Baked Anode Density Improvement with Rotary Coke - A Success Story of ALBA

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Abstract

The gradual deterioration in anode grade coke quality over the past two decades and its impact on anode quality has been well documented. One of the most affected properties is the coke porosity, commonly measured by the vibrated bulk density (VBD). It is well known that a drop in VBD has a direct impact on the baked anode properties, especially baked apparent density (BAD). A drop in BAD due to a deterioration in coke quality can be compensated by blending high-density shaft coke with rotary coke. Carbon plants with this blending capability can achieve good BAD's. ALBA has its own rotary calciner and produces calcined petroleum coke for captive use, meeting 80 % of ALBA's coke requirement. The worldwide deterioration in green petroleum coke has impacted ALBA's calcined coke porosity leading to low anode BAD's. This paper describes some measures taken by ALBA that enabled an increase in BAD by 0.03 g/cm^3 when using only rotary coke. This was important since one of ALBA's four carbon plants does not have the capability to blend shaft coke with rotary coke. A complete analysis of the process and equipment settings and parameters was carried out and several aspects were considered for improving density. The most significant being the changes made in crushing, mixing and forming parameters. This paper shares the ALBA success story to achieve baked anode densities ≥1.580 g/cm^3 with rotary coke only.

Keywords: Rotary coke, baked anode density, Rhodax, mixing and cooling energy, counterweight

1. Introduction

Aluminium Bahrain (ALBA) is the world's largest single-site aluminium smelter with an aluminium production of more than 1.6 million tonnes (2024) and is known for its technological strength and innovative strategies.

Potline 6 was commissioned in 2019 with DX+ Ultra technology, originally designed to operate at 460 kA. Within six years, it had reached 478 kA an impressive increase of more than 4 % over its original design, Figure 1.

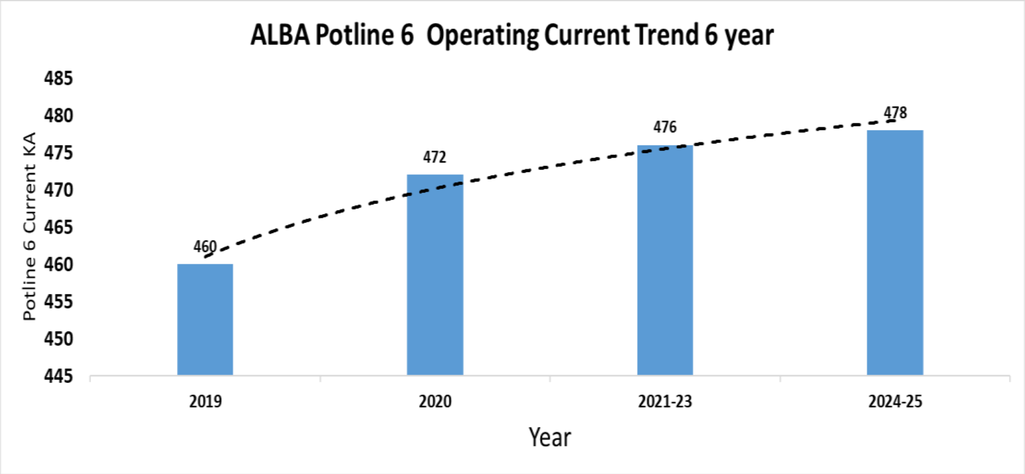

Figure 1. ALBA potline 6 operating current trend.

One of the critical factors in sustaining high amperage operation is anode quality. Potline 6 performance has shown notable sensitivity to baked anode density (BAD), likely due to the higher anode current density compared to other potlines. A reduction in BAD to < 1.56 g/cm^3 during Q3 2024, had a negative impact on potline performance, prompting the formation of a specialized team to optimize process parameters and increase BAD to ≥1.58 g/cm^3.

BAD is influenced by raw material quality, dry aggregate granulometry, mixing energy and anode forming parameters.

This paper presents ALBA's comprehensive approach to enhancing BAD from 1.55–1.56 to 1.58 g/cm^3 and above using relatively low VBD rotary kiln calcined coke. The optimization strategy focused on optimization of key process parameters affecting BAD and equipment capability enhancements. These included improvements to crushing efficiency, mixing energy, and anode forming parameters in the paste plant.

ALBA's Paste Plant 4, commissioned in 2019 to supply anodes to Potline 6, incorporates state-of-the-art technology, including:

- **Rhodax® crusher** for dry aggregate preparation, Figure 2a.
- **IMC® process (Intensive Mixing Cascade)** for paste mixing and cooling using an Eirich mixer RV33 and Cooler RV33, Figure 2b.
- **Xelios™ vibrocompactor** for anode forming equipped with vacuum and counter pressure.

All the dry mix materials are fed into the Rhodax® crusher, and the output of the crusher is processed through a Mogensen screening system, where materials are classified based on particle size. In this plant, two fractions comprising grains (0.3–30 mm) and fines (< 0.03 mm) are being used for green anode production.

