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VERTICAL STUD SØDERBERG TECHNOLOGY DEVELOPMENT BY UC RUSAL IN 2004 – 2010 (PART 1)

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Abstract

Due to the considerable number of VSS cells (more than 60 % of the total capacity), RUSAL continues to develop the Søderberg process successfully. Alumina point feeding systems (APF) and dry gas scrubbers were introduced, and anode paste production was modernized in the Krasnoyarsk smelter. The amperage was increased in all VSS potlines. These actions have increased the aluminium production efficiency and environmental sustainability. Besides, the company's Engineering and Technological Centre (ETC) has successfully fulfilled the R&D program creating the new modification of VSS technology (so-called "Eco-Søderberg") reaching a new environmental standard. The results of these and other activities of the company from 2004 to 2010 are shown in the present article.

Introduction

Søderberg technology (VSS & HSS) is being used at most of the aluminium smelters in the former Soviet Union including two of the largest in the world situated in Bratsk and Krasnoyarsk due to the features of industrialization and development trends in the global aluminium industry in 30 - 60 years of 20th century (See Table 1).

Table 1. UC RUSAL's Søderberg capacities in 2010

Smelter	Technology	Start up	Capacity (2010)
Bratsk	VSS	1966	981 000
Krasnoyarsk	VSS+PB	1964	864 000 (VSS)
Novokuznetsk	HSS+VSS	1943	267 000
Irkutsk	VSS+PB	1962	233 000 (VSS)
Volgograd	VSS	1959	155 000
Bogoslovsky	HSS	1945	112 000
Kandalaksha	HSS	1951	65 000
Nadvoitsy	HSS+PB	1954	52 000 (HSS)
Zaporozhie	HSS	1933 / 1949	24 000
Total			**2 753 000**

All of the Søderberg technology's advantages and disadvantages are very well known [1]. Cheap manufacturing and maintenance of the anode are the most obvious benefits. According to our estimates, with other things being equal, the cost of Søderberg anode paste is 23% cheaper than prebaked anode (PB) assemblies' production due to the absence of anode baking and rodding. So the total energy consumption for VSS and prebaked technologies are approximately the same, since the production of 1 tonne of PB anodes consumes 5 to 6 times more energy than production of 1 tonne of Søderberg anode paste (taking into account the energy used for obligatory coke calcination).

At the same time, the difficulties associated with sealing of the pots makes this technology unattractive for expansion. Currently, only a few examples of Søderberg expansion are reported:
- expansion of the VSS potlines in Brasiliero du Aluminio (CBA) in Brazil,
- positive experience of the Elkem Lista smelter (Norway) modernization with a further partial replication in VSS Alivas Alcoa smelter in Spain [2].

According to the website [3] Søderberg capacities will decrease by 3 percent in 2012 due to the closure of old smelters and their conversion to PB technology. The total of Søderberg share will then be 12% versus 15% in 2009.

Following the world trends, RUSAL has, and will be, erecting all new smelters using prebaked technology, including:
- Khakass smelter RA 300 technology (started in 2007),
- Boguchansky smelter RA 300 technology (projected for 2013),
- Taishet smelter RA 400 (projected for 2013 - 2014).

