Seasonal Influence on Aluminium Cell Heat Balance and Performance

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Abstract

Some aluminium smelters in Norway occasionally experience hot cell sides and reduced current efficiency during the summer season. The increase in cell side temperatures is typically larger than what would be expected from modelling, where such changes are usually said to roughly follow the ambient temperature. The root cause of this phenomenon is not fully known, even though being subject to substantial research for years. In this paper we discuss different mechanisms that could contribute to such a behaviour. These contributions are theoretically evaluated and analysed in combination with results from targeted experiments and measurement campaigns. Furthermore, a detailed pot room model has been established looking at the effects of ventilation – cooling due to ventilation is probably the most difficult to measure and (perhaps) the easiest to model. The simulations confirm that the pot shell, if seen as isolated with no heat flux change, indeed follows the ambient temperature increase with some dependence on the initial conditions. Our results show that several different mechanisms contribute to higher cell side heat fluxes during summers, some more than others. However, the results also indicate that these mechanisms alone may not explain the observed operational behaviour. A new hypothesis is presented, suggesting that decreased current efficiency as the Anode-Cathode Distance (ACD) is squeezed might be another source for the temperature increase seen.

Keywords: Aluminium electrolysis cells, Cell performance, Hot cells, Pot room ventilation, Anode cathode distance.

1. Introduction

Aluminium electrolysis cells are dependent on having a protective layer of frozen electrolyte on the inner walls. The delicate energy balance entails that the cell can function only within a certain (narrow) range of operating parameters mainly defined by the cathode design. This implicitly limits the current, since a larger quantity than acceptable would generate too much heat. Still, it has been possible to improve the performance considerably for given cell technologies (capacity creep). As an example, the productivity in four Hydro Aluminium plants was increased by nearly 40 % from 1983 to 2006, while at the same time reducing the specific energy consumption [1]. Enabling factors included longer anodes, increased anode stub diameter, new cathode designs, new side-lining materials, and lower anode-cathode distance (ACD). All these enhancements have been utilized fully in the new HAL4e technology at the Karmøy Technology Pilot (KTP) [2, 3]. However, there are restrictions to every improvement, and the technology may be pushed to the limit in some locations.

In some plants it was observed that cell performance deteriorates during the summer months ("summer effect"). The pot shell temperature increases, sometimes much more than the ambient temperature, and the current efficiency (CE) decreases. Modelling tools struggle to reproduce these seasonal variations. The effect of ambient temperature on aluminium electrolysis cells' performance is also scarcely treated in the open literature, although exceptions can be found [4]. It was decided to carry out a theoretical and experimental study to reveal the root causes for the variations. The purpose of the present paper is to present some hypotheses on what is causing the "summer effect". Estimates, calculations, modelling results, and experimental data are presented, aiming to reveal the relative importance of different effects. The study is still ongoing. Although the results are not conclusive, it appears that there must be several reasons for the "summer effect".

2. The Challenges

There is no doubt that the last decades' systematic performance improvements, increased data acquisition and better accuracy have given both opportunities and challenges. As shown in the introduction, technologies are pushed and squeezed to increase nominal production, and the cells operate with tighter margins and less tolerances for deviations. However, enhancements tend to follow cell generation changes, and explanations that at some point seem rather obvious might take several years to reveal.

Relations between ambient conditions and pot shell temperatures have been subject in a previous study. Haugland et al. [4] reported measurements showing correspondent ambient and pot shell temperature changes, which fit quite well with Computational Fluid Dynamics (CFD) calculations presented below. However, in the recent years some smelters have seen deviations from this 1:1 correspondence. Recent long-term measurements have shown significantly larger pot shell temperature changes compared against ambient temperature, see Figure 1. The seasonal variations do follow each other, but the absolute values have ratios close to 2.5:1. Maximum "average" ambient differences somewhat above 30 °C have given rise to around 80 °C shell temperature variation. Higher pot shell temperatures are undesirable, as these give lower margins for errors and cause disturbances and challenges for the operations.

In addition to hot pot shells, smelters also report decreased CE during the summer season. No absolute figures will be given, and the reader will acknowledge that CE with such quite small time periods as 3-4 months could be contaminated with relatively large errors. Still, the trend is clear, with a seasonal variation also in CE. Presumably these changes are connected.