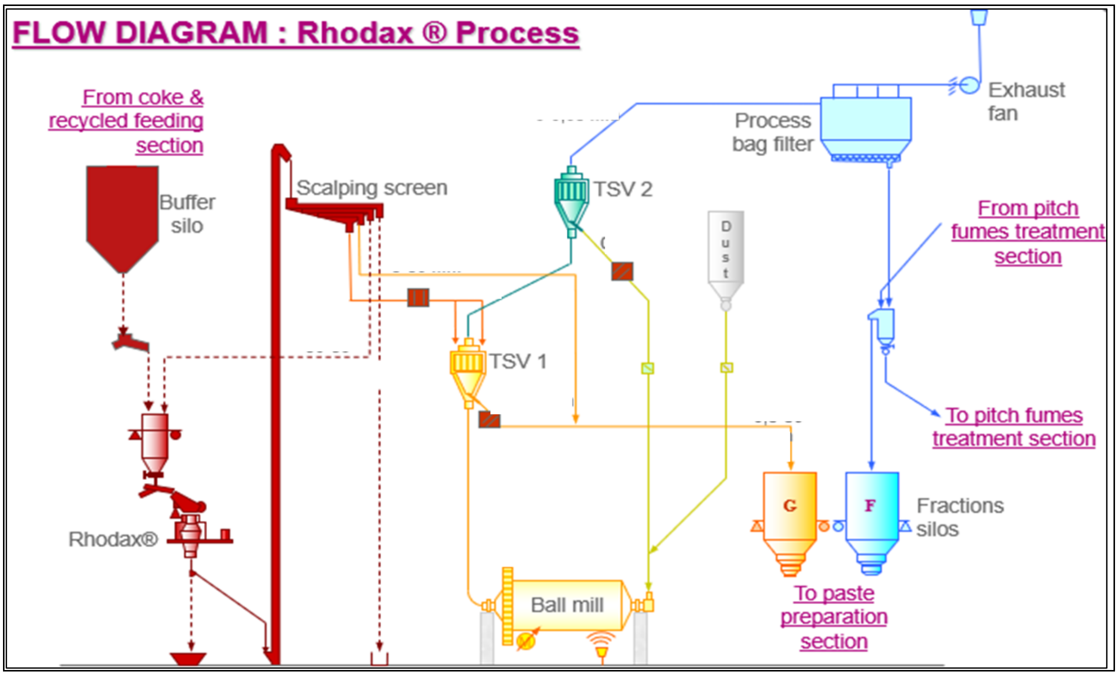

Figure 2a. Dry aggregate preparation line.

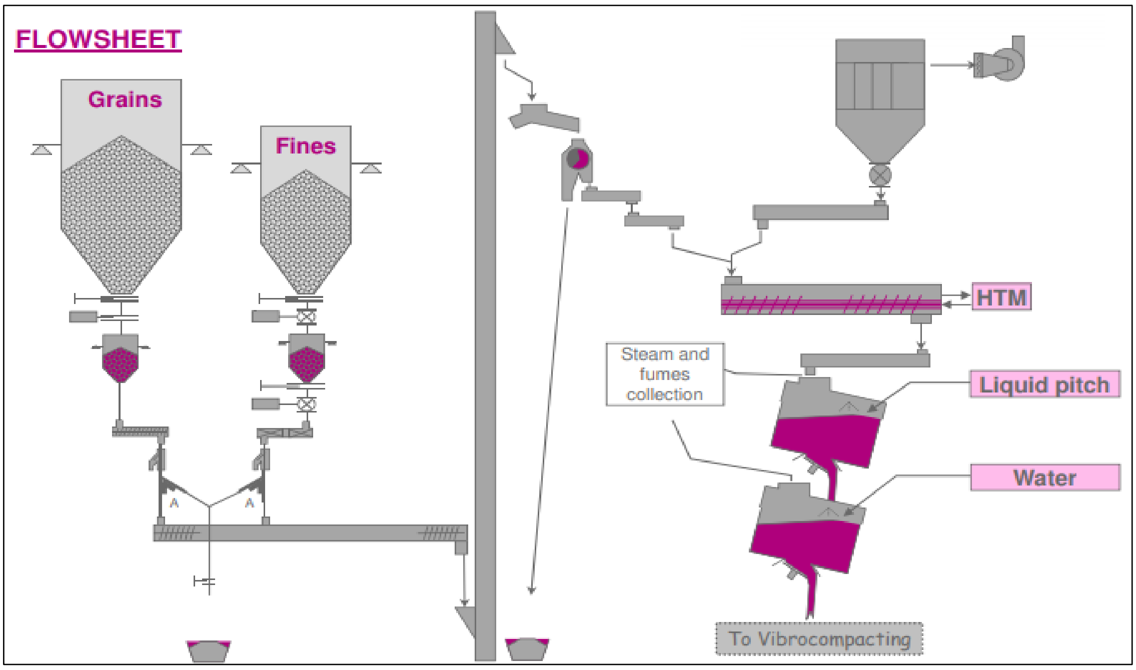

Figure 2b. Paste mixing and anode forming line.