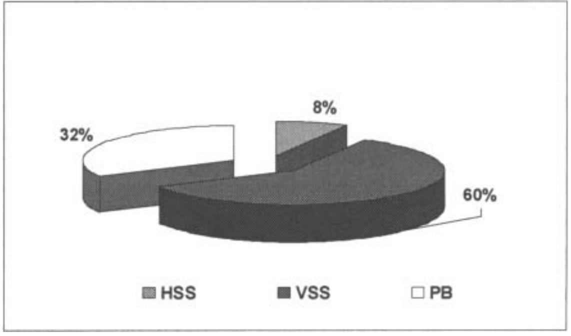

Figure 1a. UC RUSAL's production capacities in 2010

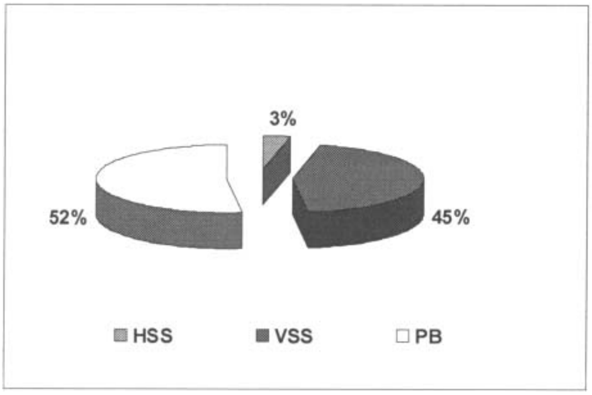

Figure 1b. UC RUSAL's forecasted production capacities in 2018

Nonetheless, even after the commissioning of new smelters, the company's share of Søderberg capacities will decline, but still remain around 45%. Figures 1a and 1b show the forecast of UC RUSAL capacities change in 2018 versus 2010.

Taking into account the scale of Søderberg capacities, converting them to a more environmentally friendly prebaked technology would involve a huge investment equal to the construction of several Greenfield smelters with a CAPEX of about 4000 $/ t Al.

Moreover, the smelters feel growing pressure from the government's environmental control due to the rise of environmental consciousness in the Russian society. This motivates the people to constantly improve the Søderberg technology's environmental and economic efficiency. In particular, the company has been carrying out a phased ecological modernization, while increasing the productivity to obtain funds to realize it. The first phase of this modernization was held in the Krasnoyarsk Aluminium Smelter (KrAZ) in 2003 - 2007.

First Phase of Søderberg Modernization in KrAZ

The Krasnoyarsk Aluminium Smelter (KrAZ) was commissioned in 1964 with a nameplate capacity of around 850000 tpy (See Figure 2). In 2011 the VSS cells produced 864 000 tonnes of aluminium out of 977 000 tonnes of KrAZ's total output. It's about 27% of aluminium produced in Russia, and 3% of the whole world's production.

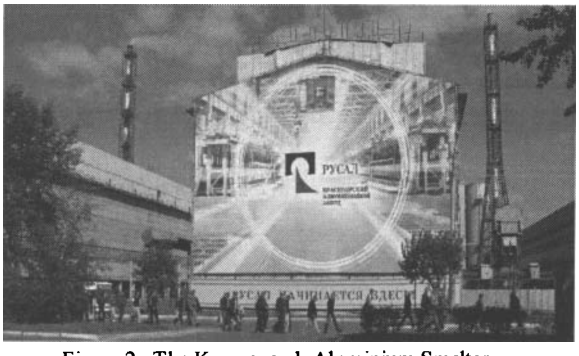

Figure 2. The Krasnoyarsk Aluminium Smelter

KrAZ has 25 potrooms:
- 21 equipped with 174 kA VSS pots,
- 1 potroom - 168 kA VSS pots,
- 1 potroom - 185 kA VSS pots,
- 2.5 potrooms equipped with 140 and 185 kA prebaked pots,
- half of a potroom with 75 kA pots for aluminium high purity production using the three-layer purification technology.

A bank feasibility study for modernization was developed by RUSAL Engineering - Technology Center with the assistance of the Hatch Kaiser and was approved in 2003.

The first phase of the modernization plan consisted of:
1. erection of 19 alumina dry gas scrubbers for potrooms,
2. installation of alumina point feeding systems (APF) on VSS pots (see Figure 3), including:
   - new process control algorithms for feeding control,
   - compressor stations installation to provide compressed air for APF,
   - vehicles for APF's alumina charging,

