Optimizing Baking Furnace Performance and Anode Quality at Hindalco Renukoot Smelter

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Abstract

The production of aluminium from alumina through the Hall-Héroult process requires carbon anodes as a key input. These anodes are primarily composed of calcined petroleum coke and coal tar pitch, along with reusable anode butts. Anode production involves three critical stages: green anode manufacturing, anode baking, and anode rodding. Among these, the anode baking process is crucial, as it significantly impacts anode quality through the baking level and heating rate, potentially resulting in physical defects such as cracks or air burn. These factors directly affect the anode performance in electrolysis cells. Ensuring precise control and efficient operation of the baking process is of utmost importance, as any deviations can compromise both safety and anode quality in the pot room. This paper discusses the various challenges encountered in the anode baking furnace at the Renukoot Smelter Plant (a unit of Hindalco Industries Ltd.). It explores technical challenges related to process, operations, and maintenance, along with in-house solutions implemented to sustain and enhance furnace performance, productivity, and environmental compliance. Additionally, the paper highlights the impact of furnace refractory conditions on the operation of the fume treatment plant (FTP) and their influence on anode baking quality.

Keywords: Carbon Anode, Aluminium Smelter, Anode Baking, Process Parameters, Anode Quality.

1. Introduction to Hindalco Renukoot Smelter

Hindalco, Renukoot, is one of Asia's largest integrated primary aluminium producers, with operations that span the entire process from bauxite mining and alumina refining to aluminium smelting and downstream activities such as rolling, wire rod production, and extrusions. The Hindalco Renukoot Aluminium Smelter Plant, commissioned in 1962, is one of India's oldest and most significant aluminium smelting units. It represents a pivotal milestone in India's industrial development and established Hindalco Industries Limited (HIL) as a leader in the aluminium sector. As an integral part of the Aditya Birla Group, the Renukoot smelter exemplifies operational excellence, integrated manufacturing, and long-term sustainability.

The smelter operates as a closed-loop aluminium production facility, strategically integrated with the Renukoot Alumina Refinery and supported by the Renusagar captive power plant. These integrations ensure seamless coordination and operational efficiency. The adjacent refinery supplies the essential raw material, alumina, while the Renusagar power plant provides uninterrupted and cost-effective power, offering a significant competitive advantage in this energy-intensive industry. The smelter utilizes the Hall-Héroult electrolysis process to convert alumina into primary aluminium, leveraging technology originally provided by Kaiser Aluminium Corporation Ltd of the USA.

Over the years, the facility has undergone multiple phases of technological upgrades and modernization to enhance operating performance and productivity. The smelter plant comprises 11 potlines with 2 138 operating pots. The potlines are supported by a carbon plant to ensure a continuous supply of anodes and rectifier units for reliable power supply.

2. Introduction to Anode Baking Furnace

The carbon plant ensures the production of the pre-baked anodes required for the smelter. The carbon plant at Renukoot comprises of 3 production units i.e. Green Anode Plant (GAP), Anode Baking Furnace (ABF) and Anode Rodding Shop (ARS). In GAP the initial anodes, termed as green anode is being produced using calcined petroleum coke and coal tar pitch as primary raw material along with the spent anodes recycled material (butts) received from pot room. In the next step, this green anode is subjected to a controlled heat treatment process termed as anode baking at Baking Furnace. During Anode baking step, the thermal, electrical and chemical properties of anode get enhanced to sustain the operating parameters of electrolysis process at pot room. After baking process, the baked anodes are subjected to rodding process where the carbon anode is fixed with an electrically conductive metallic hanger i.e. rod for the current carrying as well safe handling of anode block.

To meet the anode requirement of smelter plant, carbon plant has gradually upgraded its production capacity to 2 260 anodes per day.

