# EFFECT OF ELECTROMAGNETIC FIELD ON THREE-PHASE FLOW BEHAVIOR

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*Summary*

The multi-phase transport phenomena frequently take place in metallurgical processes, for example, in electrolysis process of magnesium, where there exists three-phase flow including liquid magnesium, molten electrolyte and chlorine gas under the electromagnetic field. In this paper, the three-phase flow behaviors under the electromagnetic field were investigated by CFD simulation. Ansys 11.0 was used to calculate electromagnetic field and Lorentz force; FLUENT6.3 was used in flow field simulation of three phase flow, where Lorentz force was added to fluid dynamic equations as the momentum source term, in order to research the effect of electromagnetic field on three-phase flow behavior.

*Keywords:* Three-phase flow; Electromagnetic field; CFD simulation; electrolysis of magnesium

## Introduction

With the development of powerful CFD solver and faster and cheaper computers, multiphase flow models have been improved significantly during the last decade, and some complex multiphase flow behaviors also can be predicted by numerical simulation[4-7]. In this paper, the three-phase flow behaviors under the electromagnetic field will be investigated by CFD simulation and PIV measurement. These complex transport phenomena frequently take place in the metallurgical processes. For example, in the electrolysis process of the molten magnesium salt, the current above 400kA, magnesium is produced from cathode as droplets, while the by-product chlorine gas is produced from anode as bubbles, both trying to rise the surface of the electrolyte as a result of the density difference with the electrolyte, so a three-phase flow under the stronge electromagnetic field will be formed in the electrolytic cell. In this work, we focus the research on the three-phase flow behavior in the advanced diaphragmless electrolytic cell, where the cell with the dimension 2.91x1.87x1.40m, 8 anodes with dimension 0.95x1.14x0.15m, 9 cathodes with dimension 0.95x1.05x0.05m, and the anode and cathode distance as 0.07m. Firstly, the numerical simulations on the electric field and the magnetic field are done, respectively, where the order coupling method to calculate the coupled field is adopted and the current distribution is regarded as the input of the magnetic field distribution. Ansys 11.0 software is used in the simulation for calculation of electromagnetic field. Fluent6.3 was used in flow field simulation. Lorentz force was added as the momentum source term in order to combine the effects of magnetic field on flow field.

## Mathematical Model and Calculation Procedure

**Fluid dynamics equations for three-phase flow:**

Fluid dynamics is based Navier–Stokes equations, for multi-phase, volume of fluid (VOF) is an effective method for the calculation of the three-phase flow field in magnesium electrolyzer. The equation has the following forms:

Continuity equation

$$\frac{1}{\rho_q}\left[\frac{\partial}{\partial t}\left(\alpha_q\rho_q\right)+\nabla\cdot\left(\alpha_q\rho_q\vec{v}_q\right)=S_{\alpha q}+\sum_{p=1}^{n}\left(\dot{m}_{pq}-\dot{m}_{qp}\right)\right] \quad (1)$$

The volume fraction equation will not be solved for the primary phase; the primary-phase volume fraction will be computed based on the following constraint:

$$\sum_{q=1}^{n}\alpha_q=1 \quad (2)$$

Considering the effects of electromagnetic field on the multiphase flow field, the Lorentz force was added to momentum equation as source term:

$$\frac{\partial}{\partial t}\left(\rho\vec{v}\right)+\nabla\cdot\left(\rho\vec{v}\vec{v}\right)=-\nabla_p+\nabla\cdot\left[\mu\left(\nabla\vec{v}+\nabla\vec{v}^T\right)\right]+\rho\vec{g}+\vec{F} \quad (3)$$

Where F is the Lorentz force $F=J\times B$.

Based on Maxwell equations and Ohm’s law, the Lorentz force can be calculated in advance. The differential forms of Maxwell partial differential equations are described as follows:

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$$\nabla \times H = J + \frac{\partial D}{\partial t} \quad (4) \qquad \nabla \times E = -\frac{\partial B}{\partial t} \quad (5)$$

$$\nabla \cdot D = \rho \quad (6) \qquad \nabla \cdot B = 0 \quad (7)$$

The detail procedures of calculation for three phase flow field under electromagnetic field are show in figure 1.

