Heat Dissipation Study in Hall- Héroult Cells During Power Outage

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Abstract:

The power outages in aluminium smelters are troublesome and could be frequent phenomena in few smelters. During power outage, heat loss distribution in the pot gets modified as the materials will lose the stored heat. The ledge thickness increases as time passes and may make it difficult to bring the pot back to life after 4–5 hours of power outage. Therefore, it becomes very important to consider this phenomenon while developing a cell lining for productivity enhancement or energy reduction, thereby enabling pot to perform robustly and recover successfully after outages. To investigate this phenomenon in detail, a computational study has been carried out using transient thermo-electric model to compare the behavior of different lining designs. It has been observed for some cases that, the temperature of anode cover decreases with time, whereas for few others, it increases initially for around an hour before proceeding on downward trend. Temperature of the steel shell near collector bar & bottom decreases after outage, however, the regions on shell near metal & bath may get heated up initially under certain conditions. The findings of this study have been used to finalize the new cell lining design which is expected to maintain higher temperature as compared to existing design during power outage. To extend the survival time of the pot in case of prolonged outage, high heat capacity insulation material at specific locations (internal as well as external) are evaluated, to retard the bath solidification. This paper would discuss the results in detail about various measures to enhance the sustainability of pot during power outages.

Keywords: Outage, Heat loss distribution, Transient computational analysis, Lining design, Pot operation

1. Introduction

The Hall-Héroult process is used to produce liquid aluminum through electrolysis of alumina in molten cryolite bath. During the reaction, alumina reacts with carbon anode and form liquid aluminum and CO_2 gas. Internal joule heat is generated due to current passing through various cell components. Under steady condition this heat is dissipated from the cell boundaries while maintaining the operating temperature in the cell. The total heat loss distribution of a cell reported by A. Jha et. al. [1] is ~40 % of total heat is dissipated from top, ~44 % from side walls, ~11 % from bottom and ~5 % of the heat is lost through collector bars. The heat loss distribution can be diverse for different technologies however, the greatest proportion of heat is lost from the top and sides of the cell. In an aluminum reduction cell, the cell lining is designed to provide thermal resistance to the heat being lost through cell boundaries. This helps in maintaining the required isotherms at proper locations in the cell.

During a power outage, internal heat generation stops in the cell / pot, and at this zero-power scenario, the cell loses the heat from all the boundaries thereby, the pot starts cooling and thus disturbs the thermal balance of the cell. The heat dissipation rate may remain unaltered initially for short period, but pot starts to lose the internal energy stored in it. In absence of heat generation, the bath starts to solidify on the ledge, and it may extend towards the center of the cell. As the time passes, ledge will start building up ultimately reducing the heat flux through the sidewalls. Due to lack of heat source, other boundaries like top cover, cell bottom, etc. will also start cooling. In case pots have a forced cooling network (FCN) system, shell temperature should increase initially due to stoppage of FCN. If outage sustains for longer durations, pot may need to be shut down as bath will solidify completely below ~ 850 °C [2]. Zhao *et al*. [3] reported few quick actions like closing the feeding holes, tap holes, increase the anode cover thickness, etc. to reduce heat loss.

To increase the pot survival time, the lining insulation and other pot parameters should keep the bath & metal in the molten phase for a long time after a power outage. Therefore, it is very important to consider heat dissipation during a power outage while developing a low energy cell lining. Lining material with low thermal conductivity along with high heat capacity should delay the solidification of bath. Modifications in lining arrangement can also be considered to increase total solidification time. Apart from cell lining, a provision of temporary insulations during outages at sidewalls, top of anode cover or pot cover reduces the cooling rate.

2. Methodology of the Study Performed

To investigate the cell cooling tendency in the power outage scenario, a computational study has been carried out by using a 3 dimensional (3-D) thermo-electric slice model. Steady-state model development and its validation for 86 kA pot has been published earlier [4]. Steady state calculations were performed at 367 kA line current, and its results were used as an initial condition for transient simulations. Since composition of solidified bath (ledge) is different than molten bath, hence while cooling, bath density also changes due to change in composition (especially AlF_3 wt%), and it may lead to inversion due to increased density of molten bath. However, in the present analysis metal and bath have been assumed to remain at the same position. The change in bath chemistry due to cryolite freezing resulting in increase in AlF_3 wt% leading to the lowering of liquidus temperature. This phenomenon will slow down the rate of cryolite freezing. Since, the computational model doesn't incorporate any change in bath composition with outage time, therefore, rate of cooling of bath is being over predicted. The changes in bath ratio (ratio of wt% of NaF to wt% of AlF_3) & liquidus temperature [5] with outage time have been plotted using a MATLAB-based dynamic model and shown in Figures 1 & 2. The change in bath volume & composition due to solidification of cryolite has been considered in the dynamic model. The values of liquidus temperature obtained at the different points in time were used to track isotherms obtained from computational model.

