

Reduction of Energy Consumption at Khakass Aluminum Smelter

Viktor Buzunov¹, Viktor Mann², Andrey Zavadiak³, Andrey Anisiferov⁴, Vladimir Yarnykh⁵ and Viktor Chesnyak⁶

1. Director, Aluminum technology & technical implementation,

6. Head of Reduction Technology Department

RUSAL ETC, Krasnoyarsk, Russia

2. Technical Director,

RUSAL Aluminum Management, Moscow, Russia

3. Deputy General Director for Aluminum Plants Modernization,

UC RUSAL PTD, Krasnoyarsk, Russia

4. Director, Aluminum Production Technology & Development

5. Reduction Technology Manager

SAZ, RUSAL ETC, Sayanogorsk, Russia

Corresponding author: Viktor.Buzunov@rusal.com

Abstract

Khakass Aluminum Smelter (KhAZ) is the first aluminum smelter launched by RUSAL in modern Russian history at the site of Sayanogorsk Aluminum Smelter. KhAZ consists of one line in two potrooms with 336 of Rusal's RA-300 cells. The first metal was produced in December 2006, and the design capacity was reached at the end of 2007: amperage 320 kA, current efficiency 94.6 %, specific energy consumption 13740 kWh/t Al. Later, taking into account market conditions, the amperage was decreased to 310 kA, and some energy saving measures were implemented, including:

- 100 % graphitic cathode blocks,
- Improved top anode shape; the anode width was increased by 1 cm,
- Increased anode cover height,
- Improved computer control,
- Decreased anode-cathode distance (ACD).
- The implementation of anodes that are 10 cm longer is in progress.

As a result, in 2020 the specific energy consumption was 12911 kWh/t Al, a decrease of about 800 kWh/t Al.

Keywords: Khakass Aluminum Smelter, RA-300 cells, Reduction of specific energy consumption, Increased anode length, Decreased anode-cathode distance.

1. Introduction

Khakass Aluminum Smelter (KhAZ) is the first successful experience of RUSAL in implementing a project on construction of a new smelter using its own resources. The first cell RA-300 was successfully developed, tested and implemented. The general designer of the smelter was the design institute RUSAL VAMI. The aluminum smelter was built within record-breaking time – 25 months – the first cubic meter of concrete was laid in the KhAZ foundation in October 2004, and the first metal was produced in December 2006. The design capacity was reached in November 2007.

KhAZ Reduction Area consists of two potrooms that have the same length (1224 m) and width (27 m) with the cells 3.0 m above ground level. The version of potrooms is two-storey, single row with pot center to pot center spacing of 6.5 m. The, potroom centers are connected by a passage that is 15 m wide, also in the southern and northern ends they are connected by transport passage that are 12 m wide. There are 336 RA-300 cells installed in total in two potrooms, 168 cells in each potroom. The cells are in a single-row, side by side arrangement. Each cell is equipped with

four automated alumina point feeders and one automated aluminum fluoride point feeder, the anode body consists of 36 three-studded anodes each 1445 x 700 x 605 mm in size (in accordance with the initial project), the cathode shell is a single self-supporting unit, the side lining is silicon-carbide, the bottom is made of 48 carbon blocks with a graphite content of 30 %.

The potline is equipped with two Dry Gas Treatment Centers. Alumina is fed to bins of the automated alumina point feeder by a centralized alumina distribution system. Maintenance of cells is carried out by eleven pot tending assemblies. To fill pot tending assemblies with the covering material, there are 4 filling units for pot tending assemblies installed in each potline. Anode cover bath is reprocessed at Crushing Area located between pot rooms. Cells are controlled by the Process Control System SAAT developed in-house by RUSAL.

The following parameters of the potline were considered in the design stage:

- Amperage – 310 kA;
- Current efficiency – 94.5 %;
- Specific gross anode consumption – 553 kg/t Al;
- Specific process power consumption – not more than 13 400 kWh/t Al (here and farther 1 t is specified as 1000 kg);
- Design capacity of the smelter – 278 836 tpy.

After the potline was commissioned in 2009–2012, the following results were achieved:

- Amperage – 320 kA;
- Current efficiency – 94.6 %;
- Specific gross anode consumption – 529.8 kg/t Al;
- Specific process power consumption – 13 760 kWh/t Al;
- Primary aluminum production output – 298 056 tpy.

2. Main Technical Solutions

2.1 Implementation of 100 % Graphitic Cathode Blocks

One of the ways selected to improve the power efficiency of RA-300 cells, in order to achieve the specific energy consumption lower than the designed value, was increasing the graphite content in the cathode blocks from 30 to 100 %. Test results showed that that allows to reduce the cathode voltage drop by ~20 mV (Figure 1).

