer for thermal insulating materials.

Considering symmetry, we assumed that there were no heat transfer and current between the slice and other slices. The boundary conditions were applied as following:

Electrical: The end area of steel bar was chosen as the zero potential and a constant current density was forced with a floating constant potential on the anode carbon steel bar top surface. This was achieved by coupling the voltage on the surface nodes while forcing constant current on one of its node [11].

Thermal: Heat losses through heat convection on the shell surface with the ambient air.

The heat transfer of the cell surfaces, as the third boundary condition. The total coefficient of the heat transfer is calculated in terms of the following formula [12]:

$$\alpha_{wa} = \alpha + \sigma_0 \varepsilon_w (T_w^4 - T_A^4)/(T_w - T_A) \quad (3)$$

Where α_{wa} is the total coefficient of the heat transfer;

T_w is the surface temperature;

T_A is the environmental temperature;

σ_0 is Stefan-Boltzmann constant;

ε_w is the emissivity;

α is the heat transfer coefficient of the natural convection between the surface and environment, and it has different calculating formula with different direction of three surface:

Top surface:

$$\alpha = 1{,}31(T_w - T_A)^{1/3} \quad (4)$$

Vertical surface:

$$\alpha = 1{,}52(T_w - T_A)^{1/3} \quad (5)$$

Bottom surface:

$$\alpha = 0{,}58[(T_w - T_A)^{1/3}/L]^{1/3} \quad (6)$$

Where L is the length of shorter side on the surface.

RESULTS AND DISCUSSION

Current distribution in the cell were calculated under the following conditions: 1)Ledge ideally formed; 2)The metal liquid height equal to 17 cm, electrolyte height equal to 20 cm and the polar distance equal to 4 cm.

In a conventional cathode, the collector bars are embedded in the substantially horizontal carbon bottom. Within the cell, the current flows through the cathode

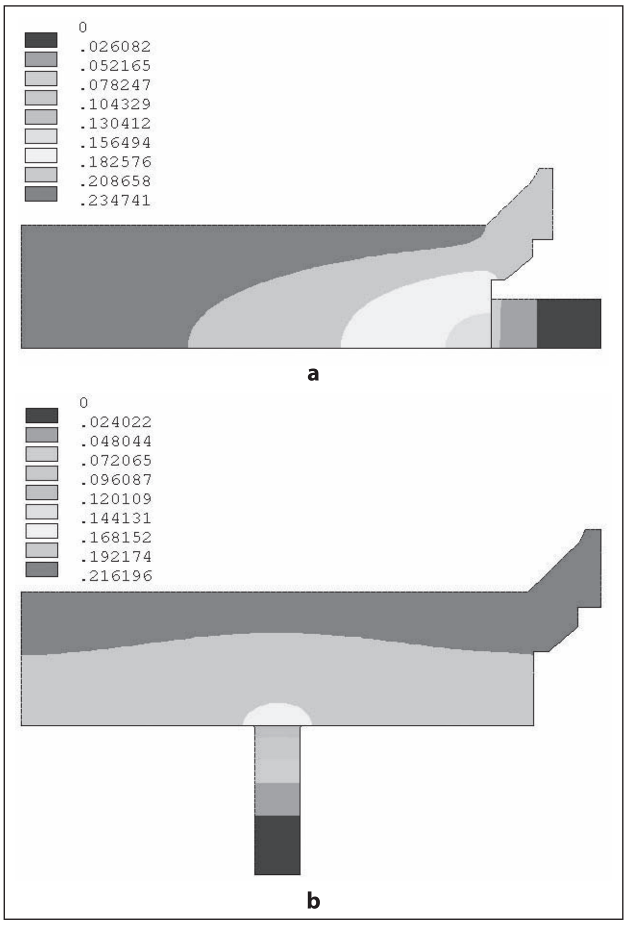

Figure 4 Contours of voltage (V)
a) Conventional collector bar b) Vertical collector bar

carbon and exits the cell via steel collector bar. The flow of electrical current through the aluminum pad and carbon cathode naturally follows the path of least resistance. The electrical resistance in a conventional cathode collector bar is proportional to the length of the current path from the point at which electric current enters the cathode collector bar to the nearest external bus. The lower resistance of the current path starting at points on the cathode collector bar closer to the external bus causes the flow of current through the molten metal pad and carbon cathode blocks to be skewed in that direction.

The contours of voltage drop of the cathode are shown in Figure 4. As can be seen in the Figure 4, although the voltage drop of the cathode is close to each other, the two contours are noticeably different. The novel cell has a uniform voltage (electric current density) in the cathode carbon across the entire cell width. This is achieved by arranging the vertical collector bar in the middle of the carbon floor. By that the current is led out from the collector bars at a position remote from the side of the cell.