2. ALBA Line-6 Anode Quality and Impact on Potline Performance

As mentioned previously, ALBA operates four carbon plants, three of which have a coke blending facility (rotary + shaft), enabling them to achieve the desired BAD using shaft coke.

Comprehensive evaluations were conducted across Paste Plants 1 to 3 to assess the influence of varying shaft coke blending ratios on anode quality parameters. The trial outcomes demonstrated a positive correlation between increased shaft coke content and enhancements in both green anode density (GAD) and baked anode density (BAD), indicating that higher proportions of shaft coke contribute to improved anode density, Figure 3.

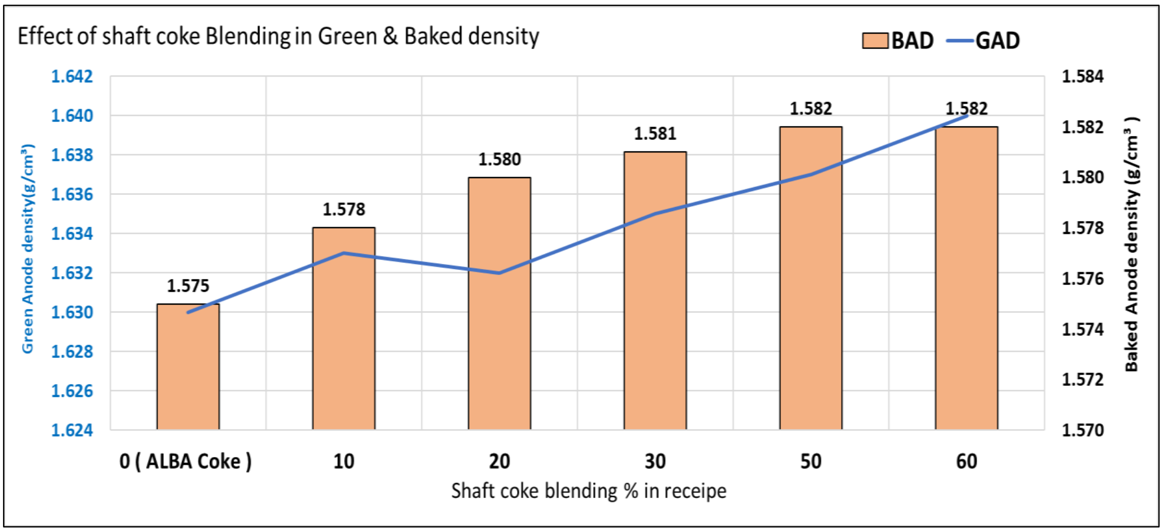

Figure 3. Carbon 1-3: Different shaft coke blend & effect on baked anode density.

Between June and October 2024, a decline in baked anode density (BAD) was observed in carbon plant 4 anode, with values dropping to approximately 1.55–1.56 g/cm^3 (refer to Figure 4). A similar downward trend was noted in Carbon Plants 1 to 3, primarily attributed to the limited use of shaft coke blending (10–20 %) to mitigate potential adverse effects on other baked anode properties.

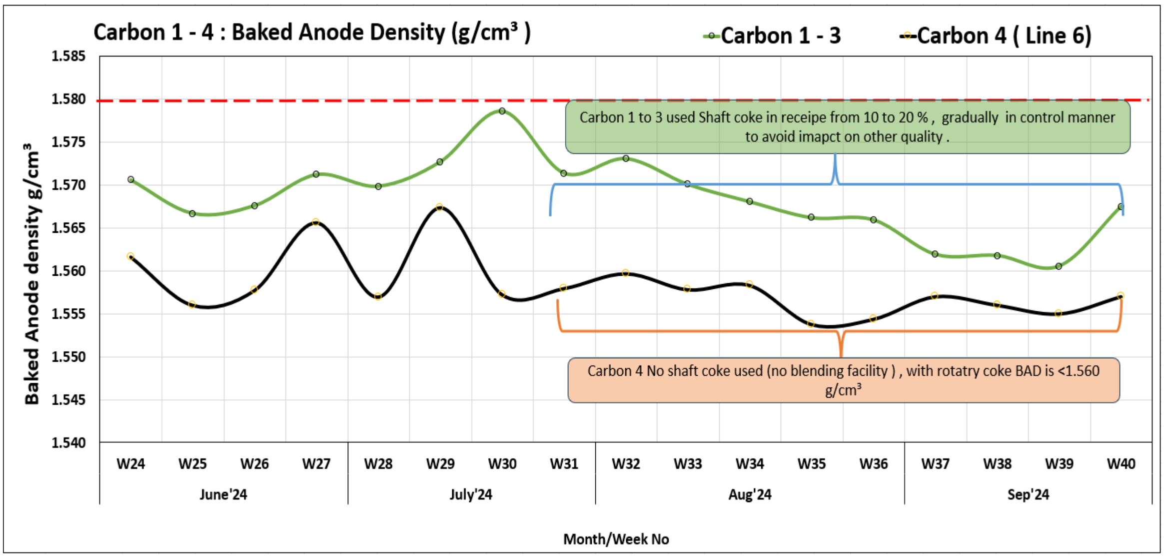

Figure 4. Carbon 1-4: Baked anode density (2024).

