

CB18 - Anode Properties Improvements at Sohar Aluminium

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Abstract

The present study describes the relevant technical, operational and maintenance practices that contributed in improving anode properties in Sohar Aluminum Smelter. The physical-chemical properties and correlations that improved the anode quality are demonstrated in this paper.

The superior level of anode properties like baked anode density (BAD) and CO₂ reactivity (CRR) is supporting the plant load increase plans and improving pot performance with a stable anode setting cycle and stable anode butt weight. The anode plant has pursued for several years a strategy of investments in key equipment, standardized approach towards reliability and maintenance schedule compliance. A joint team with technical, operation and maintenance on a daily management system in place is one of the main levers for the recent accomplishments.

As a result, the baked anode density reached 1.610 g/cm³ and the CRR was increased beyond 94 %. The paper highlights as main technical contributors for the optimization, the coke and butts aggregate optimum sizing, setting of process parameters, new maintenance routines, vibro-compactors performance optimization and a better raw materials management.

Keywords: Baked anode density, CO₂ reactivity, Coke Sizing, Aggregate distribution, Maintenance strategy.

1. Strategy to Meet Future Carbon Need in Potlines

Sohar Aluminium's business plan is to exceed 400 kA in pots during the next 5 years. Due to the limited carbon available in the current anode (weight and butt size), several options were considered.

As a first option, it appeared that the anode size increase (length, height and width) is limited due to the AP-40 anode baking furnace (ABF) dimensions. The ABF modifications would trigger a multi-million dollars investment project [1].

A second option to supply more carbon to the potlines is to reduce the anode set cycle in the pots from 80 to 76 shift cycle. It implies an increase of 5 % in the number of anode assemblies produced. This is the selected solution in the long-term. The new cycle will generate an extra 40 kg of carbon available per anode for future amperage creeping.

However, the drawback of this option lies in the short-term. In the first years of the amperage creeping, the extra carbon mass is only partially consumed. This will result an additional cost of production due to higher gross carbon consumption. The benefits, though, will only follow the annual amperage increments.

The third option would consist in increasing the anode density without changing its size nor the anode production figure. As shown in Figure 1, the green anode density (GAD) weekly average may vary from 1.65 g/cm³ to 1.68 g/cm³ during the year, at various instances. Assuming that the pot amperage requires an anode weight limited by the lowest values of density, a reduction of variation in density would definitively benefit the smelter in the short-term at least.

Decision: Third option. Working to reduce density variation and in the midterm the eventual implementation of the second option (anode cycle set reduction). This decision will postpone by a few years any need of investments in capacity increase.

As a reference, a variation in density of 0.01 g/cm³ between the highest and the lowest weekly figures corresponds to an extra mass of approximately 4 kg per anode. It means one additional year of production at 80 shift cycle saved. The solution to produce extra anode mass to the potlines required for the amperage creeping focused initially in the reduction of the density variation.

2. Density Variations Reduction

2.1 First Approach: Density Reject Criteria

The first approach consisted in rejecting the anodes produced below a certain density. On Figure 1, it was set a minimum density at 1.625 g/cm³. Any anode under this value was rejected, causing 0.9 % of the anode plant production to be rejected and recycled. To gain an additional 4 kg in the anode, the reject criteria should be set at 1.645 g/cm³. This could generate a rejection rate of 8.1 %, which was not acceptable. This approach was abandoned.

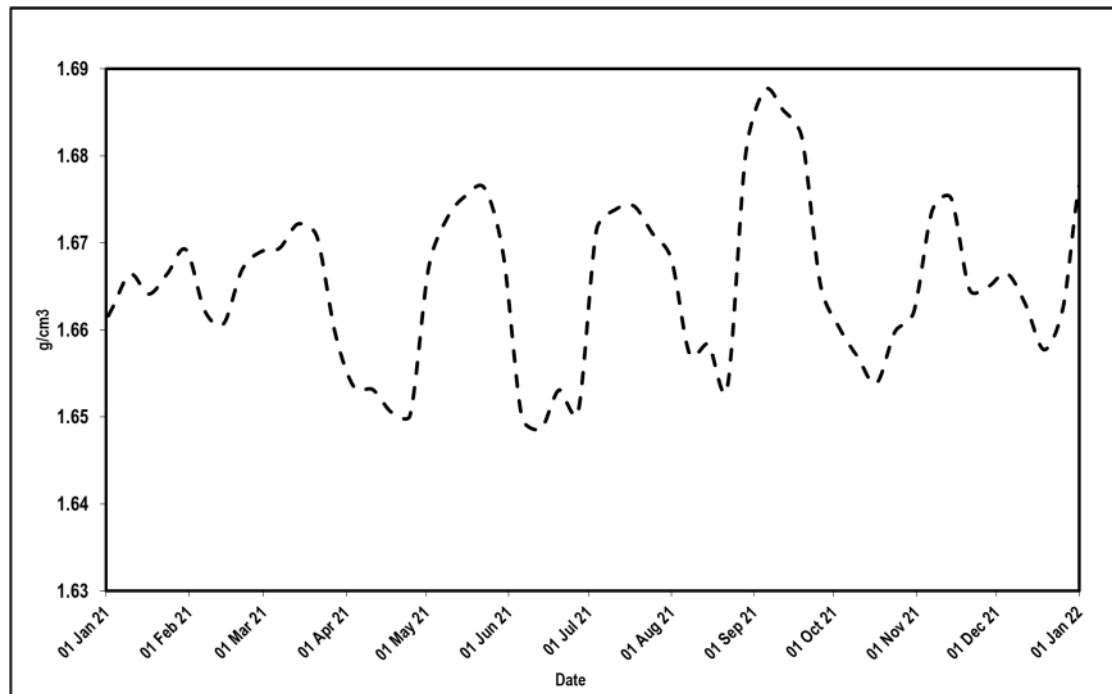


Figure 1. Variation of GAD (g/cm³) 2021.

An investigation of the cyclic variations of the GAD was undertaken. To understand the study, a short comparative introduction to the anode plant of the Sohar Aluminum smelter is required.

2.2 Sohar Aluminum Smelter - Specificity of the Anode Plant

Sohar Aluminum uses two sources of cokes named coke A and coke B, at equal rates to produce its anodes. The coke is received by shipment of 11 kt and stored in a 15 kt capacity silo at the Sohar port. The coke is trucked daily to the anode plant 400 tons silo.

As shown in Figure 2, the dry material preparation section of Sohar Aluminum anode plant consists of two fractions of dry aggregate added together to create the anode aggregate. The “Fines” fraction (20 %) and the “Grains” fraction (80 %).

The production of these two fractions is obtained following several steps. Firstly, the coke is mixed with the recycled anode (butts) at the plant inlet. The mixture is crushed using a single crusher, named “Rhodax” [2]. Afterwards, the material is separated into 2 fractions. The coarser fraction (greater than 3 mm) goes to the “Grains” fraction silo while the finer material (smaller than 3 mm) is separated by a turbo ventilated classifier (named TSV). Typically, particles smaller than 0.3 mm will be crushed by the ball mill to produce the “Fines” fraction. The particles greater than 0.3 mm and smaller than 3 mm will go to the “Grains” fraction silo.

The principle of maintaining the 2 fraction silos levels is based on a variable speed of the classifier TSV. The faster the TSV, the finer is the material sent to the ball mill but also the lesser the quantity. Inversely, when the “Fines” fraction silo level is low, more products will go to the ball mill. Consequently, to maintain the “Fines” fraction silo level, the particles size “cut” of the TSV depends on the presence and availability of the fines in the inlet product.

Conversely, as shown in Figure 3, in a conventional anode plant the aggregate fractions are prepared using specific and isolated product sources. Coke is not mixed with recycled butts. The very fine materials (dust) have dedicated silos. So more than 4 fractions may be used to establish the anode aggregate formula. Each fraction is produced using a crusher, a vibrating screen and a classifier that separates the fractions. The fractions composition and size are well defined.

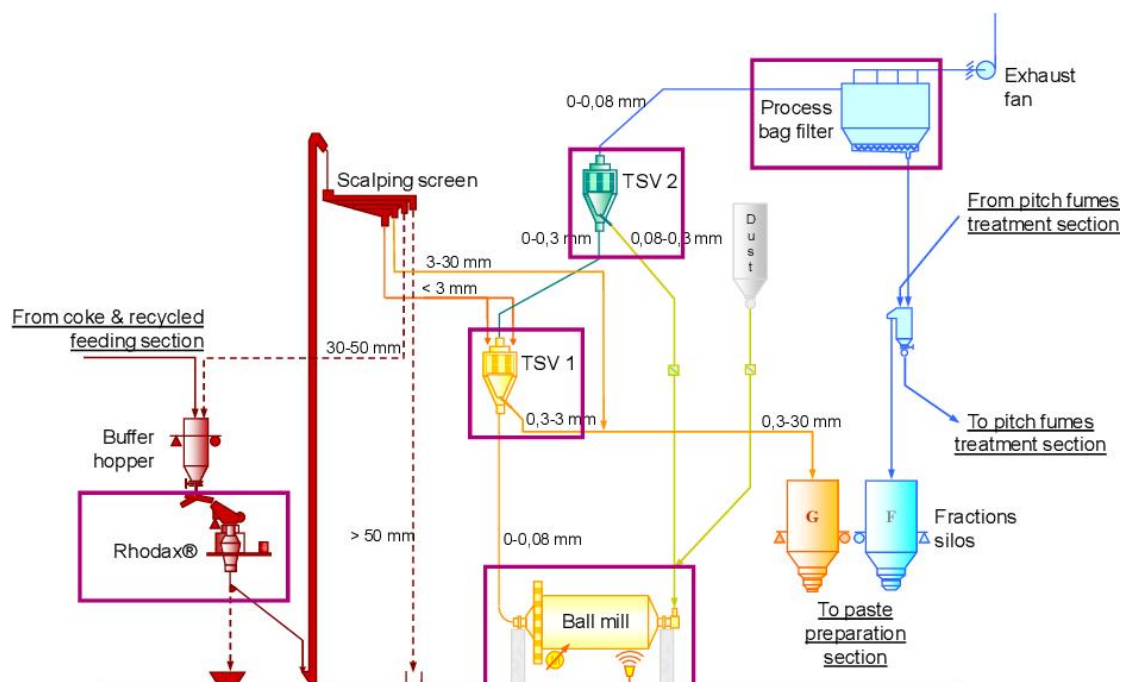


Figure 2. “Rhodax” paste plant in Sohar Aluminum – aggregate fractions preparation.

