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Methods for Decreasing the Electrical Energy Consumption in the Aluminum Production

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Abstract—The results of testing cathode blocks with cast iron casting carried out at the series of electrolysis of the JSC Kazakhstan Electrolysis Plant are presented. The behavior of cathode blocks with cast iron casting during operation was studied; the effect of these blocks on the technical and economic performance of electrolysis cells was analyzed with the goal of decreasing the energy consumption. As a result, it was shown experimentally that application of cathode blocks with cast iron casting would decrease the voltage drop across the bottom by 20 mV and, hence, this would reduce the electricity consumption by 80 kW h per ton. The productivity was 0.2% higher for electrolysis cells equipped with cathode blocks with cast iron casting than for the cells with carbon-sealed cathode blocks.

Keywords: cathode block, aluminum, electrolysis cell, voltage, electrical energy

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INTRODUCTION

The current trend in the production of primary aluminum is directed towards the application of electrolysis cells with increased current load of 300–400 kA, which in turn requires the use of cathode blocks with a reduced electrical resistance [1, 2]. The use of raw materials subjected to high-temperature pretreatment to produce cathode blocks increases their stability to thermal stress and chemical resistance to the electrolyte melt. An increase in the graphite content in cathode blocks to 70–100% reduces the electrical resistance, but the thermal conductivity of the blocks simultaneously increases, which finally complicates the task of decreasing energy consumption [2–4]. An alternative way to decrease the resistivity is to decrease the voltage drop across the bottom, which in turn increases the service life of electrolysis cells [3]. The voltage drop across the bottom is related to the quality of the cathode block—collector bar electrical contact [4, 5].

There are several ways of sealing collector bars in cathode blocks; the most widely used are the following (Fig. 1):

- using special carbonaceous paste;
- using cast iron casting.

Considering the sealing technique, the method using carbonaceous paste is the most facile and does not require additional resources. Sealing with cast iron is more expensive and more technically complicated,

(a) (b)

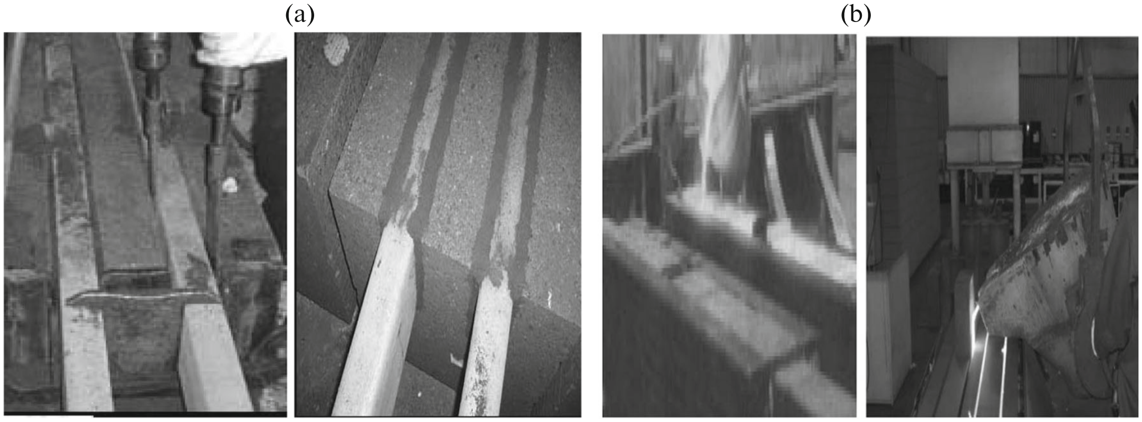

Fig. 1. Cathode blocks with collector bar sealed with (a) carbonaceous paste and (b) cast iron casting.

but this method makes it possible to reduce the electrical resistance in the cathode block–collector bar contact. Correspondingly, the decrease in the electrical resistance implies lower specific consumption of the electrical energy, which makes this technique economically beneficial [4–6].

This technique also becomes relevant because of annual increase in the cost of electricity and the electricity shortage in general.

Sealing of collector bars in cathode blocks by cast iron casting has been used for quite a long time. However, adverse factors that accompany the use of this method, such as fracture of the blocks due to crack formation in the walls and corners, which in turn reduce the service life of electrolysis cells (Fig. 2), hamper the wide use of this method. The crack formation in cathode blocks is caused by thermal shocks and differences between the thermal expansion coefficients of carbon and steel. The risk of crack formation caused by more pronounced thermal expansion of the hardened steel collector bar compared to the carbon block will be greater in the case of insufficient preheating before casting [7]. The cast iron composition is also an important factor. The cracks in the walls are usually caused by the lateral pressure from the collector bar, while the corner cracks are related to longitudinal bending of the collector bar and thermal shock [8, 9]. In order to eliminate these defects, some changes were made in the shape of the cathode blocks and collector bar (the number of gutters in the blocks increased to two and the collector bar was manufactured in parts rather than throughout the cathode block length) and the collector bar started to be sealed by carbonaceous paste [8–10].

