Linking Electrochemistry, Modern Aluminium Cell Design and Operating Conditions, for a Better Understanding of Anode Reactions and Various Levels of PFC Co-evolution

Part 2: The Impact of Cell Design and Process Conditions on Energy Utilization and PFC emissions and general cell Performance.

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Abstract

This paper is Part 2 of 2 and builds on the improved understanding of the electrochemical and anode reactions (Part 1) and deals with the impact of these changes in aluminium cell design and process conditions over time. With the generally higher operating current densities in modern aluminium reduction cells the anode potential at a fixed alumina concentration is higher. Consequently, because control systems rely on modulating the average dissolved alumina concentration in the cell, there is a much higher risk of the interfacial electrode potential increasing to a value above the limit that is necessary to enable co-evolution of PFCs. The problem is magnified by the increased time-lag required for dissolution and distribution of alumina when fed at a higher rate. Furthermore, extracting the increased amount of heat required during the over-feeding cycle from the surrounding electrolyte becomes more difficult because of the reduced electrolyte volume in modern cell designs. This means that the mixing requires high transverse electrolyte velocities under the anodes and these cannot be readily achieved in modern cells with slotted anodes. Examples that will be presented include undetected low level PFC co-evolution, uneven consumption rate of anodes – sometimes even leading to anode spike formation – and a generally higher process energy consumption.

Keywords: Aluminium reduction, PFC co-evolution, cell design, process conditions, energy consumption.

1. Introduction

As discussed in Part 1, the quality of raw materials and operating conditions determine the range of products that are evolved from anodes in cells. We have also seen that limitations, work practices and control practices cause further deviations from target operating conditions and can aggravate the situation. Throughout the history of aluminium smelting there have progressively been changes in cell design and operating practices in order to overcome weaknesses and achieve the goals of the smelter.

Cell performance is measured against many different parameters such as current efficiency (CE%), energy consumption, cell life, operating cost, capital cost, metal quality, and environmental performance. Frequently the emphasis of developments has been biased towards whichever of these parameters has the greatest needs. By integrating design advances with better fundamental understanding, improved process control and better materials available, there has been spectacular progress as seen in Table 1. The data included in Table 1, is compiled from operating records made available to the authors for a large range of cell design and technologies encompassing the full period of commercial aluminium production.

In the last two decades environmental performance has become much more important. With that there has also been a linked driver to reducing energy consumption per unit production because of the scarcity of electrical energy that has a low greenhouse gas footprint. Published papers and press announcements associated with performance of new technologies being developed in test groups by Hydro and Rio Tinto indicate that there is an ability to design and operate cells at and even below the 12 DC kWh/kg Al barrier. However, these are not included in Table 1 due to the absence of long-term, complete potline operating data as the respective technologies are only in operation for a limited amount of time.

Table 1. Typical key performance indicators (KPIs) of Selected leading cell technologies for the era.

KPI	**Units**	***The Changing Performance Indices***				
Era ± 10 yrs		1920	1955	*1955* Søderberg*	1985	2015
Cell Size	kA/cell	14	55	*100**	180	> 420
Gross Carbon Consumption	kg C/kg Al	0.65	0.58	*0.54*	0.5	0.5
Net Carbon Consumption	kg C/kg Al	0.58	0.47	*0.54*	**0.405**	0.42
Current Efficiency (CE%)	% theoretical	77	83	*85*	**95.5**	94
Energy Consumption	DC kWh/kg Al	22	16	*16*	**12.7**	13
Anode Effect Frequency	AE/cell-day	3.5	3	*3*	0.35	**0.03**
Cell Life	Days	500	700	*700*	**3000**	2000
Environmental Issues	Type		Fluoride SO_2 and dust	Fluoride, SO_2 dust and PAHs		**PFCs co-evolving**

1.1. Brief Historical Trend of Technology

The above table shows that the most recent technology has shifted in a manner that some of the key performance indicators (KPIs) are below those achievable earlier. Therefore, in order to understand the technological changes so that the best path can be developed for future metal production, this paper reviews some of the key technical changes that have happened, followed by an assessment of their impact.

The Søderberg technology introduced in the early 1920s a major capital expenditure advantage by eliminating the need for an anode plant and its associated facilities. It also proved to be very beneficial on work practices by eliminating the need for anode change whilst it also enabled a significant increase in operating line current. Consequently it expanded rapidly especially during World War II when there was a high demand for aluminium. No new potlines using Søderberg technology has been installed in the Western world for more than 30 years because their energy efficiency, environmental footprint and carbon consumption will always lag that of prebaked cell technology through technical reasons.

The major step in the improvements occurred in the period between 1955 and 1985. During this period there had been intensive R&D at many smelters in order to address the harmful fluoride emissions and eliminate problems that lead to performance deterioration. But equally important, it coincided with the explosion in solid-state electronics and the digital era. For example, strong transverse electrolyte flow, which is less likely with the slotted anodes and low anode cathode distance.

4. Conclusions

The common consequence of the retrofits made to increase productivity, is an increase in the tendency to have spatial variability of cell conditions, by slowing down the flow and mixing of the electrolyte to the extent that concentration gradients are established, to the point where conditions approach or exceed those necessary for PFC co-evolution.

While productivity of the cells continues to increase, it comes with a general increase in the net energy consumption rate per unit production. Coupled with this are significant reductions in cell life compared with those achievable with more resistive cathode blocks, which tend to have a much more even cathodic current distribution and lower wear rate.

Redesign of cells coupled with changes in control and feeding strategy and the introduction of better sensors such as continuous individual anode current monitoring, should lead to better environmental and operating performance.

However the the design and wisdom of some of the changes introduced could benefit from re-assesment.

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6. References

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