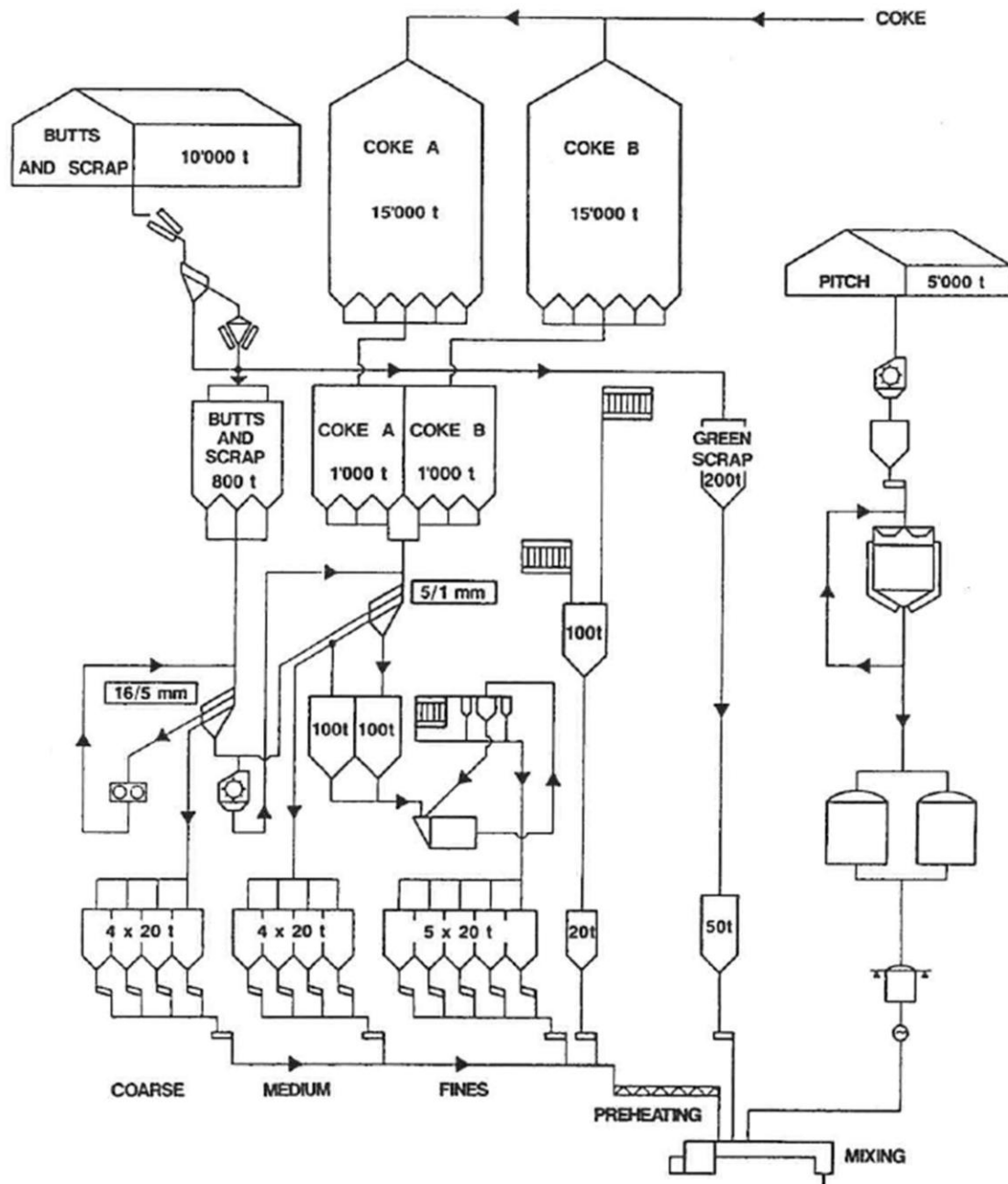


Figure 3. Conventional plant – aggregate fractions preparation.

The cyclic nature of the density variation was investigated following the manufacturing process is described in Figure 4 below.

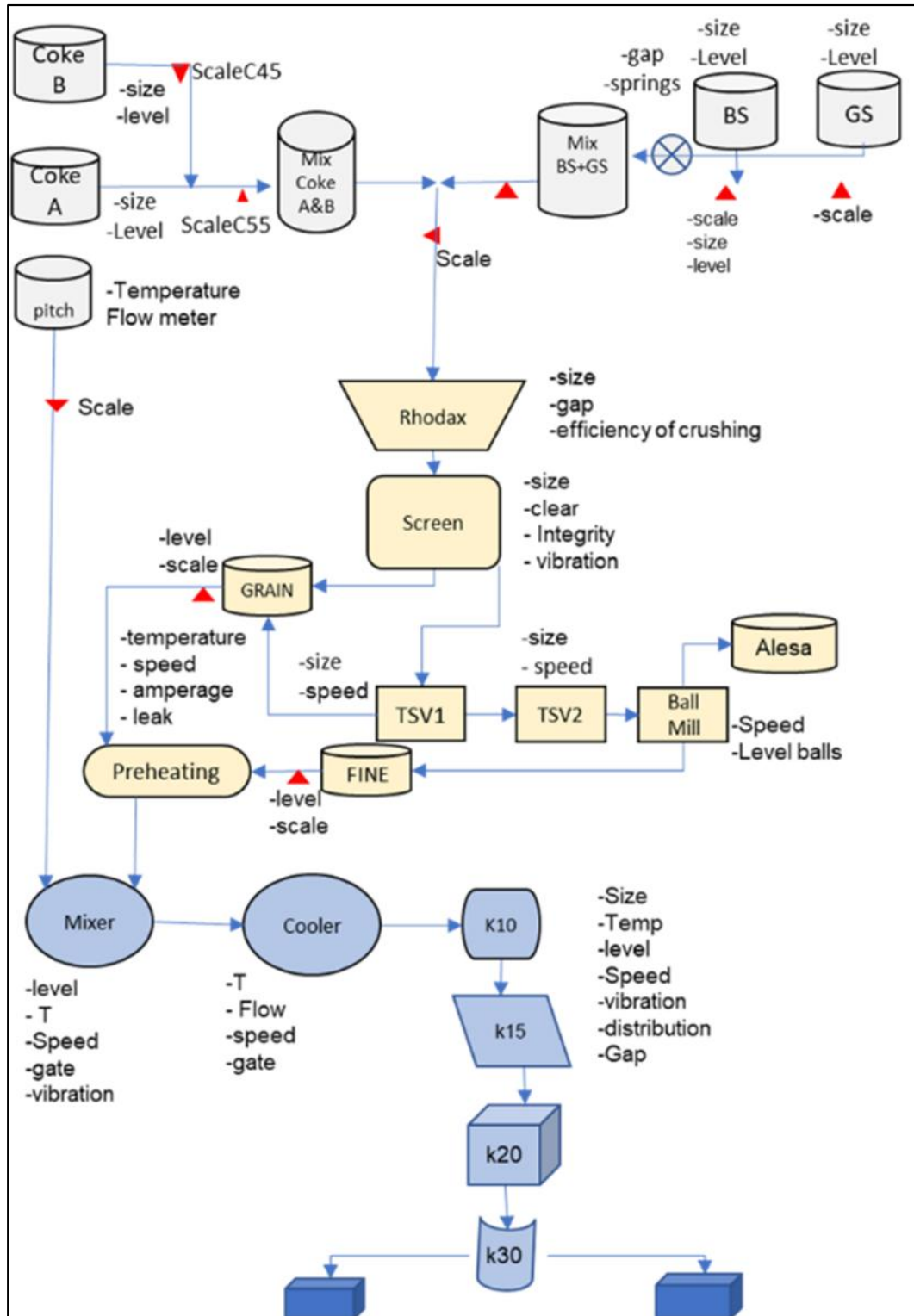


Figure 4. Anode manufacturing process in Sohar Aluminium.

2.3 Process Parameters Correlating with GAD Variations

During the investigation, it was found that the preheater amperage slightly correlates with the density as shown in Figure 5. When the amperage of the four preheating screws increases, the anode density drops. Observations showed a variation of the material level inside the preheater.

