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REDUCTION IN POWER CONSUMPTION AT UC RUSAL'S SMELTERS 2012–2014

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Abstract

UC RUSAL remains one of the world's leaders in primary aluminium producing eight percent of total world output in 2013. In 2012, following the global industrial trends, Management initiated several technical projects with the goal to decrease power consumption in all reduction technologies used. Below are the major measures:

1. Energy balance adjustment to reduce heat generation by a stage-by-stage decrease in the anode-cathode distance (ACD) down to the Limit values, resulting in the specific power consumption has decreased by 300 DCkWh/t.
2. The introduction of slotted anodes for the PB cells at the Krasnoyarsk and Irkutsk smelters decreasing specific power consumption by an average of 200 DCkWh/t.
3. Advanced energy-saving cathode designs are currently tested with a potential for decreasing 300 DCkWh/t or more.

The rest of this paper will describe how these projects decreased the specific power consumption in all RUSAL smelters between 2013 and 2014.

Introduction

The methodology is based on the assumption that the reduction cell is a dissipative structure with multiple stationary states [1]. This means that the cell can operate under different process parameters: amperage (I), metal pad and bath level, AlF_3 content in the bath (CR), superheat (t_s), side ledge thickness (h_l), working (operational) voltage (U_{cell}), ACD and other parameters within the Operational Window [2] and there is a unique entropy generation associated with each set of parameters. The more entropy is generated, the more irreversible is the process [3].

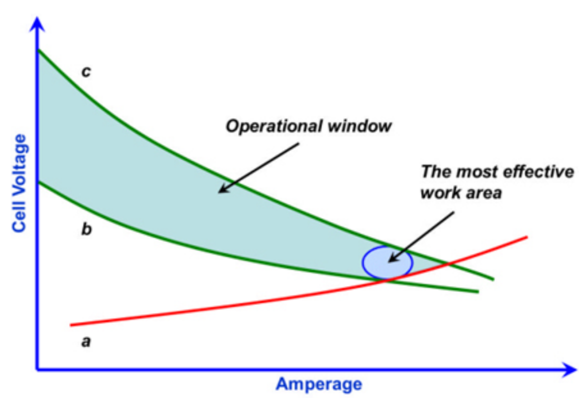


Figure 1. *Operational window* (by B. Welch [2])

According to the first law of thermodynamics, the electrical work done over the cell is consumed to change the enthalpies of the starting (initial) materials and maintain the ambient temperature favoring chemical reactions:

$$I \times U \times \tau = \Sigma n_i \times \Delta H_i + Q \, , \qquad (1)$$

where: I – amperage, A; U – cell voltage, V; τ - time, s; n_i - number of reacting moles of the materials; ΔH – changes in the enthalpies of the materials involved in transformation, J/mol; Q - heat dissipation to the environment, J.

The left-hand side of the equation (1) is the electrical work done over the cell. It is well known that, other things being equal, the rate of heat dissipation determines the efficiency of the reduction process: the less is heat dissipation, the more efficient is the process [4]. Moreover, the heat dissipation can be managed by means of adjusting the energy balance of the cell and the cell design. Maximum heat losses (up to 40% of the total losses) occur at the sides of the cell. The dissipation work reaches its maximum in the bath zone where the heat dissipation is governed by the design of the sidewall and the thickness of the side ledge which is a function of the bath superheat, t_s [5]:

$$t_s = t_{bath} - t_{lq} \, , \qquad (2)$$

$$Q = h \times t_s \times S \times \tau \, , \qquad (3)$$

where: t_{bath} – bath temperature, K; t_{lq} - liquidus temperature, K; h - total heat transfer coefficient, W / (m^2 * K); S – sidewall surface area, m^2; τ - time, s.

