Computational Model Development for Performance Analysis of Anode Baking Furnace

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Abstract

Hindalco's Renukoot smelter uses prebaked carbon anodes in Aluminium reduction cells. In past one year, pot room has reported several occurrences of anode cracking and carbon dusting. Quality control lab have frequently reported high electrical resistivity (> 56 μΩ-m) and low crystalline length (< 30 Å) in baked anode samples. These shortcomings in anode quality can be attributed to raw material quality, recipe, green anode process, and baking process. Based on plant data analysis and process study, baking process was identified as the major influencing factor. To find out root causes behind the sub-standard baking, performance analysis of Anode Baking Furnace (ABF) was carried out. A 3D CFD model was developed for analysing flue gas distribution and anode temperature profile during baking cycle. Thermal mapping experiment was performed to measure anode temperature at various heights in four different pits of a section. Model was calibrated and computed results were validated against the measured anode temperatures. Samples of anodes from these four pits were collected and analysed in laboratory. Velocity distribution of flue gas was analysed with CFD model. It was observed that, due to low velocity of flue gas in top region of flue wall, cold spots are created. Non-uniform gas flow distribution and heat losses from packing coke surface results in lower baking temperature and residence time of anodes located in top layer. Hence, quality parameters (ER, Lc, RD etc.) of these anodes were found below acceptable limits

Keywords: Anode baking furnace, CFD model, Thermal mapping, Performance analysis, Anode quality.

1. Introduction

Hindalco's Renukoot smelter operates with low amperage potlines which uses prebaked carbon blocks as anodes. Daily requirement of these anodes is fulfilled by one paste plant, three anode baking furnaces and one anode rodding shop. Having a good quality anode is important to ensure efficient and smooth operation in smelters. Properly compacted and baked anodes exhibit maximum service life, low anode voltage drop and ability to work at higher current densities. In past one-year, increased carbon dust and incidents of vertical anode cracking was reported by pot-room operation team. Anode quality data trends for this period show consistently high values of electrical resistivity (ER) and less than desired crystalline length (Lc).

Detailed studies have been performed to identify causes behind carbon dusting and anode cracking [2]. Poor anode baking, high Sodium and Vanadium content and insufficient anode covering are known as the most dominant causes behind carbon dusting due to wear of carbon anodes [1,2]. Vertical anode cracking mainly results due to: (i) excessive internal stress generated due to high differential gradient between thermal expansion coefficient between yoke and carbon block, (ii) High heating rate during baking [2]. High heating rate during baking can be correlated with placement of anodes near the flue wall or bulged structure of flue-wall. High ER of carbon anodes can be attributed to poor Calcined Petroleum (CP) coke quality, under or over-pitching, improper compaction, and poor graphitization of green anodes during baking. Baking temperature and soaking time of anodes play critical role in graphitization and hence, in deciding final Lc of baked anodes [3].

In current study, chemical composition and physical properties of raw material coke were critically examined and found in desired range. Historical trends for significant green anode process parameters like granulometry of raw coke, mixing temperature, vibration time, vacuum, die pressure and green anode density were also found in desired limits. However, based on poor Lc trend, baking process was identified as the most dominating cause. To analyse the performance of anode baking furnace (ABF) in detail, a computational model was developed in the present study. ABF under study is a horizontal ring open top furnace. It is comprised of 2 fires. Each fire is divided into 13 sections. Green anodes are loaded in loading section. Loading section is followed by preheating 1, preheating 2 and preheating 3 sections. Preheating sections are followed by 3 heating or burner bridge sections. Heating sections are followed by 5 cooling sections. Last section is used for unpacking of anodes. Each section consists of 9 pits and 10 flue walls. Each pit is loaded with 77 anodes, 11 layers and 7 columns. Schematic of the furnace can be seen in Figure 1.