Carbon plant 4, which supplies anodes to potline-6, lacks an integrated coke blending system and relies solely on rotary kiln coke with a vibrated bulk density (VBD) of around 0.860 g/cm^3. This limitation significantly hampers its ability to achieve the target BAD specifications. The resulting low-density anodes contributed to increased carbon dusting and spikes in Line-6.

To address these challenges, a cross-functional task force comprising experts from Carbon Operations and Process Control was established. Drawing upon operational expertise, literature reviews, and technical references [1–3], the team initiated a series of targeted trials aimed at enhancing BAD performance.

3. Initial Trials: Optimization of Process Parameters

During an initial period using the above methodology, paste plant and equipment parameters were optimized as much as possible to achieve maximum BAD's. To re-validate this work, another set of optimization work was done and with this initial and subsequent optimization work, the BAD improved slightly from 1.55 to 1.56 g/cm^3. A summary of the optimization work performed in this phase of work is shown in Table 1.

Table 1. Results of initial paste plant process optimization.

Process Parameters	**Units**	**Before Optimization**	**After Optimization**
Preheating Temperature	°C	180	190
Pitch temperature	°C	190	195
Fines in recipe	%	21	22
Ultrafine in recipe	%	13.5	14
Grains to Sands Ratio (GSR)	-	6.5	7.0
Counter pressure	bar	1.2	1.6
Vibration time	sec	50	60
Vibration speed	rpm	1300	1320
Coke preheater speed	rpm	4.2	3.9
Results			
Baked Anode Density	g/cm^3	**1.55**	**1.56**

4. Optimization Beyond Equipment Design Capability

The initial optimization work was limited by equipment maximum design capacities. At this stage, it was decided to challenge equipment capabilities and explore upgrades beyond the original equipment design. The critical process and equipment list identified for improvements in the BAD are listed below:

- RHODAX crusher: to improve crushing efficiency and improve dry aggregate granulometry.
- Paste and mixer cooler: to increase mixer energy beyond equipment design capacity.
- Vibro-compactor: to push forming parameters to achieve higher vacuum and forming temperature without negatively impacting electrical resistivity (ER).

4.1 Improve the Crushing Efficiency of the Rhodax® Crusher

The RHODAX® crusher operates through the rotation of four unbalanced masses (vibrators), each driven by a separate motor. Figure 5 illustrates the operation of the crusher cone and ring from a side view. The material is funnelled between the crushing cone and the crushing ring, undergoing compression due to the alternating motion of the ring. As the material descends by gravity within the chamber, it undergoes successive movements while the cone rotates over a bed of material, progressively reducing its thickness to just a few millimetres.

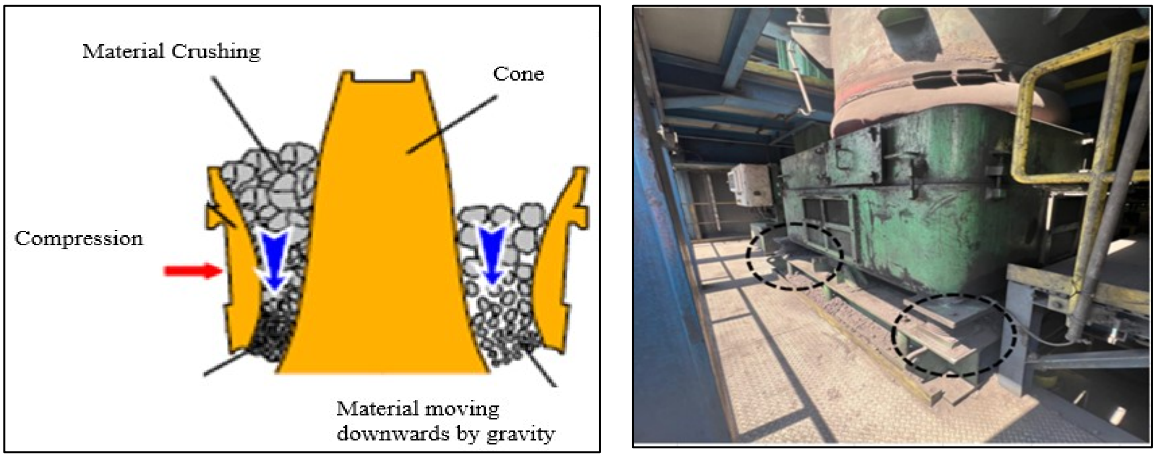

Figure 5. Rhodax crusher design (left) and suspension pad (right).

