Challenges of Prolonging Life of Aged Anode Baking Furnace-1 at Aluminum Bahrain (ALBA)

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Abstract

Anode baking process is the most critical step in anode production. It has strong influence on anode quality in terms of baking level, heating-up rate, physical defects such as cracks or air burn and affects performance of anodes in electrolysis cells. Therefore, it is utmost priority to have good baking process control and operation. In addition, the anode baking furnace capacity is usually the bottleneck of increasing anode production without compromising anode quality. To increase bake anode production, anode baking furnace is to be operate at faster fire cycle compared to design value which required process optimization and no tolerance on process deviations. This paper shares the experiences of sustaining, improving the condition and performance of Anode Baking Furnace #1 (ABF#1) at Aluminum Bahrain (ALBA). ABF#1 is the oldest furnace in ALBA, having 51-year-old concrete casing and 26-year-old headwall/insulation. Due to thermal and mechanical stresses during the baking process and high age of ABF#1, the integrity of the concrete casing is affected, resulting in high headwall deformations which pose many challenges in operation, process and flue wall maintenance. The technical challenges encounters in process, operation, maintenance and innovative solutions implemented to sustain and improve the furnace condition, productivity and environment is further discussed. The paper also outlines the impact of flue wall condition on the fume treatment plant (FTP) operation and anode baking process and quality.

Keywords: Anode baking furnace, Corbel, Concrete casing, Headwall, insulation, Anode quality.

1. Introduction

Aluminum Bahrain (ALBA) is the world's largest single-site aluminum smelter ex-China with an aluminum production of more than 1.56 million t/year (2021) is known for its technological strength and innovative strategies. ALBA is always striving to maximize the productivity and reduce consumption of resources to continuously reduce impact on environment, improve safety and overall business. Hand in hand with continuous increase in metal production in the potline, the carbon plant has also been increasing the production and improving bake anode quality. ALBA has got four paste plants, five baking furnaces and four rodding plants to cater the anode requirement in terms of quality and quantity to Potline 1-6.

Several papers have been published on anode quality and what defines good performance in the potline. The anode quality is defined by low variation, low CO_2 and air reactivity, low air permeability, low electrical resistivity, low metallic impurity levels and high density [1][2]. Anode baking is one of the critical steps of anode production, which has significant influence to achieve better and consistent anode quality (such as density/reactivity).

The anode baking furnace (ABF) is where the anodes are heat-treated to calcine the pitch binder and to develop the desired anode quality for use in the potlines. ABF is made up of high quality refractory materials. It consists of a series of parallel flue walls in which the gas is injected to get desired temperature. The space between flue walls is called pits, where the anodes are placed during heat treatment. A group of adjacent pits is called section. Each section is separated from the next by a headwall.

Anode baking furnace #1 (ABF#1) is the oldest anode baking furnace among all five baking furnaces at ALBA. It supplies baked anodes to Potline 1-3 and has a production capacity of 92500 t/year. It was originally a closed-type furnace, built in 1971. It was converted to an open-type furnace in 1996. It consists of 50 sections, with 5 pits and 6 refractory flue walls in each section. Headwall expansion gaps are located in the middle of the pit. It has three fire groups equipped with Innovatherm firing control system. Each fire group consists of eight numbers of ramps including three numbers of burner ramps, one fume measuring ramp, one zero pressure measurement ramp, one exhaust ramp, one blowing ramp and one cooling ramp.

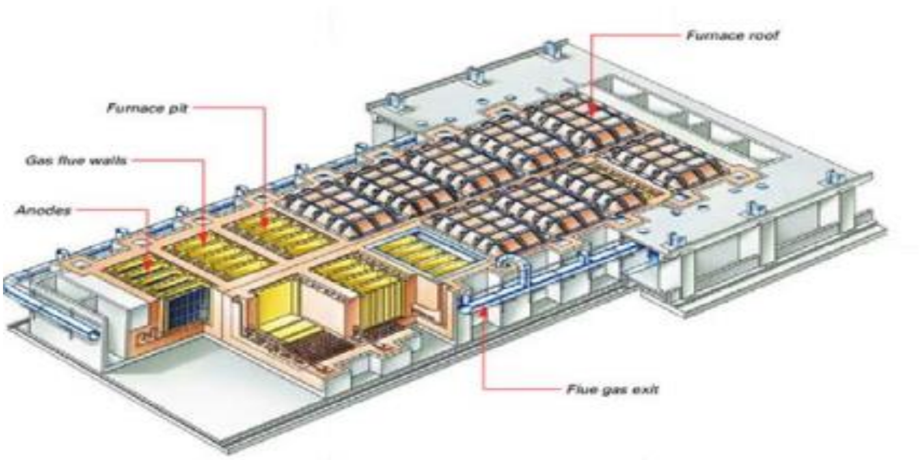

Figure 1. Original closed type technology of ABF#1.

While ABF#1 was converted from a closed-type (Figure 1), to an open-type ring main furnace, the original concrete casing/tub was repaired and modified to a single central ventilated wall configuration. Sixteen more sections were added to the existing furnace by extending on both ends of the furnace (north and south end side).

Anode baking is the most expensive process step in anode production. Fuel and refractory maintenance represent approximately 15 % of total anode manufacturing cost The condition of ABF plays a key role in maintaining good baking process and low anode rejection (< 0.5 %). A good ABF ensures tar/soot free baking process by sustaining the required draft and a uniform temperature distribution inside the flue wall (± 50 °C). The quality of Anodes used in the potline depends strongly on baking process. It is require to achieve uniform temperature inside the anode during heating process. The flue walls in ABF deform over a time under cyclic heating and cooling process, leading to difficulties in loading and unloading of anodes, and inconsistent of anode heat treatment. It is important to regularly measure the deformation to assess the rate of deterioration and prediction of flue wall life. The aging of ABF, and the deformation of flue walls and headwalls results in non-homogeneous heat treatment of anodes and consequently to a deterioration of anode quality [3][4].

Refractory linings of ABF suffer severe corrosion during operation. The service life is therefore in relation to the construction of the flue channels and walls, operation procedures of the loading and unloading of anodes, firing conditions, quality of anode raw materials, and packing coke and recycled spent anode. During furnace operation, the released vapor phase from anodes and fuel react with the refractory material. Reaction products mainly are carbon-, sulphur-, alkaline and fluorine compounds. Due to thermal expansion of the wall, anode and packing coke, tie bricks and flue wall bricks are exposed to thermo-mechanical stresses. Also the blocking of expansion joints due to filling with carbon packing leads to enhanced stresses within the lining. These often results in crack formation or pinching of Flue walls [5][6].

