Modernization of the cathode assembly of aluminum electrolysis cells with Soderberg anode during the AAFS introduction

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Abstract. The state of the cathode assembly on Soderbergh electrolysis cells is analyzed, and measures for its improvement are proposed.

1. Introduction
Aluminum electrolysis with Soderberg anodes now constitute about 70% of all types of electrolysis cells in Russian plants. The dominant part of these cells was developed in the 50’s of the last century and was designed for the technology in which the electrolyte was fed by alumina periodically (every 3 or 4 hours). In these conditions the electrolyte mass should absorb as much alumina as it is necessary for the cell to work for 3 to 4 hours. The labour costs for the delivery of alumina to the cell and its immersion into the electrolyte melt account for 40% of the total labour of technological personnel.

At the moment the work on the introduction of the automated alumina feeding system (AAFS) at Krasnoyarsk Aluminum Plant has been completed, and in a number of plants the work on the introduction of AAFSSs is still being carried out. The introduction of AAFSSs not only increases the productivity of technological personnel, but also completely changes the electrolysis technology – the frequency of anode effects is sharply reduced, the concentration of alumina in the electrolyte and the magnitude of the inter-pole distance, etc. are stabilized. However, this technology change is not accompanied by a corresponding change in the cell design.

With the introduction of AAFSSs the duration of alumina supply to the melt is sharply reduced – from 3 to 4 hours to several minutes. In these conditions the required volume of electrolyte is reduced.

Unfortunately, in the educational and technical literature there is no method for determining the volume of electrolyte in the shaft, which complicates the justification of the minimum value of the technically necessary volume of electrolyte in the conditions of its feeding with alumina by AAFSSs.

2. Calculation of the electrolyte volume in the cathode assembly
Below is a procedure for determining the volume of electrolyte in the cathode assembly, and its scheme, used to calculate the mass of electrolyte in the cathode assembly, is shown in figure 1.

The volume of electrolyte $V_e$ (dm$^3$) in the cathode assembly is determined by the expression:

$$V_e = (S_m \cdot H_e) - S_a \cdot (H_e - L_{ipd}),$$  \hspace{1cm} (1)

where $S_m$ – the melt surface, dm$^2$;
$H_e$ – the height of the electrolyte column above the metal, dm;
$S_a$ – the anode area, dm$^2$;  
$L_{ipd}$ – the inter-pole distance, dm.

![Figure 1. Calculation scheme.](image)

The surface of the melt $S_m$, taking into account the average thickness of the side accretions $n$ (dm), is determined by the following expression:

$$S_m = (L_{ca} - 2sa) \cdot (B_{ca} - 2sa),$$  \hspace{1cm} (2)

where $L_{ca}$ and $B_{ca}$ – the length and width of the cathode assembly, dm.

The anode area $S_a$ (dm$^2$) is defined by the expression:

for Soderbergh electrolysis cells  
$$S_a = L_a \cdot B_a,$$ \hspace{1cm} (3)

and for BA cells  
$$S_a = n_b \cdot S_b = n_b \cdot L_b \cdot B_b,$$ \hspace{1cm} (4)

where $L_a$, $B_a$ – the length and width of the anode, respectively, dm;  
$n_b$ – number of anode blocks, pcs;  
$S_b$ – the area of the anode block dm$^2$;  
$L_b$ and $B_b$ – the length and width of the anode block, respectively, dm.

The electrolyte mass $M_e$ (kg) in the cathode assembly is equal to the product of its volume $V_e$ (dm$^3$) by the density of the electrolyte $d_e$, which is about 2.08 kg/dm$^3$:

$$M_e = V_e \cdot d_e. $$ \hspace{1cm} (5)

For calculations it is convenient to use the concept of the electrolyte specific mass, $m_e$ (kg/kA), which is equal to the ratio of the electrolyte mass, $M_e$, to the current $I_c$ (kA):

$$m_e = \frac{M_e}{I_c}. $$ \hspace{1cm} (6)

3. Results and discussion

To determine the required amount of electrolyte in the cathode assembly, we determine the demand for alumina $q_{al}$ (kg/kAh) per 1 kA for one hour. To do this, we determine the specific capacity of the cell $q_a$ (kg/ kA·h) for a time $t = 1$ h at a current strength $I_c = 1$ kA and an output current $\eta = 0.9$:

$$q_a = 0.3356 \cdot I_c \cdot t \cdot \eta = 0.3356 \cdot 1 \cdot 1 \cdot 0.9 = 0.30,$$

and the specific demand for alumina $q_{al}$ for the production of aluminum $q_a$ will be
The solubility of alumina in the electrolyte depends on many factors, which are discussed in detail in [1]. During in-line treatment of the crust, the maximum value of the alumina concentration in the electrolyte $C_{\text{max}}$ occurs some time after it is fed into the electrolyte. In the process of electrolysis not all alumina dissolved in the electrolyte is consumed, since an anodic effect occurs when a certain critical value of its concentration $C_{\text{cr}}$ is reached. In order to avoid the occurrence of anodic effect, it is necessary to introduce the next portion of alumina into the electrolyte at the moment when its concentration value will be the minimum allowable $C_{\text{min}}$, but above the value $C_{\text{cr}}$. Thus, the amount of alumina that can be produced from the electrolyte depends on the difference in values:

\[
\Delta C = C_{\text{max}} - C_{\text{min}}. \tag{7}
\]

Depending on the quality of alumina, electrolyte parameters, anode current density, the value of $C_{\text{max}}$ with modern technology is about 6.0% [1], and $C_{\text{min}}$ – about 2.5%. Then the value of $\Delta C$ is about 3.5% of the electrolyte mass.