An increase in the butt's percentage in the recipe can be used to target a higher BAD but there is a constraint/limitation in running the Rhodax at a higher speed to deal with the high butt's level and additional crushing required.

The higher speed causes excessive vibrations exceeding 20 mm/sec. To address this, the Rhodax suspension pad was redesigned, Figure 5. This allowed the Rhodax to operate at a higher power and the speed was increased from 420 rpm to 520 rpm, Figure 6.

This allowed the dry aggregate material to shift towards a finer size, Figure 6. This in turn, provided the flexibility to increase the butt's percentage in the recipe without causing high vibrations and disturbances to the RHODAX operation.

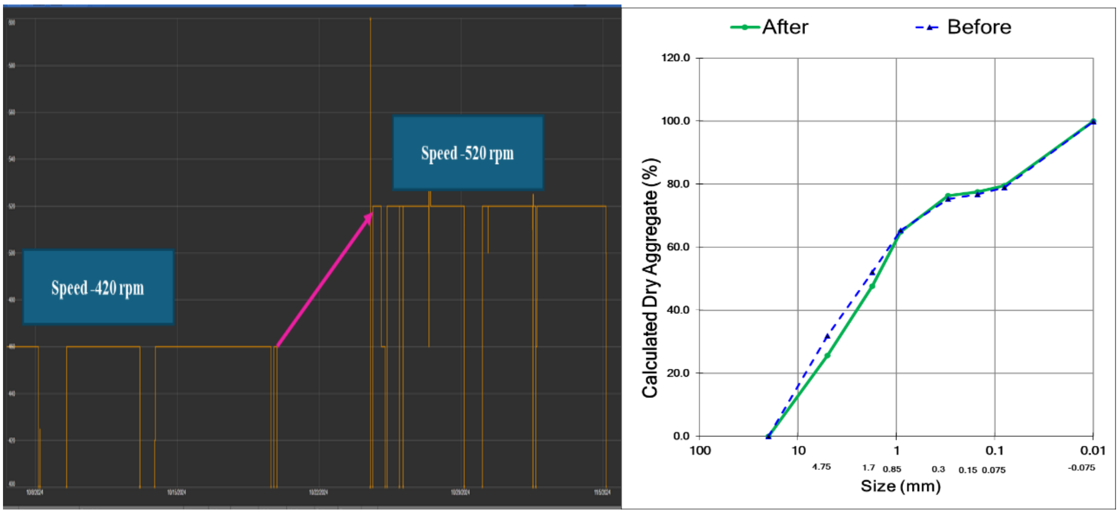

Figure 6. Rhodax speed (right) and dry aggregate curve (left).

Table 2 summarizes the process changes made as a result of the above.

Table 2. Result of changes to Rhodax crusher operation.

Process Parameters	Units	Before	After
Rhodax® speed	rpm	420	520
Average butts % in recipe	%	28	32
+16mm fraction in dry Aggregate	%	1.2	0
Recirculation material	%	> 8	< 4
Rhodax vibration	mm/sec	>20	< 10

4.2 Mixer and Cooler Energy

Alba utilizes the Intensive Mixing Cascade (IMC) technology to mix the solid material with the liquid pitch, Figure 7.

