Anode Effect Reduction at Nordural – Practical Points

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Abstract

This paper describes briefly the main tasks and methods that have led to lower total anode effect (AE) duration at Nordural smelter. Anode effect is a phenomenon which occurs when alumina concentration is low in the electrolyte and eventually increases the resistance in the pot, making instability, less aluminum production and increases PFC emissions [1]. Despite a current increase, substantial reduction of total anode effect (AE) duration has been achieved at Nordural smelter over the last three years with simple tasks that could be implemented in most smelters. The main reason for the reduction of total AE duration at Nordural is shorter reaction time among operators, analysis of AE root causes, physical experiments in pot control, prioritizing of procedures and statistical analysis as a measure of the gain of each process or control change.

Introduction

Few years ago the AE frequency was relatively high and the average duration exceeded 2 minutes/AE at Nordural while AEmin/potday exceeded 0.40 (see figure 1). With continuous improvements in smelter performance [2] and potline startup [3] the AE frequency was reduced significantly. The total PFC emissions due to AE at Nordural was identical to similar pot technology [4] few years ago but was still above some benchmark plants operating at <0.05 AEmin/potday [5]. Last few years the AE frequency and duration has decreased further with simple tasks and procedures that will be explained in paper.

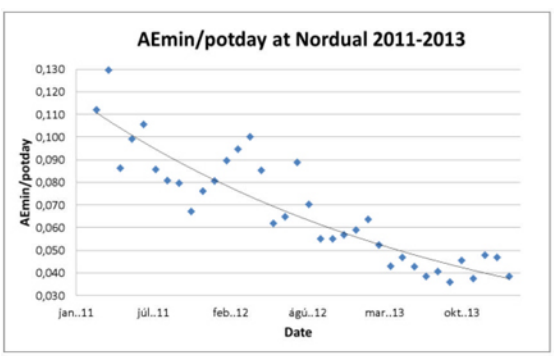


Figure 1: AEmin/potday at Nordural in 2011-2013

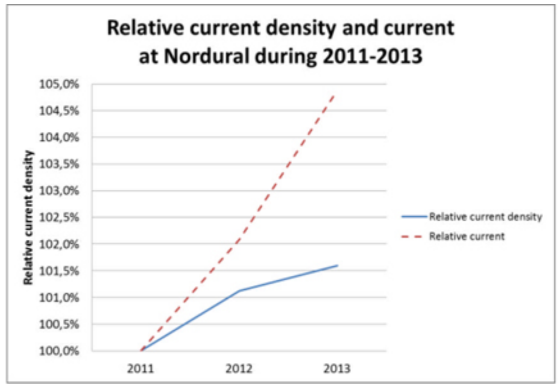


Figure 2: Current and current density at Nordural in 2011-2013 due to load and anode dimension variation in period.

Global environmental standards have increased substantially over the last years and one of the primary tasks in aluminum industry recently years is to reduce the number and duration of anode effects in order to minimize PFC emissions. The European Union has comissioned a law to set maximum allowances of greenhouse gas emissions from aluminum smelters of 1514 kg CO_2/tonne aluminum [6] produced in EU countries. If emissions are beyond this limit, extra allowances have to be bought on market that can influence the economic operation of the plants substantially. Great improvements in reducing PFC emissions [7] have been monitored during the last decades and benchmark smelters achieve AEmin/potday below 0.05. This paper describes Nordural´s work and method over the last few years to reduce AEs with good results. Nordural's pot technology is from the 1970´s. Generally, total anode effect duration increases when load and current density increases [8].

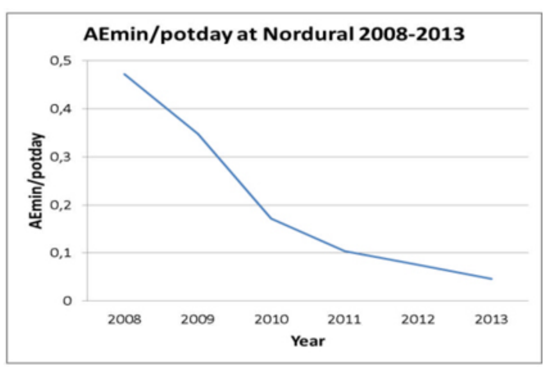


Figure 3: AEmin/potday evoluation at Nordural. The plant capacity increased during 2006-2007.

Despite current and current density increases, Nordural has decreased the AEmin/potday by 90% over the past five years and is currently below 0.05 AEmin/potday (see figure 1).

Anode Effect

Anode effect is a phenomenon where the critical current density exceeds some threshold value mainly dependent on the alumina concentration in the bath but also on bath temperature, flow, pot dimensions, etc. The count and duration of anode effect is recorded as the time period of the pot voltage exceeding threshold limits, for instance 8 volts. During anode effect, the pot voltage increases due to the rise of the concentration overvoltage, causing excess energy input to the pot, instability and production of PFC gases [9]. The main reactions that form increasing PFC emissions are [10]:

$$4/3\ N_3AlF_6 + C = 4/3\ Al + 4NaF + CF_4$$
$$E° = -2.50\ V \text{ at } 1000°C$$

$$2Na_3AlF_6 + C = 4/3\ Al + 4\ NaF + CF_4$$
$$E° = -2.69\ V \text{ at } 1000\ °C.$$

Work Procedures and Process Data

When AE occurs, an alarm is sent immediately to pot tenders in order to minimize the AE duration even if the automatic quenching is not sufficient to kill the AE. In addition, extra alarms are sent later if the duration exceeds some limits.