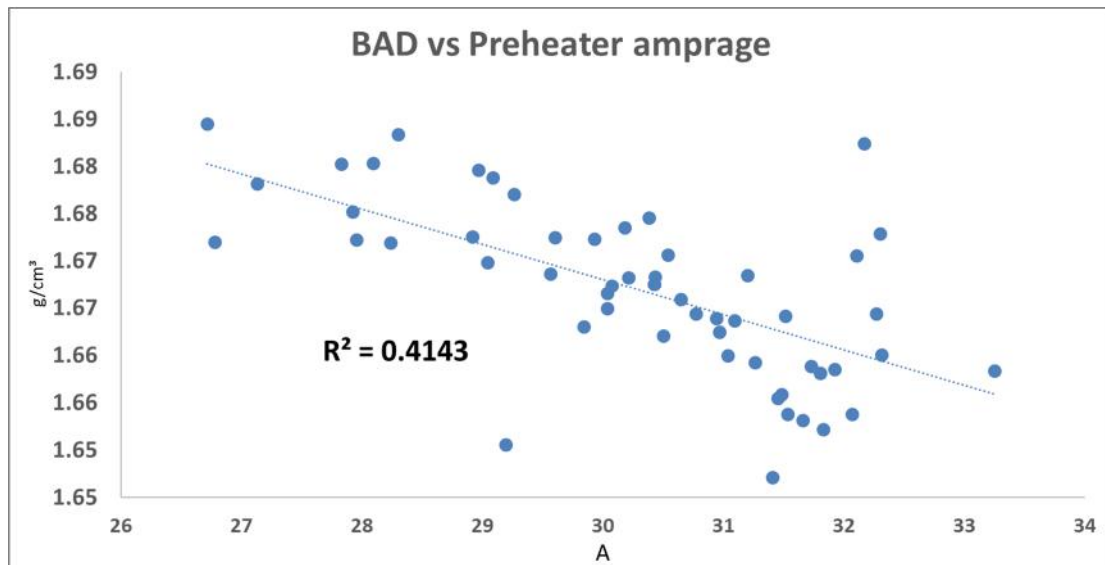


Figure 5. Correlation between coke preheater amperage and the GAD (g/cm³). Weekly averages for 2021-2022.

Therefore, the study focuses on the upstream anode manufacturing process, the dry aggregate preparation. A correlation was found between the GAD and the speed of the classifier TSV as illustrated in Figures 6 and 7. The speed of the classifier turbine and the density value are related as shown in the example (see Figure 7). When the speed expressed in % is low (below 40 %), the anode density is also low (below 1.66 g/cm³). That happens when the “Fines” silo level is low. Inversely, the periods corresponding to the speed varying freely between its lower and higher limits match the moments of greater densities.

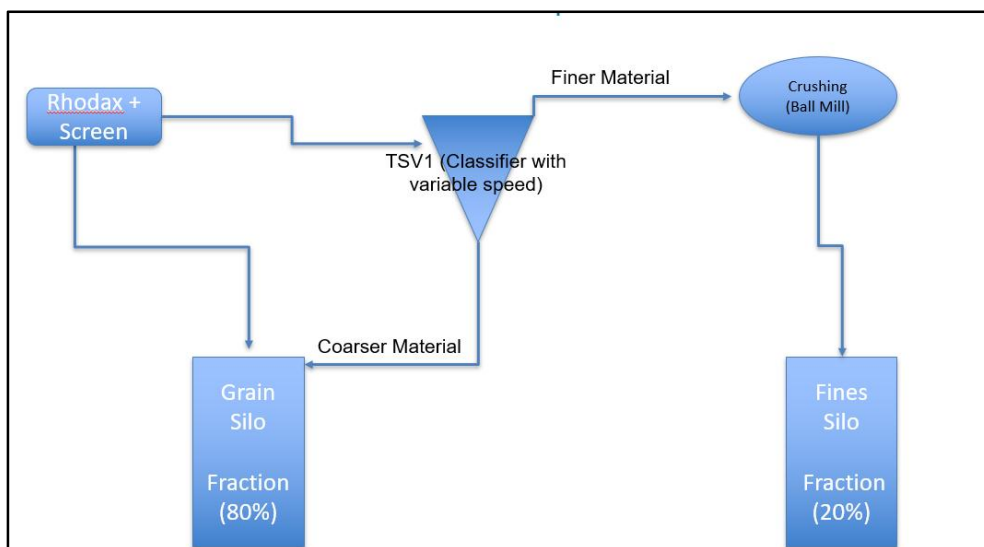


Figure 6. Summary of the role of the classifier TSV1.

The variations of the TSV indicate a modification of the granulometry of the anode aggregate. A greater speed reflects the increased presence of finer materials into the classifier and towards the ball mill.

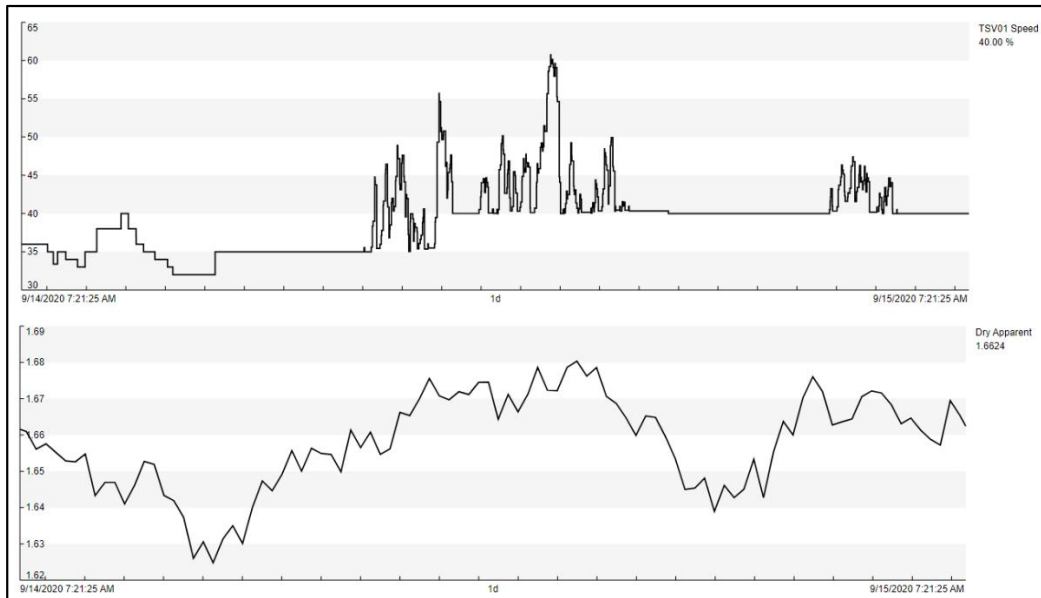


Figure 7. Example. Link between the instantaneous variations of the TSV-1 speed in % and of GAD (g/cm^3) during 24 h.

2.4 Aggregate Size Distribution Correlating with GAD Variations

The study was undertaken on the impact of anode aggregate fractions on the density [3,4]. The anode aggregate is made of 80 % of the “Grains” fraction and 20 % of the “Fines” fraction. An intensive sampling campaign was carried out to try and capture the granulometry distribution of these two fractions during the periods of low and high GADs.

The results are displayed in Figures 8 and 9. The granulometry of each sample ranges from 0.030 to 50 mm. The particle size distribution (PSD) when the GADs was on the high side (GADs $> 1.66 \text{ g}/\text{cm}^3$) is represented in black color, and on the low side (GADs $< 1.64 \text{ g}/\text{cm}^3$) is featured in red color. It was noted by Figure 8, that the “Fines” fraction, produced by the TSV selection, does not change with the GAD variation. In contrast, the “Grain” fraction granulometry distribution in Figure 9 shows strong correlation with the GAD. The coarser PSDs ($> 1.7 \text{ mm}$) will produce lower GADs.

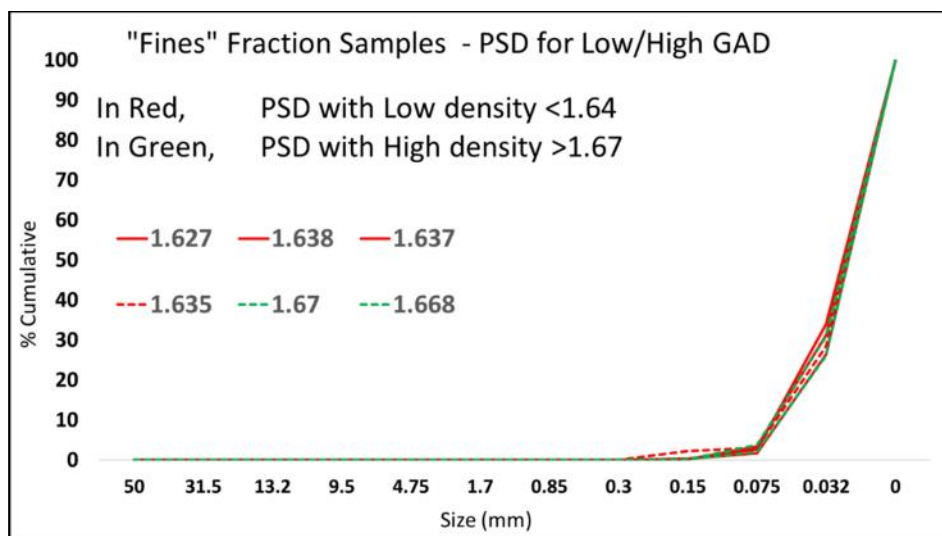


Figure 8. PSD of the “fines” fraction at different GADs.