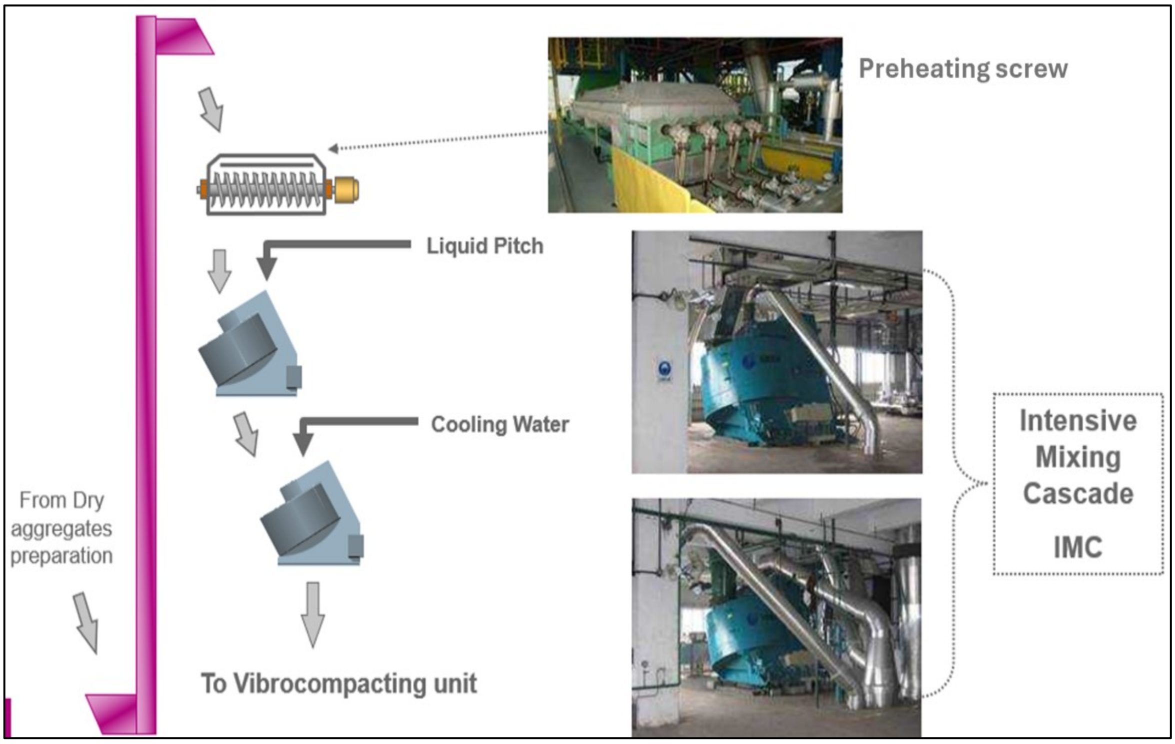

Figure 7. Intensive mixing cascade.

Previously, the mixer operated in auto mode, requiring periodic adjustments to the paste weight to maintain the target of 290 kWh of mixing power. To optimize control and reduce variability, the Proportional-Integral-Derivative (PID) system was further developed and refined to function in cascade mode, as illustrated in Figure 8. This enhancement allowed for automatic weight adjustments based on power settings, minimizing power fluctuations from one anode to another.

Name	Description	Value	Units	Average	Minimum	Maximum	Bottom	Top
Anode Parameters|Mixer Power	PLC Tag: K1_Forming.Pcs.LastAnodeProd.MixTotalPwr_W	302		294	135	322	100	350
Anode Parameters|Cooler Power	PLC Tag: K1_Forming.Pcs.LastAnodeProd.CoolTotalPwr_W	283		293	100	322	0	350

Figure 8. Mixer and cooler PID in cascade mode.

One target in the paste mixing work was to increase the mixer and cooler power but this was constrained by limitations in the rotor design. To address this, a collaboration was started with the original equipment manufacturer (OEM) to identify a solution. This led to the transition from a star-type rotor to a drum-type rotor, Figure 9.

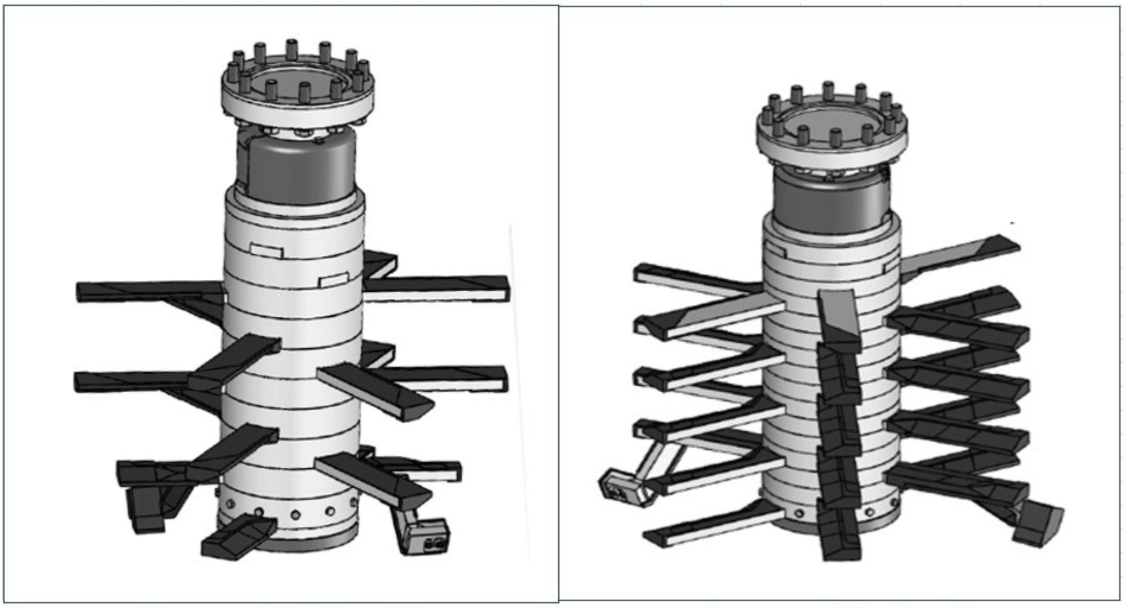
Star type rotor (No's of beater 16)   Drum type rotor (No's of beater 24)

Figure 9. Star type rotor (left) and drum type (right).

In the star-type rotor configuration, the mixer and cooler power were limited to 5.8 kW/t (each). By changing the design of the rotor which incorporates the increasing number of tools/beaters from 16 to 24, the mixer power was successfully increased from 5.8 to 6.5 kW/t (+12 %). This modification significantly improved the overall mixing efficiency, Figure 10.

