Impact of Carbon Dust on Performance of Hall Heroult Cell: A Computational Analysis

Tushar Thorat[1], Amit Jha[2] and Amit Gupta[3]
1. Scientist
2. Senior Scientist
3. Lead Scientist
Aditya Birla Science & technology Company Pvt. Ltd. Taloja MIDC Panvel, Maharashtra, India.
Corresponding author: tushar.thorat@adityabirla.com

Abstract

Carbon dust in the cell adversely affects its current efficiency and specific energy consumption. Cells with higher level of carbon dusts may show symptoms like high bath temperature, red spots on steel shell, unusual variation in bath and metal height, anode spikes/mushrooms, etc. Unlike other impurities, carbon particles remain suspended in the bath which leads to an increase of electrical resistivity and emissivity. The rise in electrical resistivity leads to anode-cathode distance (ACD) squeeze, if the cell voltage is fixed. This scenario intensifies the heat generated per mm of ACD in the bath. Carbon dust floating on the surface of bath increases radiative heat loss. This may lead to localized cooling during cell operational activities causing reduced superheat which in turn leads to spike formation in newly set anodes. The mushrooms/spikes in the cell will cause localized heating due to uneven current distribution. To investigate the impact of squeezed ACD and mushroom/spike formation on the thermal balance of the cell, a computational study has been carried out. It was observed that, the bath temperature increases by 2 to 10 °C and shell temperatures increase by 30 to 40 °C. The ledge becomes thinner by around 3-5 cm due to localized heating. Effect of increased emissivity of bath on the radiative heat loss through exposed areas such as point feeder holes, open cavity during anode change, and tap hole was analyzed. This paper also describes the use of inferences drawn from these analyses to optimize the measures, like preheating of new anode or increase in anode set voltage, to compensate the increased heat loss.

Keywords: Carbon dust in aluminum reduction cells, Anode spikes, Heat balance, Radiative heat loss, Potshell temperature.

1. Introduction

Carbon dust in the cell adversely affects its current efficiency and specific energy consumption. Cells with higher level of carbon dusts may show symptoms like increased number of high bath temperature excursions (>970 ºC), red spots on steel shell, unusual variation in bath and metal height, anode spikes/mushrooms, etc. These abnormalities can further add to poor use of the manpower due to (1) increased frequency and duration of carbon dust skimming (2) increased time required to detect and remove the anode spikes [1] (3) maintaining bath height and (4) measurements, monitoring and other corrective actions.

Unlike other impurities in bath, the carbon dust particles either remain in suspended form or floats on bath top [2] [3]. Variation in concentration and particle size distribution of carbon in bath is given by Foosnaes et al [4]. The size of these carbon dust particles in bath can range from micrometers to centimeters with an average size of 10 micrometers. Coarser carbon dust particles float on the bath surface whereas finer dust particles remain suspended in bath [3]. Carbon dust in the bath can originate from (1) poor quality anode, (2) erosion of ramming paste seam, preformed carbon blocks at side lining and cathode blocks, (3) higher carbon percentage in recycled anode cover material, (4) carbon fines captured by dry scrubbers returning to the cell through secondary alumina feeding, (5) stub protection material which is directly lost into bath [1], etc. One of the major issues associated with carbon dust is an increase of electrical resistivity of the bath. Based on the laboratory experiments, Bugnion et al. [3] reported that the electrical resistivity of bath can increase by 70 % if carbon concentration in bath increases from 0.06 % to 1.01 %. Foosnaes et al [4] presented computational study, complemented with plant scale experiment, reporting 6 % increase in bath resistance with 1 % carbon content. As bath resistivity increases, ACD gets squeezed to keep the voltage in set operating band. This effectively increases heat generated per unit depth of ACD. Such localized heating will impact bath temperature, side ledge thickness and the steel shell wall temperature.

The presence of carbon dust in the bath also increases the emissivity of bath by 23 % as reported by Bernd Rolofs [5]. Rise in bath emissivity will increase radiative heat loss from open cavity during anode change operation. Also, extra energy is supplied during anode change to compensate for heat loss and heat required by freshly installed ‘cold’ anodes to achieve the steady state temperature. Nevertheless, the increased radiative heat loss due to carbon dust will lead to localized drop in bath superheat. The decrease in superheat can lead to freezing of electrolyte on anode bottom surface causing uneven carbon consumption and eventually forming mushrooms or spikes [5], which are discussed in [6]. In older cells, lower superheat and lower ACD can cause more severe problems.

