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Dimensional Analysis in Cold Water Model Experiments of New Cathode Structure Aluminum Cell

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Abstract

Compared with the traditional cathode structure cell, the new cathode structure cell can restrain the level fluctuations of aluminum liquid, effectively reduce polar distance and decrease cell voltage, it makes greatly electricity saving into reality. In this paper, using cold water model experiment based on principle of similitude to study the level fluctuations by anode gas disturbance, and investigate the rules of level fluctuations in new cathode structure electrolytic cell. Numerical simulation of the anode structure with Fluent was also carried out. Simulation results are basically consistent with experimental results, which can verify possibilities of using Fluent to investigate fluctuations in the interface of cell. According to the analysis of experimental data, the empirical formula of amplitude are obtained by using dimensional analysis, which are associated to a variety of material factors, operating factors, equipment factors. After the theoretical analysis, Dimensionless equation is in good agreement with experimental results.

Introduction

With the support of National Natural Science Foundation and the"863 Project", based on the cathode and anode structure of new cathode structure cell and the scientific theory of process and technical operation, Northeastern University studies the influence of new cathode structure and anode structure on the fluctuations of aluminum liquid systematically, and comes up with a scientific theory which realizes minimum fluctuation in the process of aluminum electrolysis in new cathode structure cell [1-3]. The new cathode and anode structure changes the flow field and thermal field of aluminum reduction cell, Zhejiang Huangdong Aluminium Co., Ltd. has used the new cathode structure cells for 6 months, and achieved good results, the average current efficiency of the 94 cells is 93.105%, integrated AC power consumption is 12790kW•h/t Al[4]. Chongqing Tiantai Aluminium Co., Ltd. has did industry cell test on 168A cell, the average cell voltage of the 3 experimental cells during the observation period is 3.803V, the average direct current consumption of the 3 experimental cells is 12101kW•h/t Al, and it is 1250kW•h/t Al lower than the other 127 traditional cells of the same series[5]. Ziqian Wang etc. has also analyzed the mechanism of efficient energy saving aluminum cell[6]. For further study of the influence of new cathode on fluctuations of aluminum liquid, water model experiments are conducted by similarity principles in this paper the first time, physical simulation and mathematical simulation are combined to study the influence on the fluctuations caused by anode gas disturbance in the cell, the optimized cathode and anode structure can be selected in laboratory, and the optimal new cathode and anode sizes can be determined by physical and mathematical simulation of water model, dimensionless equation which relate to physical parameters, structure parameters, operating parameters and aluminum liquid amplitude, is constructed by dimensional analysis method, the results can provide scientific data and theoretical basis for the industrialization of the new cathode structure cell.

Experimental Principle and Equipment

<u>Devices of water model experimental</u>

<u>Hydraulic Pressure Equipment</u> Based on the practical field production situation, an investigation is made on aluminum electrolysis process, the concerned date which is about aluminum cell size and production operating parameters is collected [7-9], according to the practical aluminum electrolysis process, an aluminum cell of an aluminum plant is selected as the experimental prototype of the water model, based on the industrial production situation and the important sizes of the

equipment in practical production, the rate between the experimental model devices and the real equipment is made sure to be 1:3, the experimental cell, new structure cathode and new structure anode are made by synthetic glass based on the rate. A hydraulic pressure control system is designed and made for stably lifting of the anode-cathode distance.

Fig.1 is physical model photograph and Fig.2 is devices of water model experimental.