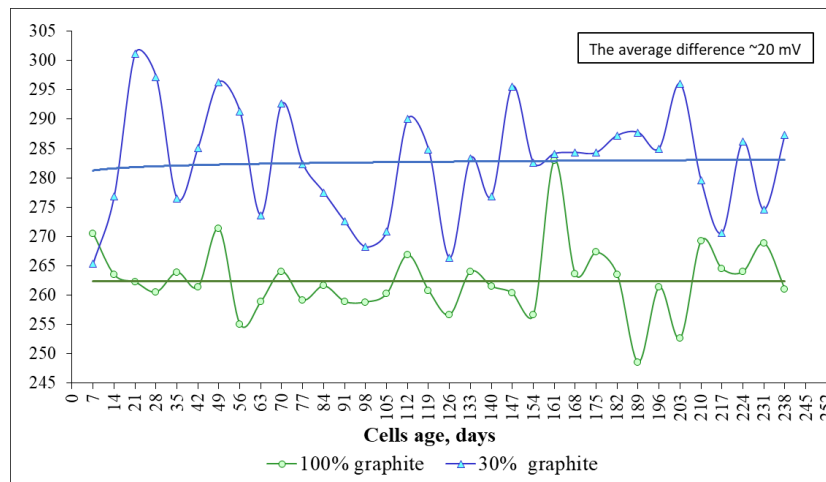


Figure 1. Cathode voltage drop on cells with 100 % and 30 % graphitic cathode blocks.

During the operation of cells with 100 % graphitic cathode blocks, process parameters were optimized – the metal level was reduced by 1 cm compared to the basic design of the cell and the voltage was decreased by 32 mV (Figure 2). Implementation of 100 % graphitic cathode blocks allowed a reduction of the specific energy consumption by ~100 kWh/t Al.

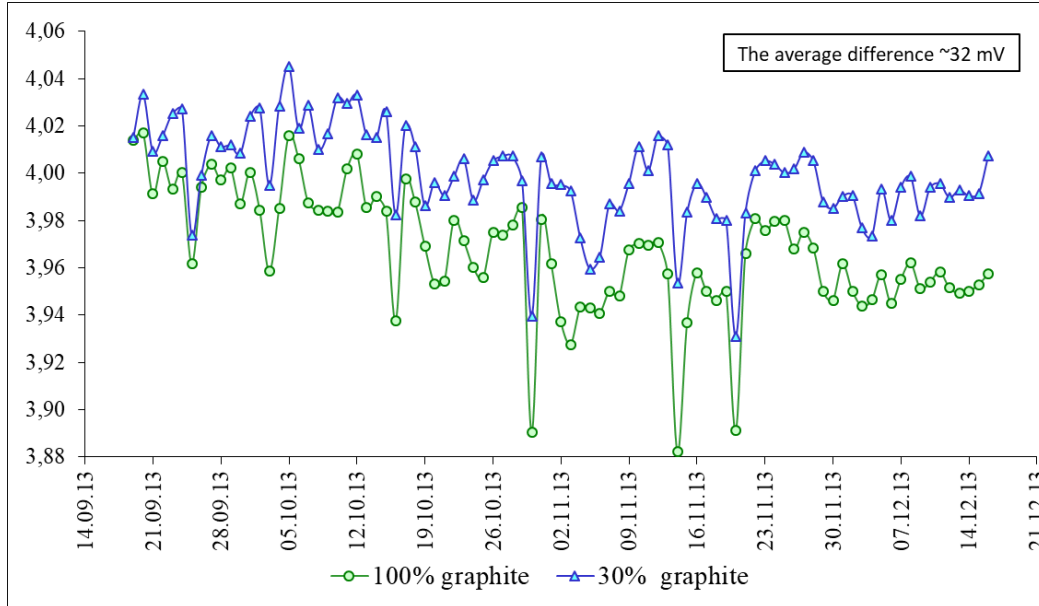


Figure 2. Cell voltage, for cells with 100 % and 30 % graphite cathode blocks.

2.2 New Anode Shape

The design size of anodes that were used at the start-up is 1445 x 700 x 605 mm, with flanges along longitudinal sides of a block 100 mm high (Figure 3).