At ALBA, the health of ABF is being regularly assessed through physical monitoring such as blocked flue wall, cracks & deformations of flue wall (S-Shape of flue wall, O-shape of flue wall, and C-shape flue wall), deformations of headwall (twisting, horizontal/vertical deflection) and condition of the concrete casing. Based on process data and physical observation, flue wall condition is being classified into five categories such as very good, good, bad, very bad and dead flue wall. Very bad flue walls are maintained less than 15 % of the total flue walls in the ABF at any time by prompt flue wall replacement plan to ensure good baking process.

Over the years, the ABF#1 condition has deteriorated significantly. Rio Tinto Alcan (RTA) conducted an audit on ABF#1 to evaluate refractory and civil work during 2019 [7]. The audit report highlighted significant deterioration in the corbel and concrete tub. These areas were the major sources of air inlet (Fig.2 & 3).

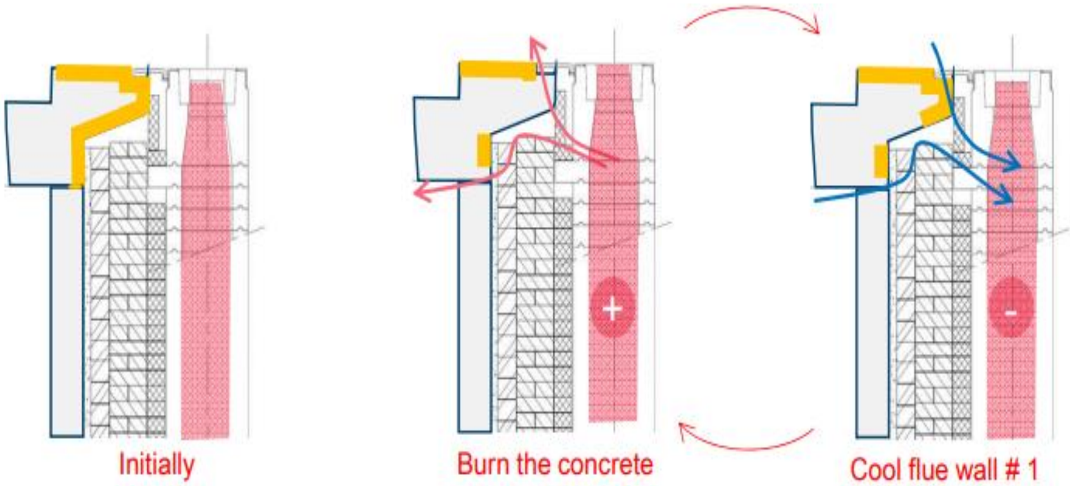

Figure 2. Air inlet to flue wall from deteriorated corbel [7].

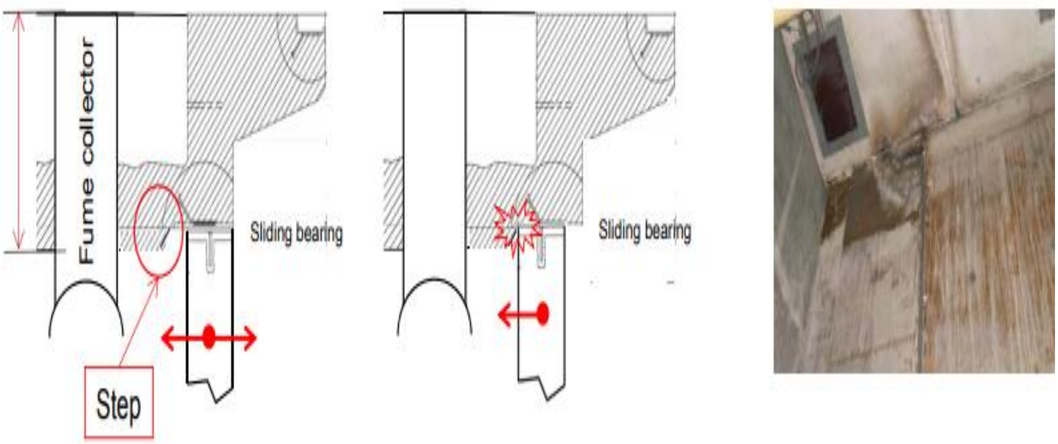

Figure 3. Damaged concrete casing in ABF#1 [7].

This has posed challenges in terms of baking process, refractory maintenance, and anode quality. The ALBA team was able to overcome these challenges through identifying & prioritizing the issues, improving refractory maintenance and, fine tuning the process. This has postponed the need for furnace revamping. This paper will be sharing the ALBA experience on:

- Challenges encountered during refractory maintenance due to deteriorated ABF# 1 conditions and implemented solutions.
- Process adaptations made to eliminate soot and tar generation during baking
- General impact on the baking process and anode quality

2. Challenges in ABF # 1

2.1 Excessive Headwall Deformation

Due to thermal and mechanical stresses, headwalls have deformed vertically as well as horizontally during last 26 years of operation. This deformation with time is typical to any anode baking furnace. Increasing anode size over the years has accelerated the deterioration. The survey for headwall deflection measurements carried out for all the 50 headwalls during years 2015, 2019 and 2020 are summarized in Figure 4. In 2020, 60 % of the headwalls were having deflection in the range of 300 to 350 mm which is significantly high. Section numbers 1, 25, 26 and 50 are the cross over sections having low or no deflection. These sections are placed at the furnace end i.e., cross over sections where fumes are entering. The deflection for 40 % of the headwalls were still increasing compared to survey done in year 2019.

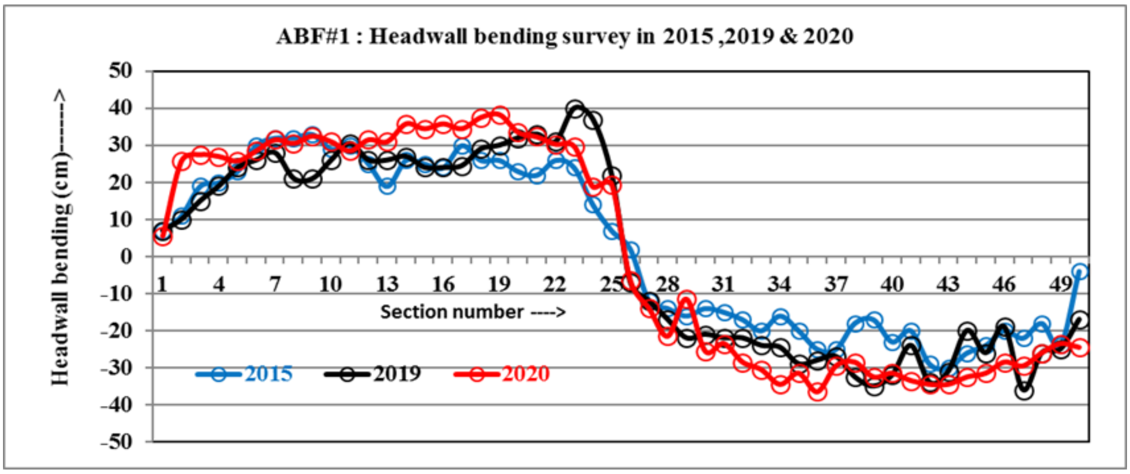

Figure 4. ABF # 1 section wise headwall deformation.