The liquidus temperature is a function of the bath composition and t_{bath} is determined by the heat flux from a chemical source of heat (enthalpy changes during back reactions) and the electrical work of dissipation in the ACD ($I \times U_{acd}$)-to-sidewall zone. In practice, the total dissipation depends on the intensity of the source and the thickness of the insulation of the sidewall which includes the side ledge as a dynamic component [5]. Thus, all other things being equal, the voltage drop in the ACD (U_{acd}) zone and bath composition (through changes in t_{lq}) determine the whole spectrum of stationary states of the cell. This spectrum is limited to the Operational Window. Kvande described several stationary states of the cell and the reasons for them [6].

Figure 1 shows the Cell Operational Window Figure [2]. As seen in this figure, the cell is stable in the zone limited by 3 lines characterizing ACD values at different amperages. Lower line ***a*** shows the MHD stability limit. (An ACD decrease down to this limit will lead to metal oscillations, short circuits and process failures.) At a low amperage, the MHD stability limit is unlikely to be reached, and this limit is considerably lower than the second ACD limit value, i.e. the lower "heat" limit ***b*** which is characterized by a low superheat (alumina has no time to dissolve producing mucks on the bottom and destabilizing the process). The upper "heat" limit ***c*** reveals another extreme case, a high superheat that leads to no side ledge formation. As a result, the current starts to flow toward the sidewall which leads to process failures. The figure shows the most effective cell operational zone which is close to the crossing of all the three lines (***a***, ***b*** and ***c***). The more accurate is cell maintenance, the more stable are raw materials, and the better (in terms of quality) is pot tending equipment, the higher is the possibility to operate the cell in the maximum efficiency zone. Within a specific working (operational) current range, there are many stationary states inside the operational window with higher or lower energy efficiency which are characterized by different ACD values (A_1 and A_2 in Figure 2).

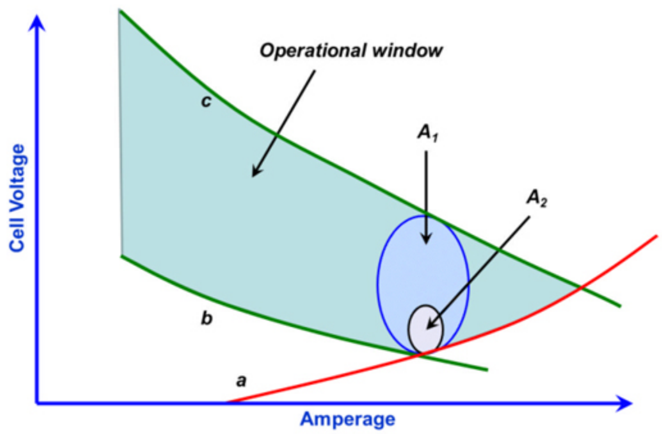


Figure 2. *Stationary states of the cell within the operational window*

Since many RUSAL's smelters were started up in the late 50's and 60's (Table 1) the operational window became narrower with the amperage increases that were initiated in 2000 (Figure 1) [7, 8]. In order to keep the stability of cell operation while increasing the amperage, process engineers made the operational window wider by:

1. increasing the AlF_3 concentration in the bath led to a higher superheat, less side ledge, and, as a result, helped maintain an appropriate process temperature;
2. increasing the metal pad. As a result, the MHD stability margin became higher; and
3. keeping high ACD values taking into account a delayed adaptation of the personnel to the changed process conditions.

However, due to the above three operational changes the amperage increases led to a higher power consumption (despite a higher CE) [7].

Table 1 shows the main RUSAL's smelter's capacities as of 2014.

Table 1. UC RUSAL's capacities in 2014

Smelter	Technology (kA)	Overall capacity, kt	Start up	Amperage incresing, kA
Kubal	PB (160)	128	1942, conv. VSS to PB in 2010	-
NkAZ	VSS (140, 170)	195	1943, 2^{nd} stage in 1957	12
KAZ	HSS (85)	76	1951	-
NAZ	PB (90)	23	1954, conv. HSS to PB in 1999	-
IrkAZ	VSS (175)	413	1962	14
	PB (300)		2008	13 (max)
KrAZ	VSS (165, 175, 180)	1008	1964	16
	PB (120, 160)		1994, 1998	17
BrAZ	VSS (105, 125, 165)	1006	1966	11
SAZ	PB (175, 190, 255, 280, 300, 400)	542	1985	45
KHAZ	PB (300)	297	2006	23 (max)

