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STUDY OF ACD MODEL AND ENERGY CONSUMPTION IN ALUMINUM REDUCTION CELLS

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Abstract

In this paper a model of the anode-cathode distance (ACD) is built according to actual production in traditional aluminum reduction cells. The critical ACD is also studied here. Based on the ACD model and the critical ACD it can be described why some cells can produce at low cell voltage in the present aluminum industry. It is possible that only 9500 kWh/t of DC energy will be required at 2.0 cm ACD and 0.8 A/cm^2 anode current density.

Introduction

Energy consumption for one ton of aluminum produced in Hall-Heroult cells can be calculated from the following formula:

$$W=2980*U/\eta$$

Here, W is the direct current (DC) power consumption in kWh per ton, and U is cell operating voltage drop in volts, and η represents current efficiency (CE).

Cell operating voltage drop is composed of several parts shown in table 1.

Table 1 Typical example of cell operating voltage compositions (for 0.75 A/cm^2 anodic current density)

	Voltage Drop/V
Anodes	~0.33
Cathodes	~0.32
Busbars	~0.2
Reaction	~1.20
Polarization	~0.45
Bath	~1.55
Total	~4.05

Note: semigraphitic blocks are used as cathodes here.

Based on the bath voltage drop, U_b, and resistivity, R_b, the anode-cathode distance (ACD) can be calculated:

$$ACD= U_b/(C_d \times R_b)$$

Here, C_d means current density.

The value of R_b can be found in the literature [1]. For example, it is suggested that R_b is 0.47Ω•cm when the cell is operated at 950℃ with bath composition of 2.3 molar ratio, with 2%~3% alumina and 5% CaF_2. If U_b is 1.55 V:

$$ACD = 1.55/ (0.75\times0.47) = 4.4 \text{ cm}$$

Tian Yingfu studied the optimum ACD for a cell operated at more than 4.2 V, and he introduced a model for ACD [2]. According to that, it is suggested that the optimum ACD is 4.2 to 4.5 cm for traditional cells operated at a voltage of 4.0 to 4.1 V.

However, according to a recent study [3], a 180 kA potline, where the current has been increased by 25 kA, has achieved 93.48% CE at 3.83 to 3.88 V, with 0.83 A/cm^2 anodic current density. The bath composition is listed in table 2.

Table 2 The bath composition used for the amperage increase study

Molar ratio	Al_2O_3 concentration	CaF_2 content	LiF content
2.5	2.07%	5%	3%

For one cell in the 180 kA potline operated at 935℃, the voltage drops are listed in table 3.

Table 3 The voltage drops

Cathode voltage drop	0.376 V
Anode voltage drop	0.349 V
Drops in all bars	0.259 V
Voltage drop between anode and cathode	2.902 V
Cell voltage drop	3.887 V

The voltage drop between anode and cathode listed the table 3 includes decomposition voltage, polarizing voltage and bath voltage. If the decomposition voltage and polarizing voltage is 1.65 V, the bath voltage is 1.253 V. According to the literature 1, the resistivity is 0.44Ω.cm, and thus:

$$ACD=1.2526/(0.44\times0.83)=3.43 \text{ cm}$$

Therefore, there are two questions: how much is the ACD with high CE, and how much is the lower of energy consumption.

The three layers ACD model

In order to answer the questions above, a model of ACD, named three layers ACD, is introduced. It is assumed that the ACD is made up of b, c and a, present the height of three layers: the top layer of bath mixed with anode bubbles, the middle transition bath layer, and the bottom metal pad fluctuation layer, respectively, shown in figure 1. So h, the value of ACD, should be equal to sum of a, b and c.

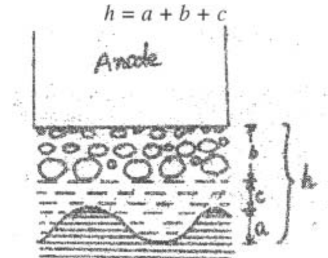

Fig. 1 Schematic diagram of the three layers ACD model

The value of a is dependent on the stability of the magnetofluid and the height of metal pad. For example, a is lower with steady magnetofluid and reasonable bars distribution. In addition, it is also lower with a larger height of the metal pad, which causes it to flow slowly and weakens the waves. The value of a is ordinarily lower than 1.5 cm. For example, with a 1.42 cm height of the aluminum waving layer, the maximum value for the Chongqing Tiantai cells designed by Shenyang Aluminum & Magnesium Engineering & Research Institute, was taken into account [4].

The value of b is dependent on the width of the anode carbon and the immerged depth in the bath, the density and viscosity of the bath, and the surface tension of the bath to anode bubbles. The b layer would become thin due to the anode gas discharging in time under the following cases, reducing the width of the anode carbon, or decreasing the bath level, or using the low-density bath, or using the low-viscosity bath, or using the bath with high surface tension. For a commercial cell with 660 mm wide anode, the b layer is about 2 cm thick [5, 6].