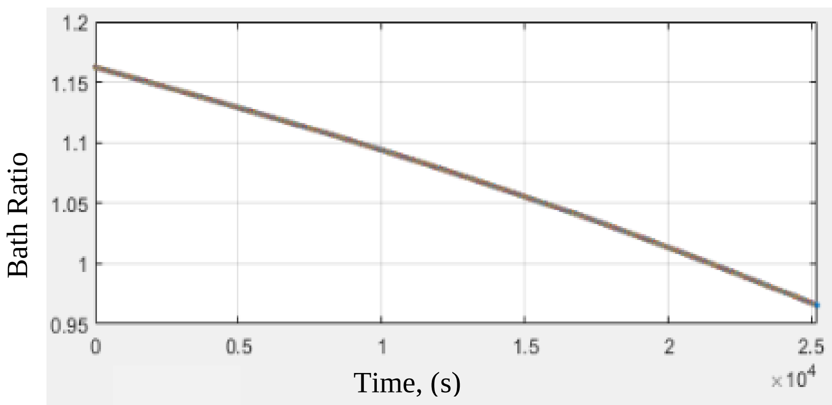

Figure 1. Evolution of bath ratio (weight ratio of NaF/AlF_3) with time.

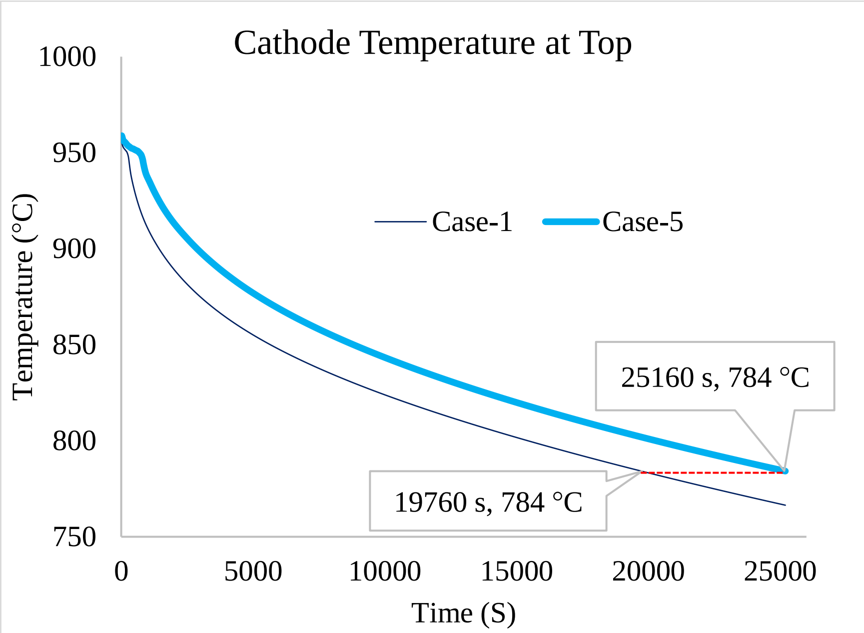

Figure 16. Combined impact of increased anode cover thickness and change in cell lining on cathode temperature.

4 Conclusions

Based on the heat dissipation study and time-variant computational simulations for a 7-hour power outage scenario, the temporal evolution of temperature at particular locations (such as steel shell sidewall, anode cover top surface, the bottom of the cell, and cathode top corner) was tracked for all considered cases and compared with the results obtained for the existing lining design (Case – 1). The following observations were formulated:

1. Using dynamic model, the variation of liquidus temperature with outage time was obtained. Liquidus temperature of bath drops at average rate of 9 – 10 °C/hour.
2. Increase of anode cover thickness by 3 cm with an existing lining helps in keeping the cathode at high temperature for additional 25–30 minutes
3. Changes in cell lining design as well as using low thermal conductivity material gives an additional survival time of well over an hour. However, the applicability of this scenario also depends on the implications of these changes for normal pot operation, which would also have to be carefully checked (beyond the scope of this study).
4. Addition of an external insulation over anode cover before or after power outage will restrict heat loss from the top of the cell and may give an extra buffer of 50–60 minutes.
5. Considering a change in lining design and increased anode cover thickness by 3 cm has shown a good thermal arrest from cell boundaries and as compared to case-1 it provides additional survival time of 1 hour 30 minutes.

5 References

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