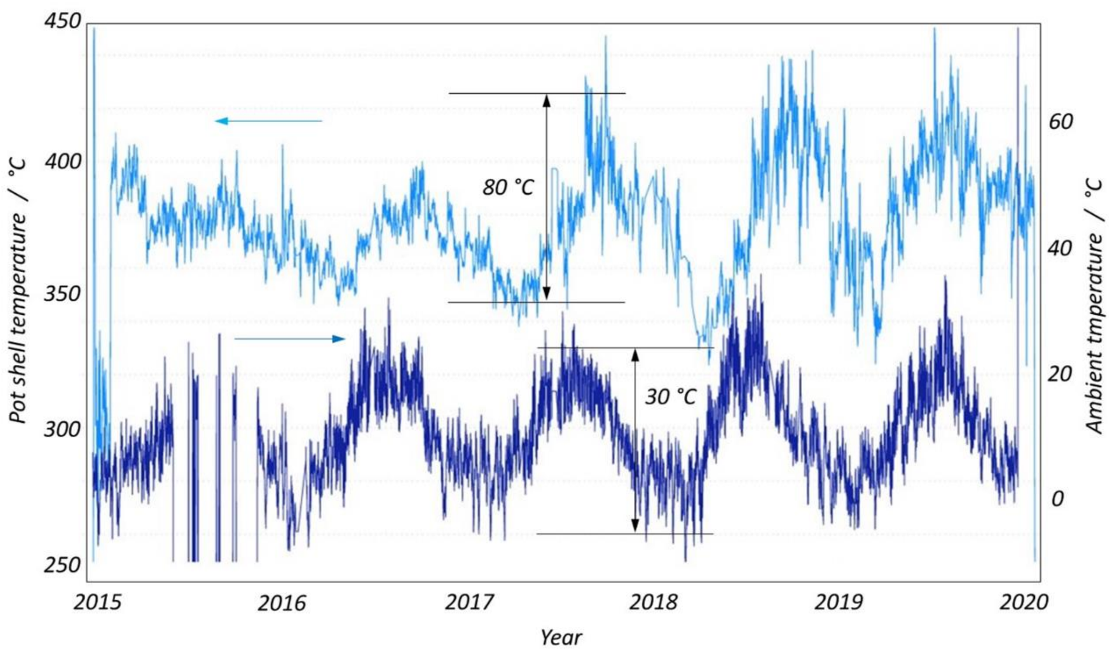

Figure 1. Example of pot shell and ambient seasonal temperature variations. Note the difference between the y-axes, which have ratio 2.5:1.

3. Initial Hypotheses and Theoretical Considerations

decreasing the heat generation in the cell, instead would increase the heat production. If correct, this indicates that we are approaching the limit of the interpolar distance. The project will be followed up with more tests and measurement. We would especially like to push the ACD during wintertime to see if this paradox can be realized.

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7. References

1. Bjørn Moxnes, Halvor Kvande, and Asbjørn Solheim, Experience and challenges with amperage increase in Hydro Aluminium potlines, *Light Metals* 2007, 263-268.
2. Pierre Reny et al., Hydro’s New Karmøy Technology Pilot: Start-Up and Early Operation, *Light Metals* 2021, 608-617.
3. Asgeir Bardal et al., HAL 4e - Hydro's new generation cell technology, *Light Metals* 2009, 371-375.
4. Elin Haugland, Håvard Børset, Håvard Gikling, and Helge Høie, Effects of ambient temperature and ventilation on shell temperature, heat balance and side ledge of an alumina reduction cell, *Light Metals* 2002, 269-276.
5. Torstein Haarberg, Asbjørn Solheim, Stein T. Johansen, and Per A. Solli, Effect of anodic gas release on current efficiency in Hall-Heroult cells, *Light Metals* 1998, 475-481.
6. Geoff Bearne, A. Jenkin, L. Knapp, and I. Saeed, The impact of cell geometry on cell performance, *Light Metals* 1995, 375-380.
7. Stuart W. Churchill, and Humbert H. S. Chu, Correlating equations for laminar and turbulent free convection from a vertical plate, *International Journal of Heat and Mass Transfer* 1975, 1323-1329.
8. J.R. Welty, C.E. Wicks, and R.E. Wilson, *Fundamentals of momentum, heat, and mass transfer*, John Wiley & Sons, Inc., Singapore, 1984.
9. EngineersEdge (retrieved June, 2022): https://www.engineersedge.com/heat_transfer/flat_plate_heat_transfer_convected_13956.htm
10. Sverre Rolseth, Tugrul Muftuoglu, Asbjørn Solheim, and Jomar Thonstad, Current efficiency at short anode-cathode distance in aluminium electrolysis, *Light Metals* 1986, 517-523.
11. Asbjørn Solheim, Current efficiency in aluminium reduction cells: Theories, models, concepts, and speculations, *Light Metals* 2014, 753-758.
12. Asbjørn Solheim, Arguments for keeping uniform alumina concentration and anode-cathode distance in aluminium electrolysis cells, *Proceedings of 40th International ICSOBA Conference*, Athens, Greece, 10 – 14 October, 2022 (this volume).
13. NIST-JANAF Thermochemical Tables, https://janaf.nist.gov/ (Retrieved May, 2022).
14. Alexander Arkhipov, Ievgen Necheporenko, Alexander Mukhanov, Nadia Ahli, and Khawla AlMarzooqi, Modelling study of exhaust rate impact on heat loss from aluminium reduction cells, *Light Metals* 2019, 625-635.
15. Sara T. Mathisen, Elin Haugland, Top heat losses at reduced duct flow. Measurement campaign July-August 2004. *Internal Report 05Q_AA0*, 2005.