During the year 2021, a survey was carried out to evaluate the verticality of headwalls. Sections were selected randomly to assess the deformation. The magnitude of deflection was found to be varying from 20 mm to 150 mm across the headwall height is summarized in Figure 5.

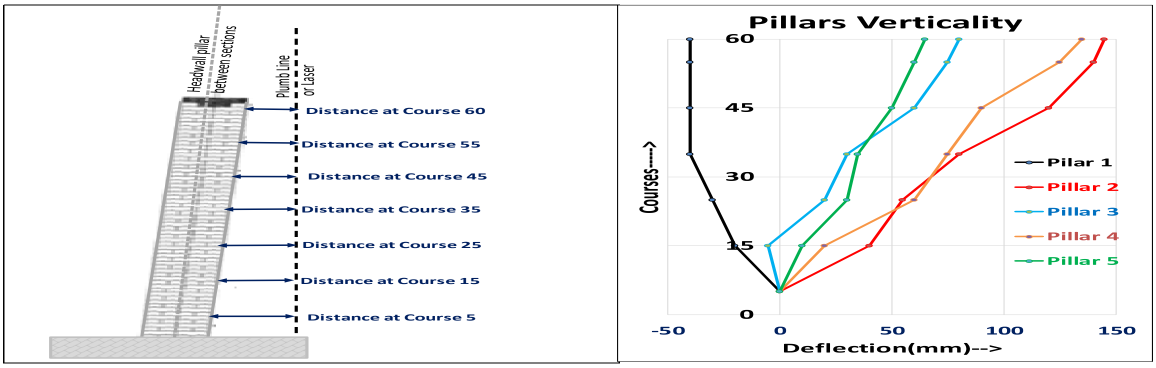

Figure 5. Vertical headwall deformation in ABF#1.

It means the pit length is varying along the height. These deflections (horizontal and vertical) were observed opposite to the fire direction i.e., opposite of the fume flow.

Due to headwall deformation, pit dimensions were impacted.

- Pit length for Section 25 and 50 (cross over entry, where the fumes are entering the baking furnace) were found to be 170 mm to 200 mm more than the original design. Therefore, it was a challenge to place the flue wall on these sections, as they were out of the headwall groove.
- Pit length for Section 1 and 26 (cross over exit, where the fumes are exiting the baking furnace) were found to be 100 mm less than the design. It is a challenge to place the flue wall on these sections, as the flue wall was touching the headwall groove with no expansion gap.
- For sections 2 to 24 and 27 to 49 (straight line sections, where the fumes are moving in a straight line), the pit length is lower than the original design value by approx. 50 mm specifically on pits 2, 3 and 4 and also varying along the headwall height. The refractory team was facing challenges while installing a new flue wall at design length due to the deviations from the original design.

Figure 6 is showing the typical headwall movement and the horizontal deflection of headwall. At the majority of the sections, there is no space between the flue wall and the headwall, while at the other side it is necessary to install two to three wedges as shown below in picture.

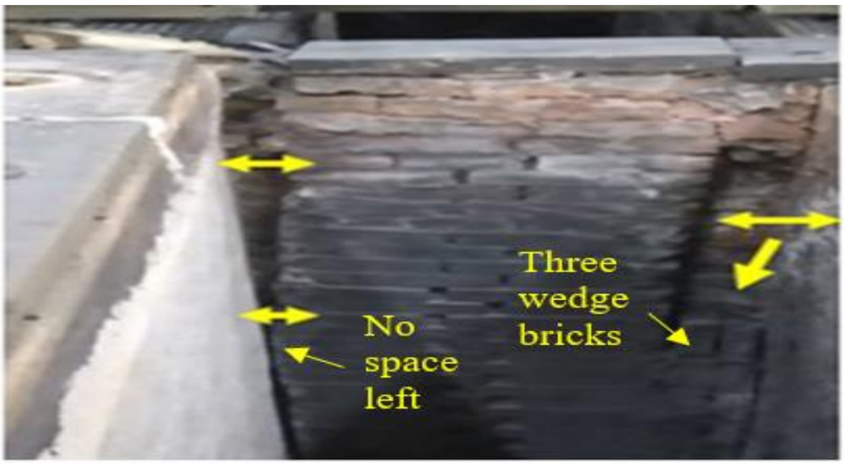

Figure 6. Showing headwall deformation in ABF # 1.

Due to significant deformation of the headwall, the following challenges arose:

- Problems in installing new flue wall due to variation in pit length from section to section.
- 60 % of the flue walls do not have space to keep wedge bricks at one side while the other side requires two to three wedge bricks (deviations from the original design).
- The headwall window is not aligned with the flue wall window in 80 % of the cases.
- 90 % of the sections had variations in flue wall expansion gap from top to bottom, even some part of the flue wall touching the headwall i.e., no expansion gap.
- Around 30 % of the flue wall came out of the headwall groove, which required to fix wedge bricks horizontally to hold the flue wall.

The conditions in the baking furnace has significantly reduced the flue wall life as shown in Figure 7, and the headwall conditions have deteriorated faster along the generations of the flue wall. Flue wall life has reduced from 145 fire cycle for the first generation to 72 fire cycle for the fifth generation.

