

ENERGY SAVINGS USING A DIFFERENT ANODE ROD DESIGN

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Abstract

Energy saving is one of the greatest challenges in the aluminum industry. In an effort to determine viable ways to improve pot design and reduce energy consumption, an Alumar team conducted a benchmark study with its sister plant (Mount Holly) and found a slight difference in the anode rod assembly design that showed a significant saving potential. Changes of the copper rod dimensions and improved welding techniques were the main improvement characteristics.

Introduction

Aluminum production requires an enormous amount of electrical energy. Each loss in every cell of the potline accumulates increasing the total energy consumption. A typical voltage breakdown of 150kA pot is shown in Figure 1.

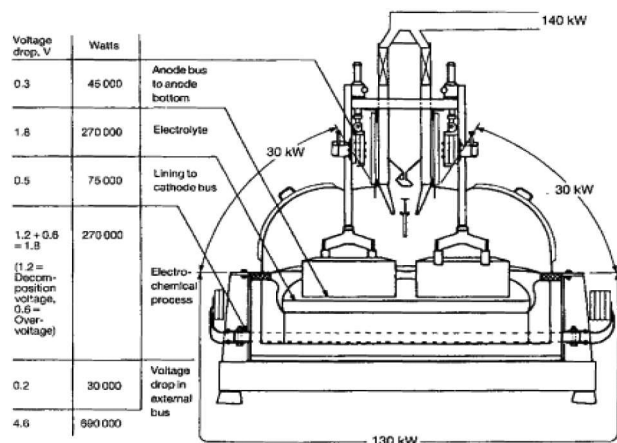


Figure 1 - Typical voltage breakdown of a prebaked aluminum reduction cell at 150kA and 4.6 V (reproduced from Kvande and Grjotheim [1]).

At Alumar the voltage drop between the copper to steel connection was around 20mV. An economic calculation including 705 pots operating in 3 potlines at 228kA (full potential) and assuming 0,06US\$/kWh for the 20mV gains is shown below:

$$(20\text{mV/pot}) \times 705 \text{ pots} \times 228 \text{ kA} \times (24\text{h/d}) \times (365.25\text{d/yr}) \times (0.06\text{US\$/kWh}) = 1,690 \text{ M US\$/year}$$

A trial was begun in one pot using anode assemblies with the Mt Holly design and another pot with the existing Alumar anodes. Several anode measurements and voltage drops were taken from each pot and the voltage savings were calculated. Statistical analysis techniques were used to quantify the decrease in the voltage drop between the existing assemblies and the modified assemblies. The results were very encouraging indicating a significant reduction of voltage drop in the modified assemblies.

This paper presents the steps used in the application of this modified anode assembly: planning, anode measurements, statistical analysis, pot parameters performance, financial magnitude of energy savings and the implementation strategy.

Previous Work

First, extensive work was accomplished in the rodding shop area to adapt the copper and steel dimensions to manufacture the new modified rod assembly with the same dimensions as the rod assembly used in the Mt Holly plant.

Next, two pots were selected, one modified for the trial and another one to use as a control pot for data comparison and analysis. Both pots were almost of the same age, located in the same pot section and submitted to the same operational procedures.

The main differences between the regular rod assemblies in use at Alumar and the trial rod assemblies based upon the Mount Holly design are shown in figure 2 and figure 4.

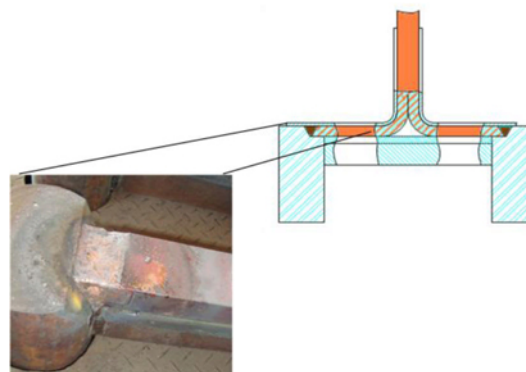


Figure 2 - Alumar Rod Design Copper-Steel weld connection between rod and stub

The analysis made by Fletcher and Madhusudana [3] relates that rough surfaces in contact have an effective area

of contact smaller than the nominal area. The flux lines are forced to converge on “contact islands”, shown in figure 3. This observation explains the main voltage reduction opportunity on the Alumar rod assembly design.

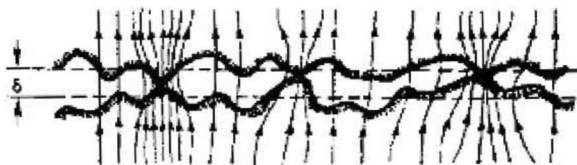


Figure 3 - Constriction of flux lines at the interface of rough surfaces (reproduced from Fletcher and Madhusudana [2]).