Under new conditions with decreased metal prices one of the main drivers of the production costs and the viability of the aluminum smelters was dependent on decreasing energy consumption [9].
In 2012, RUSAL's Technical Management initiated a number of energy-saving programs. Below are the major steps taken;

1. energy balance adjustment to reduce heat generation by a stage-by-stage decrease in the anode-cathode distance (ACD) down to the limit values, resulting in the specific power consumption has decreased by 300 DCkWh/t,
2. the introduction of slotted anodes for the PB cells at the Krasnoyarsk and Irkutsk smelters decreasing specific power consumption by an average of 200 DCkWh/t, and
3. advanced energy-saving cathode designs are currently being tested with a potential for decreasing 300 DCkWh/t or more.

Energy balance adjustment to reduce heat generation

As shown above, the potrooms operate within the operational window but with different energy efficiency. Figure 3 shows a standard Søderberg cell working (operational) voltage distribution histogram at a RUSAL smelter in 2012. Below are the main characteristics:

- average 4.480 V;
- minimum 4.225 V;
- maximum 4.762 V;
- range 537 mV;
- standard deviation 77 mV.

The potential effect of converting cells from the high-voltage group to the lower-voltage group was estimated to be a savings of up to 500 DCkWh/t.

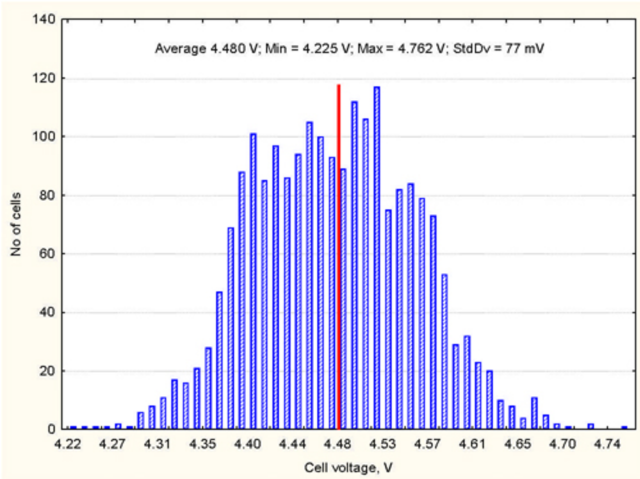


Figure 3. *Søderberg cell voltage in July 2012 (excluding startup)*

The work has been done in 3 stages;

1. determine the MHD stability limit and determine the target voltage, taking into account the MHD stability limit,
2. develop the methodology for decreasing the voltage in pilot cell areas, and
3. develop action plans, train the personnel and then implement it on a potroom level.

Stage 1. The cell MHD stability was measured by means of a step-by-step voltage decrease down to the threshold (limit) value (L_{mhd}). Below this threshold, the amplitude of oscillations was over 50mV. The difference between the initial working (operational) voltage and the threshold (limit) value is the MHD stability margin of the cell as shown in Figure 4.

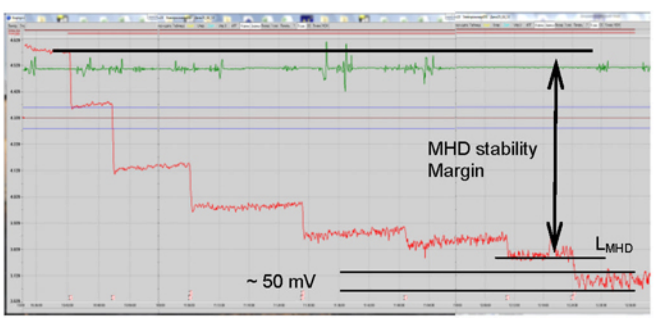


Figure 4. *Cell MHD stability margin*

As a rule of thumb, U_{cell} can be decreased down to L_{MHD} + 300-350mV in order to provide for stable cell operation (See Table 2).