In order to avoid the reaction occurring between anode gas and aluminum produced, the c layer should exist to separate the a layer and the b layer. However, the bath voltage drop would be higher with an increase of the c. For a commercial cell with a total voltage of more than 4.0 V, if C_d is less than 0.75 A/cm^2, the value of c is about 1 cm. For example, a cell operated with 0.72 A/cm^2 C_d and 1.55 V ACD voltage drop, if R_b is 0.47 Ω•cm, the ACD, h, is calculated by the following equation:

$$H = 1.55/(0.47\times0.72) = 4.58 \text{ cm}$$

So, the value of c,

$$C = h\text{-}a\text{-}b = 4.58\text{-}1.5\text{-}2 = 1.08 \text{ cm}$$

Therefore, if c is small, the cell voltage drop would be decreased.

The Critical ACD

Based on the three layers ACD model as mentioned above, h would become smaller when c decreases. When it decreases to zero, h would reach its critical value, named the critical ACD. So for a commercial cell the critical ACD, 3.5 cm, is equal to sum of a and b as:

$$hc = a + b = 1.5 + 2 = 3.5 \text{ cm}$$

If the cell is designed badly for the magnetic field or it is operated poorly, the height of the metal pad fluctuation layer would be more than 1.5 cm, and hc would be higher than 3.5 cm.

For a commercial cell with an optimal design of the magnetic field, a can be diminished to 1 cm, so hc would be close to 3 cm. In order to keep a high CE, it is suggested that the c layer should be 0.5 cm high, so the cell voltage drop would be less than 3.85 V. This has already come true in China.

For the novel structured cathodes (the NSC cells), invented by Professor Feng Naixiang [7], the height of the metal pad fluctuation layer could be controlled to less than 0.7 cm, so hc should be less than 2.7 cm. Therefore, for the NSC cell operated at 2.7 cm hc and with 0.72 A/cm^2 C_d and 0.45 Ω•cm R_b, the cell voltage drop could be 3.42 V, which is almost the same as the critical cell voltage drop, 3.428 V, measured by Yang Xiaodong, professor at SYAMI, China [8]. In that experiment, the cell voltage drop is decreased till the critical value, at which the cell become very unstable, or noisy..

DC consumption for aluminum production

Based on the three layers ACD model, in order to reduce the DC consumption for one ton of aluminum produced, the three heights should be decreased as much as possible. For the NSC cells the metal pad fluctuation height is less than 0.7 cm, as mentioned above, so c may be reduced to 0.5 cm in order to decrease the bath layer voltage drop without any CE loss, and the ACD can be controlled at about 3.2 cm. The cell voltage drop would reach 3.709 V with 0.8 A/cm^2 C_d and 0.45 Ω•cm R_b. So the DC consumption of aluminum producing in the NSC cell would then be 11760 kWh/t-Al with 94% *CE.*

Based on the ACD model, if the anode is optimized to reduce the height of the b layer, for example, by diminishing the gas bubbles by reducing the width of the anode, or by other methods releasing the anode gas in time. The voltage drop of the b layer can be decreased by 0.3 V due to the height decreasing to 1 cm from 2 cm. It means that the DC consumption can be decreased by about 1000 kWh/t-Al. In addition, the anodic overvoltage can be decreased also with decreasing of the b layer.

Therefore with the method decreasing b and some optimal technology, for example, using graphitized blocks and decreasing contact voltage drop of Fe-C in anodes, the NSF cell can operate at less than 3.0 V cell voltage, and the DC consumption for aluminum producing would not be more than 9500 kWh/t-Al. It means that the energy efficiency would reach 66%.

References

1. Zhang Mingjie, Qiu Zhuxian. Advanced Technology of Aluminum Electrolysis (in Chinese). 2001.

2. Tian Yinfu. Discussion on Best polar distance of industrial aluminum cell (in Chinese). Non-ferrous mining and metallurgy, Vol. 25(6), 2009: 23-25.

3. Li Jie. A report on *Meeting of New Cathode Aluminum Reduction Cell Technology*. Shenyang, 2010.

4. Shenyang Aluminum & Magnesium Engineering & Research Institute. Design scheme of Chongqing Tiantai Aluminum smelter, 2009.

5. Zoric J, Solheim A. On gas bubbles in industrial aluminium cells with prebaked anodes and their influence on the current distribution [J], Journal of Applied Electrochemistry, 2000, 30: 787-794.

6. Zhou Naijun, Xia Xiaoxia. The research development of electrolyte flow in aluminum reduction cell and its direction to the research on flow field in drained cell (in Chinese). Light metals, 2004, (12): 26~32.

7. Feng Naixiang. Aluminum reduction cell with novel cathodes[P]. CN 200720012231.X

8. Yang Xiaodong. A report on *Meting of New Cathode Aluminum Reduction Cell Technology*. Shenyang, 2010.