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Xianan Liao
Elkem Carbon
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In-Situ Formation of Slots in Søderberg Anodes

Alton T. Tabereaux[1] and Xiangwen Wang[2]
[1]Consultant, Muscle Shoals, AL 35661
[2]Global Primary Products, Alcoa Inc

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Abstract

Traditional carbon anode technology relies on the natural flow of gases from under the anodes during the aluminum reduction process. The anode gas bubbles generated on the bottom surface of carbon anodes during electrolysis are non-conductive and thus increase energy consumption as they increase the electrical resistance in cells. The use of single and multiple bottom anode slots across the entire bottom surface of prebake anodes is now a widely accepted practice to quickly divert anode gases into bottom slots to allow amperage creep. The slots have the potential to save about three percent of the energy required in the process depending on the number and design of slots. It has now been demonstrated in this work that vertical non-continuous slots can also be formed in-situ in self-baking VS Søderberg anodes by vertically inserting four rows/or layers of multiple aluminum plates into the top surface of the anode during charging anode carbon paste to cells. Extended plant tests confirm that these multiple slots significantly reduce the electrical resistance, lower the cell voltage, and thereby reduce the cell energy consumption in VS Søderberg cells; for example, the pot noise was found to be reduced 40%, (0.04-0.05 V) compared with traditional low noise Søderberg cells; pot noise was reduced by 80% (-0.200 V) when compared to high noise Søderberg cells. Additionally, the cell current efficiency may also be improved by increasing the cell stability.

Introduction

The use of anode slots that are cut (or formed during pressing) across the bottom surface of prebake anodes is now a widely accepted practice to quickly divert anode gases into bottom slots and thus enable a reduction in the cell energy consumption. [Ref. 1-4] Søderberg cells have only one large self-baking anode of approximate size, 2-3 meters wide and 5-6 meters length. The anodes generate a large quantity of anode gases, (40 to 50 kg CO_2/hour) which has to travel a considerable distance, from 1 to 1.5 meters before it can be released from the bottom side surface of the anode. The gas bubbles tend to coalesce and get larger before it escapes from the long sides of the large anode. The gas bubbles cover a large percentage of the bottom anode surface that results in a significant increase in electrical resistance and cell voltage. The purpose of forming vertical slots or groves in the bottom surface of large Søderberg anodes is to channel or divert the anode gases into the slots and thus reduce the total amount of gases in contact with the bottom surface of the Søderberg anode. Reducing the amount of gas bubbles at the bottom surface of Søderberg anodes will significantly reduce the electrical resistance, enabling lower total cell voltage, and thereby reduce the cell electrical energy consumption and/or allow an increase in pot line amperage to increase the production of aluminum metal in the cells.

Experimental

All trials were carried out in industrial production Søderberg cells. The overall project consisted of two major objectives: 1. determine if slotted anode idea works for Søderberg size anode by first cutting slots under an ideal condition, and 2.) determine feasibility of in-situ formation of slots by inserting aluminum metal plates from anode top when charging anode paste and "slots" formed and baked in place when the plates along with anode moving down into bath of the cell.

1. Plant Tests of "Cut" Slots in a Søderberg Anode

<u>Potential Søderberg Anode Slot Configurations</u>
There can be numerous combinations of slot configurations, but the main requirements are:

- Realistic, and feasible in engineering;
- Cost effective - minimum number of slots and maximum impact;
- Maintain of anode integrity without introduction of side effects.

The effectiveness of slots may be measured by the reduction of "average shortest distance" an anode gas bubble has to travel before reaching anode surface edge and being release. Longitudinal slots impact more than side (transverse) slots (this also holds true for anodes used in prebaked cells). For an example, 4 longitudinal slots (case 2) can have more impact than 8 transverse slots (case 1). One central slot with 4 transverse (case 3) slots can have the same impact as 6 transverse slots (case 1).

Number of Vertical Plates
The number of slot forming vertical plates will largely determine the amount of total gas diverted away from the bottom surface of the Søderberg anodes. Ideally a solid plate would be positioned between each row of steel anode spikes.