The specific mass of the electrolyte $q_{\text{e}}$ required to dissolve $q_{\text{al}}$ of alumina in the agreed conditions will be:

\[
q_{\text{e}} = \frac{q_{\text{al}}}{\Delta C} = \frac{0.567}{0.035} = 16.2 \ \text{kg/kA·h}. \tag{8}
\]

In the case of 8-fold treatment of the crust, alumina is fed into the melt approximately every 3 hours. Consequently, the required specific gravity of the electrolyte must be 16.2 $\cdot$ 3 = 48.6 kg/kA·h.

When the electrolysis cell is equipped with the AAFS system, the process is carried out with the alumina concentration about 2.5% in the electrolyte, since the electrolyte electrical resistance is minimal. Another portion of alumina is fed into the melt with a periodicity of several minutes. That is why the required amount of electrolyte should be much smaller.

For comparison we calculate the specific volume of electrolyte for the most widely used in the plants of Russia Soderberg cell of S8BM type and the modern electrolysis with burned anodes of RA-300 type installed in KhAZ, the parameters of which are presented in the table 1.

We calculate the volume $V_e$, its mass $M_e$ and the specific mass $m_e$ of the electrolyte for each type of cell.

Assuming the height of the electrolyte column $H_e$ is 1.8 dm, the inter-pole distance $L_{\text{ipd}}$ – 0.5 dm, and the thickness of side accretions in the electrolyte zone – 1.0 dm, we get:

- for electrolysis cell S8BM:

\[
V_e = (S_m \cdot H_e) - S_a \cdot (H_e - L_{\text{ipd}}) = V_e = (3606.4 \cdot 1.8) - 2394 \cdot (1.8 - 0.5) = 3379.3 \ \text{dm}^3; \\
M_e = V_e \cdot d_e = 3379.3 \cdot 2.08 = 7029 \ \text{kg}; \quad m_e = \frac{M_e}{I_e} = \frac{7029}{172} = 40.86 \ \text{kg/kA}.
\]

- for electrolysis RA-300:

\[
V_e = (S_m \cdot H_e) - S_a \cdot (H_e - L_{\text{ipd}}) = V_e = (5037.4 \cdot 1.8) - 3641 \cdot (1.8 - 0.5) = 4333.5 \ \text{dm}^3; \\
M_e = V_e \cdot d_e = 4333.5 \cdot 2.08 = 9013.6 \ \text{kg}; \quad m_e = \frac{M_e}{I_e} = \frac{9013.6}{320} = 28.16 \ \text{kg/kA}.
\]

| Table 1. Parameters of electrolysis cell S8BM and RA-300. |
|----------------------------------------------------------|
| Parameter | Measurement unit | S8BM | RA-300 |
|-----------------|-----------------|------|--------|
| Anode - length | dm              | 84   | 14.45  |
Thus, at the electrolysis cell RA-300 equipped with an APG system, at a distance between the anode mass and the cathode assembly side of 350 mm, the specific weight of the electrolyte is 28.16 kg/kA, which is 1.45 times less than in the cell of the S8BM type.

In modern foreign cells with BA, the distance between the anode massif and the side of the cathode assembly is 250 mm, and the specific volume of the electrolyte does not exceed 25 kg/kA, which is 1.63 times less than in the S8BM cells.

Reducing the width of the cathode assembly will lead to a significant increase in the cathodic current density, by which is meant the ratio of the current to the mine area. Currently, in the electrolysis cells with burned anodes, the anode current density, according to Gibson Crest Pty Ltd, is 0.85-0.9 A/cm². In this case, the ratio of the area of the anode to the area of the bottom is recommended to be within 0.85 - 0.9, that is, the cathode current density should be at least 0.72-0.80 A/cm².

The anodic current density at the Soderberg anodes is unattainable in the anode cells of Soderberg anodes. At the 173 kA electrolysis cells, the anode current density has reached 0.725 A/cm², but the cathode current density is only 0.447 A/cm². Such a low cathode current density leads to a decrease in the current output, subcooling of the bottom, the formation of floorboards under the anode, and increases the material consumption of the cathode device.

Apparently, the effective anodic current density without upgrading the Soderberg BT anodes will not exceed 0.75 A/cm², but it is advisable to increase the cathode current density, which will certainly reduce the metal losses due to the reverse reactions, or, in other words, increase the current output. There is reason to believe that the life of a narrow cathode device will increase.

4. Conclusion
The obtained results show that there is a possibility of reducing the melt volumes in the cathode assembly of the bath by reducing the distance between the anode and the side of the cathode assembly. This will reduce the material consumption of the cathode assembly by approximately 20 % and will adequately reduce the costs for general repairs. In this case, the surface area of the electrolyte will also decrease by approximately 20%, which will positively affect the emission of toxic gases into the atmosphere of the casing.

References
[1] Isayeva L A and Polyakov P V 2000 Alumina in the Production of Aluminum by Electrolysis (Krasnoturinsk: Publishing house “BAZ”) p 198