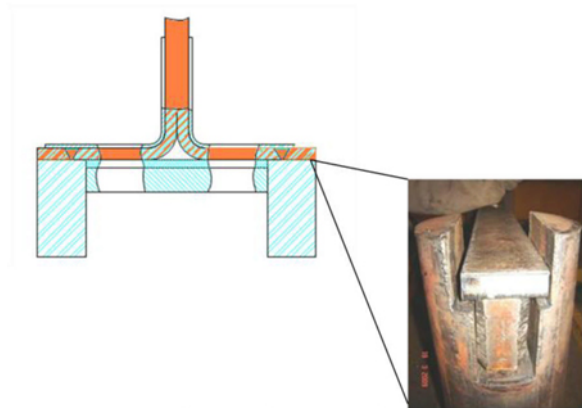


Figure 4 – Point of contact between rod and stub.

Mount Holly’s rod design shows a better contact between rod and stub, and less amount of weld on the copper and steel connection decreasing the occurrences of voids and, as a consequence, less voltage drop in this area.

Pot Control and Process Parameters

Every change in the pot configuration, its surrounding equipment and control system has “two barriers” to be overcome to be accepted by the process engineering and potroom operational teams. The first barrier is the change must have a real potential of making a significant and positive difference on pot performance, and the second barrier is that the changes would not have a negative impact on pot stability.

To compare the two test pots selected, (the modified anode assembly pot and the control pot), a control score card was developed using a daily pot data base indicating the key process parameters.

| Performance Score Card | | | | |
|------------------------|--------|---------------|-----------------------|-------|
| Control Pot (2022) | | | | |
| Indicator | Target | Results | | |
| | | Before (Avg.) | After (04/10 - 10/12) | |
| Voltage | V | 4,480 | 4,42 | 4,410 |
| Noise (SPPN) | | 0,200 | 0,163 | 0,201 |
| Temperature | °C | 956,0 | 958,8 | 958,3 |
| Anode Effect | | 0,14 | 0,19 | 0,07 |
| Sodium | ppm | 130,0 | 175,0 | 157,0 |

Table 1 – Process Parameters Score Card – Control Group

The pot voltage on the control pot was lower than the test pot before the trial started. The other control pot parameters were better than the test pot, except for anode effects. After the trial a reduction of 10mV on pot voltage was detected due to anode cathode reduction, but because of this pot noise increased to higher levels showing an indicative instability. The other parameters, even anode effect had an excellent result.

| Performance Score Card | | | | |
|------------------------|--------|---------------|-----------------------|-------|
| Test Pot (2034) | | | | |
| Indicator | Target | Results | | |
| | | Before (Avg.) | After (04/10 - 10/12) | |
| Voltage | V | 4,480 | 4,400 | 4,320 |
| Noise (SPPN) | | 0,200 | 0,159 | 0,189 |
| Temperature | °C | 956,0 | 958,9 | 956,4 |
| Anode Effect | | 0,14 | 0,10 | 0,23 |
| Sodium | ppm | 130,00 | 163,0 | 157,0 |

Table 2 – Process Parameters Score Card – Test Group

Pot voltage on test pot was lower than the target and even lower than the control pot before the trial starts. The pot was running already 80mV lower than target, which made the trial more challenging. The other parameters were also much better than planned. The data collected during the period of the trial showed outstanding results, the average pot voltage reduction were much higher than expected with values around 80mV, with no significant increase on pot noise. The single parameter negatively impacted during the trial was anode Effect/PD occurrences which were due to issues on one point feeder during the test.

The pot voltage evolution before and after trial are shown on figure 5. Regarding the anode cycle, data started to be monitored once all the regular anodes were replaced with the new designed anodes.

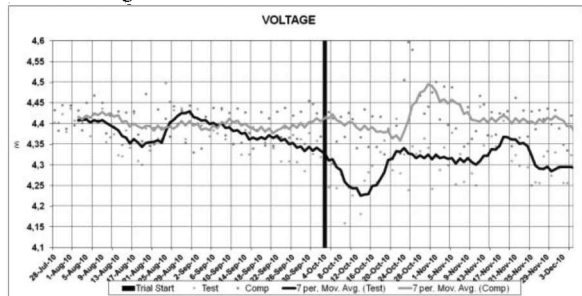


Figure 5 – Pot Voltage Graphic

Having the stability of the parameters analysis walking together with an impressive pot voltage gain, the work is not done yet. It's necessary to measure the real gain related to the modification on the design of the rod.

Anode Measurements and Statistical Analysis

The most noticeable change found during the trial was the voltage drop between the rod and the stub. The measurements were made by the process technician's team on a representative number of anodes inside the pots, at different days of the anode cycle.

Analyzing the days of measurement during the trial, a voltage drop increase was observed. Considering the period of measurements from 1 to 12 (Figure 6), where in the 1st one only one pair of anodes with 24 hour of anode cycle was measured and in the 12th was the first time that was measured anodes from 1 to 25 days of life cycle. The period from 13 to 17 the voltage drop stabilizes. So during the period 1 to 12 is clearly the evolution of the losses during anode life inside the pots.