- Thus anodes that typically have 50 total anode steel stubs would require about 11 plates per side, or 22 total plates per anode; anodes that have more pins would require more plates.
- Fewer plates can be added to cells, for example - add plates only between every two rows of anode stubs, but fewer plates will results in less gas diversion and thereby a lower reduction in electrical resistance will be achieved.
- However it may be desirable to alternated adding slot forming plates between adjacent rows of steel anode stubs in order to reduce the possibility of forming undesirable vertical cracks between plates located directly above and below each row of pins.

As a part of an overall slotted anode trial and deployment project in VS Søderberg pots, one pot trial was first carried out by potroom personnel at the Alcoa Aviles smelter in Spain November 4-19, 2004 using VS Søderberg anode with cut-slots. The objective of this one pot trial with cut-slotted anode was to:

- To determine if slots in Søderberg anode work as predicted in substantially reducing anode gas bubble noise and overall pot noise;
- To determine if the anode with slots can achieve better results than those pots with the lowest pot noise;
- To determine slot configuration impact and provide data for Aluminum plate insert trial;
- To provide data in looking for new means (such as this slotted anode trial) for reducing pot voltage, increasing CE, and amperage creep.

Actual Slot Configuration Used in an Aviles Søderberg Cut-Slot Trial:

The actual slot configuration used in the cut slot trial is shown in Figure 1. There were one central (longitudinal) and 4 angled side (transverse) slots. The side slots were angled to avoid spike holes on the anode surface. Also, the central slot was cut 7 cm deeper than the side slots, which allowed us to evaluate the effectiveness of longitudinal slot when the side slots were consumed.

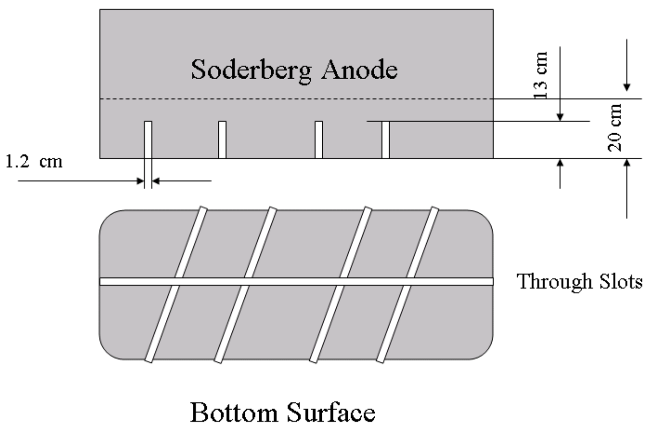

Figure 1. Actual VS Søderberg anode with cut-slots in trial.

The slots were cut in the VS Søderberg anode on October 22, 2004. It was installed in an operating Pot 421 on November 4 and the pot became stable on November 8. There were three periods in the test regarding the slot on the anode surface and measurements were conducted in these periods to track the pot performance:

- Nov. 8 to Nov. 14: All slots (central and side slots) were present
- Nov. 15 to Nov. 19: Only central slot was present
- Dec. 7 to Dec.8: as regular normal operating pot and measurements were conducted.

Results and Discussion of Tests of Cut-Slots in a Søderberg Anode

Pot Voltage Spectra of Slotted Søderberg Aviles Anode Pot 421 with and without Slots

In order to evaluate the slot impact, the pot voltage spectra as recorded using a high speed data acquisition system are measured and compared during the three periods of operations with and without slots and with its adjacent pots and those pots with high and low noises.

The differences in the pot voltage spectra for Pot 421 shown in Figure 2 during the three periods are due to large variations in gas bubble noise resulting from operating with and without slots. The lowest gas bubble noise occurred during the period of full open slots when anode gas was being diverted into slots; the highest gas bubble noise occurred when all the slots were consumed and it became a regular non-slotted anode pot. The magnitude of voltage oscillation on pot 421 without slots was several times higher than the slotted anode pot.

