Anode Performance Improvement with Limited Expenditure and Baking Furnace Options

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Abstract

The present study describes the successful attempt to enhance the anode performance in the pots by modifying its design in the anode plant of Sohar Aluminum with minor modifications of the baking furnace and conveying systems. To support the amperage creeping and improve the current efficiency in a context of low LME-driven expenditures, several options were considered to overcome the bottlenecks in anode paste plant (APP) and in the anode baking furnace (ABF). After proving the concept works with deeper and longer dummy anodes, the production anodes were successfully slotted at 350 mm while being formed within the existing vibro-compactor mold box. Anode length extension was also performed, leading to 1.5 % additional surface area for the subsequent electrolytic reaction. The challenges on baking the resulting longer anodes beyond the original equipment manufacturer (OEM) specifications (degassing joints and coke bed top insulation) in the ABF were also overcome. The extensive work led to conclusive findings regarding the monitoring of the new SO_2, CO, and H_2S emission levels on the furnace deck, heat loss, packing coke oxidation, final baking level, anodes electrical and chemical properties. Positive results were achieved in pots after several cycles.

Keywords: Anode design performance, Anode baking furnace, Longer anodes, Anode slots.

1. Requirement in Potlines

To reach the business plan of 397 300 t/y at 400 kA while sustaining the current efficiency performance, Sohar Aluminium had to decrease the current density below 0.95 A/cm^2 and the pot instability. This was a conclusion from a previous internal study showing in the pot booster section that the current efficiency (CE) decreased at greater amperage creeping. Unfortunately, the existing anode dimensions were 1600 mm (length) x 650 mm (width) corresponding to 0.96 A/cm^2 at 400 kA. The anode slots depth was 300 mm.

Confirmed by the pot designer, the pot shell could accept an additional 90 mm to the anode length, but the width had reached its limit. The additional length contributes to increase the bottom anode surface area, thus lowering the current density. Additionally, the anode slot depth could be raised to extend its positive effect during the life of the anode in the pot. Low investment was considered on this project to make it more attractive.

2. Opportunities and Bottlenecks in the Anode Plant

2.1 Paste Plant

The Anode Paste Plant (APP) extra capacity allowed weight to be added to each anode block without compromising the daily production figure of anode blocks. Besides, the plant was equipped with two vibro-compactors and each mold box permitted an increase of up to 50 mm in the anode length. The mold boxes installed in 2016 came initially with two provisory spacers on each side for this purpose. This meant the anode length could be extended from 1600 to 1650 mm (baked anode dimension) without major investment in the APP (see Figure 1).

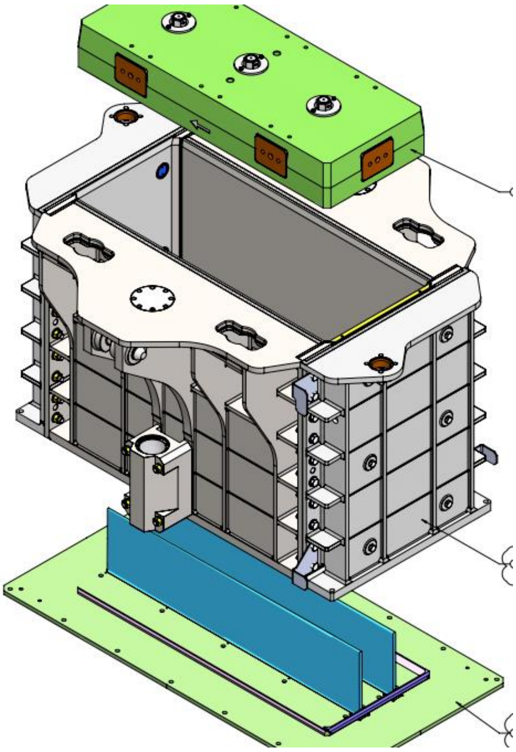


Figure 1. Vibro-former mold box with spacers.

The anode is formed with its slots in Sohar aluminium. An increase in the slot height, while technically feasible, would imply more risks of anode broken parts, missing carbon for the reduction process (referred to as Reduction in the later part of the work), and potential damages on the slot plate.

2.2 Baking Furnace and Rodding Shop

The anode baking furnace (ABF) manufacturing specifications clearly stated the anode had already reached its maximum size fitting into the pit. Any significant change in anode length might trigger a multimillion-dollar modification of the ABF refractory and furnace tender assembly (FTA) handling the anodes.