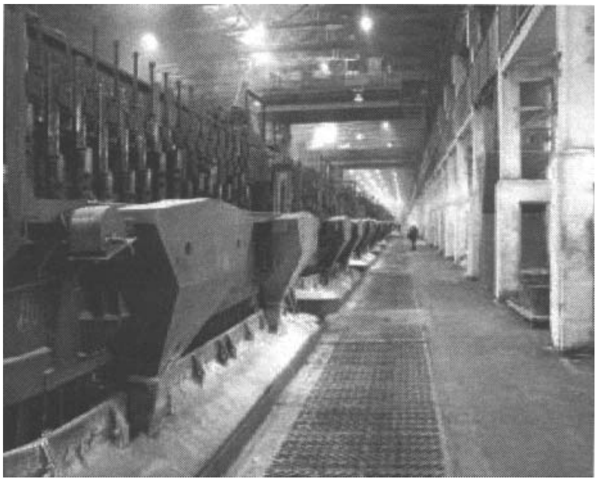

Figure 3. Point-feeding system for VSS 174 kA pots

3. reconstruction of the anode paste plant, which includes:
   - two anode paste production lines reconstruction to enable use of high softening pitch usage and dry scrubbing system,
   - introduction of secondary air supply in coke calcinations kilns,
4. 8 potrooms conversion into the "dry" anode technology (the others were converted in the period 1998 -2002)
5. Replacement of old potroom stud pulling cranes with modern ones,
6. integration of four separated potrooms into two potlines,
7. elongation of two potrooms by 40 meters to facilitate the installation of 8 additional VSS pots,
8. replacement of three rectifiers and installation of 6 boosters in order to increase the line current by 18 kA to 174 kA.

All the works were successfully carried out within 6 years at a total investment cost of 305 million US$.