Regarding the effect on the electrical energy consumption, sealing with carbonaceous paste is inferior to the use of cast iron casting (the electrical resistivity of the carbonaceous paste is less than 80 Ω mm^2/m, whereas that of cast iron is below 2 Ω mm^2/m). Due to the difference between the electrical conductivities of these materials, the cast iron method starts to be used on a large scale again. The drawback of the method related to the crack formation remains in the past. A number of methods have been developed for casting cast iron into cathode blocks in such way that the quality of the blocks is preserved and no defects are generated. The essence of the new cast iron casting method is in the preheating of cathode blocks. In order to prevent crack formation, parameters of cathode block and collector bar before cast iron casting were determined. The cathode section is a composite system with clear-cut mechanical heterogeneity: the elastic moduli and coefficients of linear thermal expansion of the component materials (collector bar, cathode block) differ by a few orders of magnitude. Thus the Young's moduli of the carbon/graphite matrix and the sintered bottom paste are 6.35×10^3 and 1.0×10^3 MPa, respectively, whereas the normal Young's modulus of the steel bar is 2.1×10^5 MPa. The calculations of the heating temperature, taking account of the thermal expansion coefficients of the collector bar and cathode blocks in the heating temperature range, for cast iron, and various types of cathode blocks indicate that insufficient preheating before casting can result in a severe damage of the blocks during heating before commissioning of the electrolysis cell. In practice, cathode blocks are heated up to 400–500°C. Irrespective of the heating parameter, when the heating temperature of the cathode blocks and collector bars is 400 to 1000°C, the stress of the block before casting is insignificant and no destruction of the cathode block takes place. The heating is performed at the block and collector bar preheating stations. A Hotwork installation is widely used for this purpose [9–11]. A positive trend is observed when the heating time is increased up to 6 hours and the cathode block is additionally isolated from the heating source. The cast iron preparation for the collector bar sealing includes cast iron melting and alloying with ferrophosphorus and ferrosilicon by adding them into the melt. Cast iron alloying reduces its prime cost and decreases its shrinkage. The smelting quality is evaluated by examining the chemical composition of a sample using an ARL-72000 emission spectrometer. As a rule, cathode block manufacturers seal the collector bars in the cathode blocks using cast iron casting by themselves, in order to expand the range of manufactured products. The assembled cathode blocks with cast iron casting are more expensive than those with carbonaceous paste. Comparison of the results taking account of labor input, the cost of carbonaceous paste, and the decrease in the energy consumption indicates that cast iron casting has advantages.

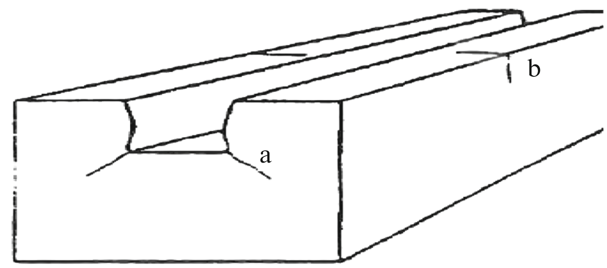

Fig. 2. Cathode block defects: (a) cracks in the walls and (b) corner cracks.

EXPERIMENTAL

Cast iron-sealed cathode blocks with 50% graphite in three electrolysis cells and 70% graphite in three electrolysis cells have been tested at the JSC Kazakhstan Electrolysis Plant (Kazakhstan) since December, 2020, until now. According to the results of voltage drop measurement at four points of the cathode block–collector bar contact (Fig. 3), the voltage drop is 15 mV in the blocks with cast iron and 50% graphite (Table 1, no. 1) and 14 mV in the case of cast iron and 70% graphite (Table 1, no. 2), while in the case of carbonaceous paste, it is 48 mV (Table 1, no. 3).