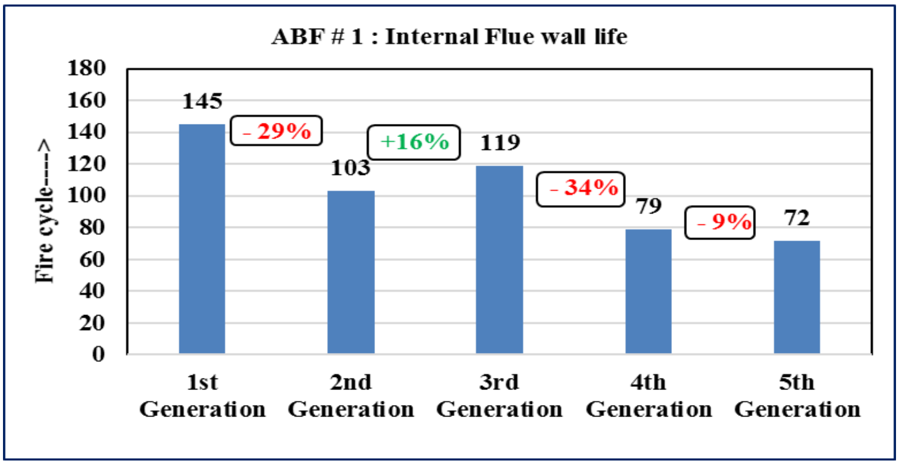

Figure 7. Generation wise flue wall lifetime in ABF # 1.

2.2 Flue Wall Condition

At ALBA common practice is to classify flue wall condition into five categories: very good, good, bad, very bad and dead flue wall. It is based on physical inspection, deviation in process (e.g. temperature and draft) and difficulty in anode charging.

1. Very good flue wall: No cracks and no deformation.
2. Good flue wall: Onset of cracks and deformation is observed.
3. Bad flue wall: Cracks > 1 m, start of pinching, one of the physical deformations exist (S shape flue wall, O-Shape flue wall or C-Shape flue wall) and less than 50 % of the tie bricks are broken.
4. Very bad flue wall: Preheating temperature < 600 °C during the last three fires, and poor physical condition is observed (Cracks > 1 m, pinched > 100 mm, broken tie bricks > 50 % of total tie bricks of a flue wall, severe deformations affecting adjacent flue wall, high probability of getting blocked during baking).
5. Dead flue wall: Blocked flue wall, difficulty in charging of anode, and all the conditions for very bad flue walls exist.

Blocked flue walls: This happens when the flue walls are filled or partially filled with packing coke and the fumes cannot flow to the exhaust manifold. This situation occurs due to damaged refractory or operational issues. These cases are serious safety concerns in any ABF [8].

The flue wall conditions in ABF#1 had deteriorated significantly over time. More than 30 % of the flue walls reached to the stage of very bad / dead flue wall condition. The cases of blocked flue walls (Figure 8) increased significantly (40 cases in 2019) causing process disruption and safety risks. Temperatures deteriorated to an unacceptable low level. The furnace started to produce tar, and this posed a risk of fire to the system. It became a challenge maintaining good health and safety close to the furnace.

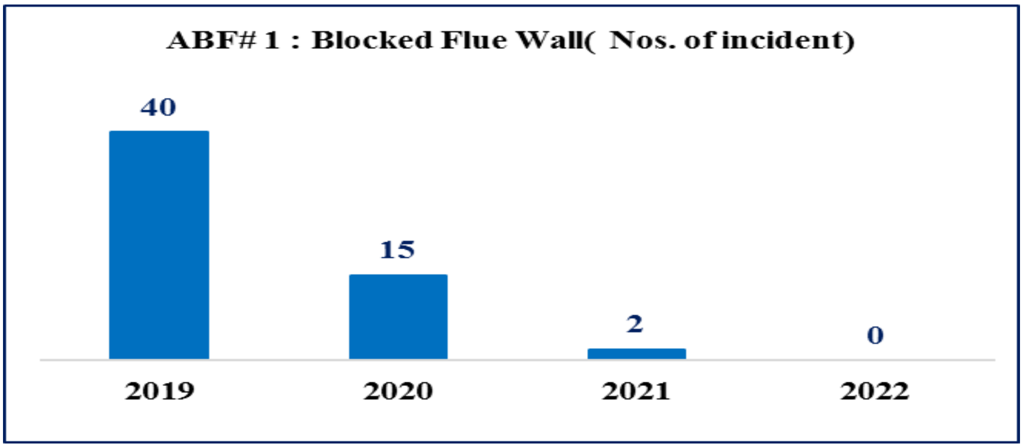

Figure 7. Generation wise flue wall lifetime in ABF # 1.

2.3 Condition of the Side Insulation, Corbel and Concrete Casing

During the external flue wall replacement, it was observed that 25 % of the side insulation was damaged. Major degradation: burns, cracks, bricks and wall instability were observed under peep hole 1 due to high thermal heat stresses.

The concrete corbel was also found affected in this area close to the civil expansion gap (these are the expansion gaps in concrete tub of the ABF) similar to that highlighted in RTA report [7]. Majority of the corbel (90 % of total 100 numbers of Corbel in ABF#1) was found to be damaged. Corbel concrete close to the expansion gap was observed deteriorated into pieces and the steel bar was visible. These areas were the major sources of air inlet shown in Figure 8.

Concrete casing: A survey was done to evaluate the condition of the concrete casing. It was observed that there are 19 sections out of a total of 50 (38 %) where the slab sliding bearing was damaged (Figure 9). This happened due to movement of forklifts used for handling of green and baked anodes in the furnace. The marks of the fumes were observed on damaged area. These corrosive fumes also having significant impact over the structural integrity of concrete [5][6]. These damaged portions are very difficult to identify as they are inside the cages which were left during the conversion from closed-type to open-type ABF. These damages were the major source of air inlet [7] which is impacting the baking process of external flue wall number 1 as well as anode rejection due to air burn. The mapping of flue wall draft was done on external flue number 1 for all the affected sections, and it confirmed significant loss of draft across the damaged part of the concrete casing.

3. Overcoming challenges – Refractory Maintenance and Design Changes

3.1 Review of Flue Wall Design

As there was low or no expansion gaps left due to headwall deflection, it was decided to reduce flue wall length. The flue wall length was reduced by 20 mm for the first time in 2008. This has improved flue wall life of 3rd generation from 103 fire cycles to 119 fire cycles. In 2013, the flue wall length was again reduced by 10 mm. It has not improved the flue wall life. However, it has helped in controlling the rate of deterioration in flue wall life. Based on the survey of headwall deflection carried out in 2020, it was decided to reduce the flue wall length by another 10 mm in 2021. After further evaluation, the flue wall length was reduced by 50 mm in 2022. Thus, the flue wall length was reduced gradually over the years from 4 321 mm in 1996, to 4301 mm in 2008, to 4 291 mm in 2013, to 4281 mm in 2021 and finally to 4 230 in 2022. The total decrease was 90 mm from the original design. The reduction in flue wall length over the years helped to improve and reduce further deterioration of the flue wall and increased the lifetime of the anode baking furnace. Worth noting is that the location of the bricks and baffles were not changed to maintain the fume flow distribution. Single tongue refractory bricks are being used to fabricate new flue walls at ABF#1. Recently we have installed five new flue walls made up of double semi tongue refractory bricks for better mechanical locking of the bricks. The impact of the design changes in refractory bricks will be assessed in the future.