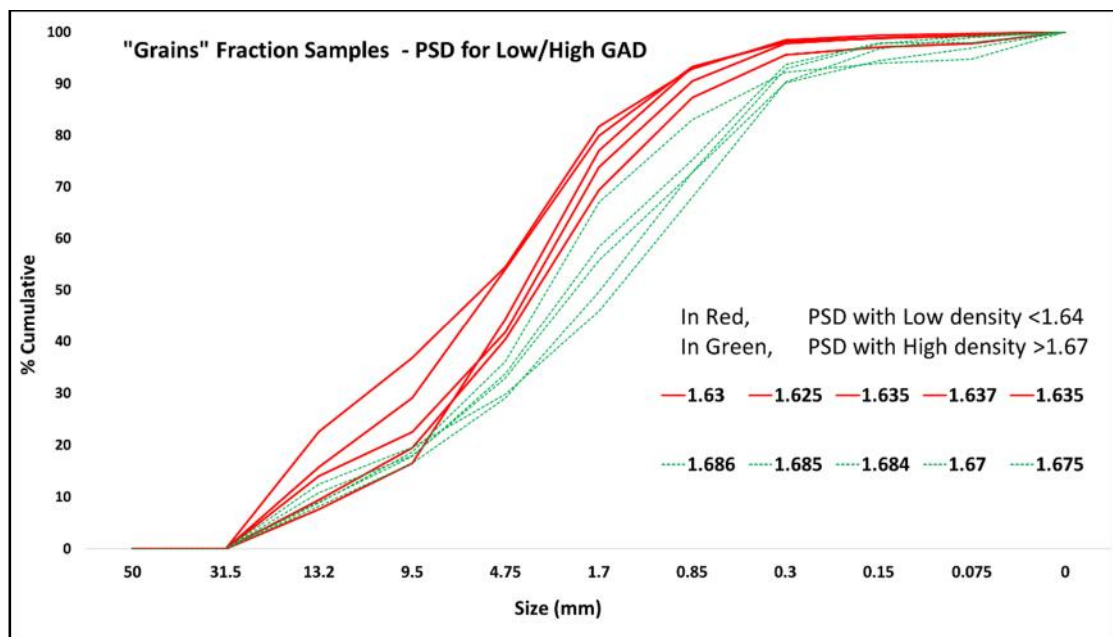


Figure 9. PSD of the “grains” fraction at different GADs.

Figure 10 shows the averaged trend of PSD for each of the two levels of GADs. The difference between the two curves is shown in Figure 11. The difference is calculated by fraction. For instance, the difference between low and high GAD for the fraction +4.75 mm -9.5 mm is equal to $(47-25) - (34-20) = 8 \%$.

Overall, the Figure 11 shows a total accumulation of 16 % of coarser material (> 1.7 mm) versus a lack of 16 % finer material.

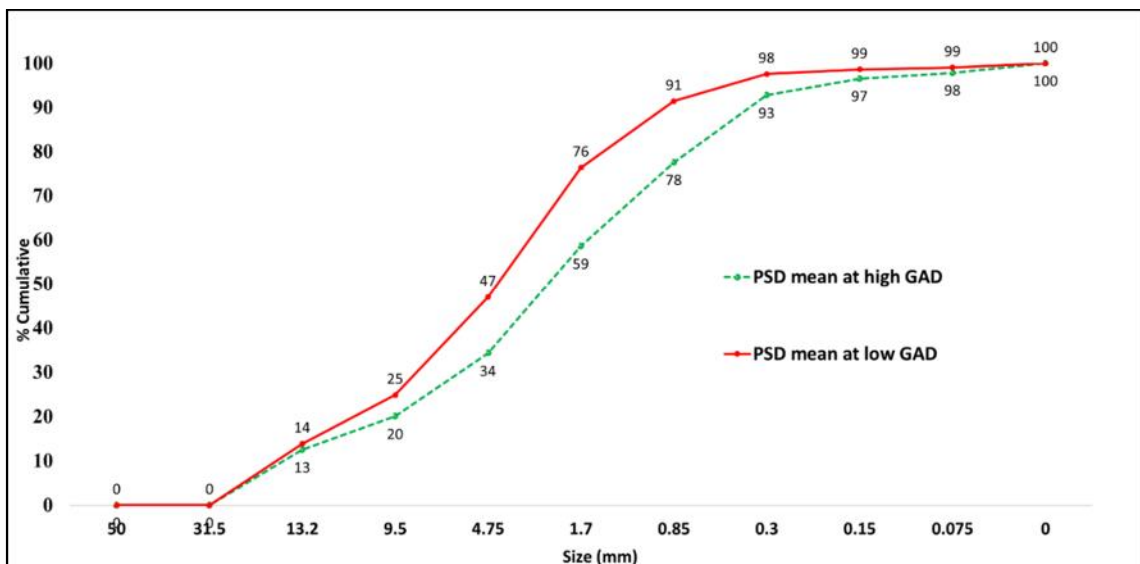


Figure 10. Existence of 2 PSDs in the “grains” Fraction affecting the GAD.

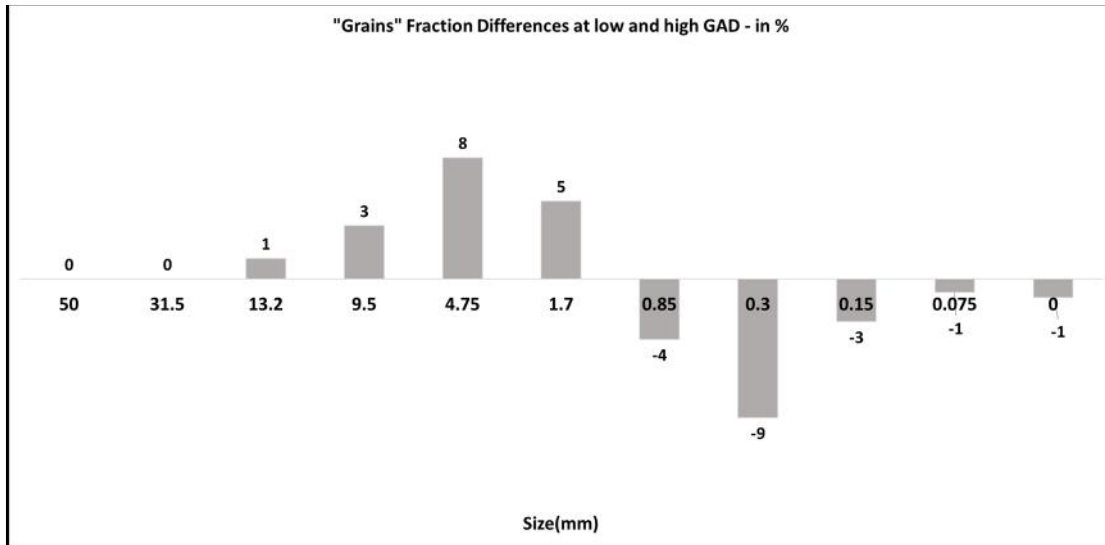


Figure 11. The differences between the two curves in Figure 10.

2.5 Confirmation of the Findings

A simple practical test was carried out to confirm the findings. Two extreme aggregates were selected (respectively aggregate #1 and aggregate #2), each corresponding to a period of specific density (respectively 1.625 and 1.684 g/cm³). Figure 12 shows the two aggregate curves. By screening and reconstituting 10.0 kg of each aggregate composition, and by measuring the density after vibration of the dry product in an empty cylinder, like the Y-blender study undertaken by Peterson [5], it was found a volume difference between the two materials of 5.6 %. Figure 13 illustrates the experiment.

This result is very close to the GAD variation of 3.7 % calculated from 1.625 to 1.685 g/cm³.

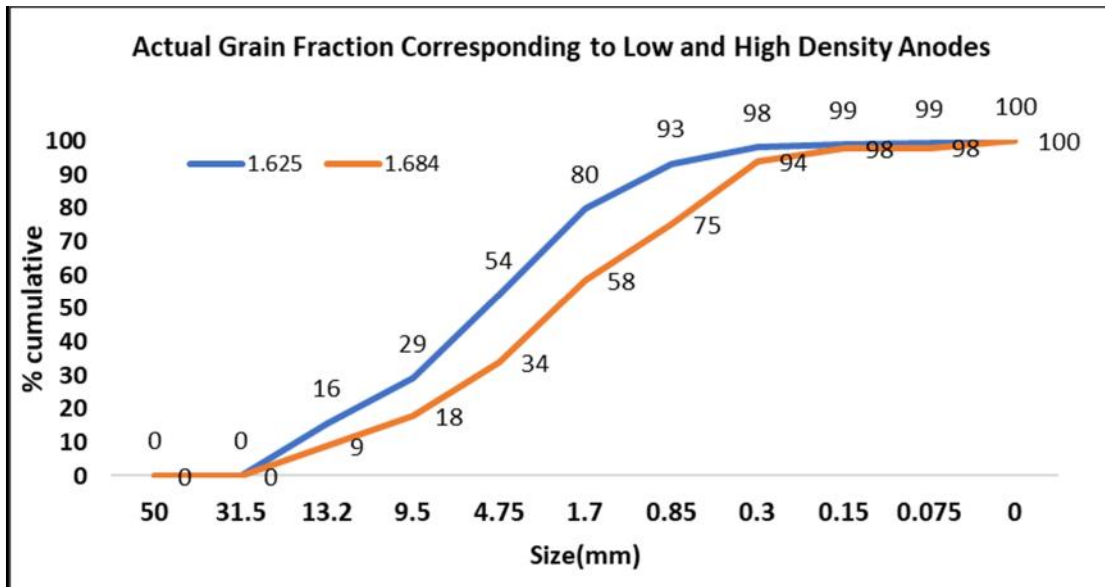


Figure 12. Aggregates reconstituted and corresponding to anodes of different GADs.