In the pit, three layers of anodes stand on each other during the baking process. These anodes, once stacked, reached the last degassing joint layer top with a margin of 10 mm as represented on Figure 2. Consequently, there was no anode length increase possible following manufacturer recommendations without a modification of the ABF refractory and civil structure.

Substantial concerns subsisted regarding the insufficient clearance between grabbed anodes transported by the FTA in the air and the underneath central conveyor anodes, as well as the lifting capacity of the stacking crane, FTA, and anode assembly conveyor. Figure 3 provides an explanation of these issues.

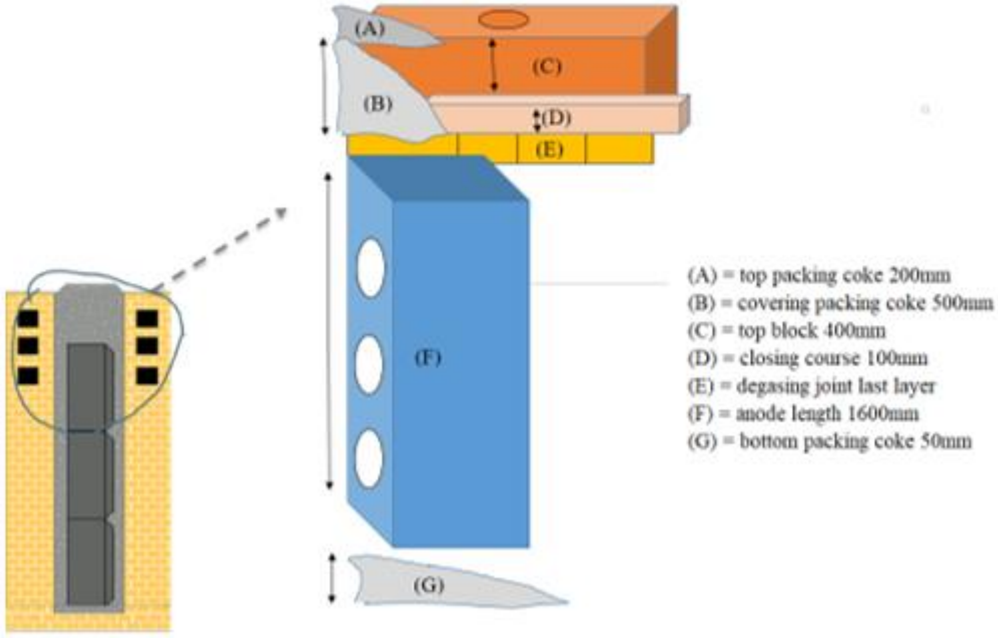


Figure 2. Third layer anode vs degassing joint.

Figure 3. Example of clearance concerns between grabbed and conveyed anode sets.

3. Decision-making for Trials

3.1 Anode Length

The APP compactor and the pot size permit an anode length extension of 50 mm. Several options for debottlenecking the ABF pit baking process were evaluated to accommodate this extension.

- At the bottom of the pit, by reducing the layer thickness of the bottom coke bed. The risk to damage the bottom anode surfaces and the practical difficulty to properly adjust the coke bed thickness applied 5 meters deeper on a variable tile surface, led to reject this option.
- At the bottom of the pit, by removing one 60 mm thick floor tile. However, the possibility of creating irreversible structural damages to the ABF foundation revoked this option.

- At the top of the pit, using a thinner flue wall top block and an additional layer of bricks and degassing joints. This was rejected due to risk of process heat loss and of elevated temperatures on the flue walls.
- At the top of the pit, by accepting that the anode exceeds the last degassing course. The risks were that the anode baking quality and the gas emissions levels could be compromised.

The latter option was finally accepted. It offered the advantage of being quick, easy to test, and immediately reversible in case of a detrimental impact.

3.2 Anode Slot Depth

A provisory dual saw prototype was jointly developed with a local contractor to cut 400 mm deep slots in baked anodes, outside of the smelter for the sake of initially proving the beneficial impact in the pot room.

Subsequently, due to the CAPEX and OPEX figures exceeding 3 M $, an alternative option was developed. In APP, a trial was planned to use the 350 mm vibro-compactor plate slots. This depth figure was considered the best compromise in terms of anode integrity risks based on computer modelling results and industry standard.