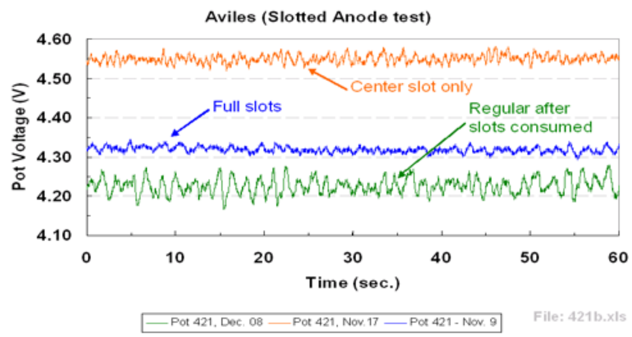

Figure 2. Anode gas bubble noise measured for the Aviles slotted anode test pot (421) during the three test periods with and without slots.

Comparison of the Pot Voltage Spectra of Slotted Søderberg Anode Pot 421 and Regular Pots without Slots

The difference in the pot voltage spectra of pot 421 having full cut-slots open with its adjacent pots (419 and 423) operating without slots is shown in Figure 3. The difference was obvious: the voltage of pot 421 only fluctuated within 0.05V while those of pots 419 and 423 oscillated at a magnitude of over 0.10V. The difference was even greater if comparing with pots with high noise. The magnitude of voltage oscillation on pot 442 was several times higher than the slotted anode pot.

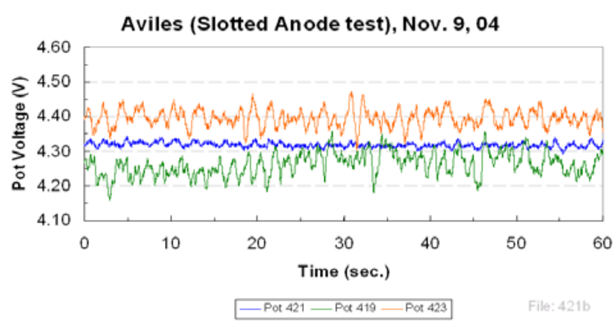

Figure 3. Comparison of voltage spectra recorded on the slotted anode Aviles Pot 421 with its adjacent non-slots pots (419 and 423).

Comparison of the Difference in Gas Bubble Noise of Aviles Pot 421 with and without Slots

The changes in the pot noise due to variations in gas bubble noise during the three periods are presented in Figure 4. The gas bubble noise levels changed in pot 421 at different stages: the lowest gas bubble noise (average 38 mV) at the period of full slots open, to medium gas bubble noise (48 mV) when only the central slot was left, and to the highest gas bubble noise (95 mV) when all the slots were consumed and it became a regular non-slotted anode pot.

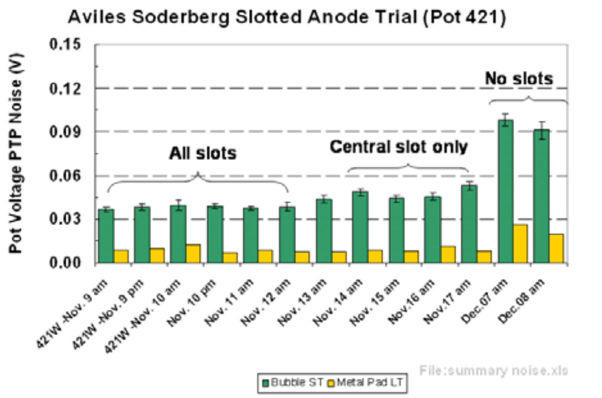

Figure. 4. Comparison of anode gas bubble noise levels on slotted anode test pot and regular non-slotted anode pots.

<u>Comparison of the Difference in Pot Noise of Aviles Pot 421 with Slots with Regular Pots without Slots</u>

The voltage noise levels (both gas bubble short term noise and metal wave long term noise) of the slotted anode test pot along with other regular non-slotted anode pots are illustrated in Figure 5. As expected, the slotted anode pot 421 with full slots open had the lowest anode gas bubble noise averaged below 40 mV and total pot noise below 50 mV. In comparison, regular non-slotted pot (pot 492) which had the lowest pot noise among all pots had an anode gas bubble noise of 77 mV and total voltage noise of 94 mV. The anode gas bubble noise for regular operating pots is 1 to 6 times greater than that for the slotted anode pot 421 with full slots open.