3.2 Flue Wall Replacement

Mapping of process temperatures and poor draft were carried out for every flue wall to identify the very bad flue walls. A joint physical inspection team of process controllers, operation and the refractory team was assembled to assess the flue wall conditions and take joint decision accordingly. All the details such as cracks, pinching, type of deformations, blocked flue wall and tie bricks condition recorded for each flue wall was noted. This helped the team to prepare a plan for refractory maintenance. Operational activities and resources were aligned to spare the sections for maintenance and flue wall replacement. The need for flue wall replacements was significantly reduced from 2020 to 2022 in ABF#1, due to these measures.

There were 92 numbers of flue walls in very bad condition at the beginning of year 2020 resulting into a high number of blocked flue walls. These incidents gradually reduced with accelerated rate of flue wall replacement. The number was reduced to 58 in 2021 and presently 45 numbers of flue wall are in very bad condition.

3.3 Repair of Corbels

The refractory team proceeded to repair all the corbels of the 50 sections. It included removal of top blocks, removal of 5 courses of flue wall and removal of 8 courses of insulation for each corbel. The damaged part of concrete of corbel was removed. Casting was done for damaged parts and all the courses of insulation and flue walls were replaced.

3.4 Repair of Concrete Casing

A survey was carried out to assess the condition of the concrete casing. 19 out of total 50 numbers of sections were identified where damages in the concrete casing were significantly impacting on the flue wall temperature and draft. Initially it was repaired from the flue wall side. Three layers of side insulation were removed to access the damaged part of the concrete wall. The damaged portion of the concrete wall was sealed with ceramic wool and castable. It survived 2 to 3 fire cycle only, hence it was decided to carry out more extensive repair from the outside with concrete mix. Nevertheless, there were access limitations to carry out such repair and the external concrete wall had to be modified to provide the sufficient access.

4. Overcoming Challenges - Process Adaptation

Along with refractory improvements, the baking process parameters were tuned to eliminate tar generation.

4.1 Optimization of Zero Pressure Ramp and Draft Set Points

During the baking process, pitch volatiles are released from the anodes. These pitch volatiles must burn inside the flue wall. To ensure complete combustion of pitch volatiles, sufficient flue wall temperature (> 700 °C) and oxygen content in the carrier gas (10-12 %) are required on preheating section 1. This combustion of the pitch volatiles contributes to maintaining the correct temperature inside the anode baking furnace. The optimum settings of zero pressure ramps ensure adequate blowing of preheated air from the blower and good draft ensures pulling of heat from the burner to maintain adequate temperature for pitch volatiles to burn.

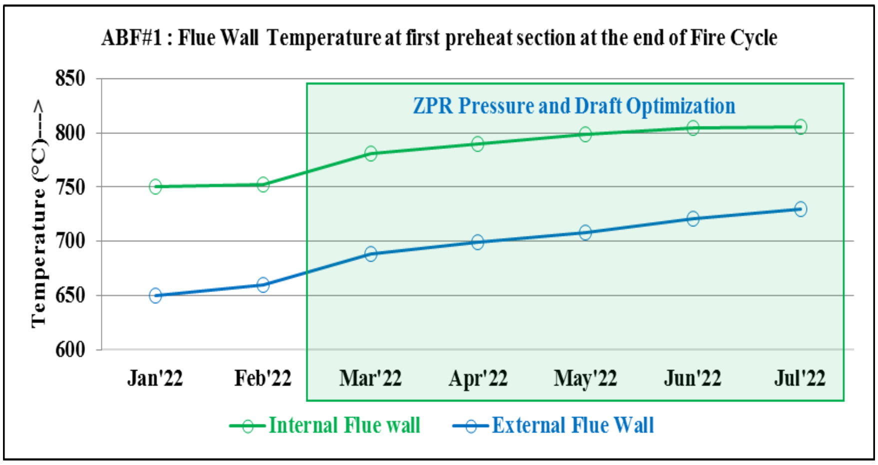

Figure 9. Flue wall temperature at first preheat section.

To obtain this the zero pressure set point was increased from 15 Pa to 22 Pa and minimum blower speed was fixed to 20 % of maximum speed. The minimum draft limit has also been increased from 50 Pa to 60 Pa. These measures have considerably reduced the tar generation. The exhaust ramp was found clean after each fire cycle. Better process control was also reflected in the increase of the flue wall temperature as can be seen in Figure 9.

4.2 Handling of Runaway Flue Walls

Flue walls reaching more than 50 °C higher temperature at first preheat section compared to the target temperature of 750 °C before 3 to 4 h of fire change, is called a runaway flue wall. Earlier these flue walls were being controlled by reducing the draft which was resulting into lack of oxygen and tar generation. The new standard operating procedure was formulated to handle such cases through partially opening of peep hole covers at first preheat section instead of reducing the draft. It has significantly reduced the tar generation, enabled better pitch volatile burning and improved temperatures.

4.3 Optimization of Temperature of First Preheating Section at End of Fire Cycle, Peak Gas Temperature and Soaking Time

These changes were done to reduce gas injection without compromising the baking level. Heating curve optimized gradually over the time. Preheating temperatures improved and Peak gas temperature reduced. The ring main duct was modified from U-type to O-type. ABF#1 was originally designed with a U-type ring main. After evaluating pros and cons, it was decided to convert the Ring main design of ABF#1 from U-type to O-type. It was done in-house similar to the anode baking furnace # 2 design. This has enabled better draft on all the three exhaust manifolds. It has also created flexibility to clean the ring main duct partially whenever required. It is being done by isolating the part of the ring main duct through fixing blind plates without taking furnace shutdown. It needs to be planned according to the fire position on the furnace. When the fire (Exhaust Ramp) reaching near to the cross over section (away from battery limit of ABF), the blind plates kept between this fire and next fire which gives around 4 to 5 days to clean the ring main duct.

5. Improvements in Baking Process, Anode Quality and Performance

All the above initiatives contributed towards significant improvement in furnace conditions in terms of baking process, anode quality and furnace environment. This was reflected in significant improvements in the performance of the fume treatment plant (FTP) and has reduced the number of outages. The life of filter bags has improved significantly. The below trends confirm these improvements.