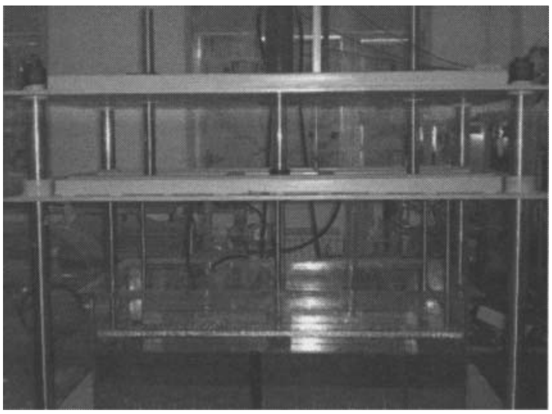
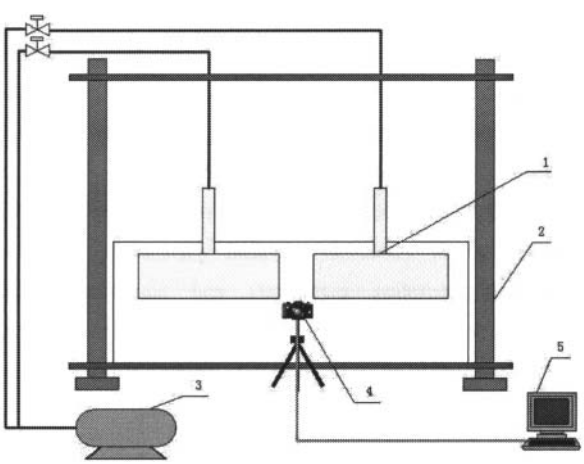
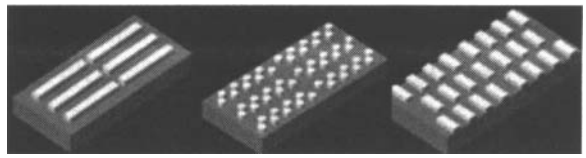


Fig.1 Physical model photograph



1-Anode carbon block; 2-Hydraulic lifting device;
3-Air compressor; 4-High-speed camera; 5-Computer
Fig.2Devices of water model experimental

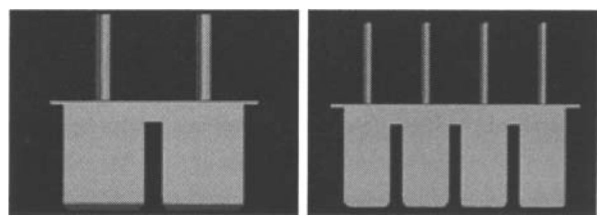
<u>The Different Structures of the Cathode and Anode</u> The structures of the three new cathode used in experiment are shown in Figure 3.



(a)New cathodes A (b)New cathodes B (c)New cathodes C
Fig.3 New cathodes with different structures

The anode used in experiment includes a common anode and four kinds of new type anodes.

Fig.4 shows the two structures of new anodes, respectively, that are 1/2 anode with chamfer and 1/4 anode with chamfer. The other two structures of new anodes respectively are 1/2 anode without chamfer and 1/4 anode without chamfer.



(a) 1/2 anode with chamfer (b) 1/4 anode with chamfer
Fig.4 New anodes with different structures

In this paper, combine with cold water model experimental results and draw lessons from the results of previous research, the experimental target parameters. the primary influence factors of fluctuation amplitude, are analyzed and summarized. For some similar phenomena, they must maintain the similarity criteria and the same criteria relationship. Through the analysis of experimental data, the empirical formula of amplitude are obtained by using dimensional analysis, which are associated to a variety of material factors, operating factors, equipment factors.

Dimensional analysis in interface fluctuation of new cathode structure of aluminum electrolytic cells

<u>The primary influence factors that effected the fluctuation amplitude A in aluminum electrolytic cells</u>

Through the analysis of experimental data, we can know the fluctuation amplitude A of aluminum interface effected mainly by the following factors:

(1) A increase with the increasing of gas flow rate Q, that is

A ∝ Qa;

(2) A decrease with the increasing of polar distance d, that is A ∝ db;

(3) A decrease with the increasing of the electrolyte level h, that is A ∝ hc;

(4) Summarize previous research on the interface fluctuations, we found the fluctuation amplitude have also related to the aluminum liquid level H; the density difference between water and oil Δρ; the viscosity of water μ1; water-oil surface tension σ, the viscosity of the oil μ2 and other factors, but they are constant in this experiment, so we would not give detailed discussion no longer.