To ensure correct procedures in quenching AEs, several operators were specialized to become pot tenders. For a start, several lectures about AE were held to increase knowledge of AE causes both theoretically and practically. One of the operator´s primary tasks is quenching and preventing the AEs occurring repeatedly and to fix the pot before it suffers several AEs in a short period. Each technical operator has pot sections for supervision and observation.

Lectures about AE and the operational effects were held for the maintenance crew as well. Alarms of alumina feeding system were established for the operators and maintenance. The most critical alarms were pulled into one interface in order to get a clearer overview of the status of the alumina transport operation. In addition, the most important alarms were sent to the maintenance crew in order to react quickly to failures that could result in AEs. The frequency of pots lacking alumina due to faults or inadequate observation has therefore decreased significantly.

Root Cause Analysis and Process Data Accumulation

Subsequent to AE kill done by the automatic pot control system or the operator, a root cause analysis of the AE is done by the operator. The causes are analyzed, the reasons recorded and stored in a database. Process engineers analyze the main causes of AE to prioritize work and improvements.

Sometimes pots were not stable immediately after an initial AE and suffered several AEs before the root cause was eliminated. Regular meetings were useful where process engineers contribute to the AE analysis with the operators. Eventually, the necessity of curing problematic pots became a higher priority among the operators as they contributed to a big part of the AE frequency and duration. It was necessary to observe which factors affected the AE frequency but one also has to consider the AE duration for each cause.

Priority of Work Improvements

The AE duration at Nordural due to the alumina conveying system or low bath height had much more weight than for instance AEs during anode setting. Although the AE frequency during setting was substantially higher than the AE frequency due to broken feeders the latter was more critical. Analysis of the duration for each root cause of AE helped to prioritize work and improvements.

Bath Level, Measurements and Covering

The crust breakers structure in Nordural make the pots rather vulnerable to low bath and aluminum height. The bath management was changed in order to minimize the risk of excessively low bath. In addition, comparison of bath height measurements revealed that carbon dust or even cover material layer was sometimes included in the bath height measurements, resulting in improper measurement and possibly excess tapping of some pots. An increased level of aluminum seemed also to have positive results and reduced anode effect frequency i.e. breakers managed more often to go through the crust.

More focus on pot tending and opening of crust breaker holes was enforced by audits in order to prevent holes filling of solid cover material which had negative effect on alumina dissolution and carbon dust cleaning.

Experiments with quenching and voltage signal

Obviously, in order to obtain a significant estimate of each process or control change on AE duration or frequency, the variation between groups of pots has to be minimized. Factors affecting AE frequency such as alumina properties have to be taken into account (see figure 4) when selecting groups of pots to test with experiments and to have identical groups of pots for statistical comparison. The conveying distances in Nordurals potrooms are long and sometimes considerable variation in grain size distribution in alumina due to attrition during transportation which affects AE frequency [11].

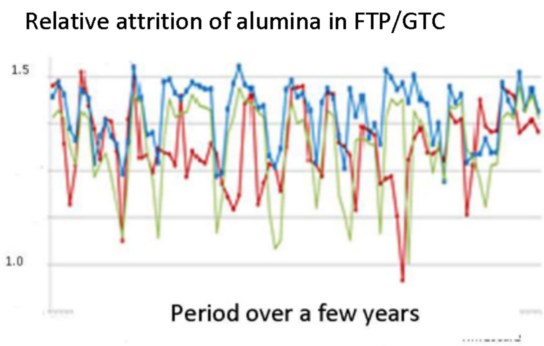


Figure 4: Variation in alumina attrition affecting AE frequency.

Various quenching procedures were tested at Nordural. The most important parameters during AE quenching experienced at Nordural was the stepwise downward shift of the anode bridge, the delay between separate downward movements and the amount of alumina feeding during AE kill.

Noise Signal and Bridge Shift

During AE quenching, some papers [12] have pointed out that it is important to reduce the ACD (anode to cathode distance) down by 1- 2 cm in order make the pot noisy, accelerate the gas escape under the anodes and increase the alumina dissolution rate. This was experienced at Nordural. It was critical that anode beam was shifted as fast as possible down to an ACD where the noise (or fluctuations in pot voltage) accelerated mixing of alumina in bath and the gas removal under anodes [12]. The average AE duration lowered substantially when the transition of the first downward movement of the anode bridge was changed to increase the probability of gaining maximum cell noise during the first downward movement (see figure 5).

