

## TOWARDS DECREASING ENERGY CONSUMPTION OF ALUMINUM REDUCTION BY USING ANODES WITH HOLES AND CHANNELS

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### Abstract

In aluminum electrolysis the energy power consumption can be decreased by lowering the cell voltage and by increasing the current efficiency. By using anodes with holes and channels, the discharge distance for the anode gas from the molten bath can be reduced. For the anode gas, the period of staying in the bath is decreased and the penetrated depth in the bath will decrease. By such measures the current efficiency of the cell can be increased and the cell voltage can be decreased. In the Qingtongxia smelter, 350 kA aluminum reduction cells are operating with anodes having holes and channels.

### Introduction

Currently, cryolite-alumina molten salt electrolysis is the main method for aluminum production. Current efficiency and direct current power consumption are used to evaluate the technology level of the electrolysis process. The DC power consumption ( $W$ ) is calculated by Equation (1):

$$W=2980*U/CE \quad (\text{kWh/t-Al}) \quad (1)$$

where  $U$  and  $CE$  is the average voltage drop and the current efficiency of the aluminum reduction cell, respectively. According to Equation (1), there are two methods to reduce the DC power consumption, i.e., to reduce the cell voltage and to improve the current efficiency. However, no matter what the capacity of the smelter is, the current efficiency is often decreased by reducing the cell voltage. Figure 1 shows a relationship between current efficiency and the cell voltage.

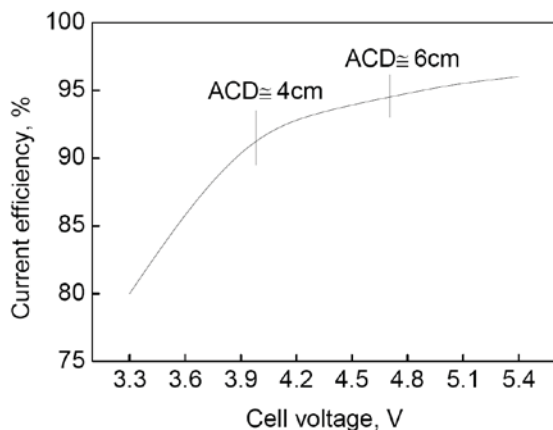


Figure 1. Relationship between current efficiency and cell voltage.

Data from Chinese smelters show that an industrial cell operated at 4.10 to 4.15 V can achieve about 94 % current efficiency. Energy consumption for aluminum production can be decreased by reducing the cell voltage, however, current efficiency will be reduced since the cell voltage is lower than 3.95 V.

According to Equation (1), energy consumption will decrease by 300 kWh per tonne aluminum with 0.1 V reduction of the cell potential. As 1 % current efficiency is lost, the energy consumption value will increase by 150 kWh/t. For a cell under the same operational conditions, reducing cell voltage means shortening anode-cathode distance (ACD). Oxidation reactions between part of the aluminum metal and the anode gas will become easier with reducing anode-cathode distance, thereby reducing the current efficiency. A reduction of 0.1 V lowers the current efficiency by 2 %, despite no difference in energy consumptions. This method of reducing the cell voltage is not advisable due to decreased primary aluminum yield.

The aluminum metal dissolved into the electrolyte can be decreased by lowering the electrolysis temperature; however, both viscosity and conductivity of the bath will change negatively. So for most plants the normal bath temperature is usually 950 to 960 °C [1]. In some Chinese smelters, the electrolysis temperature can be lowered to 910 °C as the electrolyte contains lithium fluoride and potassium fluoride, but the current efficiency of these cells is poor.

In fact the most effective way to reduce the cell voltage and improve current efficiency is to reduce the metal pad instability and the penetrating depth of the anode gas into the electrolyte. This paper presents technologies and practices for energy savings in the aluminum electrolysis.