For the baking of green anodes, Renukoot smelter has installed 6 ABFs over the time to produce prebaked anodes for potlines. At present HIL Renukoot is running with 3 baking furnaces ABF 4, 5 and 6. ABF 5 and 6 are based on Riedhammer technology while ABF 4 is based on old technology. The Furnace wise capacity is mentioned in below Table 1.

Table 1. Furnace wise technical data sheet.

Furnace	ABF #4	ABF #5	ABF #6
Technology	Kaizer	Riedhammer	Riedhammer
Start of Production	1997	Installed in 2003 and refurbished in 2018	2014
Number of Sections	32	32	34
Number of Pits	7	7	9
Number of Anodes per pit	45	66	77
Number of Fire Groups	2	2	2
Fire Cycle Time (hours)	40	28	28
Production Capacity (anodes/day)	380	792	1 188

There are several challenges with respect to the operating parameters, baking performance and baked anode quality.

3. Challenges Faced

3.1 Challenge 1: High Risk of Fire Incident due to Incomplete Combustion and Deposition of Unburnt Pitch Volatiles Inside Duct of FTP and Exhaust Ramp

The open top anode baking furnace of Renukoot comprises two parallel rows called casings made up of concrete. This concrete casing is insulated from inside and divided into a series of interconnected flue walls made by high alumina refractory materials. The purpose of flue wall is to provide passage for fuel (low sulphur heavy stock oil) as well as conveying the flue gas generated during anode baking. The green anodes are loaded in the pits surrounded by packing coke. The baking process is carried out with the help of firing system which comprises a set of equipment known as exhaust ramp, heating/burner ramp, blowing ramp, cooling ramp. The flue gas is transferred to fume treatment center for further treatment process to ensure environment-friendly production process.

During anode baking process green anodes undergo controlled heating and cooling stages to yield the desired anode quality. The pitch volatiles in the green anode burns off and the pitch cokefies to pitch coke to produce the baked anodes. Figure 1 schematically illustrates the process flow.

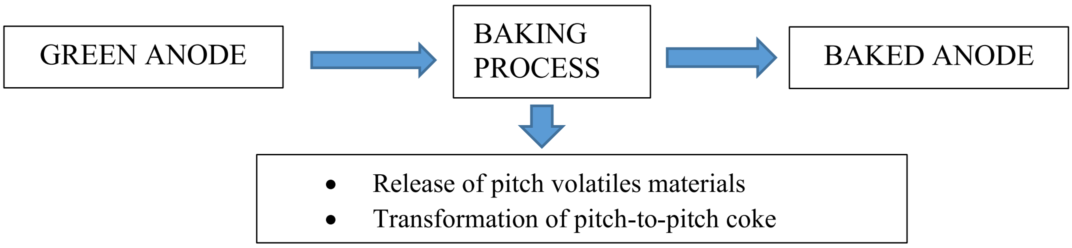


Figure 1. Schematic process of anode baking.

At Renukoot ABFs, the burning and release of pitch volatiles was inefficient. Consequently, the heat generated from the pitch volatiles was not being utilized effectively, resulting in high fuel consumption. Additionally, the incomplete combustion of pitch volatiles was leading to the deposition of unburnt particles along the exhaust ramp duct, ring main gas collector duct, and the internal surface of the conditioning tower (Figure 2). Given that this unburnt volatile material is highly flammable, there is a significant risk of fire incidents within the ABF and fume treatment plant (FTP).