The carbon and collector bar can be simplified described as shown in Figure 5.

The HEC density distributions in the bath/metal interface are shown in Figure 6. It can be seen that the vertical collector bar has great effect on the horizontal currents in the metal pad. The horizontal currents in the cell with vertical collectors are far less than that in the conventional cell. That indicates that the cell with vertical collectors will generate the minor metal turbulence. Further more, the polar distance (Figure 7) can be control in a minor and uniform value. The metal pad behavior better suited for the achievement of maximum efficiency and control.

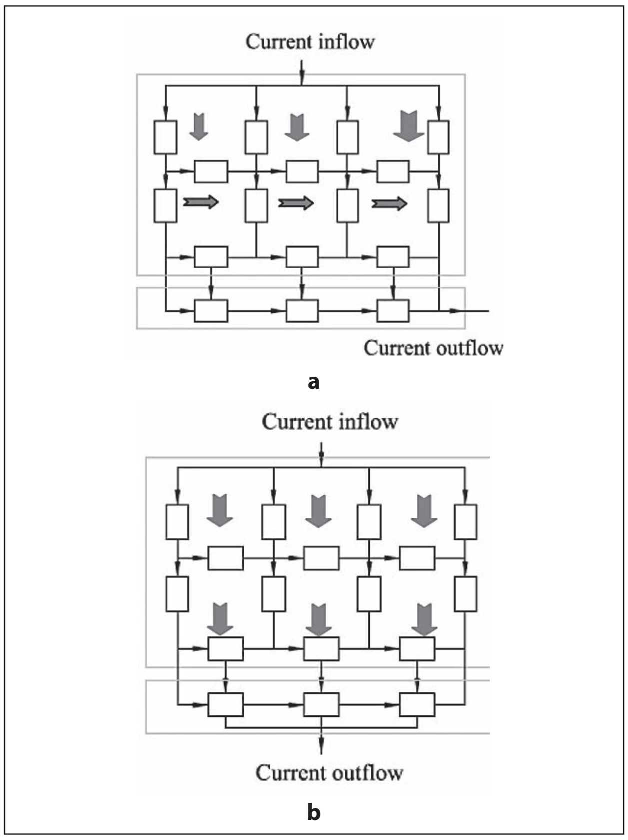

Figure 5 Equivalent circuit
a) Conventional collector bar b) Novel collector bar

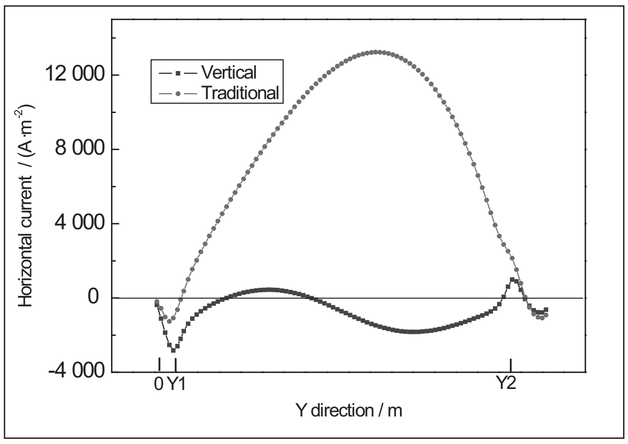

Figure 6 HEC density distributions in the bath/metal interface

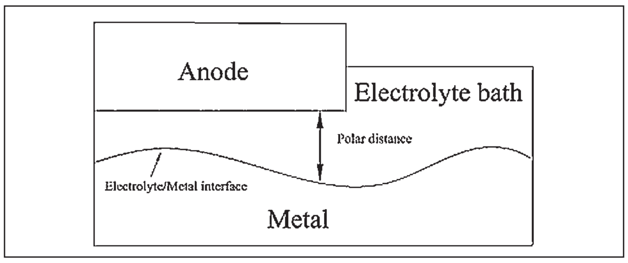

Figure 7 Sketch of the polar distance

CONCLUSIONS

A 3D thermal-electric coupled model was developed to calculate current distribution in the cathode (cathode carbon and metal pad). The results show that the vertical collector bar has great influence on current distribution in the cathode, the cell stability and current efficiency. These studies should be very helpful for understanding the effects of these factors on cell operation and taking necessary action to minimize their negative influence.

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Note: For English language is responsible the lecturer from Northea Stern University, China