### Effect of Fluctuation of the Aluminum Metal on Cell Voltage

Figure 2 presents interface waves between the aluminum metal and the bath and the penetration of anode gases into the bath. In Figure 2,  $l_0$  is the distance between the wave peaks and the bottom of the carbon anodes. The value of the ACD is calculated by

$$l = l_0 + h / 2 \quad (2)$$

where  $h$  is the height of the waves.

A lot of measurements show that the height of the wave between the aluminum metal and the bath is about 2.0 cm. The wave height is the most important factor in the anode-cathode distance in an aluminum reduction cell. The less the height value is, the more stable the metal pad is. For an industrial aluminum reduction cell,

operated at an invariable cell voltage, fluctuation of the interface causes the ACD to change. Results measured in aluminum reduction cells show that the cell voltage decreases by 36 to 40 mV by reducing the ACD by 1 mm. We assume that the height of waves can be decreased as much as 5 mm by improving the stabilization of the metal pad. According to Equation (2), in order to keep the same value of  $I_0$ , the carbon anodes can be lowered by 2.5 mm. This will decrease the cell voltage by 90 to 100 mV and, accordingly, save 280 to 320 kWh/t aluminum.

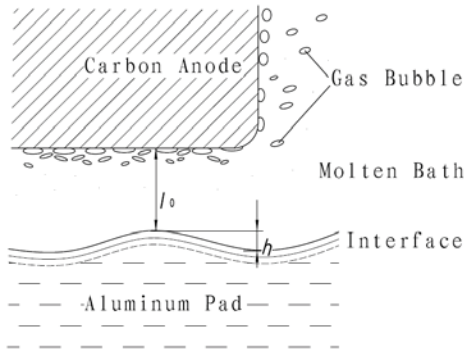


Figure 2. Wave of interface between the aluminum metal and the bath and anode gases penetration into the electrolyte

#### Causes of Movement of the Molten Aluminum Pad

For an industrial aluminum reduction cell, fluctuation of the aluminum metal is caused by:

- 1) The interaction between the magnetic force produced by the anode busbar and the cathode busbar and the horizontal current in the aluminum metal. The horizontal current in the aluminum metal is caused by an uneven current distribution in the carbon cathode, a thinner ledge or a thicker bottom freeze toe, and differences in conductivities between the aluminum metal and the cathode bars.
- 2) Anode gases generated during the aluminum electrolytic process and the bubble release from underneath the carbon anodes. The bubble release deforms the molten bath/aluminum interface.
- 3) Several operations disturb the stable aluminum pad, such as tapping of aluminum metal, anode changing and carbon dust removal.

#### Ways to Reduce Undulation of the Aluminum Pad

In order to lower energy consumption in aluminum production, improvement of the metal pad stability is one of the most important factors.

For a cell, an excellent cathode busbar design will result in a low vertical magnetic field and small gradients in the horizontal direction of the magnetic field. The design should provide an even current for all cathode collector bars.

Both a thinner ledge and a thicker bottom freeze toe cause horizontal current formation in the aluminum pad. The cathode lining design impacts the ledge profile. Too high insulation at the sidewall causes a thinner ledge. However, a thicker bottom freeze toe is a possible result of less insulation. Hence, a balanced cathode lining design is needed.

The cathode collector bar impacts the horizontal current in the aluminum pad. Figure 3 shows a schematic diagram of an aluminum reduction cell. Ideally, there are two current flow directions from position A to position B. In one alternative, current  $I_1$ , with a high horizontal factor, flows through the aluminum pad before passing through the carbon block and the ramming paste to the collector bar. In the other alternative, the current flows vertically through the carbon block and ramming paste to the collector bar at point B. The two ways may be considered as a parallel circuit, hence

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} \quad (3)$$

where  $R_1$  and  $R_2$  are the resistance of branch  $I_1$  and  $I_2$ , respectively.