5.1 Draft in Ring Main

The Ring main draft has been maintained above the minimum target consistently since 2020 as shown in the Figure 10. The data in the Figure reflects the fume treatment plant performance and adequate draft availability at exhaust manifolds of fires at all times. As can be seen from Figure 10, the draft was kept on the higher end during 2020, compared to 2021 due to refractory maintenance and optimization. During 2021, a majority of this maintenance and optimization work was finalized and the process and draft stabilized.

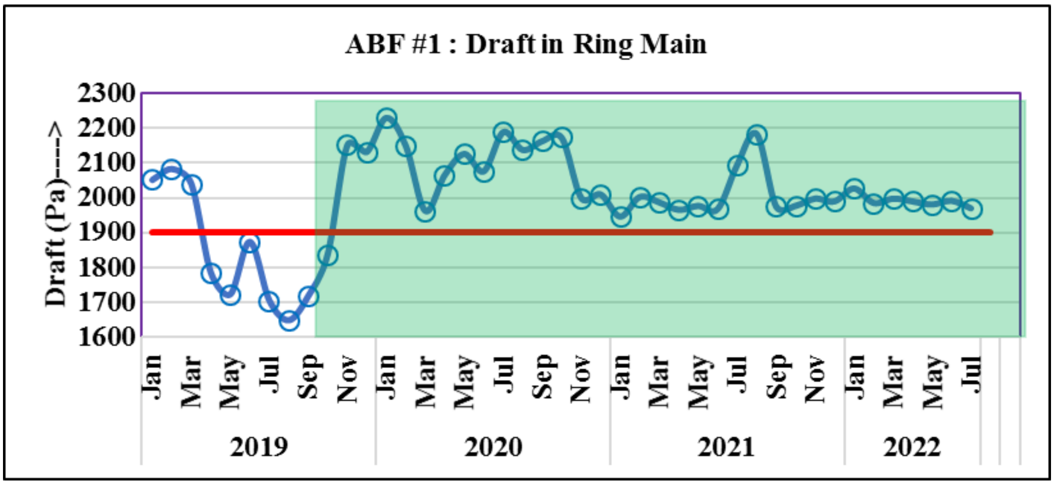

Figure 10. Draft in ring main in ABF # 1.

5.2 Draft at Exhaust Main Ramp

The draft at the exhaust manifolds have improved and have been maintained consistently above the minimum target since 2020 as shown in Figure 11. It has enabled better thermal profiles in the flue wall and thus ensuring good baking process.

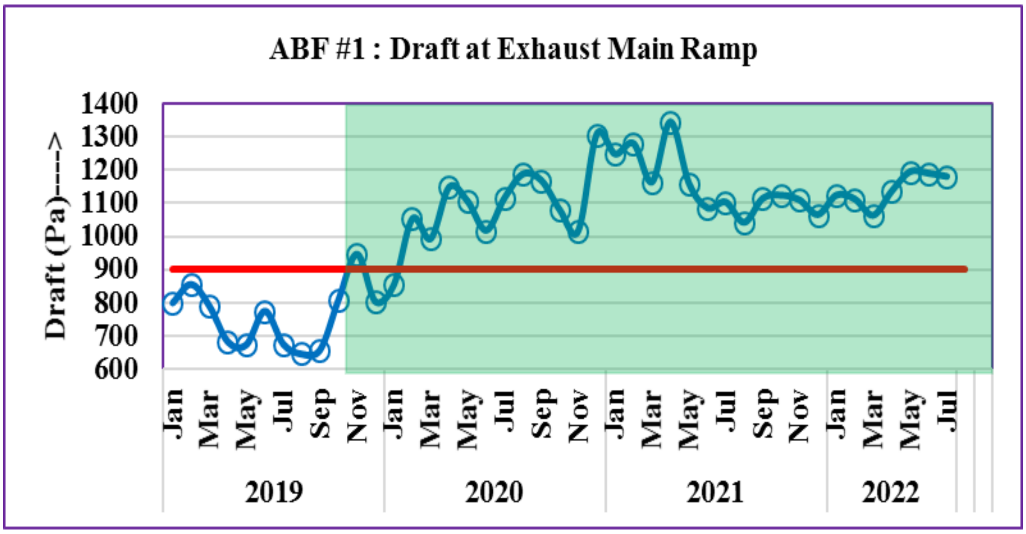

Figure 11. Draft at exhaust main ramp in ABF # 1.

5.3 Temperature at Exhaust Main Ramp

It is consistently maintained close to 300 °C as seen in Figure 12. This is the reflection of good pitch burning and a tar free baking process

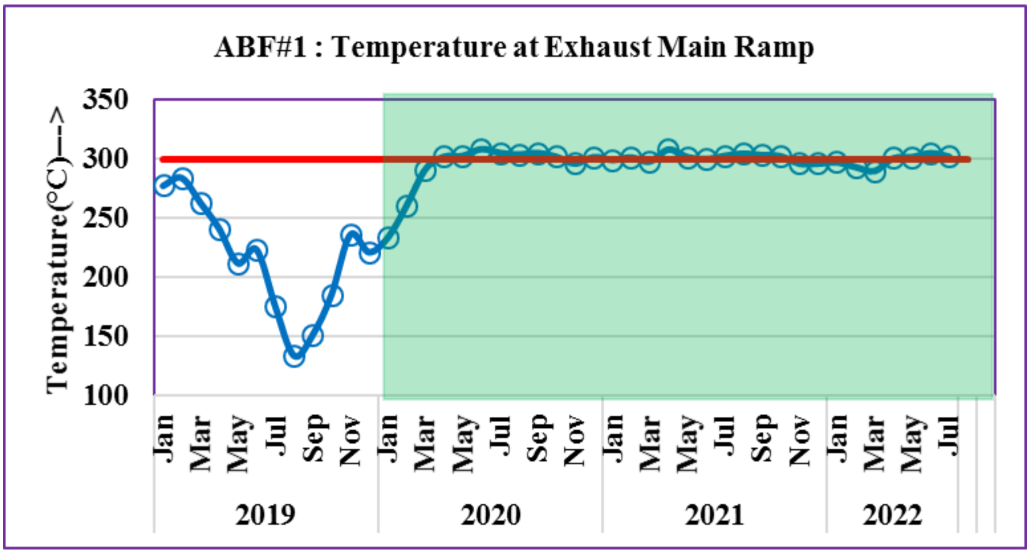

Figure 12. Temperature at exhaust main ramp in ABF # 1.