Table 2. MHD stability margin for different UC RUSAL's types of cell

Smelter, technology	MHD stability limit, V	MHD stability margin, mV	Target cell voltage, V
Søderberg technology			
KrAZ VSS 175	3.88	500	4.23
BrAZ VSS 165	3.78	500	4.13
NkAZ VSS 140	3.87	390	4.22
NkAZ VSS 170	3.70	600	4.05
IrkAZ VSS 175	3.88	520	4.23
Prebake technology			
KrAZ PB 120	4.02	410	4.32
SAZ PB 175	3.93	360	4.23
SAZ PB 190	3.82	550	4.12
SAZ PB 255	3.79	350	4.09
KHAZ PB 300	3.65	280	*
IrkAZ PB 300	3.54	450	3.84

* Current cell voltage is near the limit

According to Table 2, the MHD stability margin is within 280 to 600mV. If the MHD stability margin is < 300 mV, the limit for this particular type of cell was reached.

Stage 2. The main criteria used for decreasing the voltage were:

1. the ability to maintain the superheat in the range of 5 to 8 degrees C,
2. maintain the cell MHD stability, and
3. absence of abnormal cell operation.

An example of voltage reductions in a VSS pilot area is shown in Figure 5.

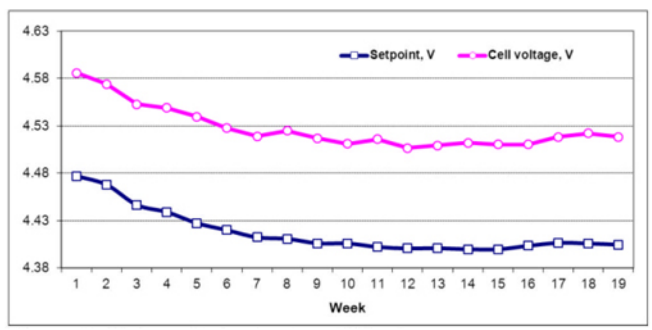


Figure 5. *Voltage Reduction in a VSS pilot area*

Voltage reduction examples in pilot cell areas at different smelters are shown in Table 3.

Table 3. Voltage reduction in UC RUSAL's pilot areas

Smelter, technology	Voltage reduction, mV
KrAZ VSS	72
BrAZ VSS	55
NkAZ VSS	73
IrkAZ VSS	72
IrkAZ PB	80

At this stage, the specific power consumption in the pilot areas was decreased by 150-250 DCkWh/t depending on the smelter, and a temporary U_{cell} limit was set based on the testing results. If a cell operated at U_{cell} higher than the temporary limit without reasonable justification, newer cells or cells with cathode problems, it gradually adapted to lower-ACD operation while the setpoint voltage was decreasing sometimes over several months. After converting most of the cells to the cell group with the voltage not higher than the temporary limit, the value of this limit started to decrease. Figure 6 shows a number of cells with the voltage higher than the temporary limit.