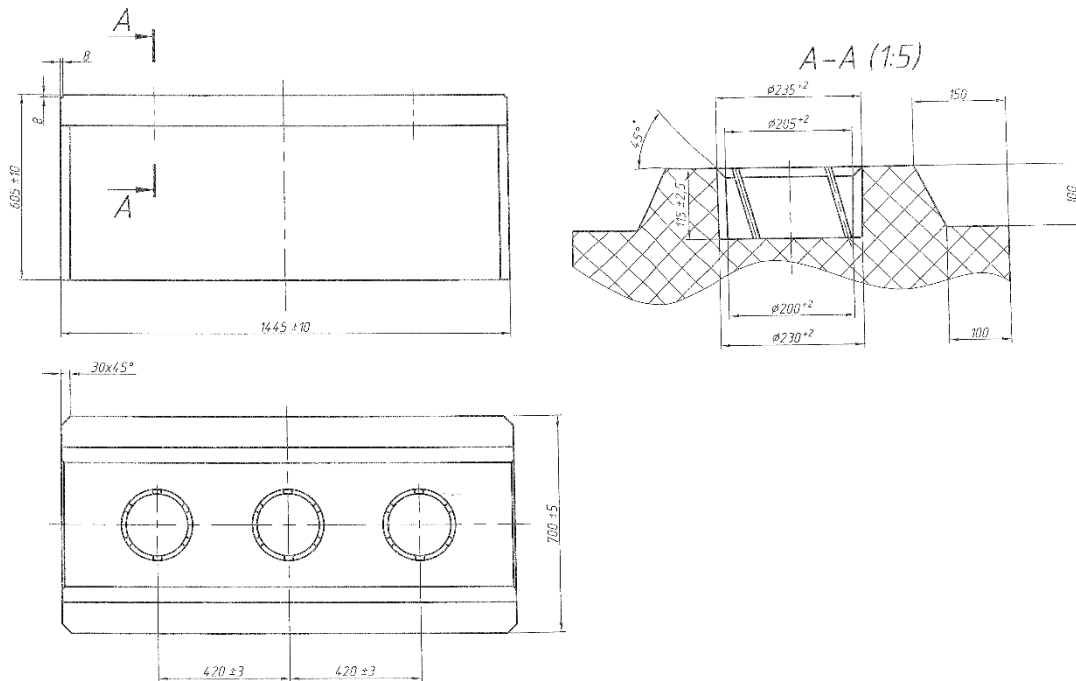


Figure 3. Anode blocks used during the startup period, according to the project.

The use of anodes of this form caused issues related to significant oxidation and shattering of spent anodes during the last stage of the anode operation, which is related to the high height of flanges along longitudinal sides of the anode. As a result, in the last days of the operation cycle there was a significant decrease in the area of the anode. Significant oxidation of anodes also resulted in excessive accumulation of carbon dust in the bath, decreasing of the cell anode-to-cathode distance, formation of spikes and degradation of key performance indicators of the production.

In 2015, a new shape of anodes was developed: the major difference is the changed shape of the top, with flanges of lower height – 50 mm – along the entire perimeter of the block. Concurrently, anode width and height were increased, the new dimensions are 1450 x 710 x 625 mm (Figure 4) [1].

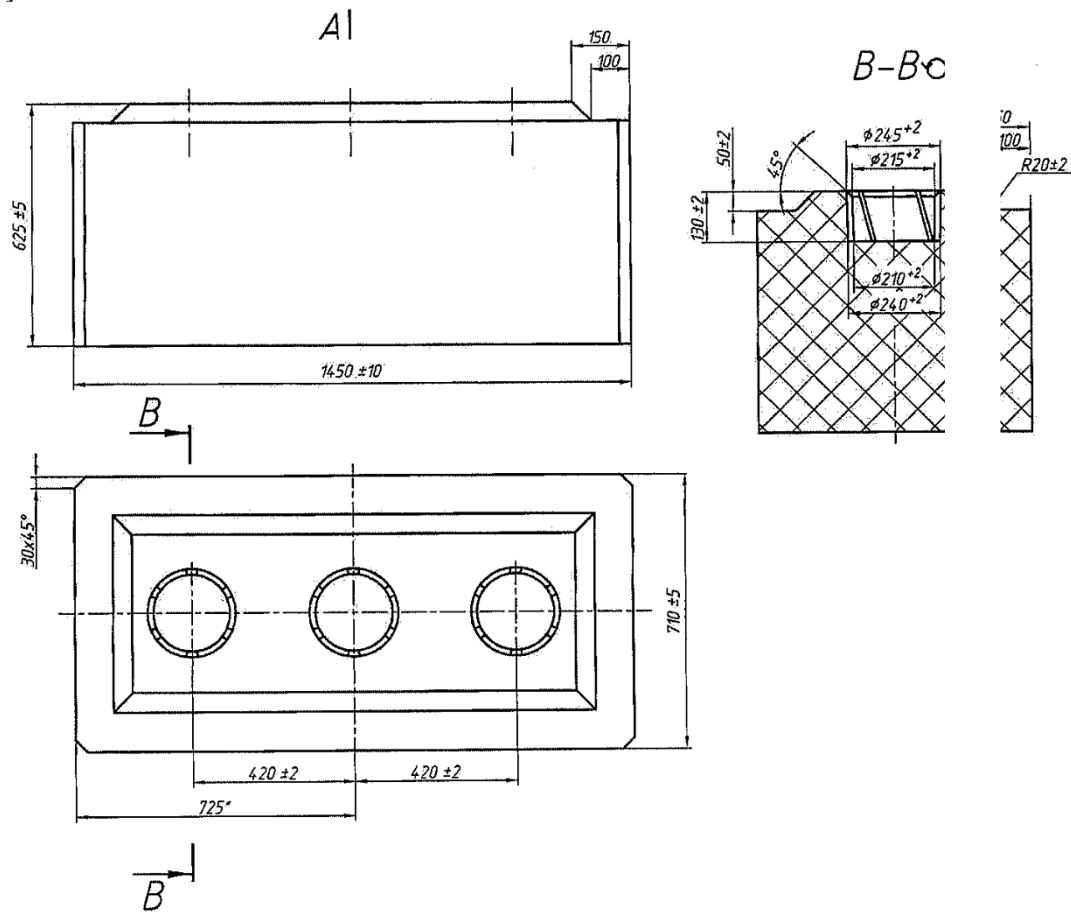


Figure 4. New shape of anode blocks.

