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FLOW FIELD COMPARISON BETWEEN TRADITIONAL CELL AND NEW STRUCTURE CELL BY CHACLO BY CFD METHOD

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Abstract

Energy saving receives more and more attention because of high energy price and environment requirement. The flow field and interface wave of new structure cell by Chaclo were studied by ANSYS and CFX combination. The results show that the maximum velocity of traditional cells is 26.7 cm/s and the maximum velocity of new structure cell is 21.2 cm/s. The maximum velocity is reduced. The interface wave of traditional cells is between -2.19cm and 3.41cm and that of new structure cell is between -1.15cm and 2.50cm. The interface wave is weakened by 34.82%. The industrial practice shows that the anode-cathode distance of new structure cell can be reduced without current efficiency loss in comparison with traditional cells.

Introduction

The Hall-Héroult aluminum reduction technology has been the only industrial method to produce primary aluminum in the world gotten continual improvement and development since its emergence in 1886. The cells' technical parameters, including current efficiency, energy consumption, and current intensity, are optimized through the effort of the worldwide engineers and experts on aluminum reduction technology. Advanced point feeding technology, automated control system and new developed equipments help the technology get more advancement.

However the electrical energy efficiency of the technology is still less than 50% because the electric conductivity of bath is lower and the anode-cathode distance(ACD) can't be shorted too much for stability and current efficiency.

The average DC(Direct Current) consumption in Chinese smelters is about 13000kWh/ton-Al. But more than 50% of the energy is dissipated. About 80% of energy consumption occurs in the bath layer, because of its poor electrical conductivity and electrochemical voltage drop. Reducing the anode-cathode distance(ACD) is an efficient method to save energy.

The fluid domain includes the bath and the molten metal. The bath is on the top of the molten metal because of density difference. The two continuous fluid phases are immiscible and their interface is flat if there are no Lorentz forces. In fact Electric currents generate magnetic fields and the Lorentz forces $\vec{F}_{mag}$ is got by the cross product of current vector $\vec{J}$ and magnetic vector $\vec{B}$: $\vec{F}_{mag} = \vec{J} \times \vec{B}$.

The Lorentz forces driven flow in the cells is helpful for the alumina dissolution and dissipation, temperature gradient reduction and so on. But the flow can also leads to the deformation of the two-phase interface, which intensify the back reaction as (1) and the current efficiency loss.

$$Al + CO_2 = CO + Al_2O_3 \quad (1)$$

Therefore the bath ACD can't be as short as possible or else the cell voltage will swing and the cells will not work normally.

In recent years the energy consumption accounts for an increasing proportion in the smelters' product cost because of energy shortage. In order to reduce energy consumption of the traditional Hall-Héroult cells a new structure aluminum reduction cell technology was invented by Feng-qin Liu of Chalco through about 10 years' efforts. The new structure cell by Chalco has gotten its wide and successful application since 2006.

CFD method has shown to be the useful tool for the investigation of fluid flow in the aluminum reduction cells[1,2]. This paper studied the flow field of the new structure cell by Chaclo and compared with the traditional Hall-Héroult cells by CFD method.

New structure aluminum reduction cell by chaclo

The new structure technology by Chalco includes key technology as follows: the new type wetted composite cathode, the new cathode and lining structure, the relative heat insulating structure cell design, and new control system and management.

<u>The new type wetted composite cathode</u>

The new structure cell by Chalco adopts TiB_2-C composite wetted cathodes by Chalco. This kind of cathode composition is helpful for the operation of new structure cell because of its wettability, resistance to Na corrosion, and mechanical strength.

The wettability of the cathode can enhance the fluidity of the metal on the cathode surface. The resistance to Na corrosion and mechanical strength can help to prolong the cell life and make this technology feasible. As a result the crack of the cathode can be avoided.

<u>The new cathode and lining structure</u>

The cathode and lining structure of the new structure cell is optimized for flow field.

The cathode with specially designed grooves is designed to hinder the flow of fluid and the negative influence of magnetic field is expected to be reduced greatly. According mentioned above, the ACD could be shortened for energy saving.

The side lining structures of the cells are modified and the anode bubbles can remove quickly from the anode surfaces, which is beneficial for the current efficiency.

<u>The relative heat insulating structure cell design</u>

As the energy input of cell is reduced because of lower cell voltage it's important to keep the heat balance of new structure cell. The preservation materials are optimized and bottom linings are modified for new heat balance.

According to energy conservation theory, the electric energy efficiency of new structure cell is increased.

<u>New control system and management</u>

The alumina feeding, heat balance and steady lower cell voltage are all included in the control system and management, which is necessary for the long-term stable operation.