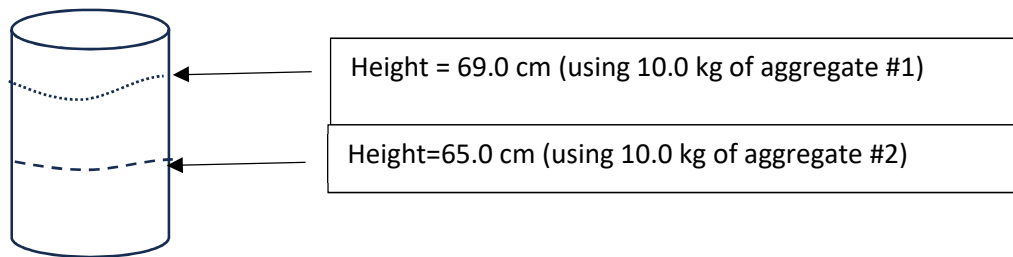


Figure 13 – Measurement of reconstituted Anode Aggregate Density.

2.6 Impact of Incoming Coke in the Process

This section relates the sensitivity of the Green Mill to the incoming coke. The “Rhodax” configuration is not able to generate the requirements in fines to maximize the GAD. Whenever the incoming coke is coarser, excessive particles > 1.7 mm will be in the PSD, causing lower results in density. The Rhodax crusher, designed to crush butt pieces together with coke, does not generate enough fines like roll crushers in conventional plants.

The segregation of the coke in the port silos causes periods of course and finer coke delivered as illustrated in Figures 14 and 15. The segregation mechanism and influence on the anode performance is well described by Sadler [6]. The production of anodes with lower GAD correlates with lower silos levels and coarser coke delivered.

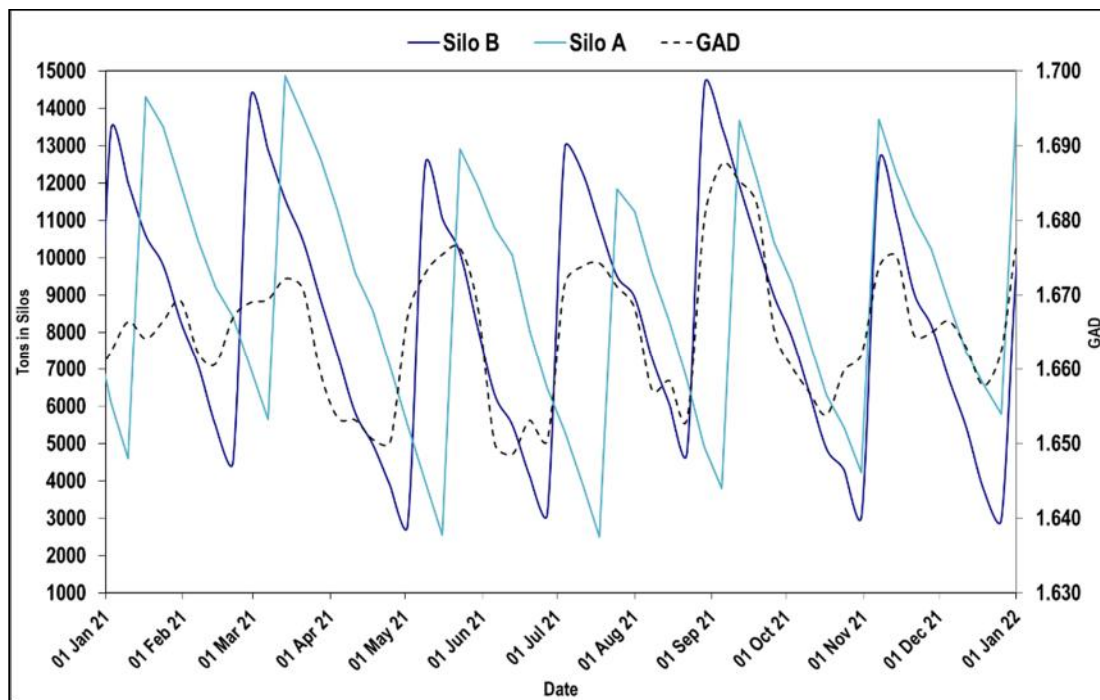


Figure 14. Link between coke port silo levels and the resulting GAD.

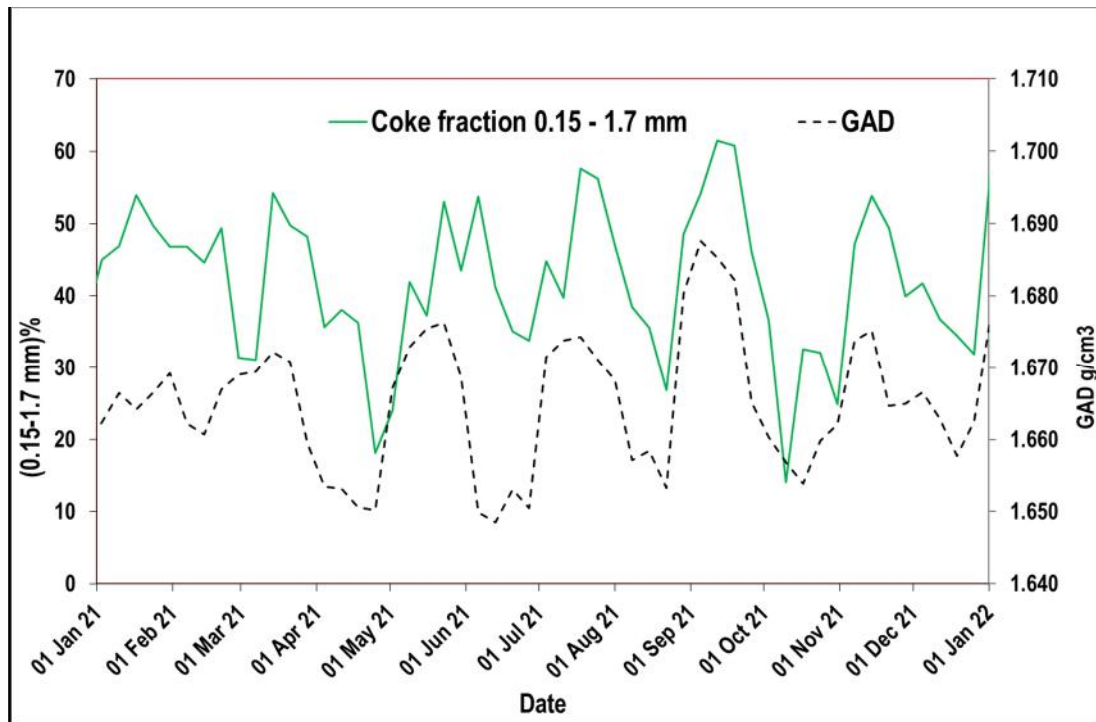


Figure 15. Link between the inlet coke size and the GAD.

2.7 Improvements

Based on the previous findings, the GAD variations were successfully reduced (see Figures 16 and 17). The approach consisted first in reducing the segregation impact for one coke by using 3 kt silo instead of 15 kt and secondly in crushing further the coke grain size to reach 14 % over 4 mesh.

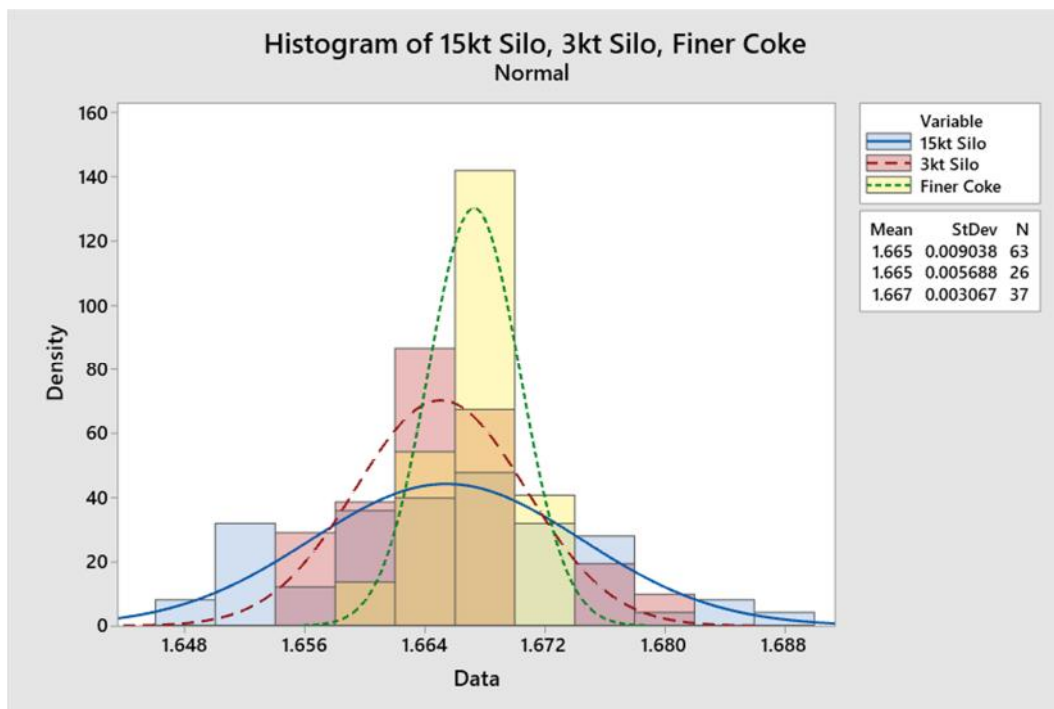


Figure 16. Statistical Improvement in the GAD Variation. Smaller silo and finer coke.