Compared to the resistance in the carbon cathode and the collector bar, the resistance in the aluminum pad is very low and may be ignored, thereby,

$$R_1 = R_C \quad (4)$$

$$R_2 = R_C + R_{Fe} \quad (5)$$

where  $R_C$  is the resistance in the carbon cathode, and  $R_{Fe}$  is the resistance in the collector bar for  $I_2$ . Equation (3) can then be written as

$$\frac{I_1}{I_2} = \frac{R_C + R_{Fe}}{R_C} = 1 + \frac{R_{Fe}}{R_C} \quad (6)$$

According to Equation (6),  $I_1$  has the lowest resistance, so increasing the working area and conductivity of the collector bar can both lower  $I_1$  and the cathode voltage drop. However, the electrical conductivity tends to follow the thermal conductivity and collector bars having higher electrical conductivity and bigger area will conduct more heat. In order to maintain the heat balance of the cells, bigger area collector bars with a normal end size can be used [2], e.g. as shown in Figure 3.

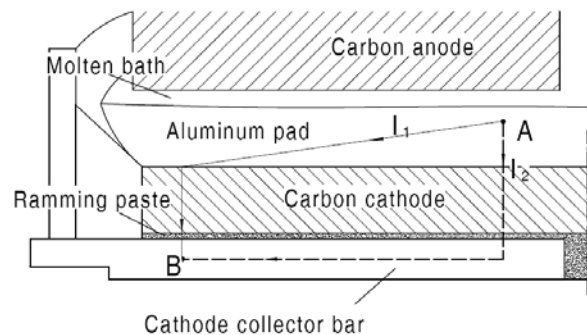


Figure 3. Schematic diagram of aluminum reduction cell using larger area collector bars.

The horizontal current in the pad is reduced when using anthracite blocks due to the higher resistance than graphitic and graphitized cathode blocks. However, graphitic and graphitized cathode blocks have the advantage of low cathode voltage drop and higher resistance to penetration of bath and sodium. In practice, there is a direct correlation between the choice of cathode materials and the

thermal balance design. For a high amperage aluminum reduction cell, high graphitic and graphitized cathodes are favorable due to better thermal conduction.

Hauptin [3] studied the effect of anode gases on voltage drop of the molten bath in industrial cells, as shown in Figure 4. In the experiment, he measured potential changes of an aluminum reference electrode versus the aluminum pad while lifting slowly the reference electrode towards the carbon anode. The results show that the potential measured is steadily increased until the distance between the reference electrode and the anode is 3.5 cm. After that, the measured potential becomes unstable due to the effect of anode bubble disturbances in the bath. Hence, for most industrial cells the ACD should be more than 3.5 cm to avoid fluctuations in the cell voltage and loss of current efficiency. Additionally, it was concluded that the thickness of the bubble layer is 2.24 cm based on the unstable potential readings.

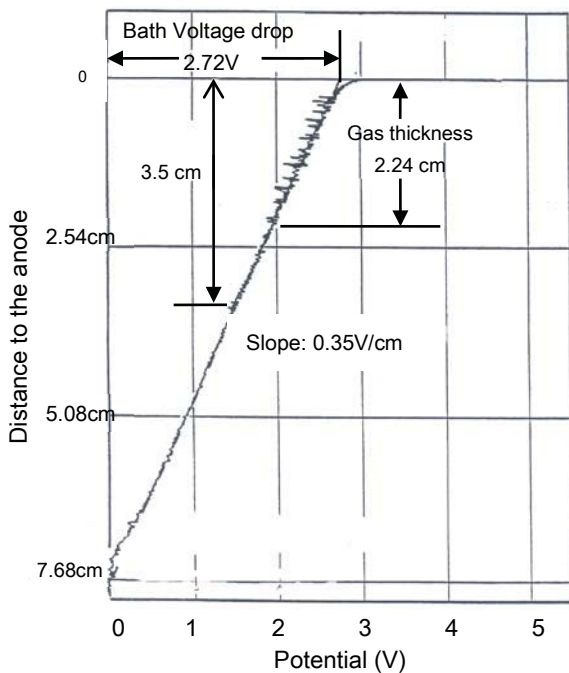


Figure 4. Potential of reference electrode versus metal pad [3]