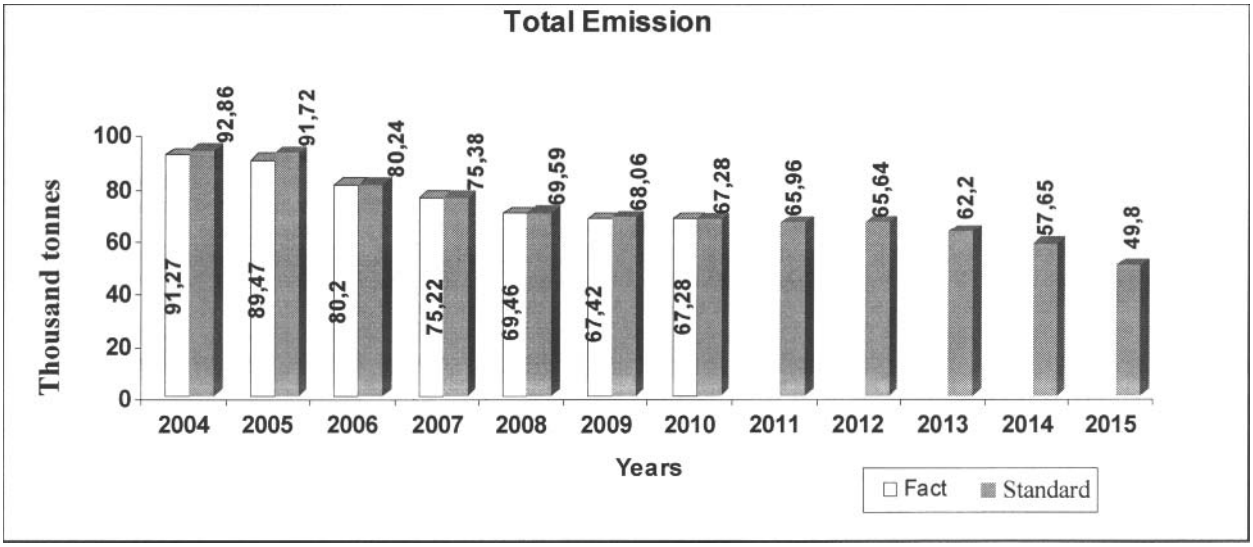

Figure 4. Total emission dynamic from the Krasnoyarsk smelter in 2004 – 2010

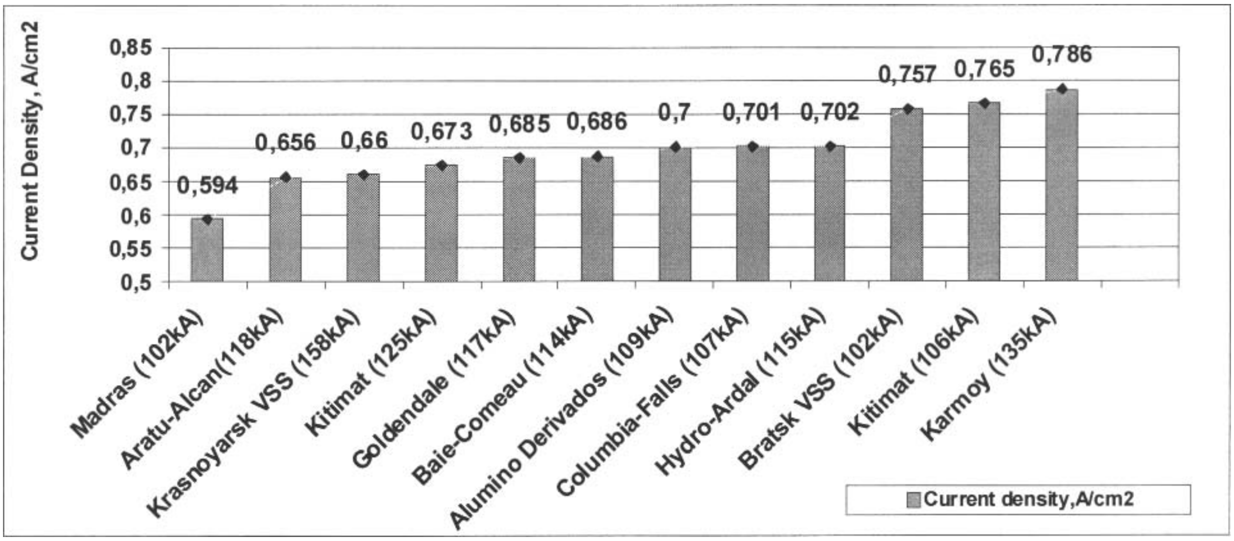

Figure 5. Anodic current density for different VSS smelters in 1990[th] and early 2000[th] [4]

As the result, the total smelter atmosphere pollutants in the nearby area decreased by 25 000 tonnes or 18% from 2004 to 2010 (see Figure 4). At the same time, according to independent municipal monitoring, the HF concentration in the surrounding areas has been reduced 2-fold, from 0.01 to 0.005 mg/m^3. The financial justification for the modernization was due to the line current increase and the additional cells.

Line Current Increase in Krasnoyarsk Aluminium Smelter

Faraday's well-known equation (1) indicates only three ways to improve the pot productivity, namely the increasing of:
- line current,
- current efficiency (CE),
- and number of pots.

$$M = I \times 0.336 \times \eta \times \tau \times n \qquad (1)$$

where:
M - mass of metal produced per day, kg,
I - current, kA,
η - current efficiency, as a fraction,
0.336 - electrochemical equivalent, g / A × hour,
τ - time, hours,
n - number of pots.

In accordance with (1), 1 kA of current gives 7.2 kg of metal per day per pot (CE =0.9). An electrolytic cell as a chemical reactor has a fairly wide window of allowable process parameters to operate stably. Different VSS smelters in the world have been working within a large range of anodic current densities: from 0.55 to 0.8 A/cm^2. (See Figure 5). In particular, most of the KrAZ pots worked with a current of 156 kA and a current density of 0.63 A/cm^2. The program of line current increase started in Krasnoyarsk aluminium smelter in the early 2000s, just before the global modernization. A test section equipped with a 25 kA booster consisting of 24 VSS pots (or 1/4 of a potroom) was established. At the same time mathematical modeling of thermal, electrical and magneto-hydrodynamic fields of typical VSS pots was carried out by the ETC. It was done using step by step simulation of pot energy balance up to 180 kA. The model showed that the pot can stably work at 174 -175 kA (with a current density of around 0.73 A/cm^2), see figure 6.

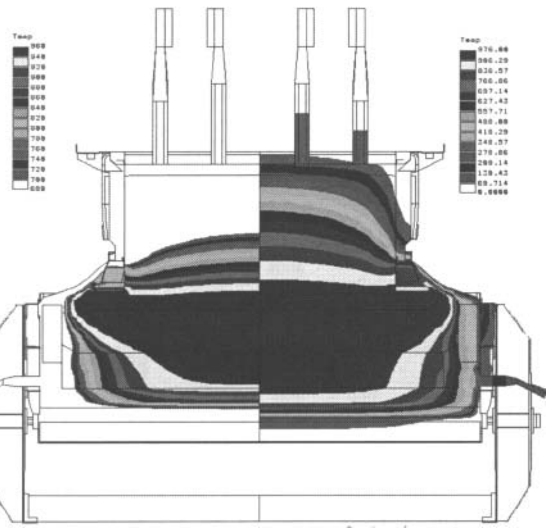

Figure 6. Simulation of temperature field (right) and ledge profile (left) for the VSS pot with the current of 174 kA.

The basic operational parameters affecting the energy balance, like: pot voltage, metal and bath levels, bath composition, and temperature were defined by modeling and checked in the test section pots.