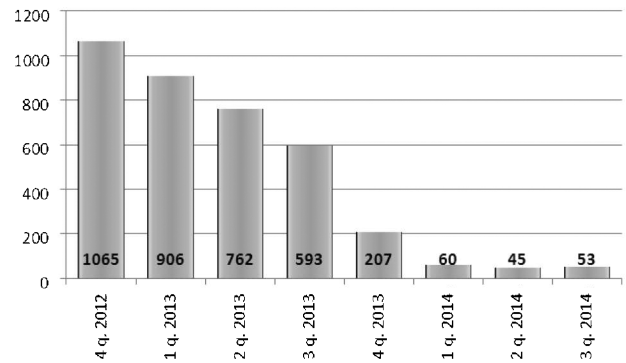
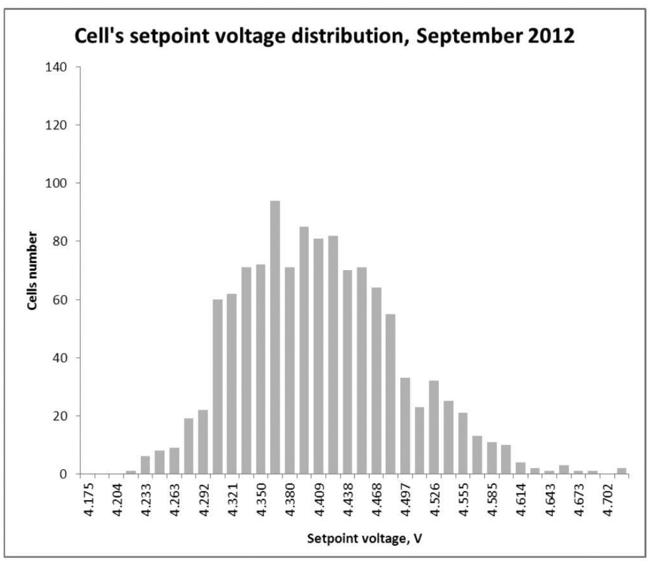


Figure 6. *No. of cells with the setpoint voltage higher than the temporary limit at a VSS smelter.*

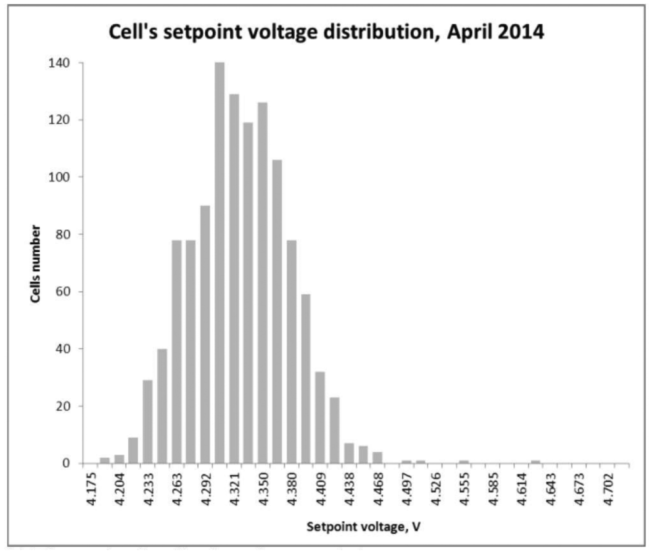
Stage 3. At this stage, the average voltage of cells in operation was decreased without any cell refurbishment (revamp) See Figure 7.



a) The main distribution characteristics:

- average 4.403 V;
- minimum 4.219 V;
- maximum 4.717 V;
- range 498 mV;
- standard deviation 81 mV.

Figure 7a. *Setpoint voltage distribution at one UC RUSAL's smelters as of September 2012*



b) The main distribution characteristics:

- average 4.320 V;
- minimum 4.181 V;
- maximum 4.629 V;
- range 448 mV;
- standard deviation 51 mV.

Figure 7b. *Setpoint voltage distribution at one UC RUSAL's smelters as of April 2014*

As seen in Figures 7a and 7b, the standard deviation of the setpoint voltage decreased from 81 to 51mV and the average voltage decreased by 83mV.

To keep the cells within the operational window under electrical work reduction conditions the heat losses were reduced in the following two ways depending on the cell technology;

1. Bath superheat (t_s) reduction by changing bath composition in order increase h_r.
2. Anode insulation (prebake cells) by increasing the thickness of the anode cover.

1. VSS Technology

In VSS cells, the decrease in U_{cell} was accompanied by an increase in CR while the superheat was decreasing and the side ledge thickness was increasing. The dynamics of these parameters are shown in Figure 8 and Figure 9.