From the above analysis, using dimensional analysis methods, the general function form can be drawn as follows:

$$A = f(Q, H, h, d, \Delta\rho, \mu_1, \mu_2, \sigma, g)$$

or:

$$f(A, Q, H, h, d, \Delta\rho, \mu_1, \mu_2, \sigma, g) = 0 \qquad [1]$$

Various dimensionless variables was list in table1:

Table1 Dimensions of variables

	A	Q	h	d	H	μ_1	μ_2	$\Delta\rho$	σ	g
M	0	0	0	0	0	1	1	1	1	0
L	1	3	1	1	1	-1	-1	-3	0	1
T	0	-1	0	0	0	-1	-1	0	-2	-2

Establishment of the Dimensionless Equation Formula of Undetermined Parameter

According to the analysis theory of the π theorem, the total number of variable n=10 and number of independent variable k=3 is known in this paper, which can create n-k=7 dimensionless parameter of the combination. If H、σ and Δρ is selected as independent variable, that variable A, h and d only contains dimensionless length. So the constructor of dimensionless π theorem can be expressed with the independent variable H. π can be expressed in all out.

For π_0, dimensionless relationship can be obtained into various dimensionless variable:

$$\left[M^0L^0T^0\right] = [L]^{\alpha_0}\left[MT^{-2}\right]^{\beta_0}\left[ML^{-3}\right]^{\gamma_0}\left[L^3T^{-1}\right] \qquad [1]$$

so:

$$M: 0=\beta_0+\gamma_0$$

$$L: 0=\alpha_0-3\gamma_0+3$$

$$T: 0=-2\beta_0-1$$

Solve for: $\alpha_0=-3/2$, $\beta_0=-1/2$, $\gamma_0=1/2$, so:

$$\pi_0 = H^{-\frac{3}{2}}\sigma^{-\frac{1}{2}}\Delta\rho^{\frac{1}{2}}Q$$

can be also written as:

$$\pi_0 = \frac{\Delta\rho Q^2}{H^3\sigma}.$$

Similarly available:

$$\pi_1 = \frac{\mu_1^{\ 2}}{H\sigma\Delta\rho},\quad \pi_2 = \frac{\mu_2^{\ 2}}{H\sigma\Delta\rho},\quad \pi_3 = \frac{H^2\Delta\rho g}{\sigma}$$

so:

$$f\left(\frac{\Delta\rho Q^2}{H^3\sigma}, \frac{\mu_1^{\ 2}}{H\sigma\Delta\rho}, \frac{\mu_2^{\ 2}}{H\sigma\Delta\rho}, \frac{H^2\Delta\rho g}{\sigma}, \frac{A}{H}, \frac{d}{H}, \frac{h}{H}\right) = 0 \qquad [3]$$

It can be also written as a form of the explicit function.

$$\frac{A}{H} = f\left(\frac{\Delta\rho Q^2}{H^3\sigma}, \frac{\mu_1^{\ 2}}{H\sigma\Delta\rho}, \frac{\mu_2^{\ 2}}{H\sigma\Delta\rho}, \frac{H^2\Delta\rho g}{\sigma}, \frac{d}{H}, \frac{h}{H}\right) \qquad [4]$$

Where H, Δρ, μ1, σ, μ2 and g is quantitative, so:

$$\frac{A}{H} = kf\left(\frac{\Delta\rho Q^2}{H^3\sigma}, \frac{d}{H}, \frac{h}{H}\right)$$

The specific changes between

$$f\left(\frac{\Delta\rho Q^2}{H^3\sigma}, \frac{d}{H}, \frac{h}{H}\right)$$

and

$$\frac{\Delta\rho Q^2}{H^3\sigma}, \frac{d}{H}, \frac{h}{H}$$

need to be determined by experiment.

Determination of the Dimensionless Equation

According to the expression (4) and experimental results, Empirical Formula could be set up. In this work, different structures of anode and cathode had the same form of the formula base on the Dimensional analysis but the results of

Empirical Formula were different.

Empirical Formula could be expressed as a power function of the argument within a certain range. Empirical Formula could be expressed as fellow:

$$\frac{A}{H}=K\left(\frac{\Delta\rho Q^2}{H^3\sigma}\right)^x\left(\frac{d}{H}\right)^y\left(\frac{h}{H}\right)^z \quad [5]$$

where: K, x, y and z were the fitting coefficients.