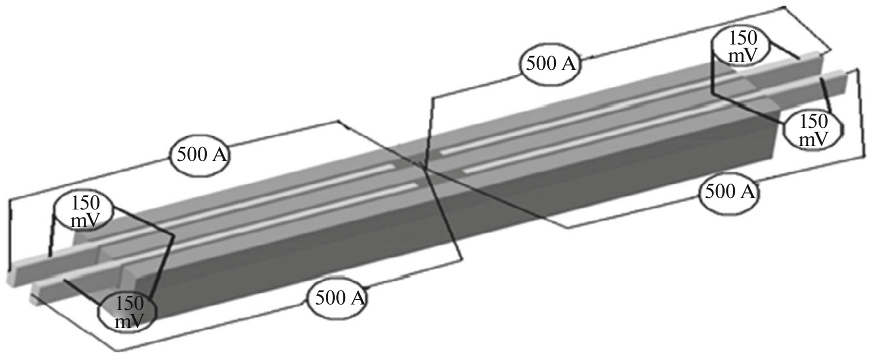

Fig. 3. Measurement of the voltage drop in the cathode block—collector bar contact.

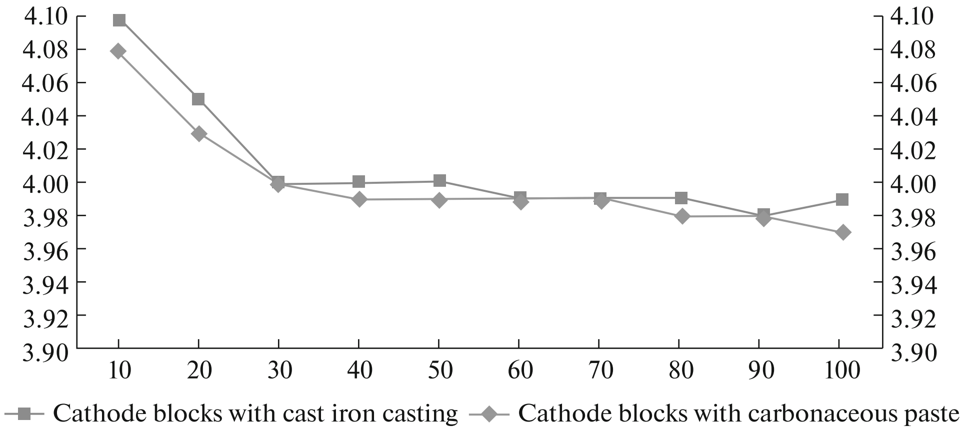

Fig. 4. Decrease in the set voltage after the start of operation of the electrolysis cells

The greatest voltage drop in the cast iron-sealed cathode blocks with 50% graphite is 31 mV, that for 70% graphite is 26 mV, and that for carbonaceous paste sealing is 122 mV.

In the electrolysis cells equipped with cathode blocks with cast iron casting, the measured voltage drop across the bottom is 290 mV, whereas in the electrolysis cells with cathode blocks assembled using carbonaceous paste, this value is 320 mV (Table 2).

An important factor for evaluating the effect of cathode blocks with cast iron casting is the set voltage in the electrolysis cell. After the post-launch period (90 days after the start of operation), the set voltage for electrolysis cells equipped with cast iron-sealed cathode blocks is 3.97 V, while that for carbonaceous paste-sealed cathode blocks is 3.99 V (Table 3).

This decrease in the set voltage corresponds to a decrease in the electrical energy consumption by 80 kW h per ton.

As can be seen from Fig. 5, the set voltage in the electrolysis cells with cast iron-sealed cathode blocks

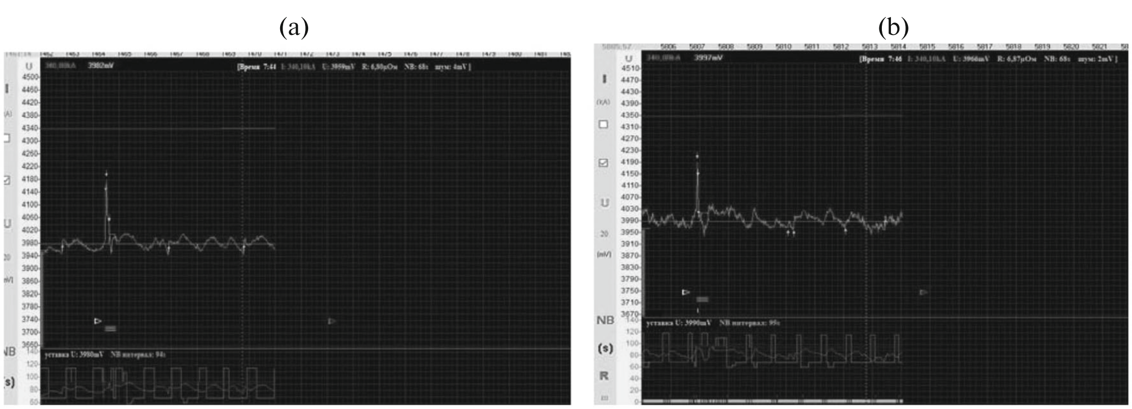

Fig. 5. The set voltage is (a) 3.97 V in electrolysis cells with cast iron casting and (b) 3.99 V in electrolysis cells with carbonaceous paste.