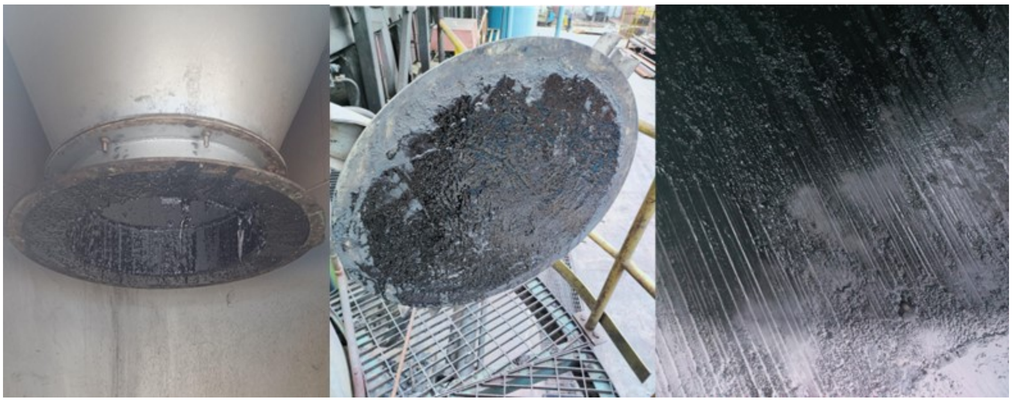


Figure 2. Unburnt pitch volatiles inside the duct of FTP and conditioning tower.

3.2 Challenge 2: High Specific Energy Consumption During Baking of Anode

The ABFs are operated with liquid fuel low sulphur heavy stock oil. Due to deteriorated furnace refractory condition and incomplete combustion of pitch volatiles, the oil consumption was higher in the ABFs compared to the designed limits of 2.4 GJ/t baked anodes (BA) as shown in Table 2.

Table 2. Specific energy consumption per tonnes of baked anodes.

Time Period	Specific Energy Consumption (GJ/t BA)
2022-23	2.58
2023-24	2.56

3.3 Challenge 3: Baked Anode Quality Not as Per Target

Due to various operational challenges as well as overall condition of furnace refractory, the key process parameters could not be maintained. As a result, the quality of the baked anodes was not as per the target. The key quality properties of baked anodes over the last few years are shown in Table 3.

Table 3. Baked anode quality properties over the last 3 years.

Time Period	Geometric Density, g/cm^3	Electrical Resistivity, µΩ·m	Crystallite Size (Lc), Å	Air Reactivity Residue, wt%	CO_2 Reactivity Residue, Wt%
Target	1.580	< 58	> 32.5	> 70	> 90
2022-23	1.565	59.2	30.6	64.3	89.1
2023-24	1.556	59.8	30.8	61.4	88.8

The quality of baked anode plays important role in deciding the performance of anodes in pot. Due to this sub-par anode quality, the performance of anodes in pot electrolysis process was not satisfactory, The Net Carbon Consumption was gone up to 435 kg/t of produced aluminium.

4. Analysis of the Problem and Findings

4.1 Finding 1

To find out the reason of incomplete pitch volatile combustion, a detailed analysis of gas pressure, oxygen content in the flue gas, negative draught at different locations were checked. It was found that the root cause of this incomplete combustion is the low draught at the exhaust ramp. It can be summarized as shown below in Figure 3.

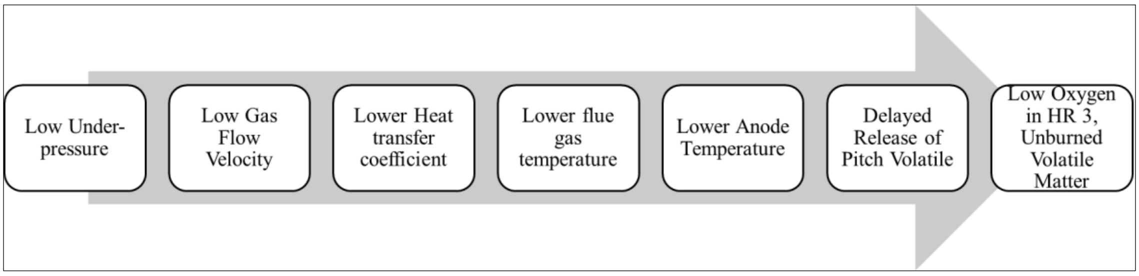


Figure 3. Root-cause analysis for incomplete combustion of pitch volatiles during baking.