The technology has gotten large scale industrial application in 160kA, 200kA, 300kA, 350kA, and 400kA cells. The average DC energy consumption of new structure cell is about 12000kWh/ton-Al, which is about 1000kWh/ton-Al than the traditional Hall-Héroult aluminum reduction cells. Further studies are done for the continuous optimization of the new structure cell.

Mathematical model

The magnetic field was finished by ANSYS based on Maxwell's equations.

$$\begin{cases} \nabla \cdot D = \rho \\ \nabla \cdot B = 0 \\ \nabla \times E = -\dfrac{\partial B}{\partial t} \\ \nabla \times H = J + \dfrac{\partial D}{\partial t} \end{cases} \tag{2}$$

Where: D,electric flux density vector. ρ,electric charge density. B,magnetic flux density vector. E,electric field intensity vector. t,time. H,magnetic field intensity vector. J,total current density vector. D,electric flux density vector.

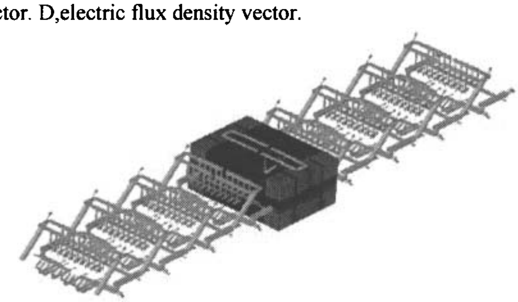


Figure1. Model of magnetic field

The Maxwell's equations are solved by magnetic scalar potential approach, which allow to handle current sources as primitive rather than element. This advantage is useful for the study on magnetic field of aluminum reduction cells and the complex bus bars don't need to be part of the finite element mesh. The element type SOURCE36 is used to model the complex bar system of the aluminum reduction cells. The element type SOLID96 is used to model the cell body because the magnetic model is meshed with hexahedral mesh type. The line current is applied at the anode top surface and zero voltage at the cathode steel bars' end. Zero Magnetic potential is applied in the external nodes of the air box.

The electromagnetic force is transferred to CFX by user routine. The mesh is refined for precise. The electromagnetic fore was interpolated on the nodes.

The two-phase flow was modeled by Euler-Euler method and conservation equations include one set of continuity and N-S(Navier-Stokes) momentum governing equation for each phase, the bath and the melt. The bath and the metal are separated by a free surface, which can be regarded as a free surface flow. So the bath and the metal are both treated as the continuous phases. Free surface flow with inhomogeneous model is adopted to allow entrainment of one phase within another. The inter-phase drag force coefficient $C_D = 0.44$ and their couple is achieved through inter-phase momentum exchange terms. The effect of anode bubbles and alumina particles is neglected.

The continuity governing equation:

$$\frac{\partial}{\partial t}(r_i \rho_i) + \nabla \cdot \left(r_i \rho_i \vec{U}_i\right) = S_{MSi} \tag{3}$$

$$\sum_{i=1}^{N_P} r_i = 1 \tag{4}$$

The momentum governing equations:

$$\frac{\partial}{\partial t}\left(r_i \rho_i \vec{U}_i\right) + \nabla \cdot \left(r_i \left(\rho_i \vec{U}_i \otimes \vec{U}_i\right)\right) = -r_i \nabla P_i + \nabla \cdot \left(r_i \mu_i \left(\nabla \vec{U}_i + \left(\nabla \vec{U}_i\right)^T\right)\right) + F_{Mi} + M_{mag} + M_i \tag{5}$$

Where: t, the time. r_i ,the volume fraction for the ith phase. ρ_i, the density for the ith phase. $\vec{U}_i$ is the velocity vector for the ith phase. S_{MSi}, the mass source for the anode bubbles. N_p ,the number of the phases. P_i is the pressure for the ith phase. μ_i, the dynamic viscosity for the ith phase. F_{Mi}, the body force for the ith phase. M_{mag}, the magnetic force. M_i is the interaction force.

The turbulence governing equation:

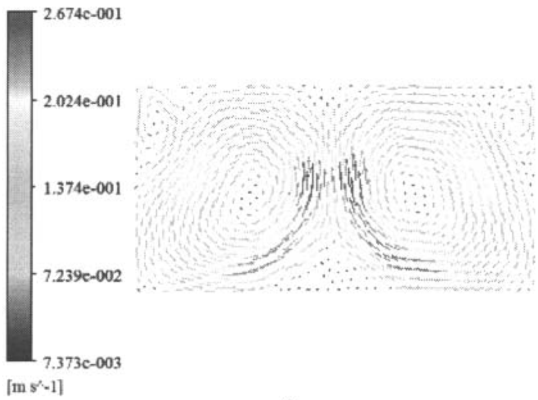
The homogeneous two equation k - ε turbulence model is used.