Making the logarithmic transformation of expression (5) could get expression (6):

$$ln\frac{A}{H}=ln K+x\,ln\frac{\Delta\rho Q^2}{H^3\sigma}+y\,ln\frac{d}{H}+z\,ln\frac{h}{H} \quad [6]$$

According to the expression (4) and experimental results, the value of the fitting coefficients could be get as fellow:

K=0.019226, x=0.019226, y=-0.54706, z= -1.07766,

so:

$$\frac{A}{H}=0.019\left(\frac{\Delta\rho Q^2}{H^3\sigma}\right)^{0.26}\left(\frac{d}{H}\right)^{-0.55}\left(\frac{h}{H}\right)^{-1.08} \quad [7]$$

Analysis and Discussion of Dimensionless Equation with Wave Amplitude

Effects of Gas Flow in Amplitude under Different Anode-cathode Distances

Aluminum liquid level H=170mm, electrolyte levels h=160mm, The gas flow respectively is 0.6m3/h、0.7m3/h、0.8m3/h、0.9m3/h、1.0m3/h、1.1m3/h、1.2m3/h,the anode-cathode distances respectively is 30mm、35mm、40mm、45mm、50mm the density difference between oil and water $\Delta\rho$=100 kg/m3 and surface tension σ=0.02 N/m was assumed. The following formula was got by calculated:

$$A=0.04797Q^{0.51934}d^{-0.54796} \quad [8]$$

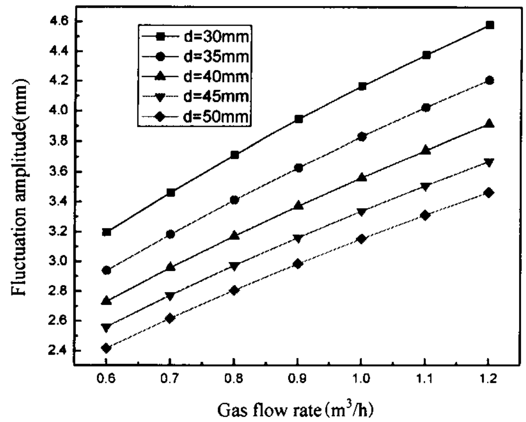


Fig.5 Effects of gas flow in amplitude under different anode-cathode distances

Figure 5 showed that the fluctuation amplitude increased with the increasing of gas flow rate under different polar distances. Because under a certain polar distances, higher gas flow rate could intensify the fluctuation of interface of the two phases.

Conclusion

The aluminum electrolysis process consumes too much electric power, the anode-cathode distance of traditional aluminum electrolysis cell has already achieved the minimum, and cell voltage can not be reduced greatly. To solve this key problem, a kind of new cathode structure technology is proposed. The characteristic and mechanism of the technology are: reducing aluminum liquid fluctuation, anode-cathode distance, cell voltage and current efficiency effectively, when the new cathode structure is applied on aluminum electrolysis cell.

When new cathode structure is applied in Zhejiang Huangdong Aluminium Co. and Ltd.,Chongqing Tiantai Aluminium Co., there is obvious reduction of average current consumption contrasting with the other traditional aluminum electrolysis cell, for further study on the wave reduction effect of the new structure cathode, the optimized cathode and anode structure is selected in laboratory.. Based on the National Natural Science Foundation" Study on fundamental theory of aluminum electrolysis in new cathode structure aluminum cell", this paper uses the cold water model, and focuses on the aluminum liquid and interface fluctuation in new cathode structure aluminum cell, by analyzing experimental data with dimensional analysis method, the amplitude of fluctuation dimensionless equation relating to physical factors, operating factors and equipment factors is obtained, the main conclusion is as follows: by observing and analyzing the main factors influencing the amplitude of fluctuation in water model experiment, the specific influence parameters are enumerated. Formula of similitude-criterion is established based on homogenized principle and Buckingham theorem, so the corresponding fitted numbers is obtained from each disposed concrete experimental data, and then the amplitude of fluctuation dimensionless equation:

$$\frac{A}{H}=0.019\left(\frac{\Delta\rho Q^{2}}{H^{3}\sigma}\right)^{0.26}\left(\frac{d}{H}\right)^{-0.55}\left(\frac{h}{H}\right)^{-1.08}$$

Based on the dimensionless equation, analyzing the influence of gas flow rate on the amplitude of interface fluctuation theoretically, the dimensionless equation about the influence of gas flow rate on the amplitude of interface fluctuation is obtained.

$$A=0.04797Q^{0.51934}d^{-0.54796}$$

The results getting from the dimensionless equation through dimensional analyzing theoretically is the same as the experimental results.

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