The experience gained in the test section was quickly spread to other KrAZ potrooms (see Figure 7). Increasing line current was done more smoothly due to special motivation programs that were implemented for potroom personnel and the development of the new operating procedures for the increased current and corrective actions. The regulations included:

1. stabilization of process conditions after the prior step of line current change: the criterion of stability was the minimum percentage of deviations from the specified range of variations in bath temperature, bath composition, metal and bath levels, and amount of skimmed carbon dust;
2. audit of technical and technological potroom readiness to the next stage of current increase. The audit result was a formal act about the potroom readiness. The audits were conducted by the potroom people and ETC process engineers together; and
3. taking the next increase of the current after the audit's decision.

Basic electrolysis parameters were also adjusted during the current increase, in particular, the bath molar ratio was reduced from 2.5 to 2.32, and the metal level was raised from 46 to 51 cm. The rate of current increase was about 5 kA per month (spring 2003) and later it significantly slowed down in 2006 – 2007: the current ramping up was 3 kA only due to approaching the pot design and rectifiers limits. Thus, the current in the VSS potrooms was increased from 158 to 174 kA, which gave around 80 000 additional tonnes of metal annually.

The main negative factor associated with the current increase was the pot voltage increase and consequently the specific power consumption growth (see Figures 8, 9). It happened because of ohmic voltage components and anode overvoltage increasing that could not be adequately compensated by the anode - cathode distance decrease.

The reduction of the specific power consumption is a great challenge for all companys' smelters. Nowadays the action plans of reducing energy consumption were developed and are being accomplished in every smelter.