4.2 Finding 2

As the negative draught (under pressure) was not as high as recommended (actual operating range was 900–1000 kPa), the flue gas temperature at exhaust manifold was much less than targeted, i.e. 230–240 °C. This low exhaust manifold temperature is further validated by the low temperature at the pressure ramp which was in the range of 580–650 °C. This lower temperature indicates the incomplete combustion of pitch volatiles during the preheating stage. That means the utilization of the heat energy (theoretically up to 45 %) from the pitch volatiles was not happening in the ABFs of Renukoot. Hence, to compensate this heat loss, additional fuel was used during baking which led to higher specific energy consumption. Besides, there was higher oxygen content in the flue gas in the preheating zone compared to the requirement oxygen level (Figure 4), which related to the leakages in the furnace refractory lining and at various expansion joints locations. The oxygen content data as per Figure 5 clearly shows air ingress in the furnace. As a result, the oxygen concentration increased from preheating section 3 (PH3) to preheating section 2 (PH2). In an ideal case the oxygen concentration should decrease from PH3 to PH2 due to its consumption during pitch volatile combustion in PH2.

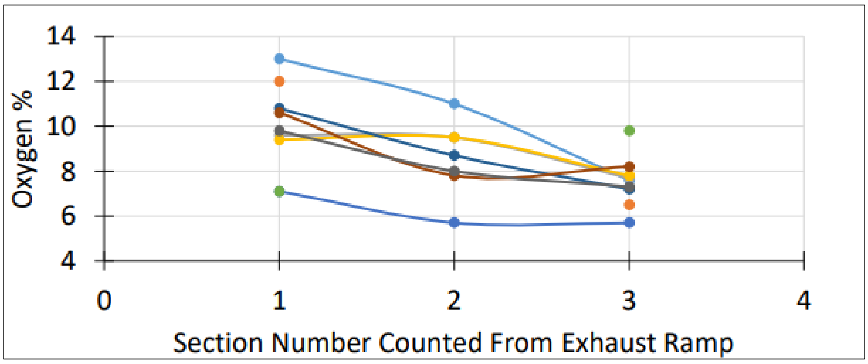


Figure 4. Oxygen content in flue gas in preheating zone.

4.3 Finding 3

The baking furnace refractory lining and healthiness of refractory lining governs the performance of baking furnace in terms of thermal balancing. At Renukoot ABF, the condition of ABF refractory lining was not in good shape. Several leakages sources were present in Furnace. Expansion joints were found deformed and not maintained as per its original standard. This poses a serious threat of air ingress to the furnace and further deterioration of process parameters as well as anode quality. Some of the abnormalities of baking furnace can be visible as below (Figure 5).

In proper Sealing of Head wall-Flue wall expansion joint

Air ingress from Fluewall-concrete casing expansion joint

Severe Misalignment of top blocks of flue walls

Figure 5. Various sources of cold air ingress/leakage in baking furnace.

4.4 Finding 4

As per the original design of the baking furnace, it was recommended to operate the firing system with liquid fuel in co-current mode i.e. fuel injection in the direction of the flue gas movement. Due to this co-current fuel injection, it was observed that the deposition of fuel at the bottom of the flue wall and over- heating at the bottom zone of the flue cavity (Figure 6). The image shows presence of cold spot at the top region and fuel deposition at the bottom of flue cavity.

Figure 6. Flue cavity showing deposition of fuel at the bottom.

4.5 Finding 5

Due to the above findings, the result is reflected in terms of lower anode baking temperature. The final anode temperature was achieved in the range of 1 080–1 090 °C with a population of 30–35 % baked at maximum temperatures less than 1 080 °C. This low final anode temperature has direct impact on the baked anode quality in terms of baking level and electrical resistivity [7]. So, these two important anode quality parameters were not as per the target.