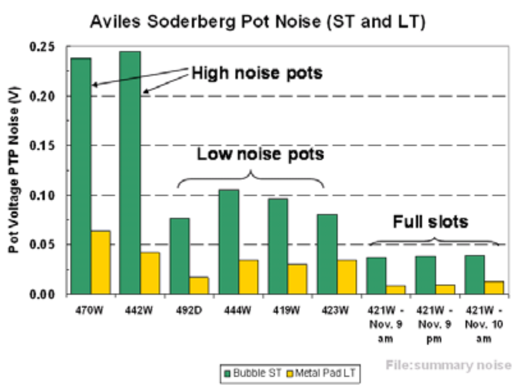

Figure 5. Comparison of anode gas bubble noise levels of Aviles slotted anode test pot and regular non-slotted anode pots.

To make sure the pot was operated at normal anode-cathode distance and anode was not in contact with metal pad, anode beam was intentionally moved up and down a considerable distance. The noise level maintained at a level of 35mV on average and no significant change was observed, indicating pot 421 was indeed operated at a normal ACD distance.

Major test results are summarized:

- Two different slot configurations were evaluated in one test. Central longitudinal slot had greater impact than side transverse slots in reducing anode gas bubble ST noise and overall pot noise which is in agreement with our model predicted.
- When all slots were completely consumed, the anode gas bubble ST noise was measured to be 95 mV on an average, and the total pot noise was 118 mV.
- When all slots were present, the anode gas bubble ST noise was 38 mV and the total pot noise was 47 mV. A reduction of 60% both the gas bubble ST noise and pot total voltage noise was achieved. This reduction was due to the impact by both central longitudinal and side transverse slots.
- When the side transverse slots were consumed and only central slot remaining, the gas bubble ST noise was measured to be 48 mV and the total pot noise was 57 mV. A reduction of 50% in both the anode gas bubble ST noise and total pot noise was obtained.

Due to the short test periods, no attempt was made in quantifying slot impact on such as pot voltage, current efficiency and anode effect (AE) rate. Any such efforts have to be carried out involving more pots for a longer period of time.

2. Plant Tests of Slots formed In-situ in Søderberg Anodes

A proprietary method was developed by Alcoa for the in-situ formation of slots in the bottom of self-baking Søderberg anodes. [5] Expanded trials for the in-situ formation of transverse slots in five VS Søderberg anodes were conducted at the Alcoa Aviles smelter in Spain and Pocos smelter in Brazil. Aluminum plates were inserted into the top five Søderberg pots 492, 494, 496, 498 and 500 at Aviles on July 1, 2005. Slots reached the bottom surface of anodes in October 2005. Six aluminum plates were initially inserted into the top of Pot 353 as a trial of the technology at Aviles in July 2005 and slots were successfully formed in October 2005. Six aluminum plates (six per row) were then inserted into the tops of pots 353, 361, 363, 364 and 366 at Pocos in January 2006 and they operated with slots in May 2006. New aluminum plates were then inserted in alternating layer at different locations in the Søderberg anodes every 18 days.

Vertical slots or grooves can be formed and maintained in VS Søderberg anodes, demonstrated by the slots shown in Figure 6, by periodically inserting solid plates of aluminum metal shown in Figure 7 in alternating layers in the anodes using metal guides welded to the top anode casing as shown in Figure 8.

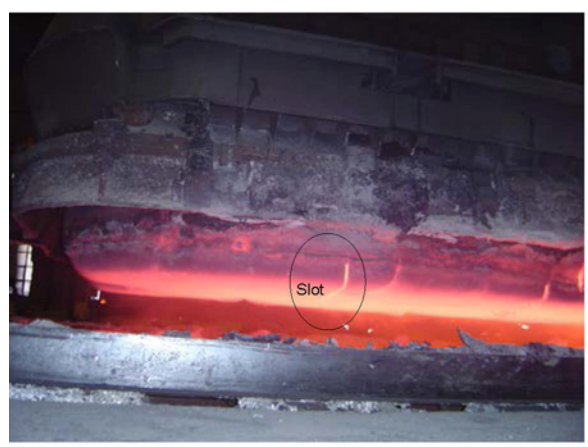

Figure 6. Vertical slots formed in-situ using aluminum plates in a VS Søderberg cell at the Aviles.

Figure 7. Aluminum plates were added to the top of anodes to form slots in VS Søderberg anodes at Aviles.