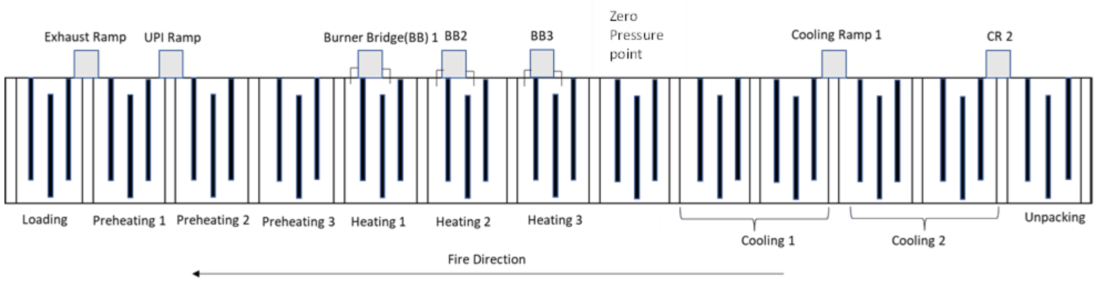

Figure 1. Process flow diagram of anode baking furnace under study.

Description of functional and physical features of these 14 sections are tabulated in Table 1.

Table 1. Summary of ABF operation.

Section	Flue inlet temperature	Flue exit temperature	Anode inlet temperature	Anode final temperature	Equipment	Physical Phenomena
Loading			50	90		Sensible heating of anodes, flue wall bricks and packing coke
Preheat 1	700	400	90	280	Exhaust Ramp	
Preheat 2	900	700	280	480	UPI (Under pressure instrument) Ramp	Pitch Volatile release from anodes and volatile combustion in flue gas, sensible heating of solids
Preheat 3	950	900	480	720		

Impact of variation in baking temperature and soaking time (time above 1000 °C) seen by anodes located at various heights in pit was reflected in final properties of anode samples. Variation in RD across the layers in pit is observed. Maximum RD was obtained in layer 4 and minimum RD was obtained in top layer. Indicates strong positive correlation with maximum baking temperature attained during fire. Lc for anodes in all layers remained in lower than usual range due to subpar baking parameters observed during fire. Maximum Lc value (29.8) was achieved in 3rd and 4th layer where greatest value of maximum baking temperature was reached. Desulphurization in carbon anodes increases with increase in baking temperature. Desulphurization leads to increase in air permeability and surface area within the anode [10]. This creates additional sites for Carbon-CO_2 reaction during electrolysis in pots. Hence, minimum Carboxy reaction residue (CRR) observed in anode placed in 4th layer can be correlated to the maximum baking temperature observed during fire. ER of prebaked carbon anodes is reported as a function of coke granulometry, sulfur content of coke, pitch content in green mix and baking parameters [11]. However, in current study strong correlation was observed between ER and baking parameters. Minimum ER value (58.8) was achieved in 4th layer where greatest value of maximum baking temperature (1073 °C) was reached. This can be attributed to high RD and Lc obtained for these anodes. Air reactivity residue (ARR) of carbon anodes is a function of differential reactivity of coke-binder matrix and content of inorganic catalysts such as Sodium and Vanadium [10,11]. In present case, ARR was found to be in range of 49 % to 69 % which is relatively low as compared to industry standard of 72-80 %. Low ARR is indicative of subpar baking, high standard deviation observed in ARR of anode samples points towards non-homogeneous temperature distribution inside the pit.

5. Conclusion

- To identify reasons behind high ER, low ARR and cracking of anodes in pot, detailed study of plant process was performed, and baking was identified as the most influential cause.
- To analyse the performance of anode baking process, a computational model was developed. Measurement campaign was carried out to study thermal evolution of anodes at various heights of pits during a baking cycle.
- Computational results were validated against the measured data. Accuracy of predicted results was found to be in range of 93 % to 98 %. Which is acceptable for industrial furnaces.
- Computed as well as measured anode temperature data show non-homogeneity in baking across height and length of the pit. This non-homogeneity strongly impacts anode quality parameters like ER and Lc. Anodes in middle layer see maximum temperature and spends most amount of time above 1000 °C. Whereas anodes in top layer and bottom layer were not able to reach the desired baking temperature. As a result, quality of anodes was found to be degrading in order: middle layer, bottom layer, and top layer. Based on these findings, authors have initiated a study to improve overall baking efficiency and temperature homogeneity inside furnace. Process parameters and flue wall design is being optimized through CFD analysis, onsite experiments, and trials. Details of this study will be communicated through another paper.

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