Name	Description	Value	Units	Average	Minimum	Maximum	Bottom	Top
Anode Parameters|Mixer Power	PLC Tag: K1_Forming.Pcs.LastAnodeProd.MixTotalPwr_W	318		314	67	335	270	330

Figure 10. Mixer and cooler power and load.

5. Vibro-Compactor Optimization

As part of the vibro-compactor optimization process, several key parameters were adjusted to enhance performance. These included eccentric mass adjustment, forming temperature optimization, and vacuum setting calibration.

5.1 Eccentric Mass Adjustment

To enhance the compaction force during anode forming, 6 mm counterweight plates were added to the vibro-compactor, Figure 11. Following this modification, multiple G-values were measured, along with the compaction force on the anode, to ensure there were no negative effects on machine lifespan or anode quality such as over-compaction or cracking.

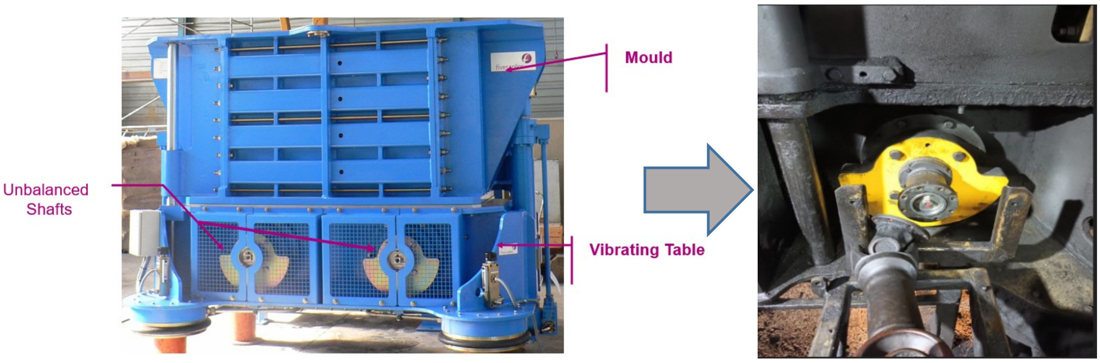

Figure 11. Vibro-compactor with mounting pads.

The results confirmed that acceleration remained below 12 mm and the compaction force increased from 0.88 to 0.94 MPa, Figure 12.

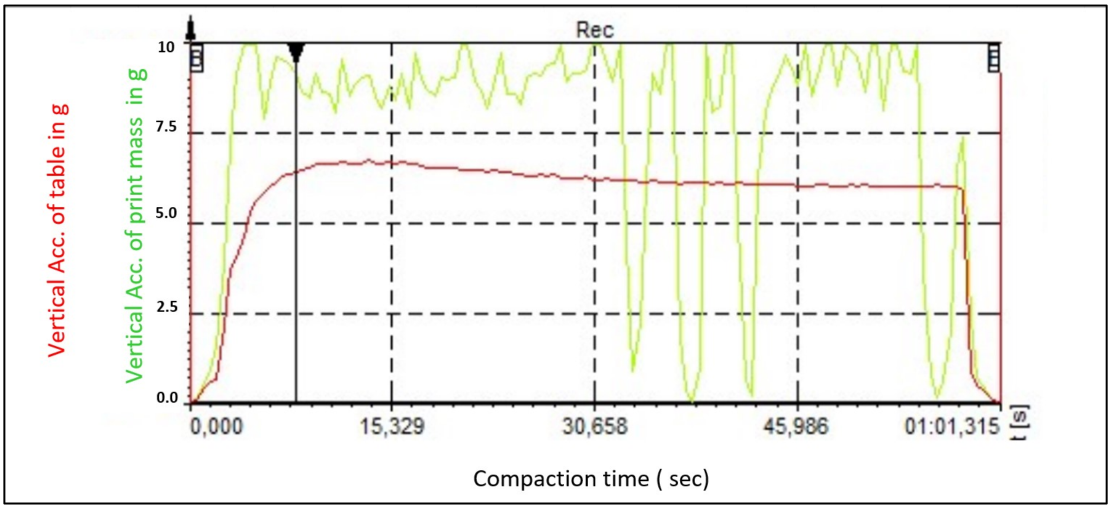

Figure 12. Vibro-compactor table and mass vertical acceleration g-value.

5.2 Forming Temperature and Vacuum Setting

Trial batches of green anodes were produced under varying forming temperatures, ranging from 168 to 175 °C. After baking, core sample analyses revealed a 0.02 g/cm^3 increase in baked anode density.

Additionally, trial batches were produced under different vacuum pressures, ranging from less than 250 mbar to greater than 150 mbar. Core sample analyses following the baking process confirmed an increase of 0.01 g/cm^3 in baked anode density.

6. Results and Discussion

The initial efforts focused on optimizing the paste plant process parameters were not sufficient to achieve the target BAD levels. The major upgrades done to critical equipment such as the Rhodax crusher, paste mixer and cooler and vibro-compactor led to an increase in the BAD from 1.55 to 1.58 g/cm^3**,** Figure 13.