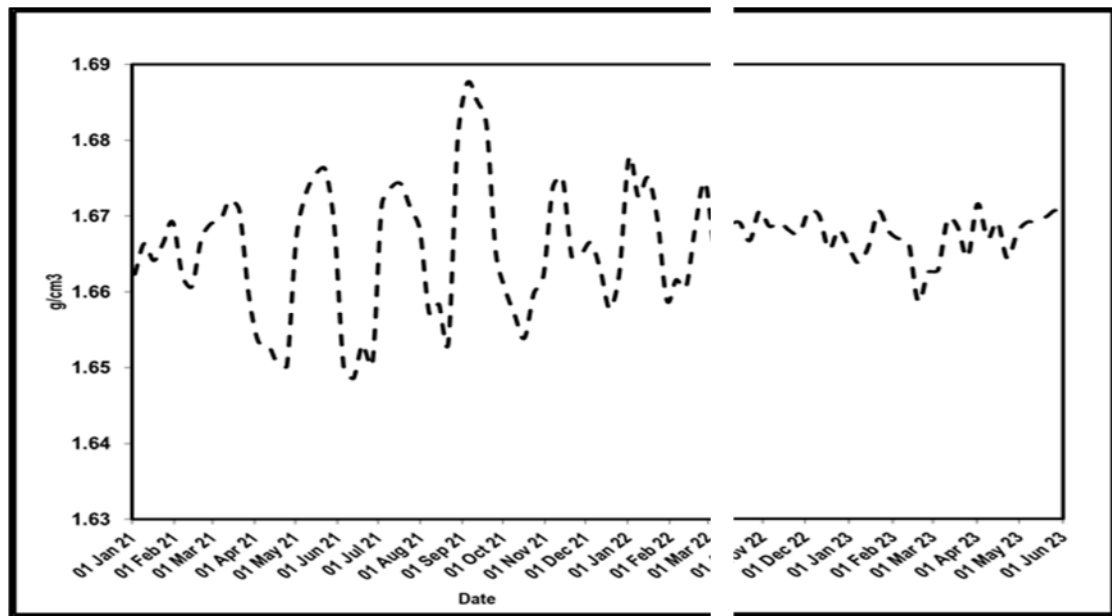


Figure 17. GAD variation reduction from 2021 to 2023.

2.8 Density Full Potential

In Figure 18, a good fit is established between the inlet coke fraction (+0.15 -1.7) mm content and the GAD using weekly averages. A stable content greater than 60 % of the inlet coke fraction (+0.15 -1.7) mm ensures a GAD of 1.665 g/cm³ minimum.

Considering that the anode former vibration time is deliberately minimized at 35 seconds for GAD exceeding 1.665 g/cm³, there is indeed a potential of increasing the GAD average. Anodes with lower GAD are the ones vibrated up to 70 s. So, there is a potential of 35s additional or +0.015 g/cm³ extra in GAD value.

In other hand this strategy is not pursued, to prioritize less variability, or lower standard deviation. Manufacturing anodes from an inlet coke fraction (+0.15 -1.7mm) by 60 % (or beyond) with a 70 s vibration duration results in GAD at 1.680 g/cm³ level.

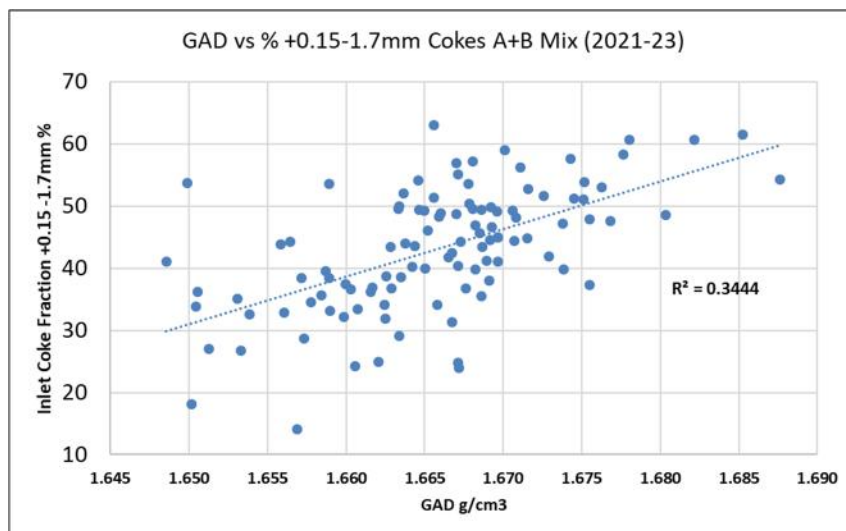


Figure 18. Correlation between GAD (weekly average) and Inlet Coke Size (3 samples weekly) -From 2021 till 2023.

3. Improvements in Anode Reactivity and Electrical Resistivity

As illustrated in Figure 19 with anode core results, the anode electrical resistivity variation benefited from the density improvement.

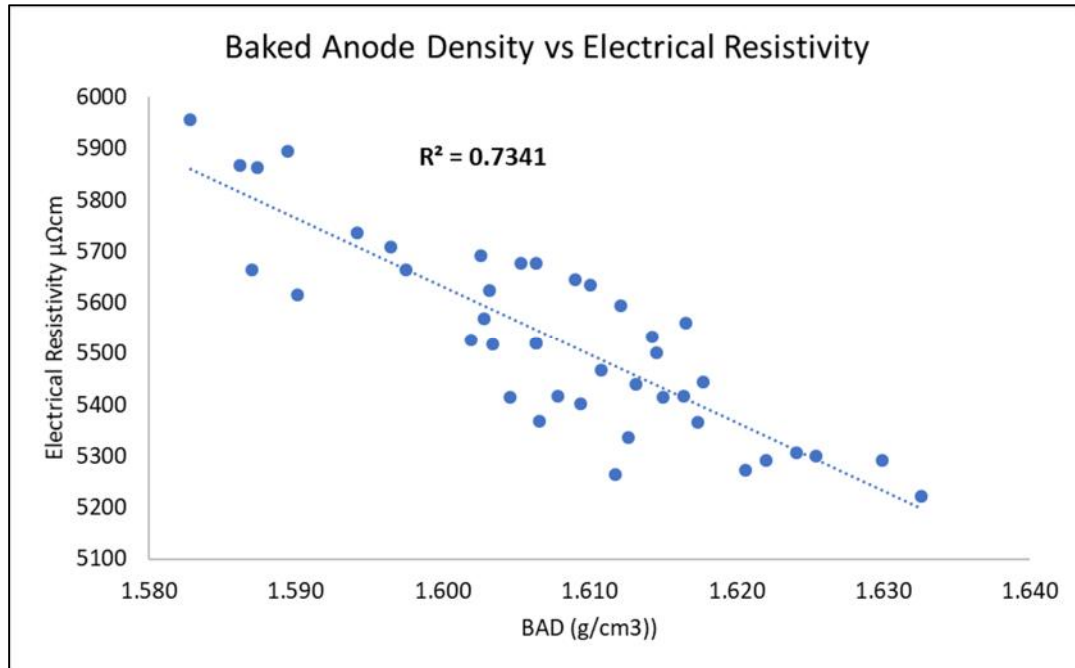


Figure 19. Baked Anode Density vs Electrical Resistivity.

The anode core residue, following exposure to CO₂, improved statistically by moving from 93.0 % to 95.5 % in the last three years (see Figure 20). Enhancement in the hot butt cleaning process and start-up pot partially consumed anodes recycling contributed to this result. The literature [7] describes abundantly the mechanisms of catalytic activity by the sodium and calcium and the sulfur inhibitive effect on the CO₂ residue reactivity (CRR). Using a dimensionless number similar to Hume's to reflect these three influences, a relatively good match is achieved in Figure 21 between the CRR trend and the presences of S, Na and Ca in the anodes.

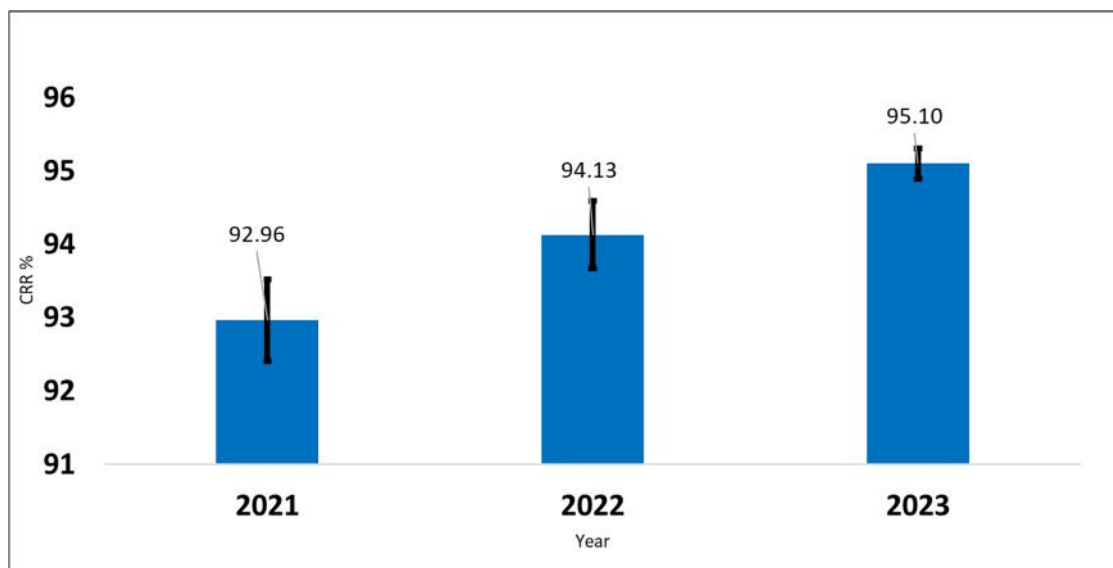


Figure 20. CO₂ Reactivity Residue as % of the Anode Core per Year.