Table 1. Voltage drop in the block–collector bar contact, mV

No. 1						No. 2						No. 3					
cathode	measuring point				average	cathode	measuring point				average	cathode	measuring point				average
	1	2	3	4			1	2	3	4			1	2	3	4	
1	12	17	12	13	14	1	9	19	26	11	16	1	40	42	51	48	45
2	13	13	17	16	15	2	7	16	19	6	12	2	54	39	31	52	44
3	17	13	14	31	19	3	7	21	20	10	15	3	58	69	60	72	65
4	11	14	16	17	15	4	16	20	16	9	15	4	49	78	53	62	61
5	15	15	12	14	14	5	10	8	10	13	10	5	72	49	118	91	83
6	13	12	16	14	14	6	6	14	11	18	12	6	74	35	63	45	54
7	10	12	13	15	13	7	9	16	21	21	17	7	25	32	47	52	39
8	12	14	13	17	14	8	26	22	13	8	17	8	25	38	29	36	32
9	15	27	21	12	19	9	18	11	11	13	13	9	23	31	39	44	34
10	14	10	13	12	12	10	21	18	10	13	16	10	41	45	53	51	48
11	9	12	9	12	11	11	14	10	11	9	11	11	33	45	50	78	52
12	19	18	14	13	16	12	16	16	21	26	20	12	63	105	98	84	88
13	13	15	19	14	15	13	17	16	11	14	15	13	41	83	37	31	48
14	14	19	15	13	15	14	15	15	14	10	14	14	40	122	48	30	60
15	11	13	19	15	15	15	13	12	16	16	14	15	41	51	25	32	37
16	12	14	14	11	13	16	15	18	18	10	15	16	79	80	26	29	54
17	12	13	16	14	14	17	15	16	15	16	16	17	50	78	32	33	48
18	14	12	17	16	15	18	14	11	18	16	15	18	42	42	62	86	58
19	12	27	14	27	20	19	12	12	10	9	11	19	25	32	47	50	39
20	16	14	19	12	15	20	17	16	10	12	14	20	35	32	49	44	40
21	11	14	15	18	15	21	10	9	11	10	10	21	46	45	44	38	43
22	13	13	13	11	13	22	10	14	20	19	16	22	21	21	20	28	23
23	14	20	15	12	15	23	8	11	8	10	9	23	33	79	31	37	45
24	15	14	13	15	14	24	13	17	9	12	13	24	21	25	23	21	23
25	10	10	8	11	10	25	8	12	11	11	11	25	55	23	34	29	35
26	11	15	30	13	17	26	12	9	19	13	13	26	37	48	39	36	40
27	18	10	18	13	15	27	10	14	11	12	12	27	28	28	92	72	55

Table 2. Average voltage drops in the block–collector bar contact, mV

Electrolysis cells	1	2	3	Average
Cathode blocks with cast iron casting	286	294	290	290
Cathode blocks with carbonaceous paste	324	320	316	320

Table 3. Average set voltage in electrolysis cells, V

Electrolysis cells	Time after the start of operation of electrolysis cell, days										
	0	10	20	30	40	50	60	70	80	90	100
Cathode blocks with cast iron casting	8	4.08	4.03	4	3.99	3.99	3.99	3.98	3.98	3.97	3.97
Cathode blocks with carbonaceous paste	8	4.1	4.05	4	4	4	3.99	3.99	3.99	3.98	3.99

Table 4. Set voltage in electrolysis cells, V

Cathode blocks	1	2	3	Average
Cast iron casting	3.97	3.96	3.97	3.97
Carbonaceous paste	3.99	3.99	3.99	3.99

is 20 mV lower than that in electrolysis cells with carbonaceous paste.

The production capacity of electrolysis cells with cast iron-sealed cathode blocks is 0.2% higher than that of electrolysis cells with carbonaceous paste.

CONCLUSIONS

The pilot tests of electrolysis cells equipped with cathode blocks with cast iron casting carried out at the JSC Kazakhstan Electrolysis Plant demonstrated that there is no significant difference between the said electrolysis cells with 50 and 70% graphitization. Meanwhile, cathode blocks sealed with carbonaceous paste are characterized by low voltage drops and a decrease in the set voltage by 20 mV. This corresponds to a decrease in the energy consumption by ~80 kW h per ton and electricity savings of 21200 MW h per year, or \$350 thousand per year. The implementation of this project is aimed at optimization of process parameters, which would lead to an increase in the production indicators, including the production capacity of electrolysis cells.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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