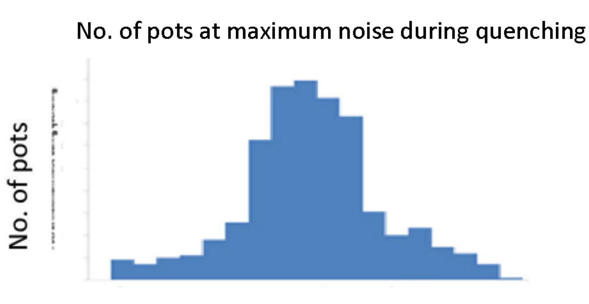


Figure 5: Statistical distribution showing frequency of pots at maximum noise during AE quenching at Nordural.

Starving of Pots and Observations

The best way to measure the efficiency of the automatic quenching was to initiate an AE and make observations during anode effect. Too little of a shift in the anode bridge elevation extended the duration of the anode effect; too much of a shift degraded the covering. If crust breakers worked too frequently an "elephant foot" was more likely to accumulate on the breakers tip but infrequent breaking increased residence time of alumina on the bath surface.

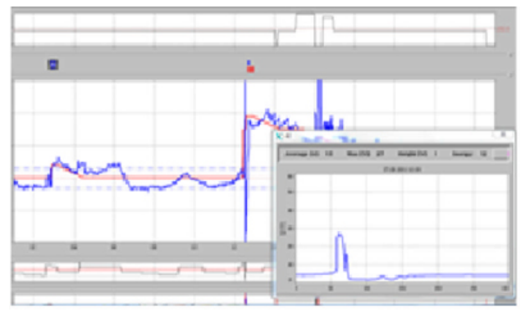
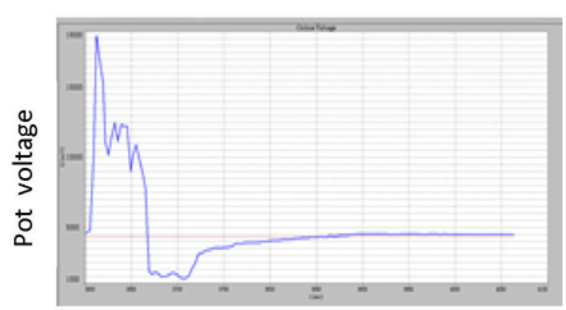


Figure 6: Voltage signal during AE.

A number of pots were starved to anode effect at Nordural in order to measure and observe the performance of the automatic quenching and alumina feeding.

Visual observations and analysis of the noise during quenching implied that Nordural had to change the existing quenching procedure to minimize AE duration. From these analyses it was decided to alter anode bridge shifting and alumina feeding during AE. Experiments at Nordural revealed that excess alumina feeding during AE quenching blocked some of the crust breaker holes. Eventually, the frequency of alumina shots during AE quenching was lowered and apparently resulted in lower AE duration on average.



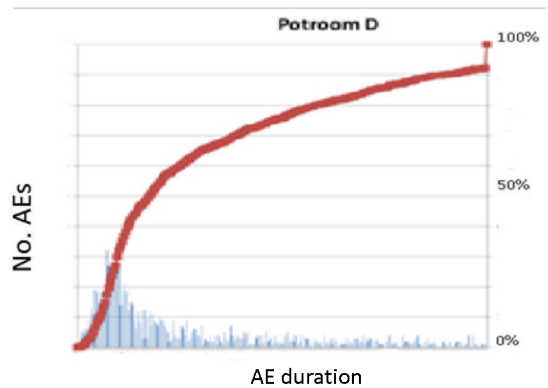


Figure 8: Histogram and cumulative sum of AE duration for group of pots at Nordural.

Statistical Estimation of Process or Control Adjustments

Statistical analysis (see figure 8) between sample groups with different quenching settings can be very useful in determining the efficiency of different quenching and alumina feeding strategies or other changes that have been established. The quenching and alumina feeding procedure was changed on a number of pots to accumulate sufficient amount of data over several weeks or months. In order to evaluate the significant difference of AE duration means between pot groups one can use statistical methods such as t-test, F-test or ANOVA analysis [13]. Null hypothesis (t-test) was a common tool to decide if significance difference between means of two distributions. If assumed that two groups have unequal sample sizes and unequal variances the random test variable is [14]:

$$t = \frac{\mu_1 - \mu_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_S^2}{n_1 + n_2 - 2}}} \quad (1)$$

where μ is sample mean, s is standard deviation of sample population and n number of samples in the group.

Remarks on Other Trials

Other trials that did not have a significant effect on the AE duration nor frequency were for instance change in energy input during anode setting, different bridge movement strategy [15] and different feed strategy.

Conclusions

Despite increased current with higher current densities (see figure 2) and less volumetric liquid bath in pots, Nordural has reduced the total AE duration/potday by 90% over the last few years with simple procedures, measurements and statistical analysis. A good approach for reducing AE frequency and duration is to observe and measure the process, do physical trial and error experiments with groups of pots to seek what fits your technology and process. Some known methods have no significant affect on lower AE duration nor frequency and statistical hypothesis testing is necessary to estimate the significance of the factor being observed or changed.

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