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MAGNETOHYDRODYNAMICS SIMULATION OF 300 KA NOVEL CELL FOR ALUMINUM ELECTROLYSIS

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A novel cathode with cylindrical protrusions was presented to investigate the effect of protrusions on the electromagnetic field and flow field in the aluminum electrolysis cell. Results show that by using the novel cathode, the maximum horizontal electromagnetic force and velocity at 2/3 height of the metal pad were reduced by 21 % and 41 % respectively, and the metal - bath interface wave decreased by 0,69 cm. The metal pad flows around protrusions. Eddies due to boundary layer separation are beneficial to the dissolution of alumina.

Key words: Aluminum electrolysis; novel cathode; magnetohydrodynamics; wave; eddy

INTRODUCTION

In a typical Hall - Héroult cell, direct electrical current passes through anodes, electrolyte and carbon cathodes, and conducts out of the cell through steel collector bars. Intense magnetic flux density (*B*) created due to high current in the busbars interacts with the current density vectors (*J*) flowing in the molten metal to generate magnetohydrodynamics (MHD) forces [1], which causes the metal flow and deform. The stability of the bath - metal interface plays an important role in energy - saving, which has attracted considerable interest amongst researchers.

Tarapore [2] took the lead in coupling electric - magnetic - flow field sequentially calculated two - dimensional turbulent flow field with electromagnetic force as source of Navier - Stokes equations. Mooney et al. [3] emphasized the computational electromagnetic aspects associated with the motion of the free surface, using operator splitting and conjugate gradient methods, calculated the two - way coupling between liquid flow and evolution of the electromagnetic field. Bojarevics et al [4], Doheim et al. [5], and Wang et al. [6] calculated effect of electromagnetic force and gas bubbles on the flow of the metal and bath, which makes significant progress in the theoretical modeling of the instability. In some investigations, design modifications to the cathode [7] and busbar configuration [8] were suggested in order to render the current density more uniform.

Unfortunately, in the industrial tests, both inert - anode aluminum reduction cell and drained cathode cell can’t significantly reduce the power consumption. In 2008, the novel cathodes with stepped protrusions were applied to three 168 kA cells in Chongqing smelter and successfully tested [9]. After 2010, Feng proposed the novel cathodes with cylindrical protrusions. In this study, electromagnetic field and flow field of the novel cathode with cylindrical protrusions were calculated with ANSYS and CFX to provide a theoretical basis for the optimization of structure.

MATHEMATICAL MODELS

For electromagnetic analysis in ANSYS, electric potential is solved from the Laplace equation

$$\nabla[\sigma\nabla V] = 0 \qquad (1)$$

where σ is electrical conductivity / Sm^{-1}, V is electric potential / V, ∇ is gradient.

The current density is calculated from equation (2).

$$J = -\sigma\nabla V \qquad (2)$$

where J is current density / Am^{-2}.

The magnetic field is calculated using Maxwell equations.

$$\nabla \times H = J \qquad (3)$$

$$B = \mu H \qquad (4)$$

where H is magnetic field strength / Am^{-1}, B is the magnetic induction / T, μ is permeability / Hm^{-1}.

The volumetric electromagnetic forces in the liquids are now obtained as the vector product of the current density and the magnetic induction

$$T_{EM} = J \times B \qquad (5)$$

F_{EM} - electromagnetic force / N.

Melt flow in aluminum reduction cell is considered as incompressible. In this study, gas bubbles are not taken into account.

Navier - Stokes equations:

$$\rho\left(\frac{\partial v}{\partial t} + v\nabla v\right) = -\nabla p + \mu_{eff}\left(\nabla^2 v\right) + \rho g + F_{EM} \qquad (6)$$

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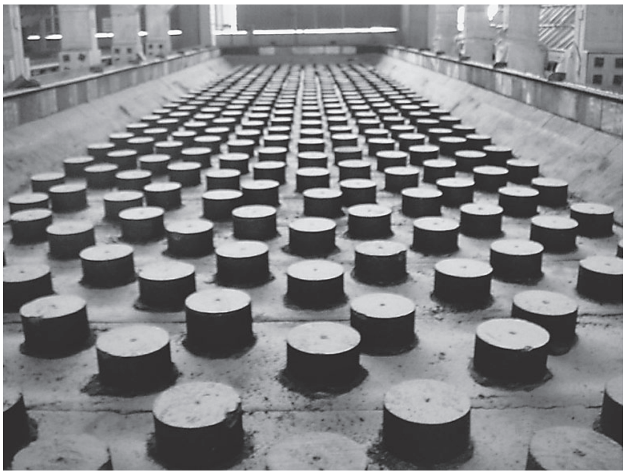


Figure 1 Novel cathode structure

g - acceleration of gravity / ms^{-2};
p - pressure / Pa; t - time / s;
v - velocity / ms^{-1};
μ_{eff} - effective dynamic viscosity / Pas.

k - ε turbulence models and homogenous flow model were employed to calculate flow field. VOF (Volume of fluid) method was used for interface tracking – Table 1.