The aluminum plates were about 1 cm wide and 1 meter long. The slot forming plates were inserted in a vertical position into the carbon anode paste at the top of the anodes between the steel anode stubs.

- As the anode is consumed the vertical plates move down with the anode mass.
- The carbon paste bake-out from 300-600° C forming a solid carbon anode mass around the vertical solid plates
- The plates remained vertical and do not tilt when passing through the anode bake zone; all bottom slots are vertical.
- The slot width was adequate as they did not collapse due to pressure.
- Slots were identical to the dimensions of the aluminum plates: length, thickness and height.
- The plates were located in alternation layers at different locations (not in continuous rows) to prevent the formation of continuous cracks in the Søderberg anodes.
- When the plates reach the bottom surface of the anode they will either melt leaving an empty space that is the exact same dimension and position of plates.
- The plates are composed of materials that will not add contaminate impurities into the cell (aluminum metal). The aluminum metal in plates is recovered in the cell metal pad.

<u>Typical Aluminum Plate Consumption</u>

- Weight per plate = 5.9 kg
- # Plates per layer in pot = 5
- # Plates per pot/month = 8.3
- Wt. aluminium per pot/day = 1.6 kg

<u>Plate Dimensions</u>

The slot forming vertical plates are designed to be the appropriate dimension to achieve the desired slot dimension with respect to width, length and height.

Figure 8. Steel guides were used to vertically support the aluminum plates in VS Søderberg anodes.

<u>Slot Width</u>

The width of the plates is selected to allow the diversion of a significant quantity of anode gas volume and not be plugged. Typical gas slots have widths about 1.0 cm, (+/- 0.5 cm).

<u>Slot Length</u>

The length of the plates should not extend all the way to the center of the anode, but only part way

- Maintain the strength and integrity of the anode carbon mass
- Less amount gas volume near the center of anode; gas volume increases and bubbles coalesces forming larger bubbles nearer the sides of the Søderberg anodes
- Typical gas slots have lengths that are from about 0.5 to 1.0 meters, but in some instances they could have much longer lengths and extend to the center of the anode, (1.0 to 1.5 meter).

<u>Slot Height</u>

- The plate height determines how long the slot will exist in the anode; slots were design to last 13 days in the anode.
- Too short slots will require more frequent addition of plates.
  - Too long slots may result in undesired cracks in the baked solid anode mass.
  - Typical gas slots have heights that are from about 3 to 5 cm, but in some instances they could be much higher to achieve a longer slot life in the anode.

Plate Location and Position in Anodes

The slot forming plates are positioned between the rows of steel anode spikes in the Søderberg anode at the Alcoa Aviles and Pocos smelters as indicated by the lines in the drawings shown in Figures 9 and 10.

- The plates are inserted with the plate height in a vertical manner
- The plates should not contact the steel anode stubs
- The plates should extend completely to the sides of the Søderberg anode in order to have open slots when it reaches the bottom surface of the anode.
- The vertical plates will be added periodically, as needed, to the top surface to semi-continuously manufacture slots at the bottom anode surface.

The locations of the aluminium plates in 8 alternating layers in operating VS Søderberg cells at Alcoa Aviles and Pocos smelters are shown in Figures 9 and 10. Each aluminum plate weighed 5.8 kg and cost approximately $63.72 USD. A Cu-Al alloy plate test was conducted at Pocos in March 2002 that verified that the aluminium in the plates reported to the metal pad in cells.

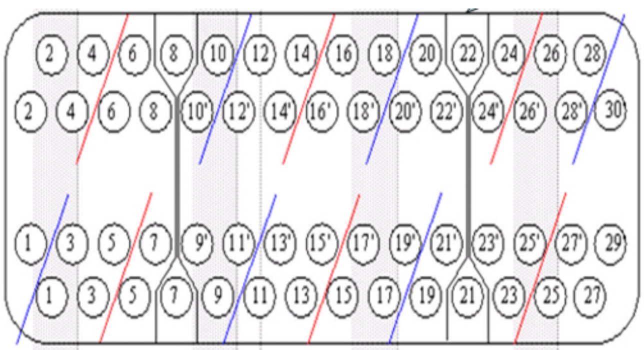

Figure 9. Location of 6 vertical slots in VS Søderberg Anode formed by Inserting solid aluminum plates in alternating layers at Aviles aluminum smelter.