Implementation of anodes with the new shape allowed a significant reduction of the oxidation and burning of the anodes in the last days of their operation, an increase of the effective anode area, reduction of the amount of carbon dust formed in the bath and reduced risk of occurrence of spikes.

When implementing the new shaped anode, all issues were addressed related to their production at anode pressing and baking. As a result of the implementation of the new shaped anode, it was managed to reduce power consumption (Figure 13), as well as to reduce specific anode consumption by means of the yield of spent anode with a higher weight and to increase the replacement cycle (Figure 5).

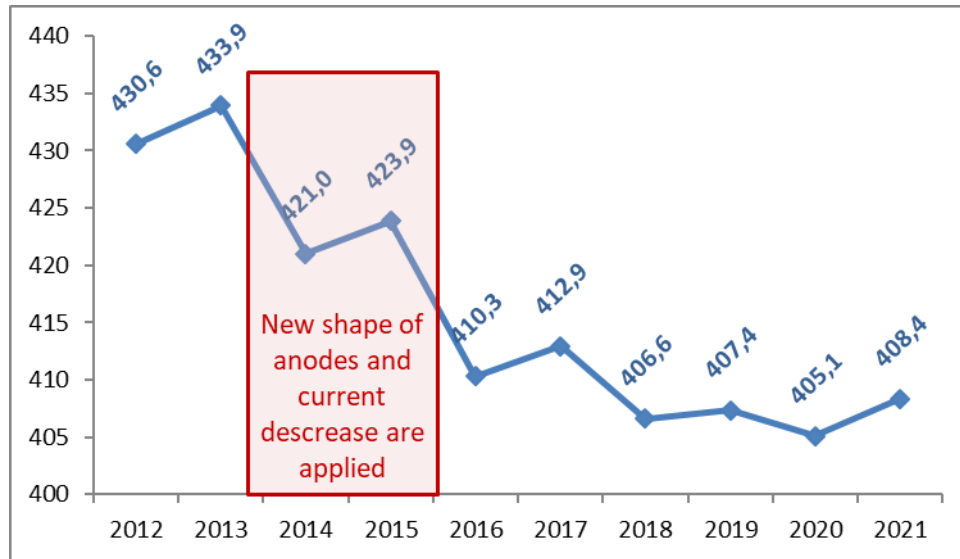


Figure 5. Anode net consumption, kg/t Al.

The optimized shape of the anode allowed decrease reduction of the voltage by 18 mV and power consumption by 76 kWh/t Al.

2.3 New Control Algorithms

a) Introduction of negative additions of voltage when skipping anode changing

During the operation of RA-300 cells, it was found that after a day during which there was no anode change, a statistically higher bath temperature was observed. To eliminate this effect, a control algorithm was developed and implemented involving reduction in voltage on a cell on the day when there is no anode change. A negative voltage addition of to 40 mV and is active until the next pressing of the anode change button on a cell control cabinet. The use of this addition became particularly relevant when switching over to anodes with the new shape and increasing the replacement cycle allowing the stabilization of the cell's heat balance.

b) Automatic voltage addition when covering changed anodes not in accordance with a regulation

Experience shows that the perfect time from anode change until their covering is 2 to 9.5 hours (2 hours is the approximate time of the formation of a hard crust around replaced anodes, 9.5 hours is the time during which the voltage addition is active after anode change). After anode replacement, in about two hours, the bath around it is crystallized creating a strong crust. Then, the installed anode heats up and starts to take up current load, as a result, in 10-12 hours the bath crust around an uncovered anode melts down. When covering a changed anode later than that time, the covering material does not stay around the anode in the form of a crust, and its part gets into the melt and to the bottom of a cell thus causing significant changes in anode current distribution and an increase in noise.

It is clear from this figure that when covering replaced anodes later than the regulated time, there is an increase in the noise level which resulted in the need to increase voltage (Figure 6).

Figure 7 shows the situation when covering of the newly installed anodes occurred within the regulated time interval after an anode change, when the voltage addition was active, then no process destabilization or increase in the noise level are observed. In real practice, situations occur when the schedule of operations on cells is disrupted due to unforeseen causes. To minimize the negative impact of these disruptions on the process, an algorithm was developed and included in

the control system that automatically activates a voltage addition upon anode covering outside a normal period.