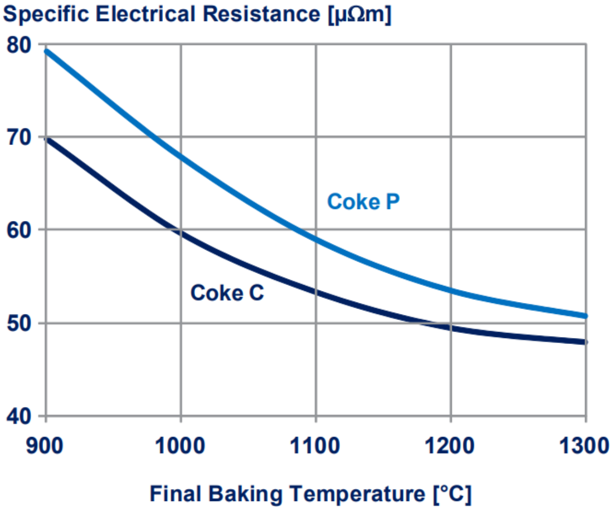


Figure 7. Relationship between final baking temperature with anode electrical resistivity. Coke P: porous coke, Coke C: dense coke [8].

5. Experimentation and Final Implementation

Based on the findings related to the key challenges, it was decided to conduct several in-house corrective trials to evaluate the actual benefits (Table 4).

Table 4. List of experimental initiatives against the critical finings.

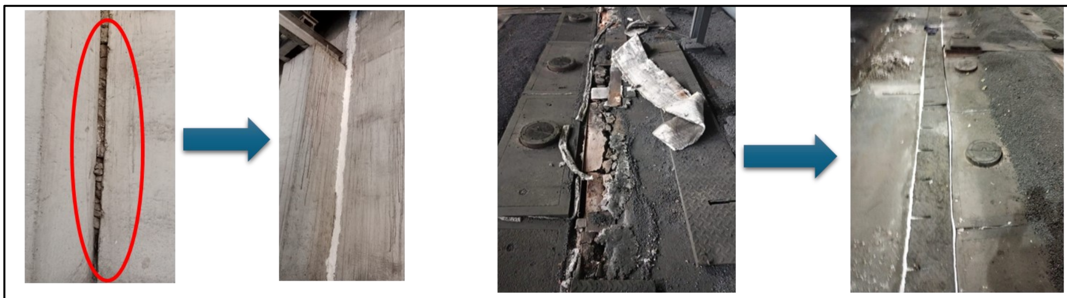
Findings	Operational practices	Design Modification
Low draught	Improvement in refractory maintenance practices	Modification of the FTP bag quality with higher permeability
	Elimination of leakage sources	Monitoring gas flow at furnace outlet to correlate with section condition.
Air ingress	Adequate sealing of headwall- flue wall joint, top block expansion joint and flue wall-corbel joint	Modification of sealing damper
	Proper positioning of ER legs and sealing	
	Air ingress through various flanges in flue gas duct arrested	
	Improvement of bag house manhole/inspection port cover tightness	
Co-current firing		Modification to counter current firing with necessary modification in crossover sections
Low anode temperature	Correct positioning of Anode thermocouples	
	Calibration & Replacement of faulty anode/FW thermocouples	
	Baking curve optimization	
	Preheating rate monitoring periodically	

6. Initiatives Through Operational-Maintenance Practices

To improve and strengthen the existing refractory maintenance practices, few initiatives were implemented as follows:

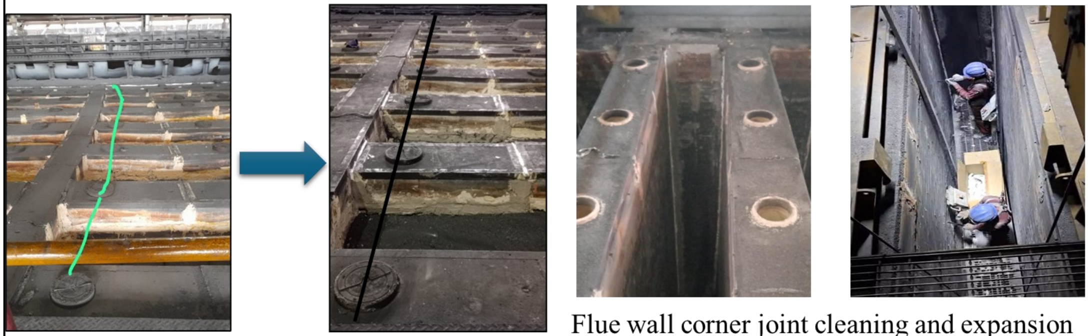
1. Mandatory cleaning of packing coke from the expansion joint at flue wall-head wall corner.
2. Inspection & maintaining the degassing gap in the recommended range of 2–6 mm.
3. Cleaning of packing coke from the bottom corner opening of flue wall & pit slab.
4. Gap sealing between end flue wall and concrete wall of ABF casing after each fire movement.
5. Expansion joints sealing in concrete casing wall with ceramic fibre and high temperature mastic glue.
6. Aligning the flue wall and head wall top blocks to eliminate the air ingress and difficulty in the ramp positioning.

The changes in operation and maintenance practices are illustrated in Figure 8.



Sealing of Concrete Casing Expansion Joints

Sealing of expansion joints between end flue wall and concrete casing wall



Alignment of Flue wall top block

Flue wall corner joint cleaning and expansion joint sealing, Degassing gap cleaning

Figure 8. Changes in operation-maintenance practices.

In addition to the operational-maintenance practice upgradation, some design modifications have been implemented in the ABF with the inhouse research and development team:

1. The fuel injection pattern has been converted from co-current to counter current pattern (Figure 9). As the original furnace design was meant for counter-current firing, to accommodate the positioning of burners, necessary modifications have been carried out in the end flue walls. End flue walls were made with larger peepholes with covers compared to the original one to hold the flue wall thermocouples.

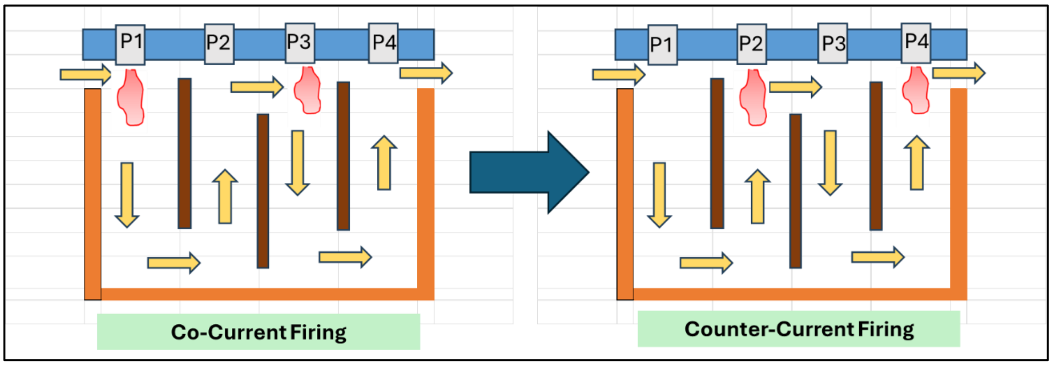


Figure 9. Conversion of Co current firing to counter current firing.

2. Upgradation of the FTP bag filter specification in terms of gas permeability. Use of higher gas permeability filters helped in reducing the pressure drop across the bag filter considering the HF & PM emission norms.

All these modifications took 4 to 6 months to see positive impact on performance.