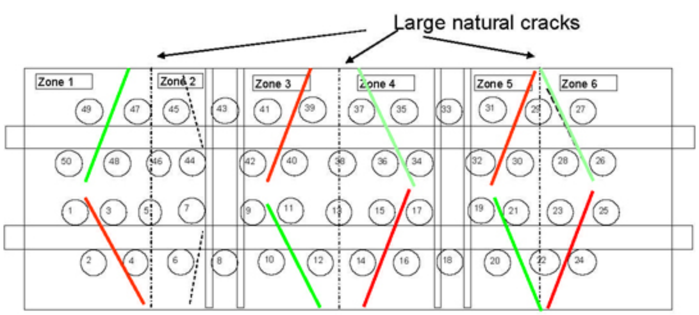

Figure 10. Slot Configuration with 5 aluminum plates per alternating layer used in VS Søderberg anode cells at Pocos aluminum smelter.

Results and Discussion of Tests of In-siu Formed Slots in Søderberg Anodes

Noise Measurements in Aviles Pot 477 with in-situ formed slots Figure 11 demonstrates a reduction in the gas bubble noise from 128 mV to 67 mV (-47%) equivalent to a reduction of 160 mV.

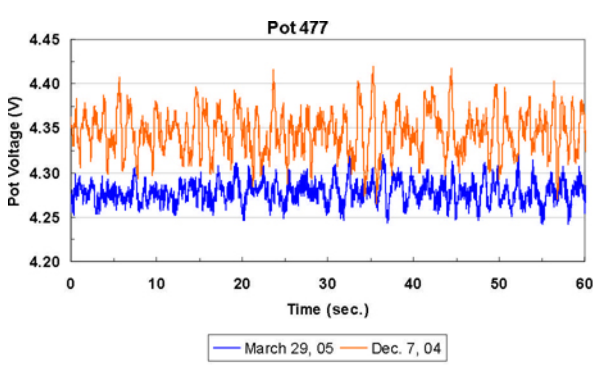

Figure 11. Comparison of the pot voltage with and without in-situ formed slots in Aviles Pot 477.

A significant decrease was measured in the anode gas bubble peak-to-peak (PTP) noise before vs. after the formation of in-situ slots in the five Søderberg pots at Aviles as shown in Figure 12. Less difference was measured on pot 494 because it was a new pot.

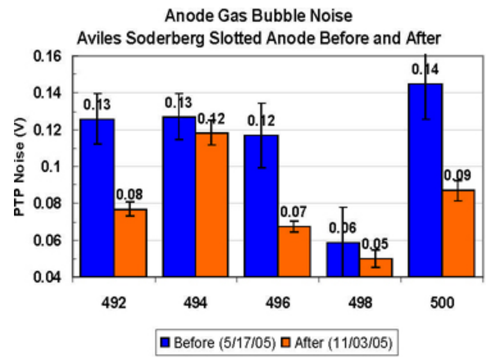

Figure 12. Anode gas bubble noise in pots before and after in-situ formed slots.

A large decrease in pot peak-to-peak noise occurred after the formation of in-situ slots during October in all five VS Søderberg anodes shown in Figure 13 due to the diversion of gas bubbles into slots.

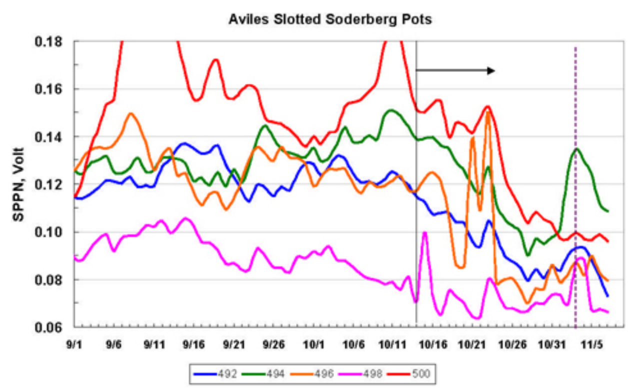

Figure 13. Changes in gas bubble noise in five Søderberg pots without and with slots at Aviles.