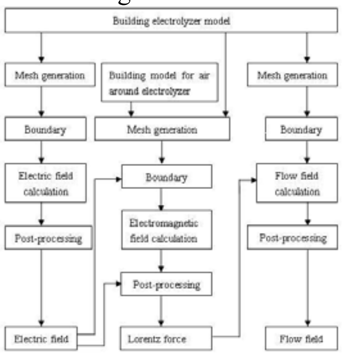


**Figure 1.** Calculation procedures for multi-phase flow field under electromagnetic field.

# CFD simulation on three phase flow field with and without the effect of electromagnetic field

### Structure, Dimension and Grid for CFD simulation

The advanced diaphragmless magnesium electrolytic cell is with the dimension 2.91×1.87×1.40m, 8 anodes with dimension 0.95×1.14×0.15m, 9 cathodes with dimension 0.95×1.14×0.05, and the anode and cathode distance as 0.07m. Grids for CFD simulation are shown in Figure 2(b).

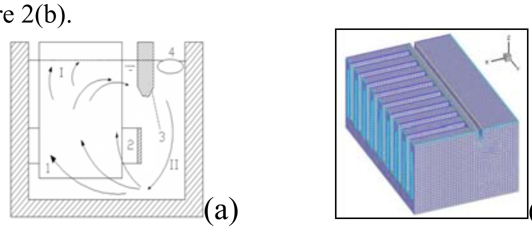
(a) (b)

**Figure 2.** Structure of the advanced diaphragmless magnesium electrolytic cell and Grid of calculation domain for the electromagnetic field and the flow field.

### Calculation of Lorentz forces

Based on Maxwell equations and Ohm's law, the Lorentz force under the electrolytic field is calculated. The typical results are shown in Figure 3. It is found that Lorentz force distributes vertically symmetrical along the electrolysis compartment, decreasing gradually from the end toward the middle, and the maximum Lorentz force reaching 0.0135N at corner.

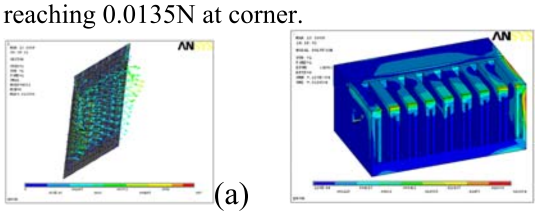
(a) (b)

**Figure 3.** Vectors of Lorentz force in special plane (a) and contours of Lorentz forces in the whole cell (b).

### Comparisons of three-phase flow behaviors with and without the effect of electromagnetic field

The typical flow fields under electromagnetic field are shown in figure 4. It showed that the whole circulation distributes symmetrically along the electrolyzer. Liquid magnesium can be delivered effectively to the collection compartment by electrolyte circulation B, which paralleled with surfaces of electrodes.

Furthermore, three phases flow behaviors with and without the effect of electromagnetic field will be researched by the CFD simulation. Comparing two typical results of flow field, the suggestion will be given how to strengthen transportation of magnesium from electrolysis compartment to collection compartment.

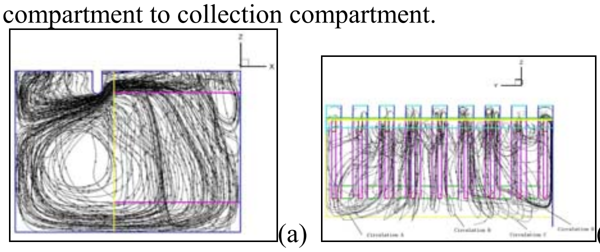
(a) (b)

**Figure 4.** Streamlines of flow field in particular plane (a) Streamlines of flow field in the whole electrolytic cell (b).


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