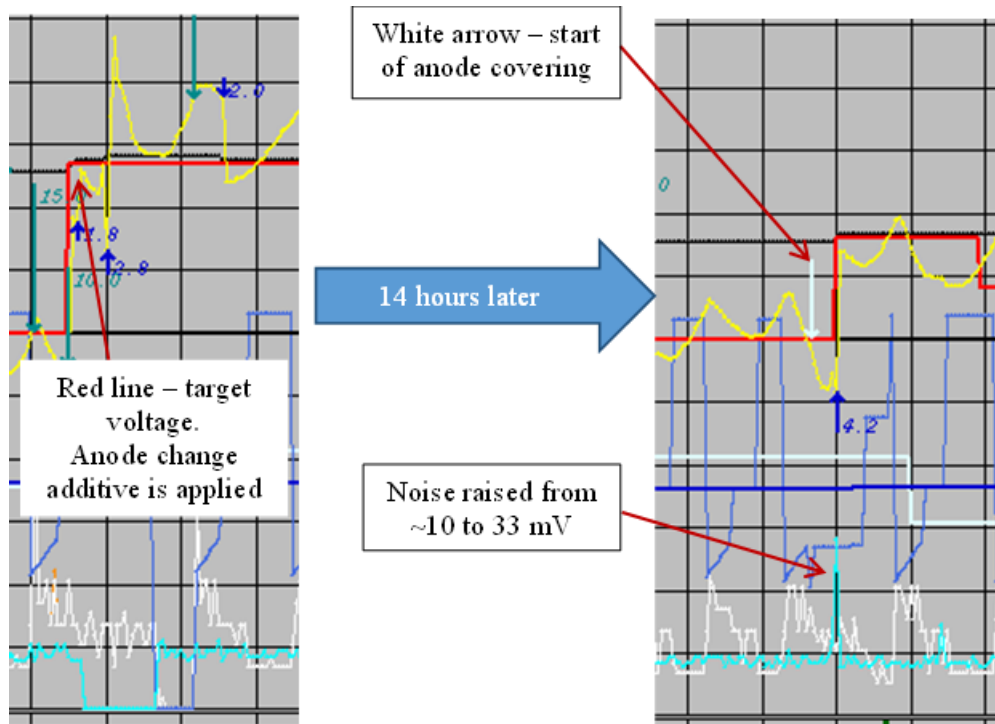


Figure 6. Anode change and covering **not** according to schedule.

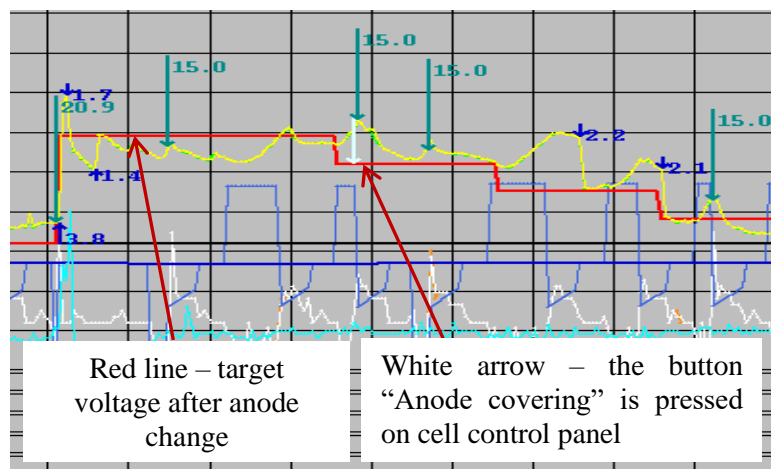


Figure 7. Anode change and covering according to schedule.

Figure 8 shows the situation when covering of newly installed anodes was carried out significantly later than the normal time, after the expiration of the anode change additive (9.5 hours), here a voltage additive +80 mV was automatically activated at the time of anode covering with subsequent reduction in two stages 40 mV each, with holding for 1 hour at each stage. This algorithm enabled prevention of a noise level increase and destabilization of the cell operation due to late anode covering.

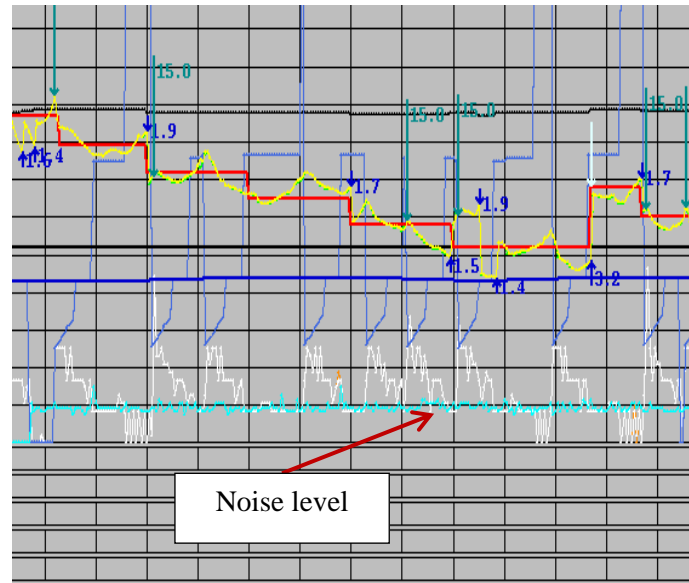


Figure 8. New anode covering delay.

c) Optimizing a control algorithm by means of the bath composition using test movements of the anode body

Capabilities of the plant laboratory allow analyzing the bath composition every 2-4 days. Sufficiently long periods of time between analyses, as well as a time delay between sampling and publishing of the result (several hours to one day) do not allow to promptly respond to changes in the cell operation conditions and bath composition. There is a low-cost method [2] that allows to promptly determine the cryolite ratio of the bath with a sufficiently high frequency (several times a day). The gist of the method is as follows: the cell control system performs small test movements of the anode with a certain frequency, according to results of these movements, a change in voltage is determined and the forecast of the bath cryolite ratio at this point in time is calculated. Operation conditions of the test movements algorithm:

- Fixed duration of the anode movement in both directions;
- The assessment is carried out only in the “nominal” feeding mode in order to minimize the impact of the alumina concentration;
- The assessment is not carried out over a certain period of time after anode change in order to eliminate the impact of this operation.