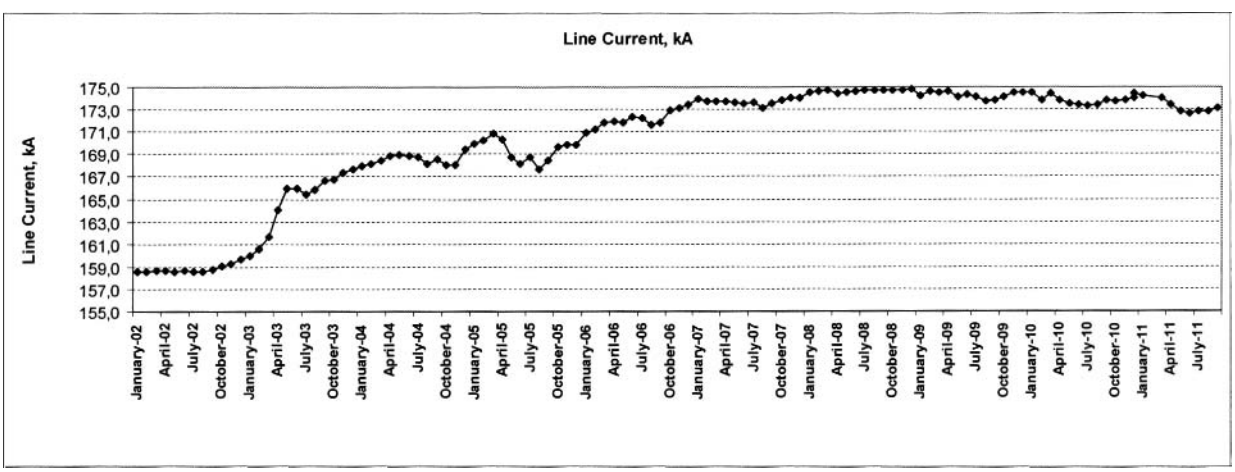

Figure 7. Line current dynamic in the Krasnoyarsk Smelter in 2002 - 2011

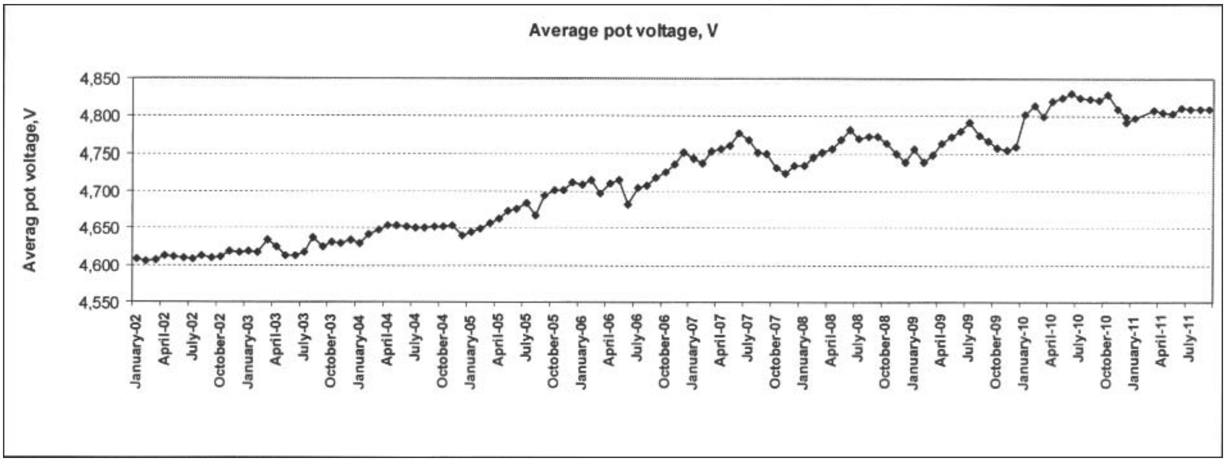

Figure 8. Avarage pot voltage dynamic in the Krasnoyarsk Smelter in 2002 - 2011

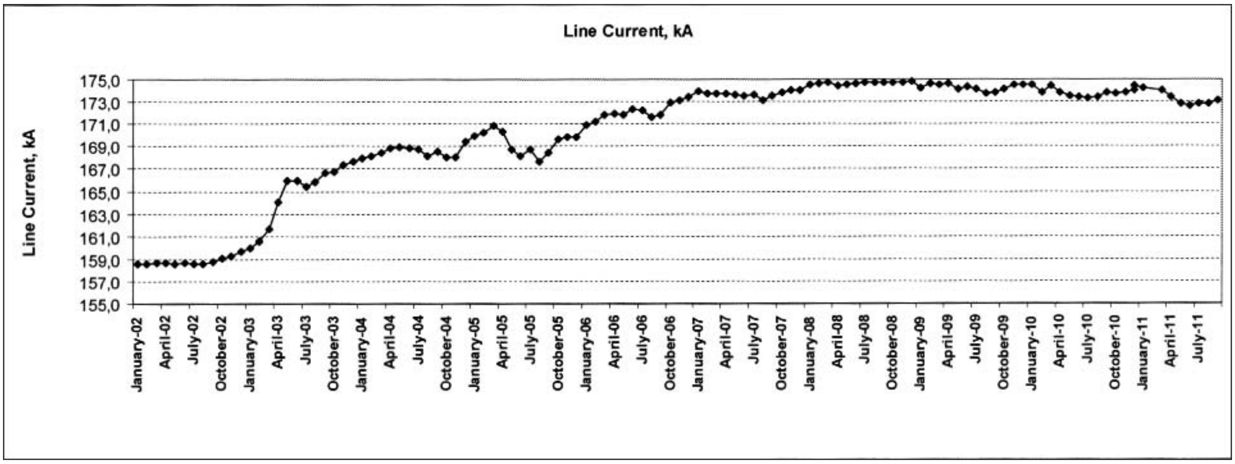

Figure 9. Specific energy consumption dynamic in the Krasnoyarsk Smelter in 2002 - 2011

Line Current Increase in Other Aluminium Smelters

Following the KrAZ's experience, amperage creep has been successfully implemented in other RUSAL facilities, as shown in Table 2.

Table 2. Current increase figures in VSS smelters

Smelter	2002 Amperage, kA	2011 Amperage, kA	Delta, kA
Bratsk	154.5	164.9	10.4
Krasnoyarsk	158.8	173.4	14.6
Irkutsk*	151.6	169	17.4
Novokuznetsk	141	152	11
Volgograd	141	155	14

* One 140 kA potline shut down is taken into account here

The table contains data for VSS only. At the same time the current was raised from 86 to 101 kA in the Novokuznetsk HSS pots. In general, the line current of VSS was raised by an average of 14 kA.