7. Achieved Results

After finalizing the inhouse modifications in operation practice, refractory maintenance practices and design modifications, the operators and technicians were made acquainted with the upgraded practices. After a sustenance period of 3 months, positive results stared visible improvements in terms of negative draught at the exhaust ramp (Figure 10), exhaust ramp temperature (Figure 11), pitch burning profile, final anode temperature (Figure 13), population of lower baking temperature (Figure 12), specific energy consumption (Figure 14) as well as quality of baked anodes (Figures 15 to 17).

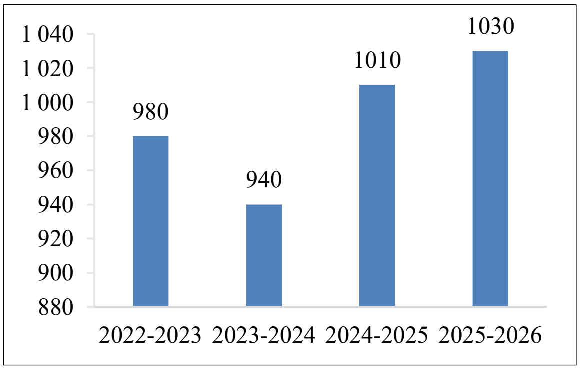


Figure 10. Average Negative Draught at the Exhaust Ramp.

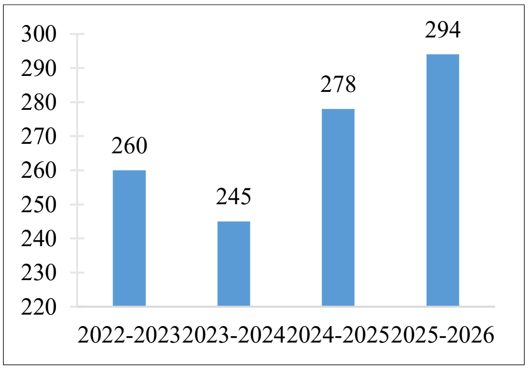


Figure 11. Average Exhaust Gas Temperature at End of the Fire (°C).

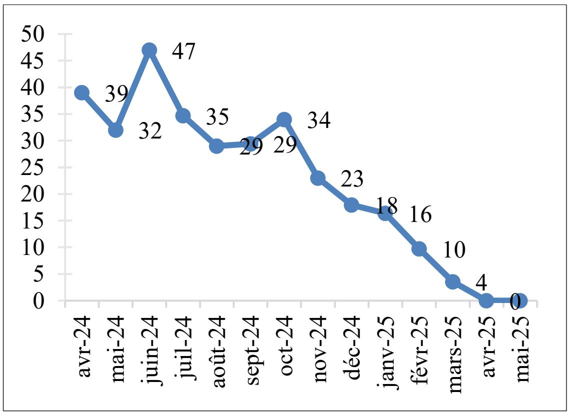


Figure 12. Population Anodes Baked at Final Temperatures < 1 080 °C.

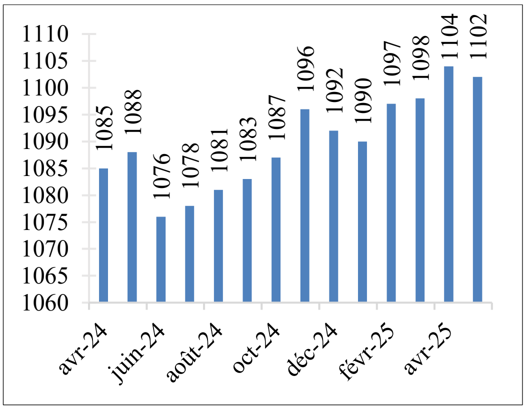


Figure 13: Average Final Anode Temperature (°C).