In order to reduce effect of anode gases on the ACD, it is necessary to change the structure of the carbon anode, such as smaller anodes, slotted anodes or perforated anodes. When using such anodes, the anode gases generated at the anode bottom escape more easily from underneath the anode. This reduces the bubble induced wave of the molten bath/aluminum interface due to reduced stirring action of the anode gases, and moreover, this reduces the back reaction between dissolved aluminum and the anode gases due to the thinner anode bubble layer. As a consequence, this provides for better current efficiency. These solutions also decrease the polarization potential as a result of lower covering of gas bubbles underneath the anodes.

## Application of Energy-Saving Technology for Aluminum Production

### Novel Structure Cathode Technology

Since 2008, three kinds of novel structure cathodes (NSC) have been developed [4, 5, 6]. The 1st generation NSC technology is widely applied in Chinese smelters. In some smelters, the whole potline is using NSC. Based on industrial tests of the 1st and the 2nd generation NSC cells, and model simulations, the 3rd generation structure with carbon cylinders has been developed. Since the 3rd generation NSC cells have a more stable aluminum pad, it results in better current efficiency. Figure 5 presents a schematic diagram of the 3rd generation structure with carbon cylinders on a sloping surface [7]. The cylinders weaken the fluctuations of the interface between the molten bath and the metal pad. The resistances in the middle of cathode carbon are lower than the side due to the sloped surface. Thus, for the sloping carbon cells, the horizontal current in the pad is weakened.

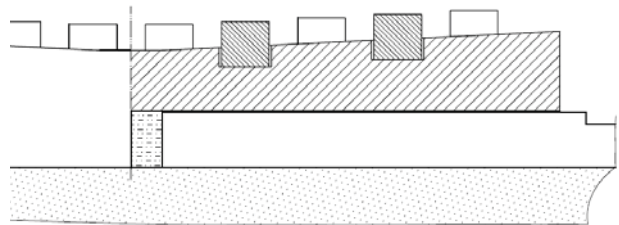


Figure 5. NSC with carbon cylinders on sloping surface of cathode carbon

### Novel Structure Anode Technology

Many studies show that slotted anodes improve the current efficiency. The present paper suggests a novel structure anode (NSA) with slots and holes [8], as shown in Figure 6. Anode gases generated underneath the carbon anode pass slots at an early stage. After the slotted part is consumed, anode gases pass holes. Thereby, through the whole electrolysis, anode gases can move short distances across the anode surface to escape. This lowers both the back reaction between the anode gas and the aluminum, and the polarization from gas bubbles, i.e., this improves both current efficiency and decreases cell voltage. Currently, the anodes are used in two 350 kA aluminum cells, as shown in Figure 6. The two cells have been working steadily at a cell voltage of 3.85 to 3.88 V.



Figure 6. Novel structure anode (NSA) with slots and holes.

### Conclusions

The power consumption of aluminum electrolysis depends on both cell voltage and current efficiency. The most effective way to reduce the cell voltage and improve the current efficiency is to reduce the metal pad instability at the interface between the aluminum metal and the electrolyte and the penetrating depth of the anode gas bubbles into the electrolyte.

Fluctuations in the aluminum metal are caused by magnetic forces produced by bus-bars, horizontal currents in the aluminum metal, anode gas movements, etc. For NSC cells operating at a proper cell voltage, higher current efficiency is easily achieved since the interface between the electrolyte and the molten metal is more stable.

For NSA, during the whole electrolysis, anode gases generated underneath the carbon anode can move short distances across the anode surface to slots and holes and escape. This lowers both the back reaction between the anode gas and the aluminum metal, and reduces the anode polarization due to less gas bubbles covering the anode surface, resulting in improved current efficiency and decreased cell voltage.

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