A comparison of the differences in pot noise, pot voltage and target resistance during a five month period at Pocos during 2006 are shown in Figures 14-17 for the five test pots operating with five in-situ formed slots The peak-to-peak pot noise is the total noise which includes the pot MHD noise and the anode gas bubble noise.

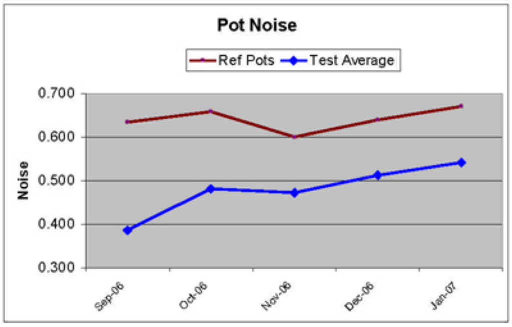

Figure 14. Average monthly pot noise for five VS Søderberg pots operating with in-situ slots during the 5 month period.

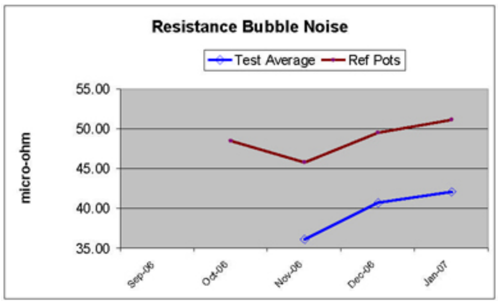

Figure 15. Average monthly resistance bubble noise (microhms) for five VS Søderberg pots operating with in-situ slots during the 5 month period.

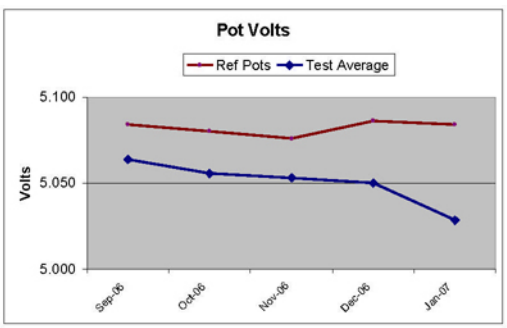

Figure 16. Average monthly pot noise for five VS Søderberg pots operating with in-situ slots during the 5 month period.

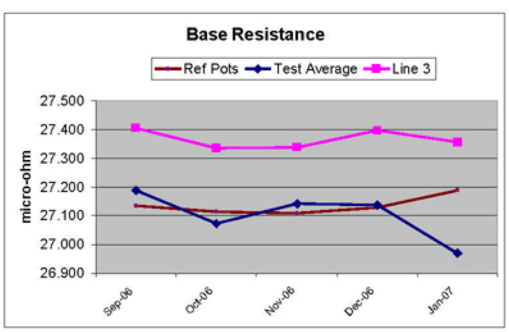

Figure 17. Average monthly target resistance for five VS Søderberg pots operating with in-situ slots during the 5 month period.

- Very few anode problems using dry anode paste at Aviles and semi-dry anode paste at Pocos.
- Very few difficulties inserting plates in tops of anodes
- Significant reduction (26%) in the sppn pot noise and gas bubble noise with 5 slots per pot.
- Copper alloy test demonstrated that the aluminum plates report to the metal pad.
- Production is same as potline reference pots after 6 months.
- Lower pot voltage and cell resistance set-point for slotted anode pots; 27.25 vs. 27.46 micro-ohms.

A comparison of actual vs. metal tap demand data for the 5 test pots from Sept. 2006 to Jan. 2007 showed very small differences.

Conclusions

Overall, the trials of VS Søderberg anode with cut slots and in-situ formed slots were very successful. The slots behaved as expected, in greatly reducing anode gas bubble short term (ST) noise and therefore the total pot noise in some cells by up to 47%. No operational problems were encountered that were associated with slots in the Søderberg anodes. However the trails were eventually discontinued in smelters primarily due to the difficulty in automating the manual process of installing the aluminum plates in the VS Søderberg anodes. Additionally most Søderberg cells operating with dry anode paste tend to naturally form large cracks in the bottom surface of anodes that also reduce pot noise.[6]

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