4. Trial for Deeper Slots

4.1 Trial with 400 mm-Deep Slotted Anodes

In Q1 and Q2/2021, about 1000 baked anodes with slots cut at 400 mm were sent in six dedicated pots for four complete anode cycles. When compared to reference pots receiving existing 300 mm slot anodes, the observations showed no damaged anodes, no increased dusting, an enhanced reduction in instability level, in power in bath and in anode effect rate. Higher sodium in metal indicated a CE improvement.

These results paved the way to maximize the slot depth but with a lower investment.

4.2 Trial with 350 mm-Deep Slotted Anodes

The trial was carried out in two steps. The first part, or feasibility test, consisted in 340 anodes manufactured on one vibro-former equipped with 350 mm slots. These anodes were baked and sent for one full anode cycle in every pot. Figure 4 shows both reference and trial anodes produced simultaneously on both vibro formers.

The second part, or analysis test, involved one month later 6 800 anodes manufactured on two vibro-formers with 350 mm slots, baked and sent for four full anode cycles in nine pots in Q3 and Q4/2021.

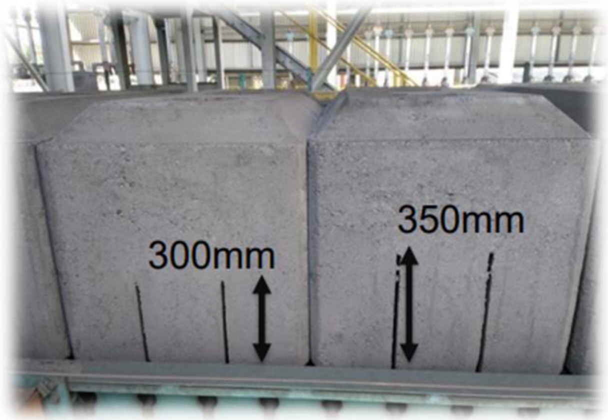


Figure 4. Reference and trial anodes.

In the rodding shop, the anodes with 350 mm deep slots were tested for physical defects. About 20 % of the anodes showed cracked on one specific side at the slot right top during the feasibility test phase. It was found that a stopper after forming had to be repositioned before the second phase.

During the analysis test no more defect was observed. The anodes integrity was successfully tested with a hammer, and anodes cored for mechanical properties validation. No differences were found.

In Reduction, the nine tested pots showed an improved instability by 5 nΩ, a reduction in pot resistance by 0.02 µΩ (8 mV) and no dusting increase. These results were in line with the initial conclusions on the 400 mm deep slot anode trial.

5. Trial Design for 1620 mm Long Anodes in ABF, Rodding Shop and Potlines

5.1 Baking Performance

For the longer anodes, a few questions remained regarding the possible negative impacts on the ABF performance. The risks of underbaking, of greater harmful emissions, of overheated top refractory, and process heat loss had to be evaluated prior to any investment and permanent modification of the vibro-formers.

In absence of available longer anodes, the test anodes would be baked higher in the pit and cored at their upper part (for the top layer) to assess the impacts. Indeed, the idea was to add sufficient packing at the bottom to raise the anodes above 50 mm of the last degassing joint layer top.

The height of the flue wall, hence the last degassing course level, varies depending on the flue wall age under the inflating influence of the sodium. Consequently, each pit was measured to calculate the exact quantity of packing coke to add at the pit bottom for the top anode to exceed the last degassing joint by 50 mm. Too low (or too high) would underestimate (or overestimate) the 1620 mm long anode impact on the baking process. The Figures 5-6 describe the setting for the test. As shown on Figure 7, a method was developed to measure the depth of 150 trial pits in order to establish the required amount of extra packing coke to add.