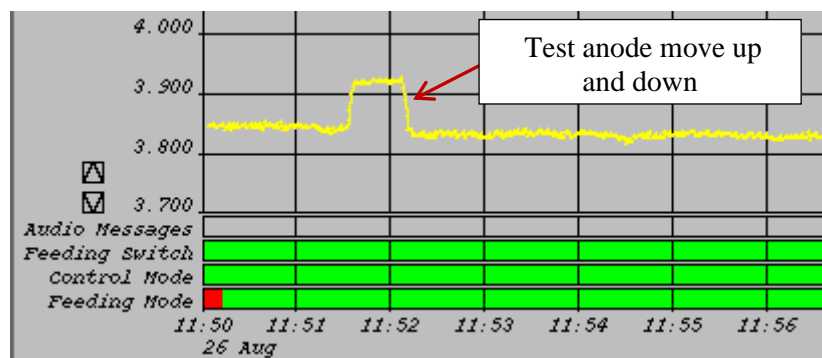


Figure 9. Cryolite ratio forecasting algorithm.

The figure shows how the algorithm works, voltage increased and returned to former values, with a time delay of 30 seconds, due to equal anode movements up and down. This method to control the bath cryolite ratio was implemented on the RA-300 cell potline. Test anode movements and calculation of the forecast cryolite ratio were carried out every four hours, the operation of the

automated aluminum fluoride feeding system is corrected according to results of the calculation. Implementation of this algorithm allowed reducing the number of deviations from process boundaries on the bath temperature and cryolite ratio by ~6 %. That enabled a decrease in the specific energy consumption by 3–6 kWh/t Al.

d) Optimizing the alumina feeding algorithm

To eliminate the risk of occurrence of anode effects, the algorithm gives additional dosages of alumina when accompanying process operations “metal tapping”, “anode change” and “anode beam raising”, if the voltage growth rate is higher than the specified value at the beginning of the mode “overfeeding”.

The number of additional dosages of alumina was calculated to the amperage of 320 kA at the start-up of the potline. After the amperage was reduced to 310 kA, a need arose to reconsider the number of additional dosages of alumina. Tests were carried out on pilot cells which allowed to optimize the number of additional dosages of alumina, as a result, the alumina concentration in the bath and the risk of a sludge were reduced. This change did not result in increased anode effect frequency and allowed to continue reducing the anode-to-cathode distance. This change enabled the reduction of the specific energy consumption by 10–15 kWh/t Al.

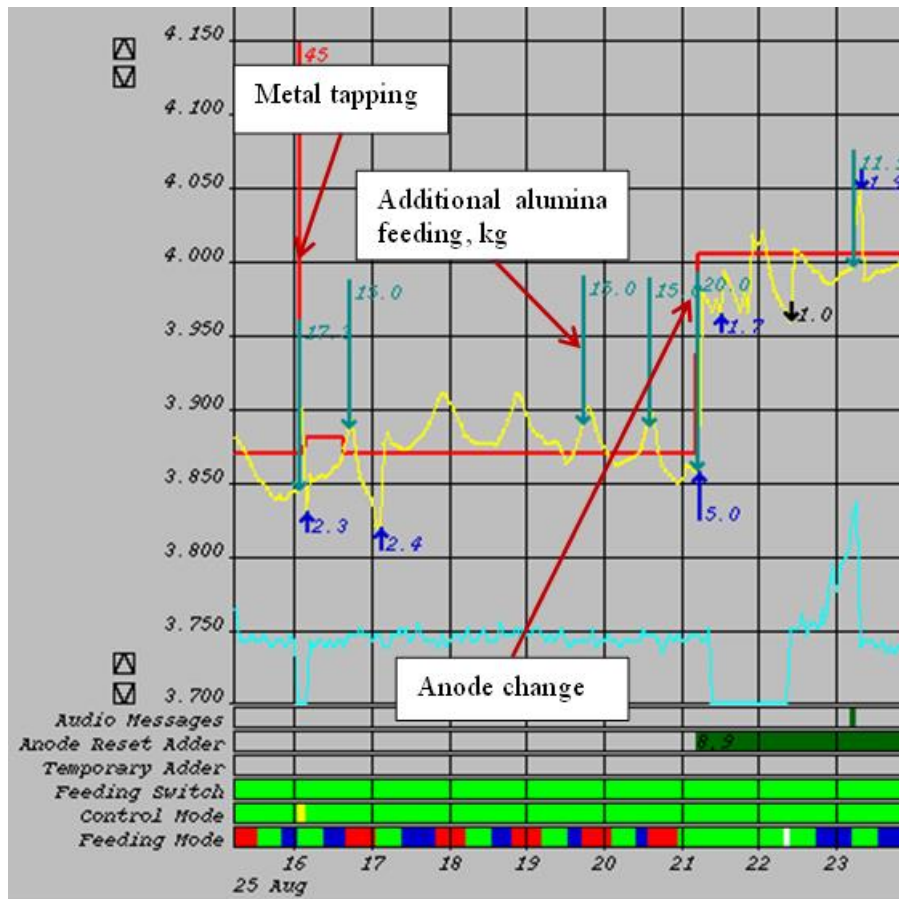


Figure 10. Additional alumina feeding during anode change.