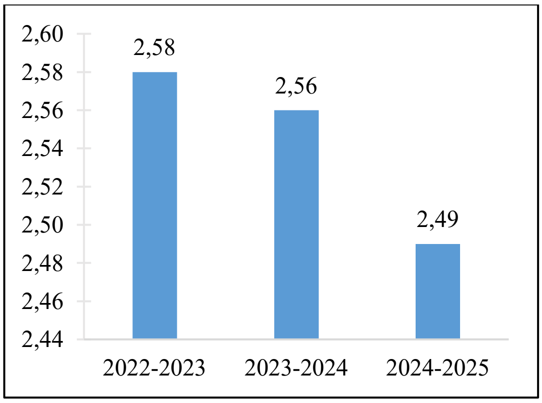


Figure 14. Specific Energy Consumption (GJ/t) of baked anode.

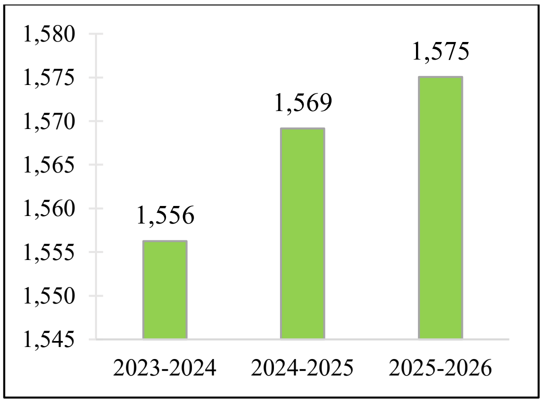


Figure 15. Baked Anode Geometric Density (g/cm^3).

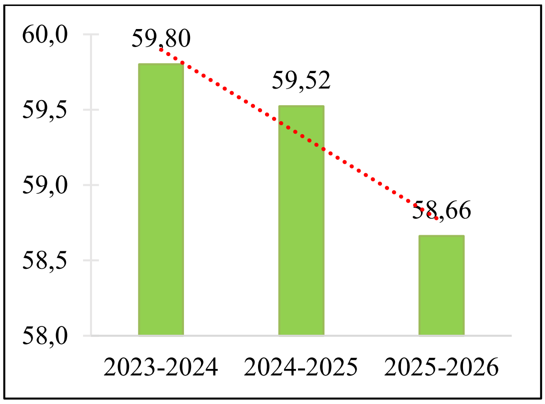


Fig 16: Electrical Resistivity (µΩ·m).

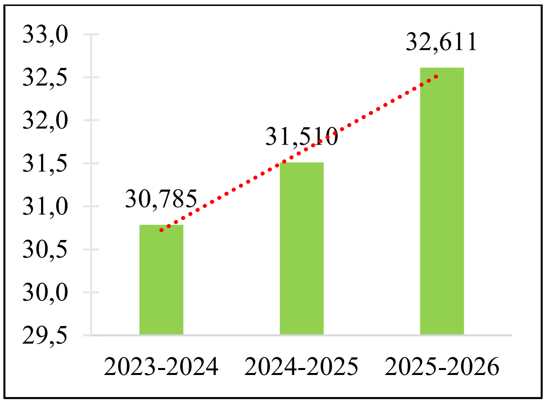


Fig 17: Anode Crystallite Size Lc (Å).

8. Conclusion

The journey of process and operation optimization in the ABFs of Hindalco Renukoot Smelter has enabled further sustainable performance of anodes in the potrooms. This paper explains this entire journey of enhanced ABF refractory maintenance practice, achievement of improved operational parameters and superior baked anode quality through a structured knowledge base development, detailed examination of the existing processes, data analysis and process modifications. After getting the positive results from the process optimizations, the SOPs were revised and ensured the proper adherence by the team members. The success of this initiative underscores the value of leveraging internal capabilities, fostering a culture of ownership, and aligning process improvements with strategic business objectives. Moving forward, the established framework offers a scalable and repeatable model for further optimization and quality excellence across other operational areas.

9. Acknowledgement

Special thanks to the whole Anode Baking Furnace Operation & maintenance Team who shown their dedication and successfully implemented the innovative process optimization measures and operational practice upgradation to improve anode quality.

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