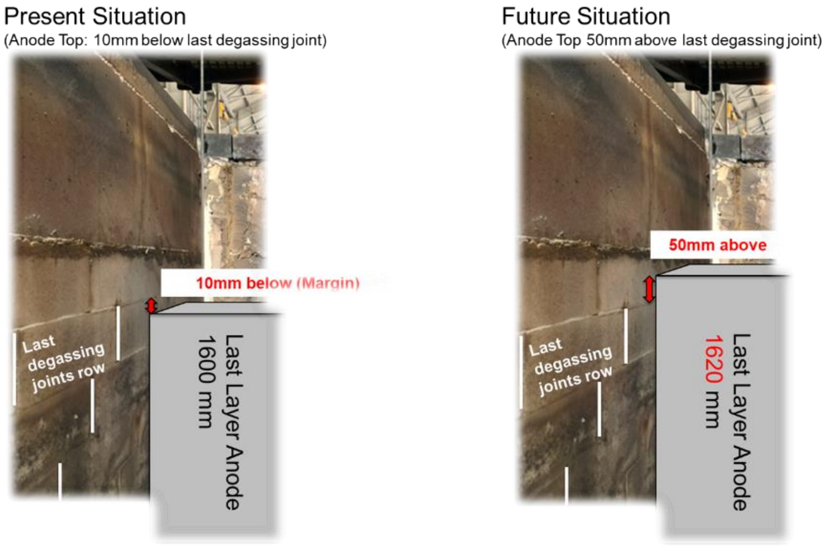


Figure 5. 1620 mm-long anode location vs degassing joint.

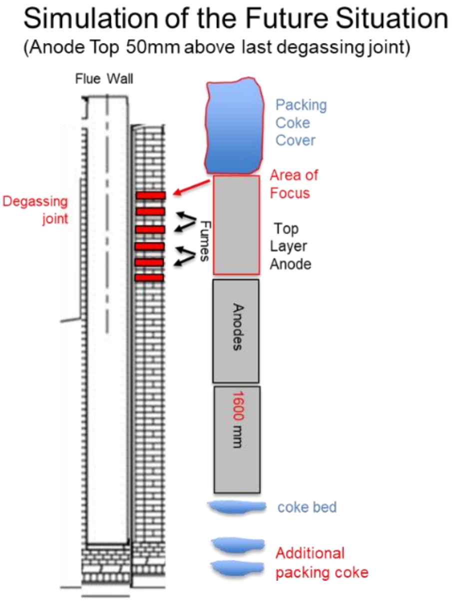


Figure 6. Configuration of the 1600 mm anodes simulating the future 1620 mm anode position in the pit.

Figure 7. Method used to add the required packing coke in each pit.

As per design, the ABF in Sohar Aluminium is a Pechiney model made of 52 sections, each having nine pits of three layers of seven anodes, for a total of three fires. The baking quality is measured by L_c within a targeted range of 34-35 Å (angstrom). The hottest and coldest anodes are cored for each section. Typically, the two external pits are the coldest ones. The design of the test was therefore the following:

- 1 fire was used as a reference
- 1 fire as a test

The study lasted three weeks to capture all the potential impacts during a representative period of time. The assessed impacts were the baking level (L_c), the electrical resistivity, the CO_2- and O_2-reactivity, anode burnt surface, the temperature of the refractory and of the packing coke, the coke burnt, and the CO_2, CO, and H_2S gas emissions on the ABF deck. As Grjotheim [1] and Mantell [2] mentioned, the baking level influences the anode reactivity. All the other aspects were daily audited for both fires to remain comparable (baking operation quality, baking settings, pit sealing operation, green anode qualit).

The upper part of the last layer of anodes could be underbaked, so the coring setup was modified. The properties of the top of the anode would be analyzed, as shown on Figure 8. Despite these precautions, it was still not possible to rule out a possible variation between sections or pits, independent from the anode length, yet affecting the trial conclusions. Therefore, to neutralize these external factors impacting the L_c values, an additional measure for double coring was developed on-line. The measures reported to conclude would be a difference between the properties of the 2 cores for each anode.

Figure 8. Double coring in the top and middle part of the upper anode.

Finally, to reflect the existing ratio of external vs internal pits in the ABF, and the hottest and coldest anodes position in the top layer, the coring pattern presented in Figure 9 was implemented for both test and reference sections.