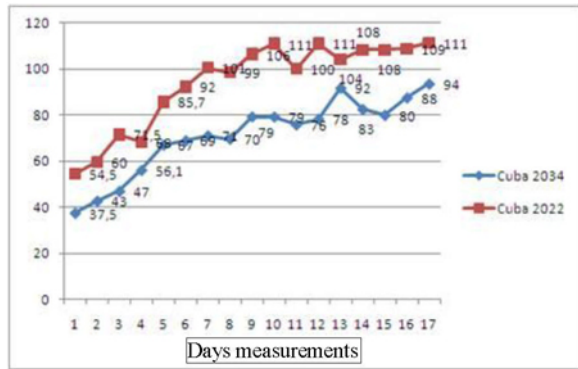


Figure 6 – Voltage drop between rod and stub.

In order to do the proper statistical analyses, it was necessary to segregate the data per anode age, then it was possible to analyze values with the same age level distribution. At first F-test was made to determine the variance of the distributions, and it was determined that all of the groups from the regular and trial pots had unequal variances.

For the second round of analysis, both groups were taken from 1st to the 25th day of age of anodes measurements, then a t-test for unequal variances was used to conclude about the statistical differences.

The t-test statistical method has a curve that is plotted with the values between each group; a rejection area is defined based on the percentage of the confidence level in use, in this case 95%.

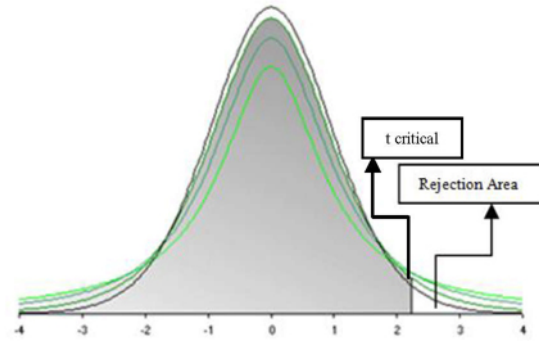


Figure 7 – Representative Curve for t-test

Finally, if the t value calculated exceeds the tabulated value then the means are significantly different at that level of confidence of 95%, using the following formula:

$$t = (\mu_1 - \mu_2 - Md) / \text{Sqrt}(s_1/n_1 + s_2/n_2)$$

t = Calculated value to be compared to t critical

μ1 and **μ2** = means of the two input series

Md = $\mu_1 - \mu_2$

s1 and **s2** = variances of the two input series

n1 and **n2** = number of data points of two input series

The statistical calculation and analysis, for rod and stub measurements comparing control group and test group, are shown in table 3:

| Idade | T critical | T calculated | mV Difference | Statiscally Different? |
|-------|------------|--------------|---------------|------------------------|
| 1 | 1,66 | 1,94 | 7,87 | Yes |
| 3 | 1,67 | 2,84 | 13,65 | Yes |
| 5 | 1,67 | 2,48 | 11,92 | Yes |
| 7 | 1,69 | 3,77 | 26,22 | Yes |
| 9 | 1,68 | 2,63 | 27 | Yes |
| 11 | 1,69 | 4,46 | 38 | Yes |
| 13 | 1,69 | 3,04 | 41,6 | Yes |
| 15 | 1,67 | 2,67 | 21,88 | Yes |
| 17 | 1,67 | 2,7 | 29,73 | Yes |
| 19 | 1,69 | 4,66 | 32,61 | Yes |
| 21 | 1,7 | 3,8 | 43,54 | Yes |
| 23 | 1,67 | 2,21 | 17,44 | Yes |
| 25 | 1,69 | 1,78 | 4,44 | Yes |

Table 3 – Statistical Analysis Between Groups

As seen all the t values calculated are in the rejection area, which means that the possibility of equality between groups is rejected. The proven gains are around 24mV.

Conclusions

All the programmed steps were followed, and the test showed impressive results. The test pot showed a significant decrease in pot voltage while maintaining good pot stability. Following these good operational parameters, the difference of the voltage loss in the control and test groups was evaluated.

As stated in the beginning of the paper, the estimated gains would be approximately 1,690 M US\$/year, or even greater if the drop of 80mV on the trial pot is considered. However

new studies are required to confirm the viability making the rodding shop adaptations in order to manufacture the new rods on a large-scale, promoting a more representative validation of the results.

References

- 1 - Kvande, K. and Grjotheim, H., "Understanding the Hall-Heroult Process for Production of Aluminium", Aluminium-Verlag, Dusseldorf, 1986.
- 2 - C.V. Madhusudana and L.S. Fletcher, Contact Heat Transfer—The Last Decade, AIAA J., Vol 24, 1985, p 510–523
- 3 - S. Wilkening, J. Côté, "Problems of the Stub – Anode Connection", Light Metals 2007.