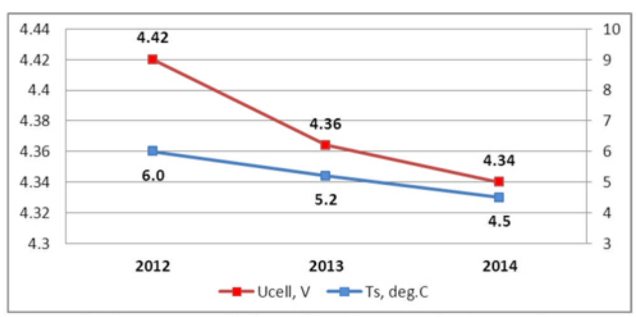


Figure 8. *Dynamics of VSS cell voltage and bath superheat*

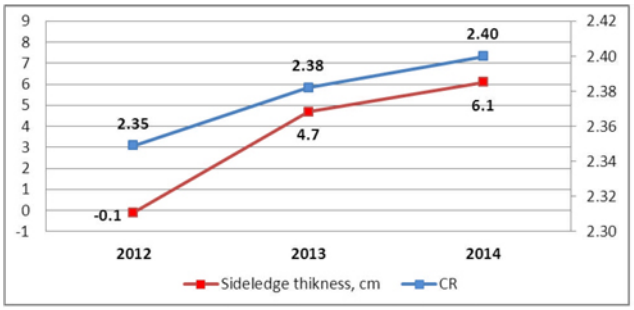


Figure 9. *Dynamics of cell CR and side ledge* thickness *-0.1cm – sidewall block destruction under no side ledge conditions*

As a result, the specific power consumption during aluminum production decreased by ~500 DCkWh/t (See Figure 10).

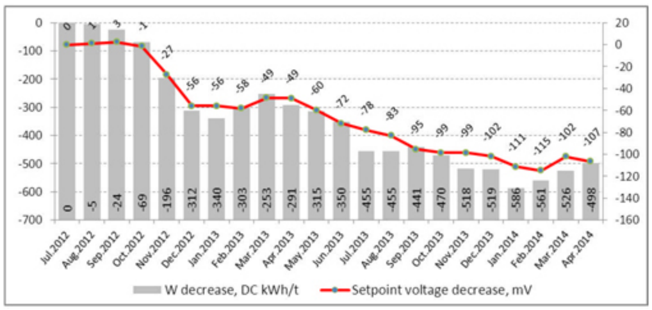


Figure 10. *Dynamics of specific power consumption and VSS cell setpoint voltage*

2. Prebake Technology

In the prebake cells the decrease in heat loss was achieved by increasing the anode cover material height by 5 to 10 cm thus decreasing the anode heat losses through the anode cover reduce the voltage while maintaining the thermal balance (See Figure 11).

a)

b)

Figure 11. *Pre-bake cell anode cover*

a) before energy efficiency improvements; and

b) today.

Figure 11 shows that the anode cover was increased up to the bottom of the anode yoke. In addition to amperage decreases in individual potlines, a higher anode cover helped decrease the specific power consumption by ~400 DCkWh/t, (See Figure 12).

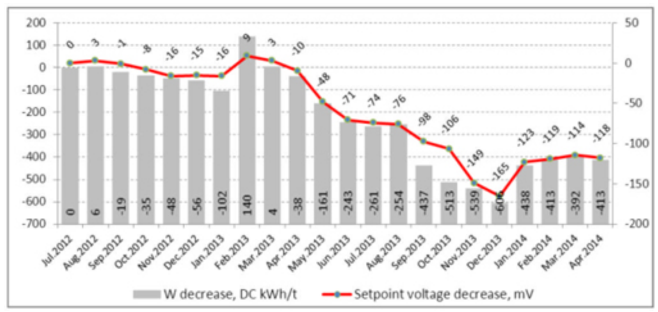


Figure 12. *Dynamics of specific power consumption and PB cell setpoint voltage*

Introduction of slotted anodes

In the past few years, RUSAL had experience of testing slotted anodes [10]. The testing results were positive, but several problems related to slotted anode production did not allow converting cells to the use of such anodes.