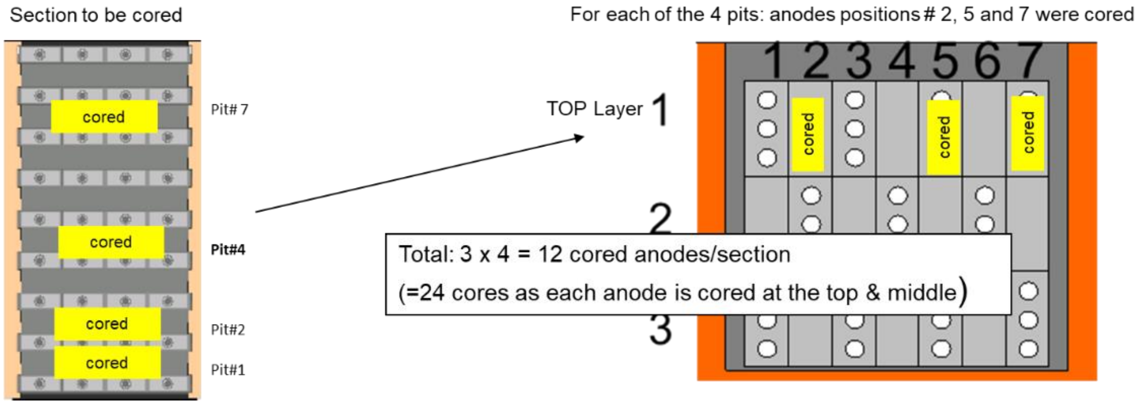


Figure 9. Anode core sampling strategy.

5.2 Transportation Clearance and Lifting Capability

The list of the modifications to bring to the equipment was based on physical measurement, use of wooden plate to simulate the 1620 mm long anodes, and manufacturer data. The review included the design calculations, the assessment of equipment condition, and the modelling of new loads on structures. As a result, the stacking crane, the FTA grab limits had to be re-rated. The anode assembly conveyor structure had to be reinforced. The baked anode cleaning station had also to be slightly modified, as well as FTA cabin cladding, P&F hangers and limits.

Figure 10. Clearances adjustment.

5.3 1620 mm Anode Setting and Behavior in Pots

All the test anodes baked at the top layers exclusively (60 mm higher than the reference anodes) were sent to 36 dedicated pots for behavior assessment (dusting, instability, anode effect) for a total of 1008 anodes for 1 cycle (see Figure 11). Their performance was compared with reference anodes. Both sets of pots were operated with the same team, methods, and standards. The performance of the anodes was monitored by a dedicated team. Note that this latter test overemphasized the detection of a poor anode performance by deliberately using in the pots 100 % of the anodes from the top layer only (worst baking conditions). Typically, the rate is 33 % in average. Figure 12 shows the modified anodes to be used to ensure the 1620 mm anodes can be easily set and changed in Reduction.

Figure 11. Third layer baked test anodes dedicated to test pots.

Figure 12. Anodes extended with 20 mm thick wooden plates.

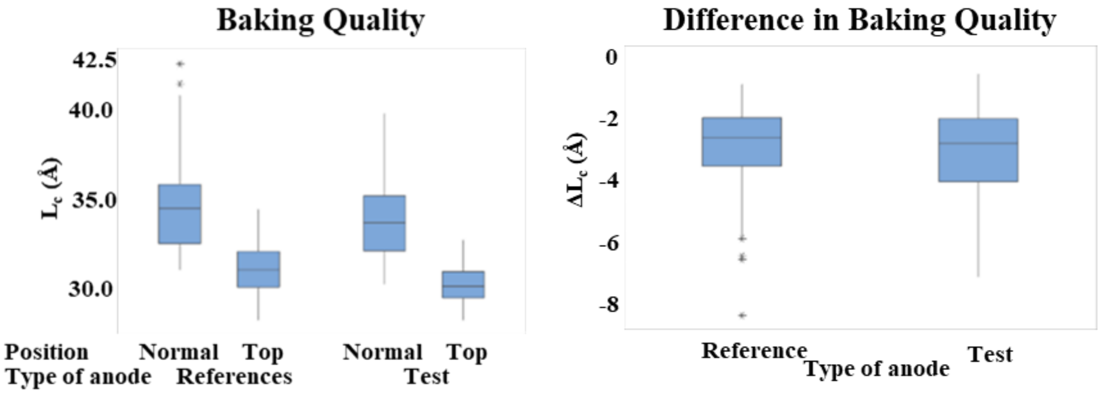
5.4 Evaluations of Using 1620 mm Anodes

The quality of the green and baked anodes, the physical anode properties, the anodes handling, conveying and cleaning systems, and the anode setting operation in the potline were all successfully validated. The Table 1 sums up the results and statistical interpretations.

Table 1. Baking performance results, comparison between test and reference sections.