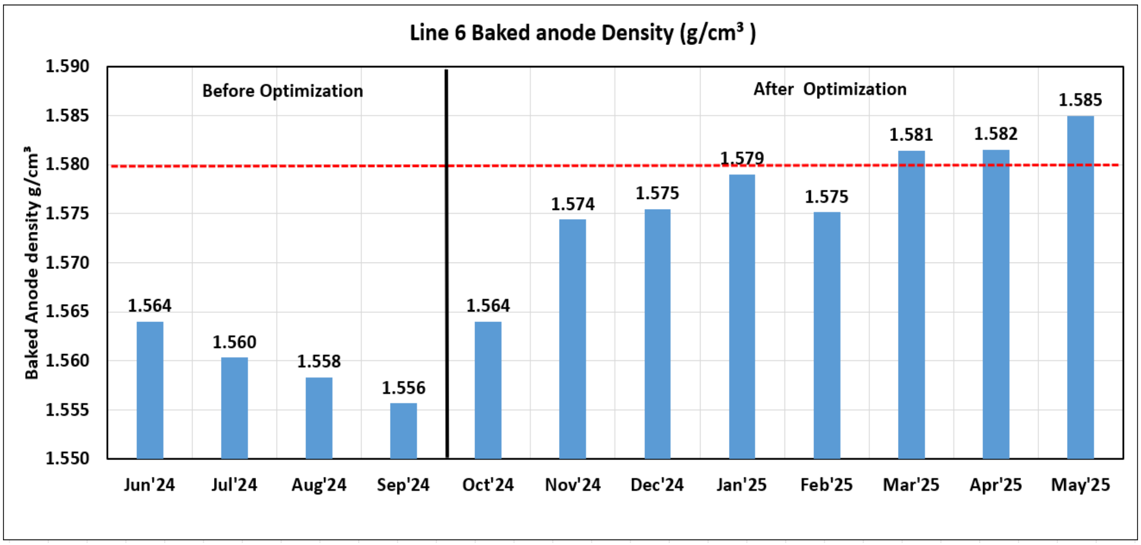

Figure 13. Line 6 baked anode density improvement.

Table 3 summarizes the results of some of the key paste plant optimization parameters and some of the major contributors were:

- Upgrade of the Rhodax crusher improved crushing efficiency and facilitated an increase in the butts percentage in the recipe. The Rhodax upgrade also helped to improve the dry aggregate particle size distribution
- Upgrade of the paste mixer and cooler helped to increase the mixing and cooling energy by 12 %
- Modifications to the vibro-compactor and optimization of the vacuum and forming temperature showed a significant improvement in density with minimal impact on equipment

Table 3. Results of paste plant process optimization.

Parameters	Units	Before	After
Rhodax® crusher Speed	rpm	420	520
Butt % in recipe	**%**	**28**	**32**
+16mm in Dry Aggregate	**%**	**1.2**	**0**
Recirculation material	%	>8	<4
Rhodax Vibration	mm/sec	>20	<10
Rotor	Type	Star	Drum
Specific power for each	**kW/t**	**5.8**	**6.5**
Total Power for each	kW	290	325
Eccentric mass adjustment	mm	0	6
Forming temperature	**° C**	**168**	**175**
Vacuum	**mbar**	**250**	**150**
Baked Anode Density	g/cm^3	**1.55 to 1.56**	**> 1.58**
Baked Anode Density < 1.56	%	**54**	**6**
Baked Anode Density > 1.58	%	**11**	**36**

7. Conclusions

Potline 6 performance is sensitive to BAD and Potline 6 performance started to deteriorate at BAD's close to 1.56 g/cm^3. The lower BAD resulted in a major constraint on increasing the Potline 6 current beyond 475 kA.

With the major equipment upgrades and optimization work undertaken, the BAD improved significantly from 1.55 to 1.58 g/cm^3. This resulted in an improvement in Potline 6 performance as the number of anode spikes in the pots reduced significantly from 6 to 2 per/day. The BAD improvement also resulted in no negative impact on other anode quality parameters, Table 4.

Table 4. Baked Anode Properties.

Properties	Units	Before Optimization	After Optimization
Electrical Resistivity	µΩ m	55.6	54.0
Flexural Strength	MPa	9.8	10.4
Air Permeability	nPm	0.5	0.5
Air Reactivity Residue	%	74.3	74.9
Carboxy Reactivity Residue	%	91.4	91.3

To further improve anode quality and facilitate current creep in Line-6, more projects are underway. Some of these projects are listed below and mainly focus on more efficient coke and butts crushing in the Rhodax plant to ensure good packing density:

- Coke crushing facility to crush coke below 10 mm before feeding to Rhodax crusher
- Optimize Rhodax crushing circuit by installing roll crusher to crush oversize material and get maximum benefit from the Rhodax crusher.

8. References

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