In 2012, UC RUSAL initiated a program to convert PB cells to slotted anodes (two slots along the anode) in PB cells at the Krasnoyarsk and Irkutsk aluminum smelters.

The introduction of slotted anodes helped decrease the noise level due to easier gas disposal through slots from below the anode (Figure 13). As a result, it led to a smaller specific area of the anode bottom covered with anode gases, a thinner bubble layer and, consequently, a lower voltage drop in the bubble layer and lower real anode current density (the amperage divided by the surface of anode bottom that is in direct contact with bath). The cell voltage was decreased by 60-80mV, and this decrease helped reduce the power consumption down by 200 DCkWh/t.

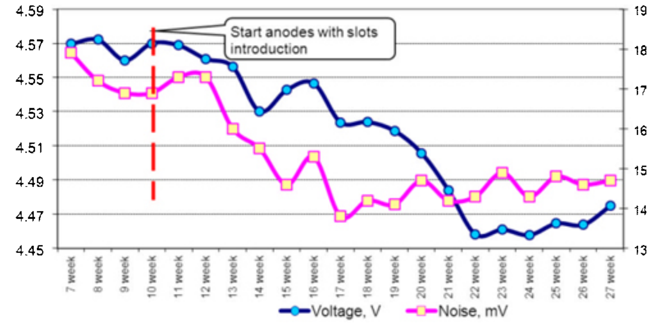


Figure 13. *Dynamics of cell voltage and noise level in the course of converting cells to slotted anodes*

In 2014, a project was initiated to convert the Sayanogorsk and Khakass smelters to slotted anodes (which means 100% cells will use slotted anodes). Information on the project will be given after completion the project.

Advanced energy-saving cathode designs

Over the years the cells used at the individual smelters were re-designed and upgraded and now new designs are being tested. It is expected that the new designs will lower the specific power consumption by 300 DCkWh/t after the project has been completed. The main results of the above work can be found in the *Proceedings of the VI International Congress «Non-Ferrous Metals and Minerals»* [11].

As a result of implementing energy efficiency improvement projects, the specific power consumption at UC RUSAL's smelters has been decreased by ~300 DCkWh/t (Figure 14) since 2012.

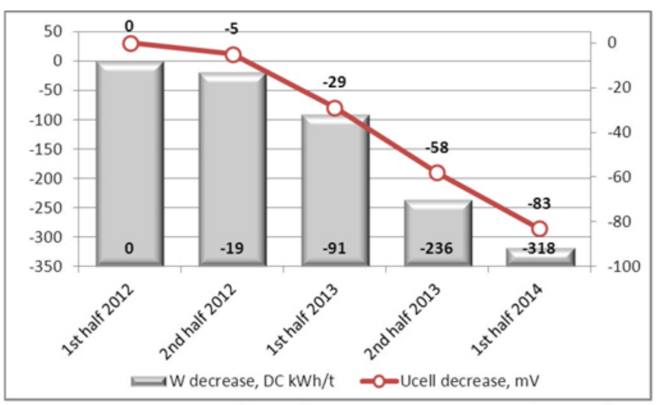


Figure 14. *Dynamics of specific power consumption during Al production and UC RUSAL's cell voltage*

The efficiency of UC RUSAL's Søderberg technology has come close to the efficiency of pre-bake technology due to a considerable reduction in power consumption (taking into account the fact that power costs of the production of 1 tonne of pre-bake anodes is 5-6 higher than the cost of production of 1 tonne of anode paste.) Success in the implementation of RUSAL's Environmental Friendly and Energy Efficient Søderberg Technology allows to increase production efficiency and feel confident about the future.

Conclusions

UC RUSAL has successfully implementing a program to improve the efficiency of aluminum reduction process at its smelters. The program includes: ACD optimization, slotted anodes, cathode energy-saving designs, and some other things not mentioned in this paper. Since 2012, the implementation of the program has helped decrease the specific power consumption by ~300 kWh/t within UC RUSAL.

Acknowledgements

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