Figure 1 shows novel cathode structure.

Table 1 **Computational parameters**

Computational parameters in CFX	
Metal height / m	0,24
Bath height / m	0,215
Anode cathode distance (ACD) / cm	5
Surface tension / Nm^{-1}	0,56

RESULTS AND DISCUSSION

Figure 2 shows horizontal electromagnetic force at 2/3 height of the metal pad. The symmetrical rotary electromagnetic force field is shown within the cell. The forces generated because of the vertical magnetic field component and internal current density distribution are the dominating driving forces of metal flow. The horizontal electromagnetic force is higher near the wall attributed to the presence of external busbars. The maximum horizontal electromagnetic force in novel cell was predicted to be 123 Nm^{-3}, which was reduced by 21 % as compared to 156 Nm^{-3} in traditional cell.

Figure 3 shows the flow fields at 2/3 height of the metal pad. The flow field is turbulent and time dependent. The maximum velocity decreased by 41 % in novel cell. The results show two large reverse vortices in the metal pad. The velocity is higher near the sidewalls in the longitudinal direction and decreases toward the center of the vortices as the impact of force in flow would be significant (Figure 2).

Because of enormous amount of grids, part of the flow field is enlarged to get flow details around protrusions. Figure 4 is sectional flow field in the middle of the metal pad, indicated by rectangle in Figure 3 (b). Metal flow around cylinder protrusions can reduce fluid kinetic energy. Due to the viscosity of the flow, the boundary layer exists in a thin region near the wall. When the pressure rises in the direction of the flow, i.e. the adverse pressure gradient, the boundary layer tends to separate from the body face and form a re - circulating flow region characteristic of separated flows. Eddies around the protrusions are present in Figure 4. The eddies can enhance the dissolution of alumina, stirring alumina sunken on the carbon cathodes to reduce anode effect caused by local lower alumina concentration.

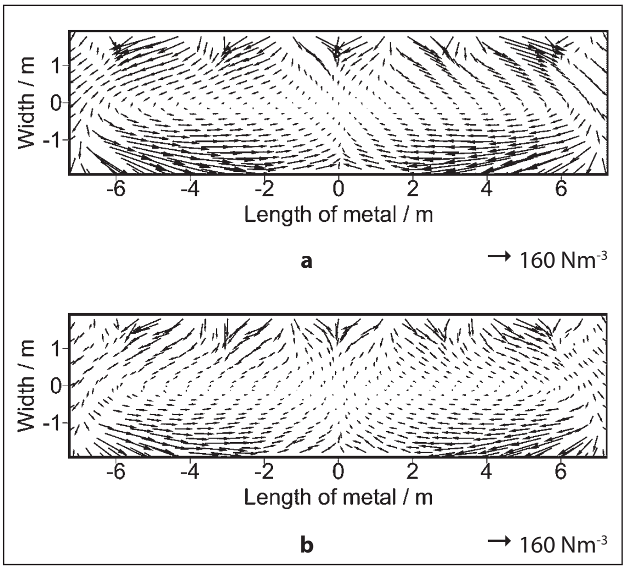


Figure 2 Horizontal electromagnetic force at 2/3 height of the metal pad / Nm^{-3} a) traditional cell b) novel cell

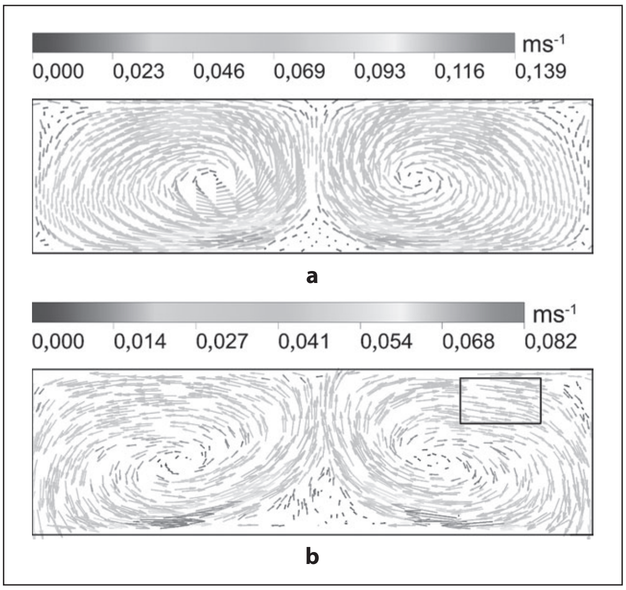


Figure 3 Flow field at 2/3 height of the metal pad, t = 100 s a) traditional cell b) novel cell