Poor control of cell thermal balance will intensify issues like mushroom formation, high bath temperature, low bath height, frequent jumps in excess AlF_3, etc. To investigate the thermal impact of increased bath resistivity, squeezed ACD, mushroom/spike formation and higher excess AlF_3, a computational study has been carried out and will be discussed in this paper. The effect of increased emissivity of bath on the radiative heat loss through exposed areas such as point feeder holes, tap holes and open cavity during anode change is analyzed through analytical calculations. This paper also describes the use of inferences drawn from these analyses to optimize the measures, like preheating of new anode or increase in anode set voltage, to compensate the increased heat loss.

2. Methodology

To illustrate the impact of increase in the bath resistivity and the anode spike on thermal balance and current distribution in a cell, thermoelectric simulations were carried out using a 3D finite element model in ANSYS APDL environment. This model was developed in the past for an 86-kA cell technology [8]. The same model was recalibrated for 235 kA cell technology. Model results were validated against thermal and electrical measurements, such as steel shell temperature, cathode voltage drop, electrolyte ledge profile, etc. To analyze impact of bath emissivity increase, an analytical equation is developed and used to quantify heat losses during anode change operation.

2.1 Increase of Bath Resistivity

Carbon dust content in bath considered for this study is in the range of 0.06 % to 1.01 %. The data of bath resistivities for different concentrations of the carbon dust in the bath are adopted from recent work by Louis Bugnion et al [3]. Based on the change in bath resistivity, ACD is being calculated for fixed bath voltage of 1.5 V and carbon content of 0.06 % (Case 1), 0.16 % (Case 2) and 1.01 % (Case 3). Case 1, case 2 and case 3 are analyzed for critical thermal parameters of the cell.

Thermo-electric simulations were carried out to analyze cumulative impact of presence of carbon dust and high excess AlF_3 content in bath. Liquidus of the bath at AlF_3 content of 15 % is

5. References

1. Neal Wai-Poi and Bernd Rolofs, Impact of energy management and superheat on anode spike formation, *Light Metals* 2002, 535-539.
2. Louis Bugnion and Jean-Claude Fischer, Effect of carbon dust on the electrical resistivity of cryolite bath, *Light Metals* 2016, 587-591.
3. Kai Grjotheim, Berry Welch and Mark Taylor, Relating operating strategy and performance in Aluminium Smelting cells-an overview, *Light Metals* 1989, 255-260
4. T. Foosnaes T et al., Anode dusting in Hall Heroult Cell, *Light Metals* 1986, 633-642.
5. Bernd Rolofs and Neal Wai-Poi, The effect of anode spike formation on operational performance, *Light Metals* 2000, 189-193.
6. Mohamed Ali and Abdel-Masser Omran, Anode spike formation in prebaked aluminium reduction cells, *Al-Azhar Engineering 12th international conference* 2012, 30-36.
7. Ali Jassim et al., Studies on preheating using individual anode signals in Hall-Heroult reduction cells, *Light Metals* 2016, 623-628.
8. Amit Gupta and Sankar Nambuthiri, Impact of carbon seam on freeze profile in aluminium reduction cells, *Transactions of Indian Institute of Metals* , Vol 6, 2017, 1-12.
9. Frank Aune et al., Thermal effects by anode changing in prebake reduction cells, *Light Metals 1996, Essential Readings in Light Metals* Vol 2 2016, 562-568.
10. Matthias Dechent et al., Carbon dust-Its short term influence on potroom operations during anode change, *Light Metals* 2021, 384-391.
11. Warren Haupins, Principles of aluminium electrolysis cell, *Light Metals* 1995, 195-203.
12. Khalil Khaji and Mohammed Qasseni, Role of anode manufaturing process in net carbon consumption, *Metals* 2016 Vol 128, 127-138.
13. R Ødegård, A Solheim and K Thovsen, Current pickup and temperature distribution in newly set prebaked Hall Heroult anodes, *Light Metals* 1992, 555-560.
14. A Solheim et al., Liquidus temperature and alumina solubility in the system Na_3AlF_6-AlF_3-LiF-CaF_2-MgF_2, *Light Metals* 1995, 451-460.
15. S.G. Shahrai et al., Quality of anode, Overview of problems and some methods of their solution, Part 1, Coal foam in aluminium electrolyzer, *International journal of applied engineering research,* Vol 12, Nov 2017, 8976-8985.
16. Andrea Lucherini, Experimental study of the behavior of steel structures protected by different intumescent coatings and exposed to various fire scenarios, *PhD Thesis, Department of Civil Engineering, Technical University of Denmark,* 2015-2016.