2.4 Reduction of the Anode-to-Cathode Distance (ACD)

Reduced demand for primary aluminum and, respectively, its price in 2012–2013 resulted in a need to reduce the cost and volume of metal production. Work was carried out as part of projects on improving the Company’s energy efficiency [3, 4]. The first stage of this route was to reduce

amperage to 310 kA. In order to increase energy efficiency, the anode cover height was increased along with voltage decrease, metal level and practices of process operations optimization. The above-mentioned measures allowed to reduce the specific energy consumption by ~520 kWh/t Al.

a) Increasing the anode cover height

One of the ways to improve energy efficiency, adopted in the new operation conditions, is to increase the cover height of the anode body which mitigates energy losses and makes it possible to reduce voltage.

The KhAZ covering material is characterized by a large content of a fine fraction (80–90 % of the fraction -0.8 mm). Thus, it was impossible to cover the newly installed anodes to the required level since such material has a small angle of repose and spreads out across the anode body surface.

The maximum height of anode cover at the first fill was 8–10 cm with the standard of 18–20 cm. In order to achieve the required anode cover height, the approach to performing operations was changed – the anode cover was arranged in several stages. The first fill allows to cover anodes to a height of 8–10 cm. In 2–3 days this portion of the covering material has hardened allowing to put a second portion of covering material for a total height of 18-20 cm. Such practice required increased anode change cycle. The crane operating time optimization for two stages of anode covering was made using connection of beam raising device to the potroom network of compressed air and power instead of crane itself.

Project solutions for anode beam raising provided for the connection of beam raising device to an operating crane, i.e. throughout the entire operation on anode beam raising a crane was continuously connected to a beam raising device (~1 hour per cell, ~ 5 hours per shift) and was not able to perform other process operations. To eliminate this drawback, a set of measures were implemented by moving the connection of beam raising devices from a crane to the potroom network of compressed air and power. That allowed increasing the use of a crane to refresh the anodes' cover by ~5 hours per shift, once in four days on every cell.

As a result of changes, it was managed to achieve the anode cover height of up to 20 cm, Figure 11.



Figure 11. Anode cover.

b) Changing the bath composition

When operating at amperage of 320 kA, the cryolite ratio was maintained at 2.22 (molar). As amperage decreased, the bath temperature decreased and the volume of ledge increased. These changes made it necessary to increase the cryolite ratio. Upon reduction of amperage to 310 kA, the bath's cryolite ratio stabilized at 2.30, No metal production decrease or any other negative consequences were observed.

c) Optimizing the metal level

A reduction in the metal level by 1 cm was tested in a pilot area of cells with 30 % graphitic bottom blocks upon a reduction of amperage. This solution allowed for reducing energy losses and preventing an excessive increase in the length of the cell ledge, and was extended to all potline cells.

d) Optimizing the cathode voltage drop measuring scheme

The dynamics of a cathode voltage drop of RA-300 cell are used to control the cell condition, as well as to automatically calculate the target voltage by the control system. Speeding up this measurement, reducing labor costs and improving the measurement accuracy were important elements of optimizing the potline control. At the time of the potline startup, a cathode voltage drop was measured in the middle of the longitudinal side of a cell between anodes Nos. 8–9 and cathode bar No. 12, as shown in Figure 12 below.

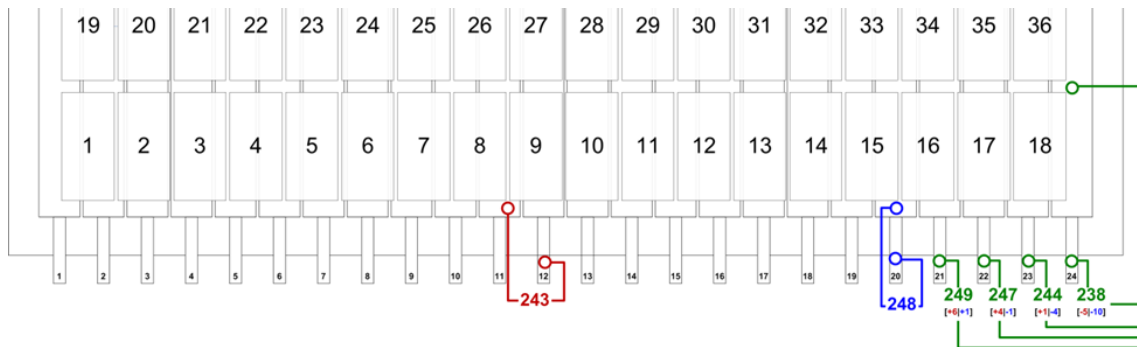


Figure 12. Cathode voltage drop measuring scheme.