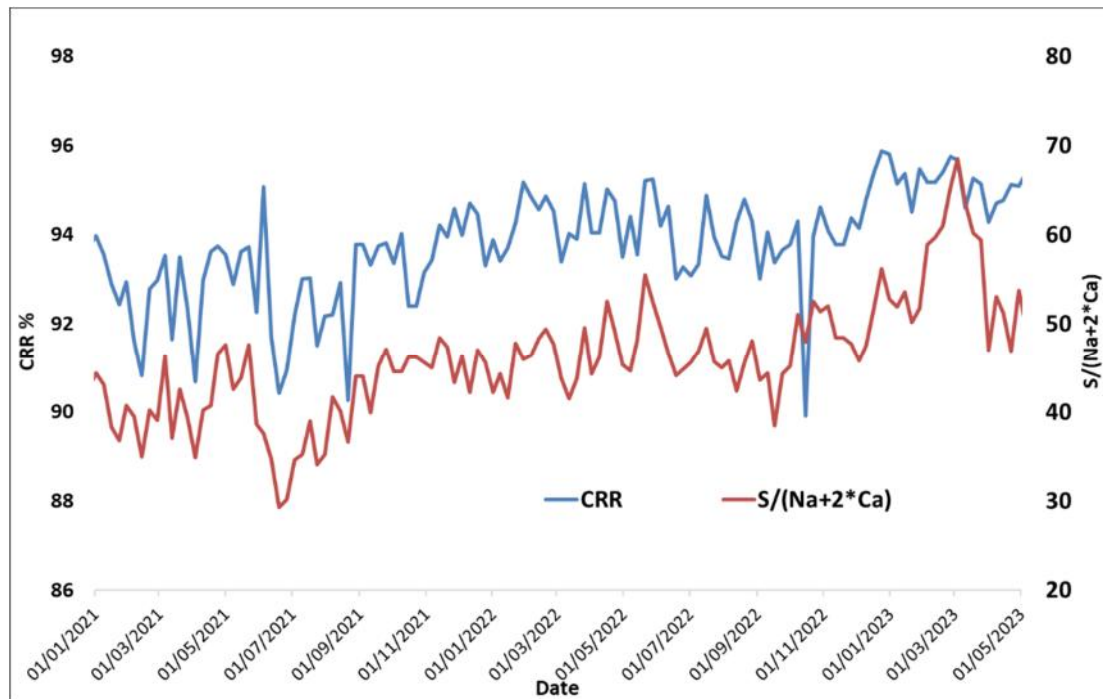


Figure 21. CO₂ Reactivity Residue (CRR) explained by the Impurities Content (S, Ca, Na).

4. Paste Plant Maintenance and Reliability Performance

The consistency in the anode density is due to the pursued maintenance strategy. Three areas of focus are responsible for the outstanding results in anode density. The plant performance is mainly based on the equipment availability improvement by daily interface meeting between the operation, maintenance, and technical teams to identify daily concerns. Predictive maintenance plays a critical role with the online condition monitoring and sending along with the tracking of actual down time data using Manufacturing Execution System- MES

Weekly planning meetings are conducted involving operations, technical and maintenance team to analyze the maintenance schedule. Preventive and proactive work orders planning is being done and the schedule is respected for 100 % compliance. Paste plant shutdown is planned every 23 days. Three days of continuous shutdown covering all the sections of paste plant.

Below are some of the major planned activities being conducted for the improved reliability of the equipment. These activities, planned, are completed as per schedule. The refurbishment of preheating screws is carried out every six months. Two screws of the preheaters are replaced with the spare screws and get repaired in the central maintenance as shown in Figure 22. Prior to installing the newly refurbished screw, thickness measurement of the preheater trough is performed, and the condition is monitored. Regarding the Eirich mixer and cooler, their beaters are replaced one shutdown out of two, with refurbished ones. Rebuilding the beaters in-house implies weight and profile compliance. The TSV and Ball Mill inspection involves the liners' wear pattern. The Rhodax crusher chamber and cone are checked every 3rd month with new measurement tactics being adopted to understand the wear condition as shown in Figure 23.

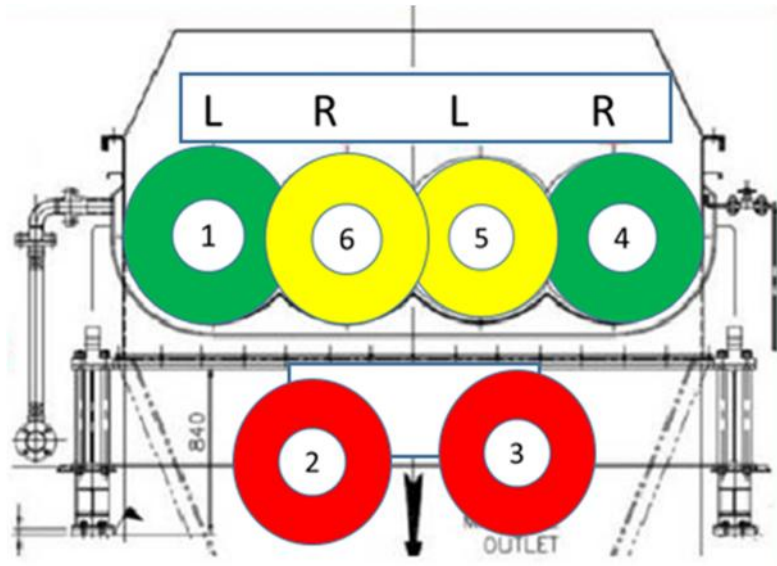


Figure 22. Preheater screws replacement.

Date :- 31/07/2023 (All Dimesions in mm)							Total Wear measured since installation on New Cone 05/06/2023					
Distance From Top(mm)	GAP	East	West	North	South	Average Gap	GAP	East	West	North	South	Average Total Wear(mm)
A	640	a	106	108	102	109	a	3	9	5	7	6
B	690	b	87	90	87	90	b	2	8	7	7	6
C	730	c	74	79	77	74	c	5	14	16	8	10.75
D	780	d	61	68	61	63	d	12	23	20	21	19
E	810	e	57	58	55	60	e	22	23	20	25	22.5
F	840	f	57	57	53	60	f	24	24	20	27	23.75

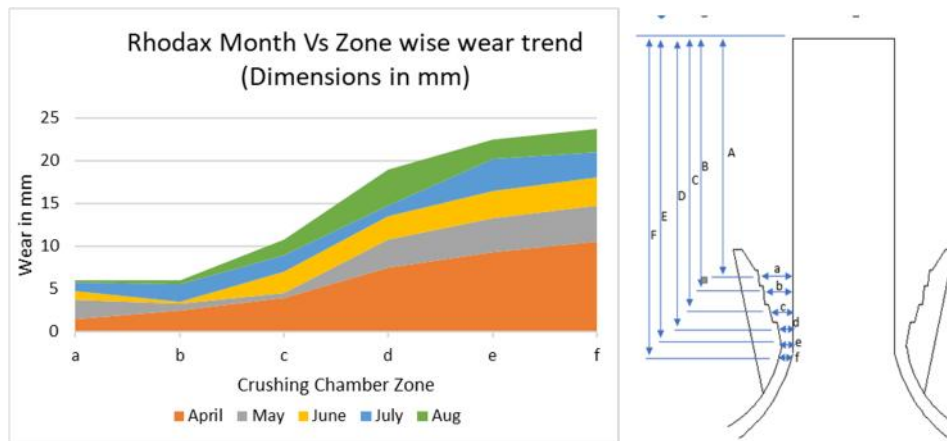


Figure 23. Rhodax wear pattern.

This leads to improvement ideas such as the installation of vibro-compactor cylinder leak pressure transmitters. The pressure reading interlocked with the operation controls raises alarm as soon the hydraulic cylinders start internal leaking. They drastically reduce the major breakdowns. Other initiatives involve the Anode Online temperature monitoring at the outlet conveyor of paste plant cooling. The vibration and temperature sensors (see Figure 24) on heat transfer medium- HTM pumps benefit from new technology via WIFI. Abnormal vibration and temperature generate mails to all concerned representatives for quick actions. Standard condition monitoring techniques using Vibration monitoring (see Figure 25 and 26), Oil analysis (see Figure 27), Thermography (see Figure 28), equipment running checks comply at 100 % routinely.