5.4 Flue Wall Temperature at End of Fire Cycle in First Preheating Section

The preheating baking curve was optimized and this has enabled better conditions for pitch burning. The need for duct cleaning has been significantly reduced. The overall performance of the furnace and FTP has improved dramatically. It has also resulted in better work environment.

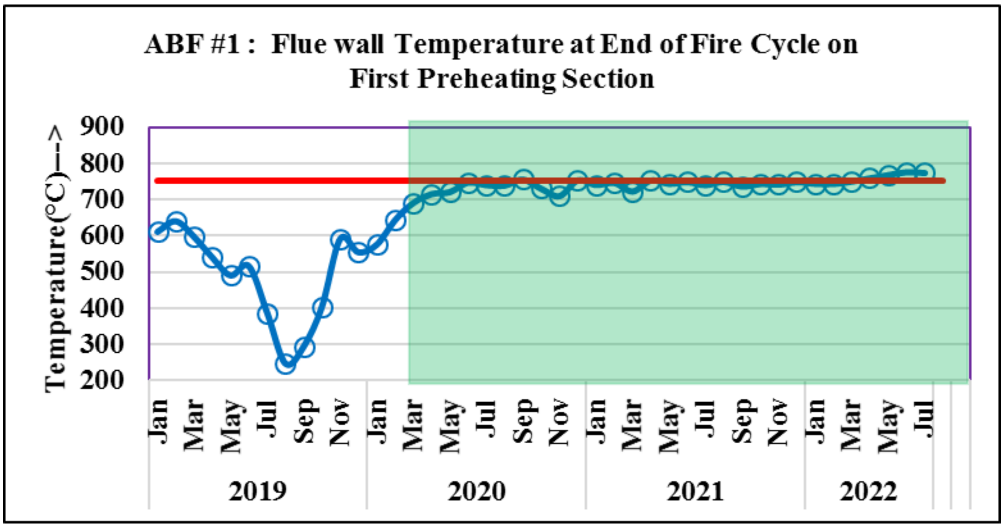

Figure 13. Flue wall temperature at end of fire cycle on first preheating section.

5.5 Flue Wall Temperature at the Beginning of Burner Ramp # 1

This is another parameter reflecting good pitch burning. The improvement in burner ramp # 1 start temperature is due to heat recovered from pitch volatiles. This is shown in Figure 14. A higher startup temperature of burner ramp 1, requires less gas injection need. Thus, it will further help pitch burning

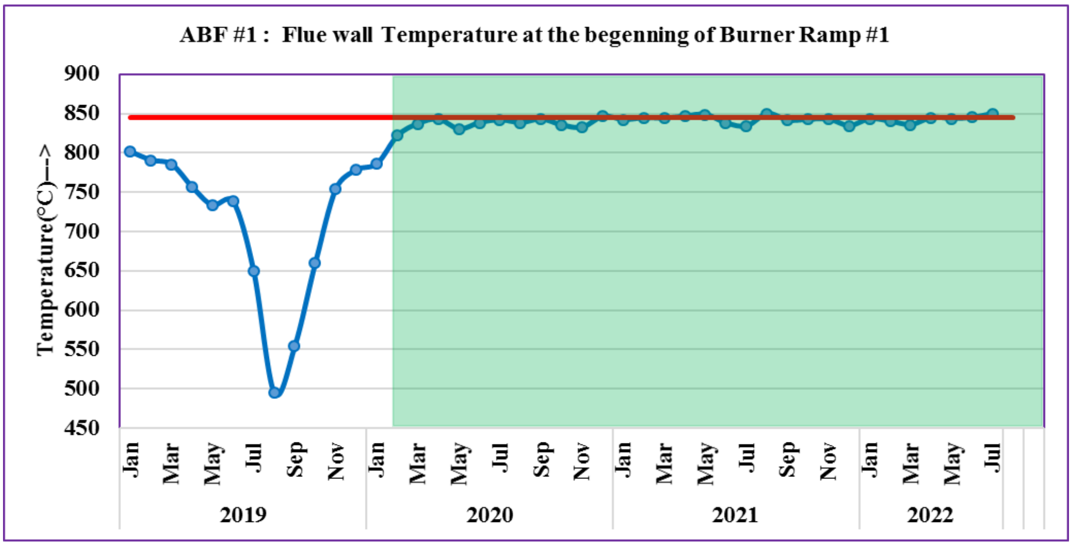

Figure 14. Flue wall temperature at the beginning of burner ramp # 1.

5.6 Anode Quality

As a results of the improved baking process, anode baking level measured as a function of L_C, has been improved greatly as can be seen in Figure 15. L_C is a measure of the degree of graphitization during calcination of the anode coke. It has improved the CO_2 reactivity residue and air reactivity residue as seen in Figures 16 and 17. Improved baked anode quality is reflected in better anode performance in potline and a reduction in spikes and anode incidents, as seen in Figure 18.

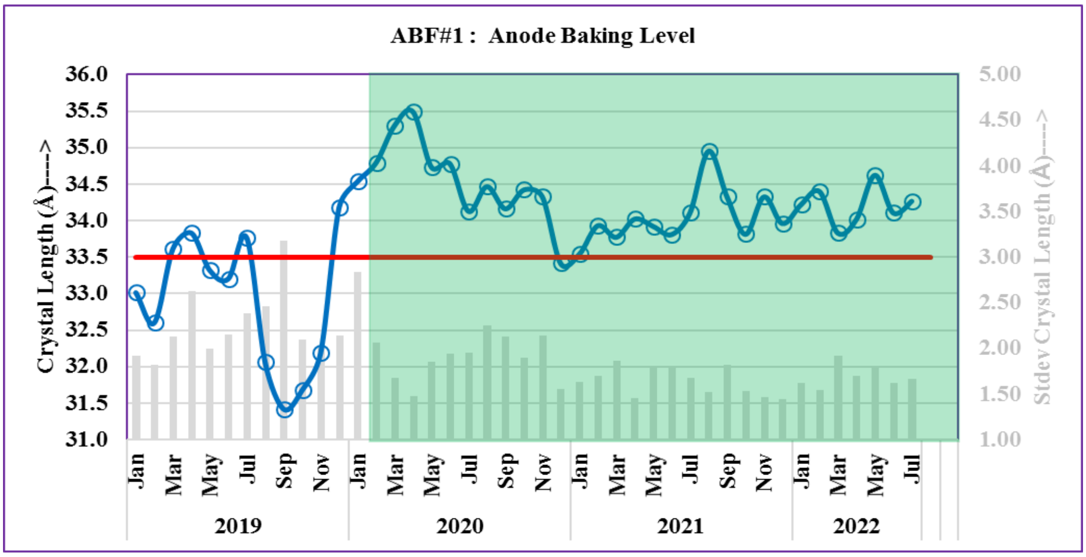

Figure 15. Trend of anode baking level (LC) and standard deviation.