Free slip wall is used on the anode surface because the anode bubbles' effect. No slip wall is used for the bath and the metal on the other walls.

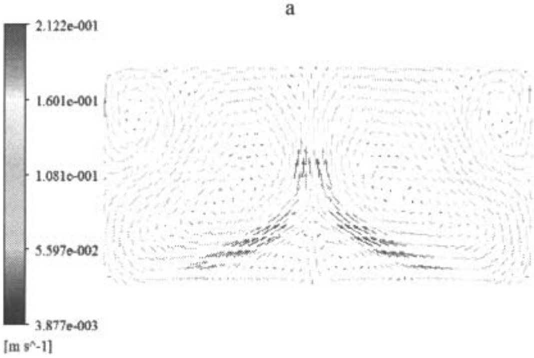
The new cathode structure with specially designed net grooves is described in[3-5].The models of new structure cell by Chaclo is meshed by hexahedral meshes with about 2,000,000 meshes. The independent of mesh size is verified.

Results

The flow field results of traditional cells and new structure cell are shown in Figures 2 and 3.



a

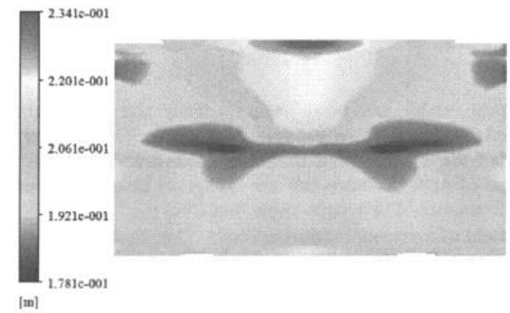


b

a. Velocity vector of traditional cells
b. velocity vectors of new structure cells
Figure 2. Comparison of velocity vectors

From figure 2 the maximum velocity of traditional cells is 26.7 cm/s. The maximum velocity of new structure cell is 21.2 cm/s. The maximum velocity is reduced.

Though the cells' ampere isn't reduced but the new cathode structure with net grooves can resist the metal flow to some extent. There were two big vortexes in the middle of metal pad, which is almost the same for both the new structure cell and the traditional cell. The net grooves reduce the velocity of the metal but the flow pattern is not changed.



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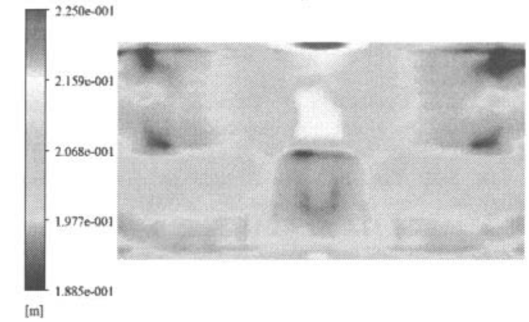

b

a. interface wave of traditional cells
b. interface wave of new structure cells
Figure 3. Comparison of interface wave

It can be seen from Figure 3 that the interface wave of traditional cells is between -2.19cm and 3.41cm and that of new structure cell is between -1.15cm and 2.50cm. The interface wave is weakened by 34.82%.

Discussion

The flow field comparison between traditional cell and new structure cell by Chalco shows that the flow field in new structure cell is weakened.

On one hand the fluid flow in cells is helpful for the alumina dissolution and dissipation, temperature gradient reduction and so on. On the other hand the fluid flow in cells can intensify the back reaction which is the cause of current efficiency loss.

There are several aspects to discuss as follows:

1) The net grooves of new structure cathode work as barrier blocks to weaken the fluid flow in cells. The industrial practice shows that the alumina concentration in new structure cell is as uniform as the traditional cells. Especially, real zero anode effect can be realized because there is no sludge and crust formation on the cathode surface and the added alumina can dissolve more easily without the barrier of thick molten metal layer.

2) The interface wave is weakened by 34.82%, which means that the ACD could be shorted further without any current efficiency loss. This is because that the fluctuation of molten metal caused by the magnetic field is greatly reduced. About 800 cells of Chalco adopt this technology and run steadily. The cell voltage is about 3.72V-3.76V.

3) The energy dissipated is reduced because of the decreased turbulence of flow flied. As a result the energy efficiency could be increased 4%-7%. Reduced energy dissipation is beneficial for

keeping heat balance of the new structure cell as the energy input is decreased because of lower cell voltage.

Summary

Two phase model has been used to study the flow field of traditional cell new structure cell by Chalco. The comparison shows that the velocity and interface wave are weakened. The advantage of new structure cell are discussed in combination of industrial practice. The results show that CFD method is effective in flow field of aluminum reduction cells. This study provides the theoretical basis for feasibility of new structure cell by Chalco.

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