Figure 5 is bath - metal interface shape. Trough and crest are the lowest and highest points of the interface. The electromagnetic force drives the metal flow and form two large heaves located near 1/4 and 3/4 length of the cell. The radial component of the electromagnetic force pushes the metal toward the center of the cell, which is the main cause of the heave in the aluminum cell [10]. The wave data is shown in Table 2.

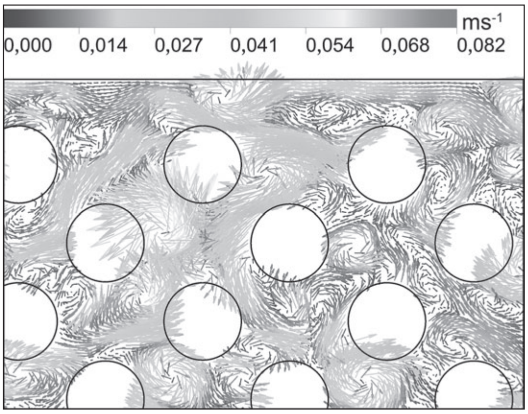
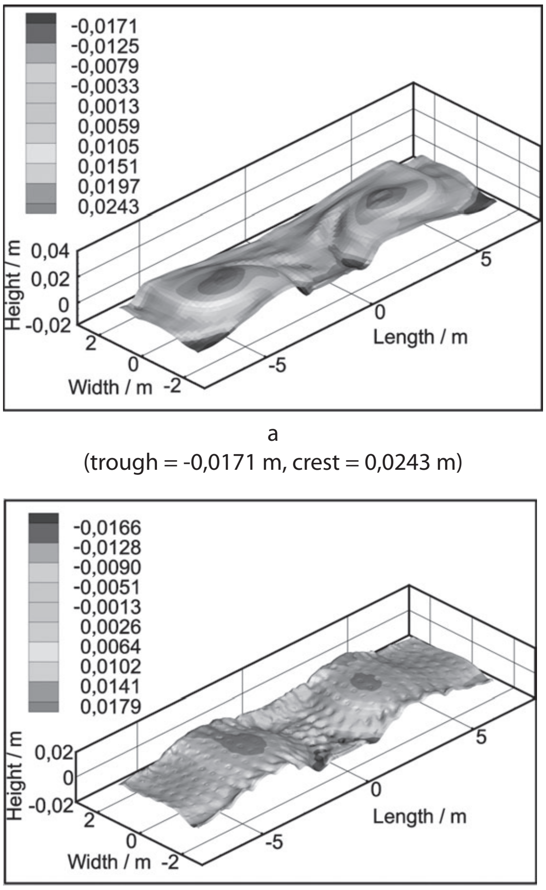


Figure 4 Sectional flow field in the middle of the metal pad in novel cell, t = 100 s



a
(trough = -0,0171 m, crest = 0,0243 m)

b
(through = -0,0166 m, crest = 0,0179 m)

Figure 5 Metal - bath interface shape, t = 100 s
a) traditional cell b) novel cell

Table 2 **MHD parameters in the metal**

Parameters	a	b
Maximum velocity / cms^{-1}	13,9	8,2
Percentage above 8 cms^{-1} / %	14,5	0,88
Percentage below 2 cms^{-1} / %	53,8	58,0
Heave (crest - through) / cm	4,14	3,45

a) traditional cell b) novel cell

Table 2 gives MHD parameters in the metal. The metal - bath interface wave decreased by 0,69 cm in novel cell. At reduced bath - metal interface, voltage fluctuation decreases and current efficiency is improved. The industrial production data in the plant shows that more than 1 000 kWh / ton aluminum in novel cell is saved.

CONCLUSIONS

A three - dimensional steady state and transient MHD model of 300 kA novel cell was developed and simulated by coupling ANSYS and CFX. Results show that by using the novel cathode, the maximum horizontal electromagnetic force and velocity at 2/3 height of the metal pad were reduced by 21 % and 41 % respectively, and the metal - bath interface wave decreased by 0,69 cm. The metal pad flows around protrusions and eddies due to boundary layer separation are beneficial to the dissolution of alumina. This indicates that cathode with cylindrical protrusions can effectively reduce the wave and power consumption.

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Note: The responsible translator for English language is Shaohu Tao, Northeastern University, Shenyang City, China