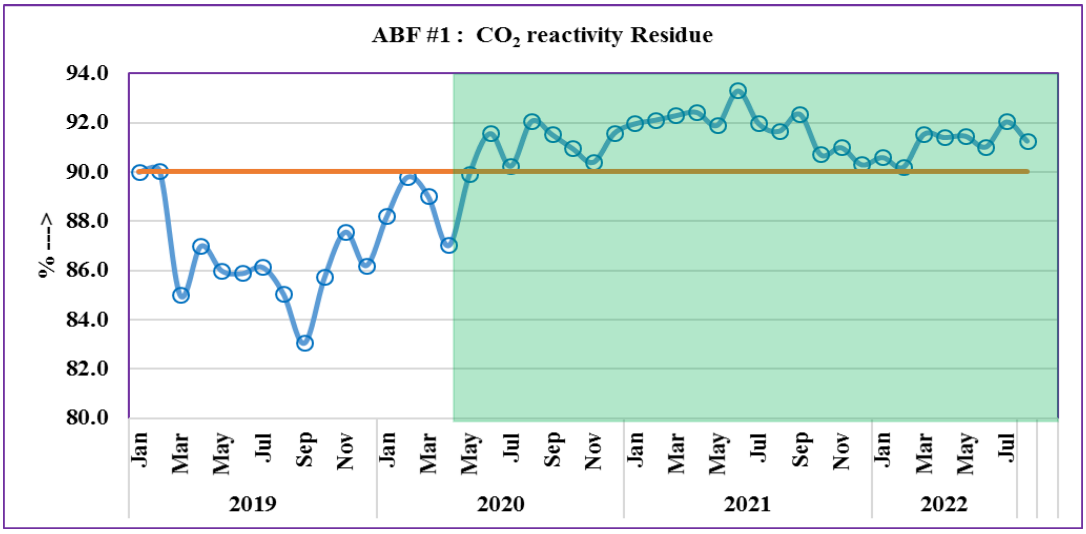

Figure 16. Average CO_2 reactivity residue of the anodes.

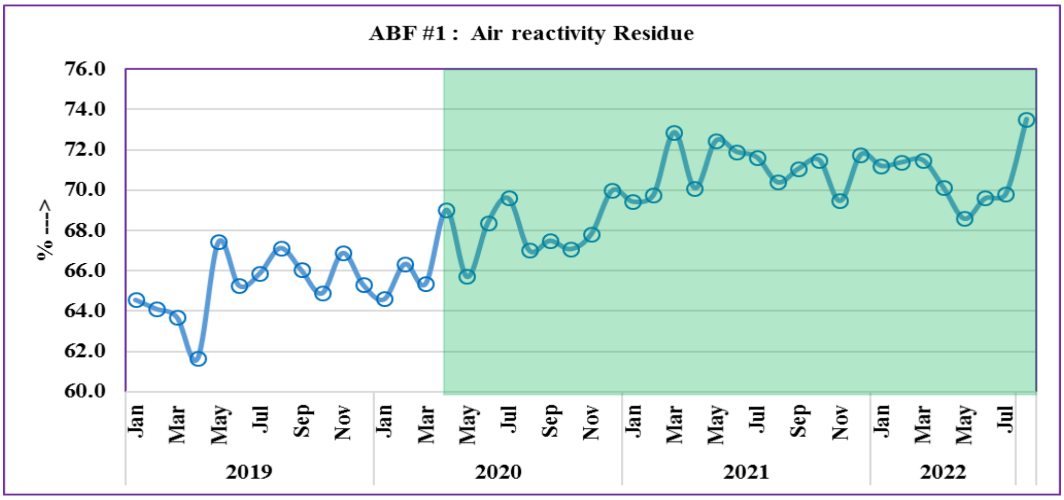

Figure 17. Average air reactivity residue of the anodes.

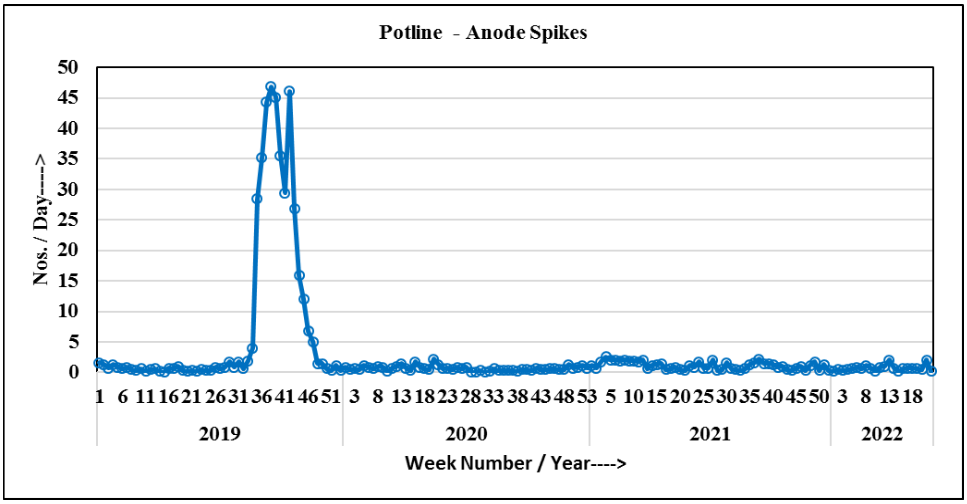

Figure 18. Anode spike trend in potline.

6. Conclusion

The performance of anode baking furnace # 1 has been deteriorating over time during its over 20 years of operation. During 2019, it became a challenge to sustain the baking process and production. The poor condition of the furnace in terms of headwall deflection, flue wall deformations, damaged corbel and damaged concrete casing resulted in significant reduction in anode quality. Bad baking process further resulted in risk of fire, poor anode quality and an increased number of anode related incidents in the potline.

ALBA team has analyzed process data along with physical audit of refractory condition to identify the issues in Anode baking furnace. A maintenance plan was implemented on the anode baking furnace to restore the refractory condition. Continual Process optimization carried out with improved refractory condition to bring the furnace back to producing well performing anodes. This has enabled ALBA to delay a full anode baking furnace revamping by more than 5 years.

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