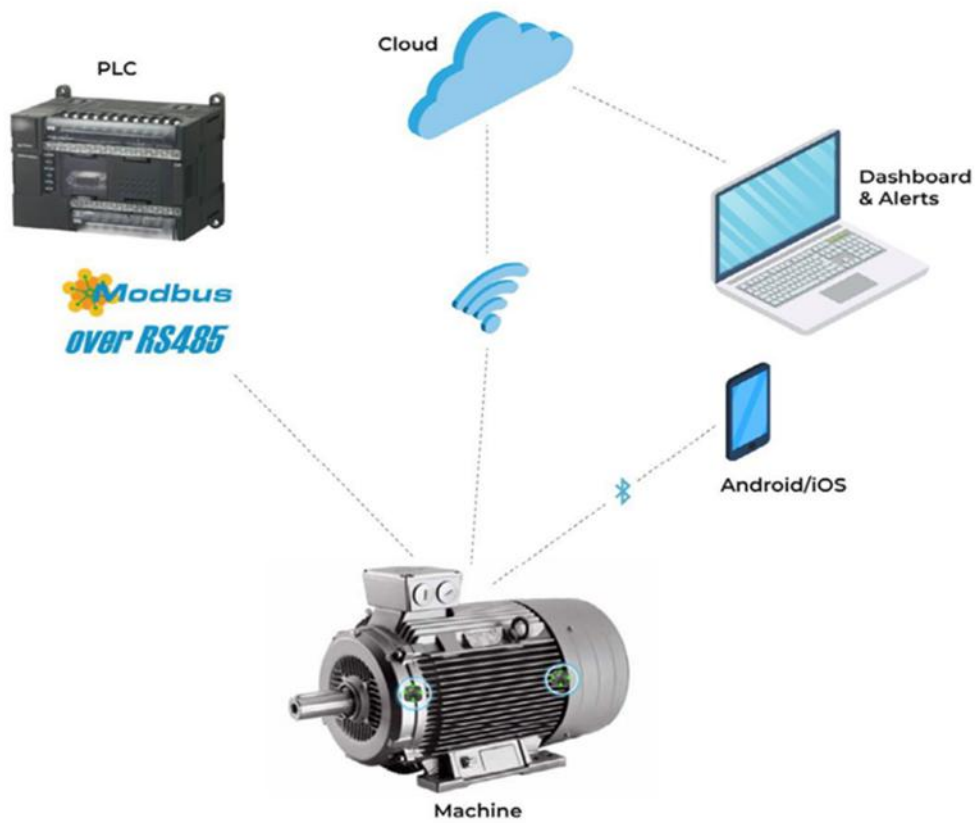


Figure 24. WiFi Technology.

**VIBRATION ANALYSIS REPORT:
Carbon, S411-J110 – Preheating Screw J110**

Observations:

- Overall vibration is increased at motor bearings location.
- Motor NDE bearing is in deteriorating condition.

Suggestions:

- Plan for motor bearings replacement.

Last Measurement Deviation Report						

PNT ID	PARAMETER DESCRIPTION	CURRENT VALUE	PREVIOUS VALUE	UNITS	ABSOLUTE DELTA	PERCENT DEVIATION

S411-J110	- Preheating Screw J110-117922			(16-Jul-23)		
	M1H OVERALL	2.001	2.967	mm/Sec	-.967	-33
	M1P OVERALL	.709	.132	G-s	.577	438
	M1V OVERALL	2.442	1.720	mm/Sec	.722	42
	M1A OVERALL	4.094	3.216	mm/Sec	.878	27
	M2H OVERALL	2.253	2.465	mm/Sec	-.212	-9
	M2P OVERALL	.363	.332	G-s	.031	9
	M2V OVERALL	2.530	2.881	mm/Sec	-.351	-12
	M2A OVERALL	2.652	3.199	mm/Sec	-.547	-17

Figure 25. Information sent.

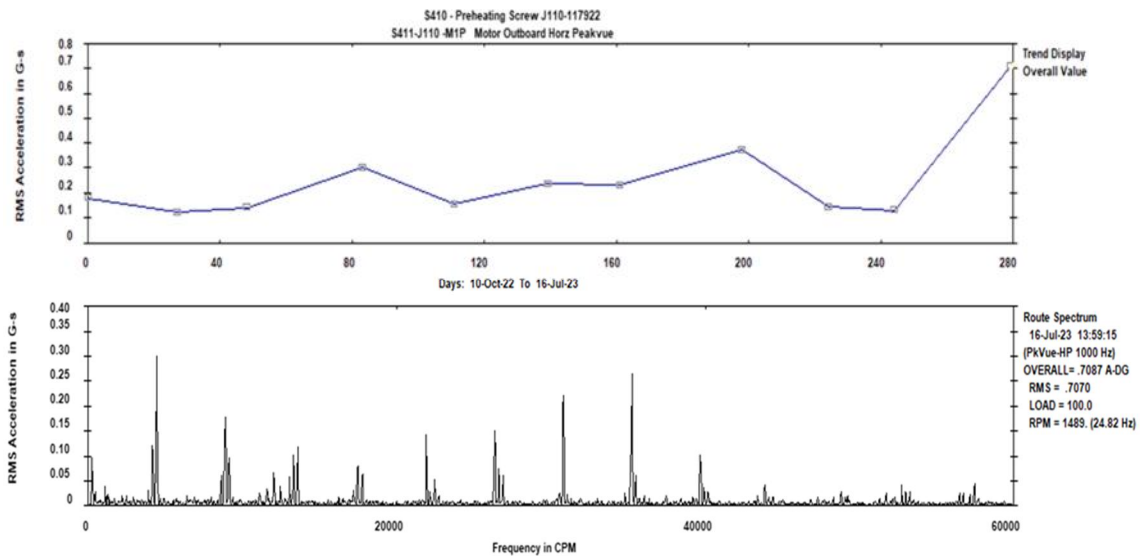


Figure 26. Vibration Analysis report.

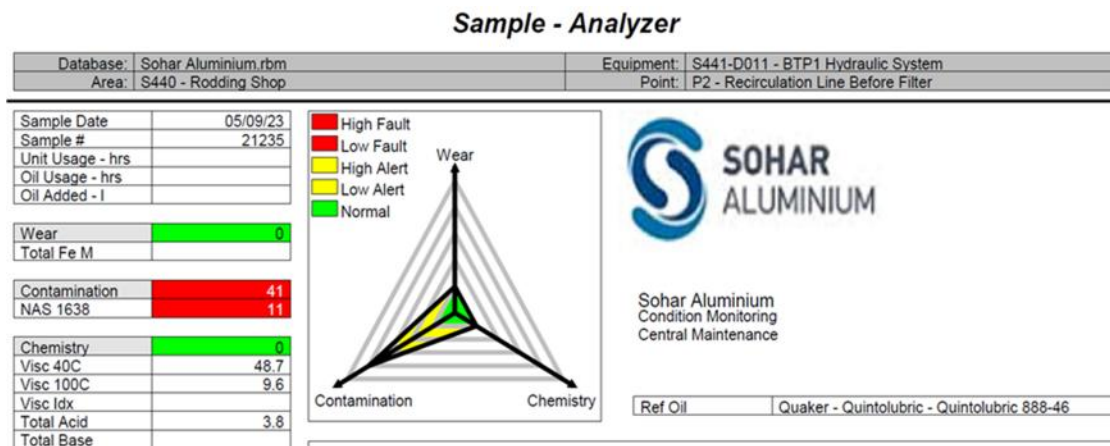


Figure 27. Hydraulic Fluid Analysis.

5. Conclusions and Recommendations

This study managed to identify the root cause behind the high anode density variations. It brought light on the segregated size of the inlet coke, and more specifically on a critical intermediate fraction of particles between 0.15 mm to 1.7 mm responsible for higher density and electrical conductivity values.

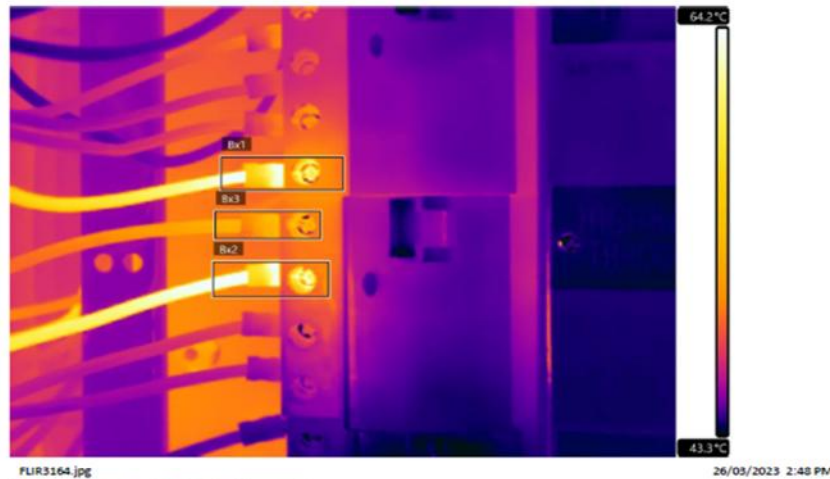
It's recommended the installation of additional crusher to assist the current system to reduce the excess of particles higher than 1.7 mm.

This existence of a minimum threshold (60 %) of the fraction in the coke, and eventually in the anode aggregate, permits not only to reduce the variations but also to maximize the highest values of anode density by using extra vibration time during anode forming.

Improvement in the anode reactivity towards CO₂ contributed to a more robust product. Reinforced by the equipment performance and reliability strategy, this study debottlenecked the anode potential for higher amperage creeping without changing the anode set cycle reduction in potlines in the short term. It paved the way for increasing further the anode density with an additional crusher project in the paste plant.

Thermography Report

Department	Carbon
Equipment	Isolator Cable(High bay Lighting fixture-X431-EJLO-0020)
Part / Location	X431-EAA1-0002
Image taken Date	26/03/2023



Bx1 Maximum	65.2 °C
Bx2 Maximum	66.3 °C
Bx3 Maximum	55.0 °C

Note: cable connector temperature is comparatively high. Needs to be checked.

Figure 28. Thermography used on baking furnace electrical cabinet.

6. References

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