Such measuring scheme required increased operating cranes working time to open holes in the bath crust for measurement. Additional crust breaks had a negative impact on the cell power and heat balance. After carrying out a series of experiments, the measuring scheme was changed – the measurement is performed between a taphole in the cell end-wall and cathode bar No. 23. The new measuring scheme showed high repeatability of results compared to the standard one, at the same time it does not require crust breaking which significantly reduces time consumption and eliminated a negative impact on the cell heat balance.

2.5 Challenges on the Way of Reducing Energy Consumption

As known, operational parameters area (operational window), in which cell working steadily, becomes narrow during anode-cathode distance reduction [5]. Small reduction of raw materials quality or pot room equipment malfunction could be a potential problem at this moment. For instance, anodes quality reduction in spring-summer 2015 and using anodes with 100 mm high shelves on longitudinal sides (Figure 3) at the same time going to rapid increasing of anode consumption and anode butts height decreasing especially during the last days of cycle, what becomes the reason of strongest “carbon crisis” in pot rooms. The spikes number on anode surface rapidly increased to a maximum of 648 spikes per month or 1.93 spikes for 1 cell per month in summertime.

The current was decreased temporally and voltage was increased insignificantly for “carbon crisis” termination. The new anode shape implementation allowing us significantly reduce chances of such “anode crisis” existence.

2.6 Implementing 1550 mm Long Anodes

The first tests of anodes with increased length were carried out in the potline as early as 2011, and a positive result was achieved. The modernization of anode production at Sayanogorsk Aluminum Smelter and construction of Taishet Anode Plant allowed the Company to use in-house anodes 1550 mm long. Testing of pilot groups of cells with in-house anodes 1550 mm long was started in 2020. It was managed to achieve a reduction in power consumption by 127–188 kWh/t Al. Since August 2020, 50 % of the potline cells have been switched to anodes 1550 mm long.

Issues encountered when switching to longer anodes:

1. The volume of the liquid bath in a cell decreased which required to make changes in the practice of controlling and correcting the bath level in a cell;
2. The amount of the covering cryolite containing raw material passing to the melt decreased during the anode cycle. That required revision of the material balance and increase the share of the cryolite containing raw material within the covering material;
3. Also, the heat balance changes. The work on optimizing process parameters is underway.

At the end of 2021, it is planned to switch 100 % of the potline cells to in-house anodes 1550 mm long. That will allow increasing the potline capacity by means of increasing amperage without increasing the specific energy consumption.

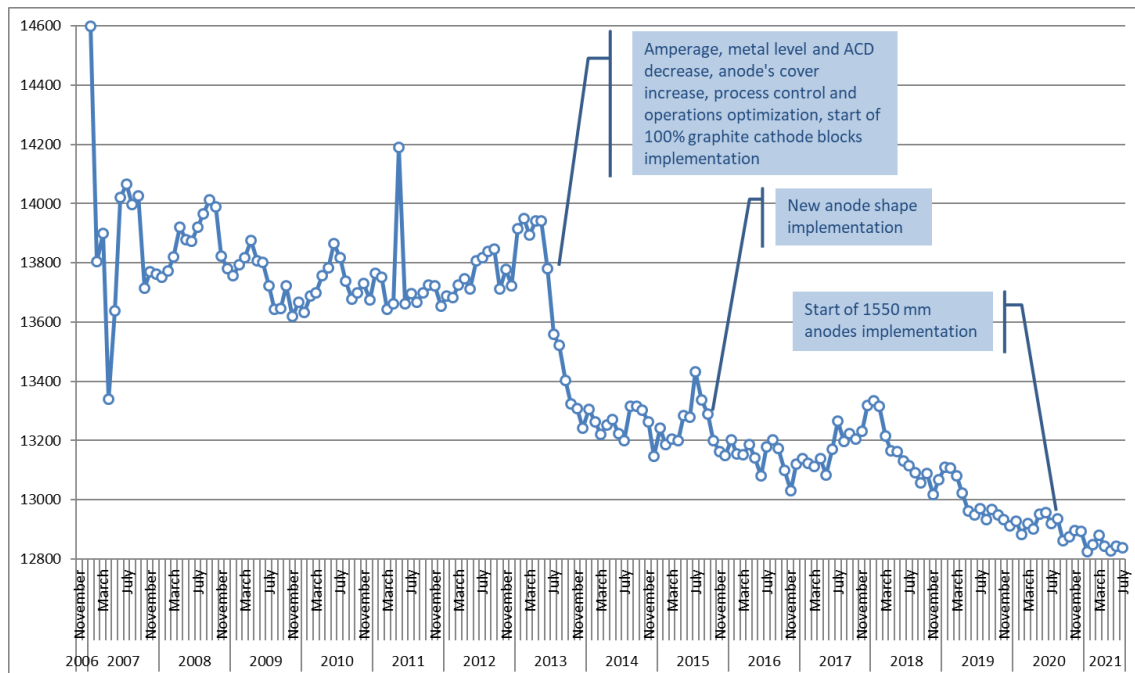


Figure 13. Power consumption, kWh/t Al.

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