Improving of Søderberg Lines Productivity by Current Efficiency

One CE percent in accordance with equation (1) gives 14 kg of metal per day per pot (I = 170 kA). Usually at the same pot design, the most effective tools to improve CE in the pot line are the reduction of process disturbances and bath composition modifications. Both of those tools to improve Søderberg technology were used.

In particular, the company has implemented a centralized technology management system. To implement the management system the ETC established satellite Technology Departments in each of the smelter supporting the smelter technologies (reduction, cast shop, anode and cathodes production).

The main functions of the satellite departments are:
1. technical procedures development, where all the production parameters, control schemes, and management tools must be described in details. The task of unification of technology and the spreading of best practice have been solved during the documentation development;

2. electrolysis theory and practice training of smelter personnel on the basis of this documentation;

3. process monitoring and it's correction in order to prevent violations of the potlines stability;

4. keeping the company's management informed about the status of the production process, with a target to make timely changes in raw materials supplies, investments and equipment repair; and

5. programs for production improvement development.

Joint work of the ETC technology departments and smelter production staff allowed to achieve stable technology in spite of external factors' influence (i.e., raw materials, limitations on power supply, equipment problems, etc.), and successfully carried out the large scale programs such as mentioned above, current increase, change of bath composition and others.

In particular, bath molar ratio has been reduced from 2.44 to 2.37 in 2003 – 2004, thanks to introduction of a new algorithm for additions calculating and dry gas scrubbers (see Figure 10).

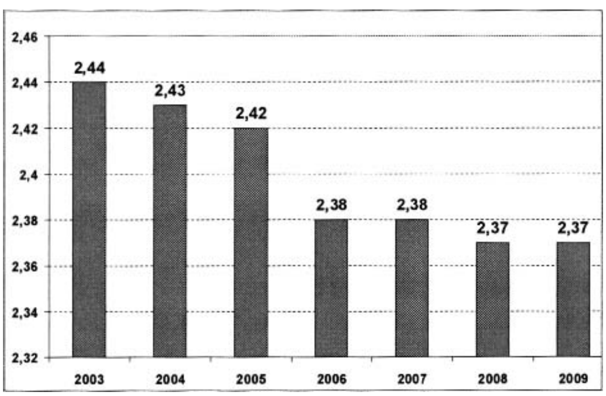

Figure 10. Molar ratio dynamic in RUSAL's VSS smelters.

The above activities have allowed increasing the VSS pots' current efficiency by 0.3% up to 89.2% in the most stable period in 2002 - 2008. Lately, CE decreased slightly as a result of the large number of pots shut down and restarting again in the crisis years of 2009 and 2010.

The Results of the VSS RUSAL Production Intensification

Figure 11 shows the growth of additional metal derived by the implementation of measures to increase production.

About 1.3 million tonnes of additional metal have bee produced by the VSS potlines in RUSAL, thanks to the line current increase since 2000. The CE contribution was 370 thousand tonnes.

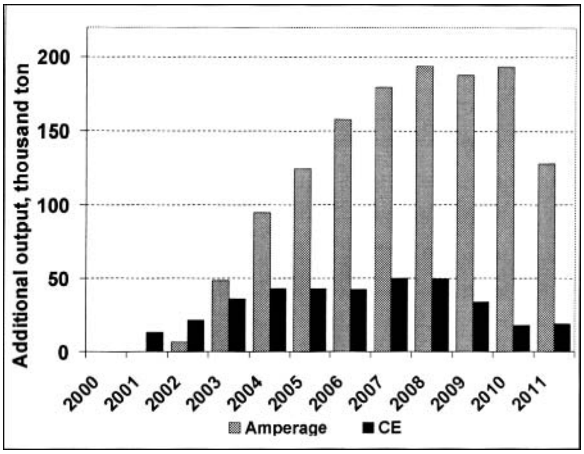

Figure 11. Additional output of aluminium delivered by the current and current efficiency in VSS potlines compared with the year 2000.

The Second Phase of Søderberg Modernization in Krasnoyarsk Smelter

The second phase of modernization began in 2010. It is based on the new so-called Eco -Søderberg technology developed by ETC in 2008 - 2009. Today, the creeping potline modernization is going on with the gradual replacement of the old design VSS S8BM pots with the new ones named by S8BM-E which meet to the environmental standards. 140 new pots are already installed in KrAZ. More details about the Eco-Søderberg technology can be found in the second part of this article.