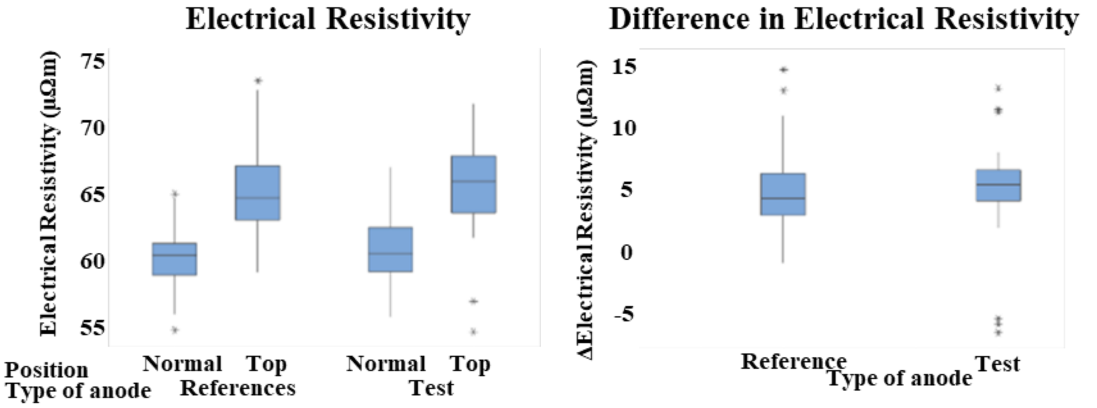
Key Indicator	Measurement Method	Risk	Results on comparison between test and reference sections
L_c	9 sections, 4 dedicated pits, 3 anode positions, x 2 coring	Underbaking	No statistically significant differences
Electrical resistivity	4 dedicated pits, 3 anode positions, x 2 coring	Larger	No statistically significant differences
CO_2 reactivity	4 dedicated pits, 3 anode positions, x 2 coring	Reactivity	No statistically significant differences
O_2 reactivity	Qualitative (6 vs 6 cores)	Reactivity	Within expected ranges
Burnt baked anode surface	Qualitative, daily visual audit	Reject	No difference
Refractory temperature	Thermal camera for FWs # 1, 2, 3 from 4 sections	Damage	No statistically significant differences
Coke top temperature	Thermal camera for pits # 1, 2, 3 from 4 sections	Consumption	No statistically significant differences
Red packing coke	Qualitative, daily visual audit	Consumption	No difference
Exposure to SO_2, CO, and H_2S gas at ABF deck	Monitoring for 6 h in blowing and preheating zones, beginning, middle and end of fire cycle and in FTA	Health	No difference (both require wearing a mask)
Performance in pot	Qualitative, one cycle with 1000 anodes from top layer only	Dusting	No difference

As expected, and shown on Figures 13 and 14, the baking level in both anode sets was lower at the anode tops (“Top”) than in their centers (“Normal”). The electrical resistivity (ER) for both sets was greater at the anode tops than in their centers.



(a) **(b)**

Figure 13. Baking quality as (a) function of core location and (b) as difference between core location (top minus normal).



(a) **(b)**

Figure 14. Electrical resistivity as (a) function of core location and (b) difference between core location (top minus normal).

6. Conversion of the Anode Plant to 1620 mm Anodes

In April 2022, the modifications were successfully finalized on the vibro-compactors, cleaning station, conveyors, and anode grabs. The 1600 mm-long anodes stock was fully consumed in the pots prior to introducing the new generation of 1620 mm-long and 350 mm-deep slotted anodes.

7. Conclusions

The extension of the anode length and of the slot life were carried out successfully and implemented in the production process. The last manufactured 1600 mm anodes with 300 mm slots and the first produced 1620 mm anodes with 350 mm slots were cored for comparison. The results showed no significance difference in their mechanical, chemical, electrical properties, confirming the findings in the previous trials. The physical aspect of the baked anodes and the reject rate remained unchanged. The implementation study followed measured steps and led to benefits without drawback, the pot rooms achieved a historical record in terms of CE performance two months after the introduction of the longer anodes. The decision to conduct both extension projects simultaneously was rewarding; on one side the anode surface extension when targeting lower current density coincided with the introduction of unwanted additional carbon mass. On the other side, the deeper slots removing anode mass, and would eventually force to reduce the anode change cycle in Reduction at a cost. Combining these two separate projects was a balanced decision. The gain in combining the two changes exceeded the initial estimation on internal rate of return for this project.

8. References

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