

Improvement in Control Strategy to Maximize Productivity and Enhance Hydrate Particle Strength in Bayer Precipitation Circuit

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Abstract

Maximizing of alumina precipitation per liter of circulated liquor (liquor productivity or yield) is a key objective of an alumina refinery which reduces operating costs as the yield increases. An equally important KPI (key performance indicator) in alumina production is the hydrate strength which is critical to avoid high attrition (tendency of alumina to breakdown during calcination process and handling). Higher attrition has potential to higher dusting, leading to the product losses and environmental concerns. It also affects efficiency and stability of pot operation in smelters. Organic build up in aluminate liquor due to high organics in feed bauxite or ageing of liquor affects the yield and the quality of product hydrate. Hence, optimization of the process parameters, including the removal of oxalate impurities from the Bayer circuit to control below the critical saturation limit (defined as critical oxalate concentration or COC) is essential for managing the detrimental effects of these impurities on the yield and the alumina quality. This paper outlines the various control methodologies adopted at Lanjigarh Alumina Refinery for enhancing the hydrate strength and maintaining optimum liquor productivity while charging high organic content bauxite. Initial data analysis of 2 years showed that a variety of factors, including higher temperature and seed charge in agglomerator led to lower supersaturation resulting in weak particle bonding and low strength. Efficient control measures like, Tschamper Ratio (TR) based control with the algorithms in DCS, oxalate inventory management for maintaining margin between circuit oxalate concentration and COC which included precipitation end tank temperature control, part diversion of oxalate enriched liquor stream for destruction through lime and seed washing were introduced. Lanjigarh Refinery has also taken up a way forward to look into possibilities of further improving hydrate strength with potential improvement in liquor productivity by the simulation of hydrate classification circuit to optimize seed charge and granulometry control.

Keywords: Yield, Hydrate strength, Tschamper Ratio, Critical oxalate concentration.

1. Introduction

M/s Vedanta Aluminium Limited is located at Lanjigarh, Orissa State, India, having a capacity of 2 MMTPA smelter grade alumina production by employing Bayer Process of low temperature and pressure digestion. Alumina hydrate in solid form is precipitated from a super-saturated aluminate liquor, produced from the digestion of bauxite ores. In the Bayer Process, an important design objective is to maximize liquor yield (defined as kg of alumina produced per liter of circulated liquor). The main advantages are as follows:

- Plant production capacity increases with more or less the same equipment (at least within a certain production range); i.e., the capital cost per annual ton production capacity drops for several process areas (e.g., digestion, decantation, precipitation, and power station)
- Lower steam and energy consumption per tonne alumina (e.g., digestion steam and overall pumping power)
- Although not straight forward, in some aspects, product quality control improves when the conditions for yield increase is provided (e.g., increasing the alumina super-saturation

of the mixture of aluminate liquor and spent liquor recycled with the seed charge in precipitation feed improves hydrate strength which is critical to avoid high attrition (tendency of alumina particle breakdown during calcination process and handling) resulting higher fines (-325 mesh) fraction in alumina).

The productivity and economy of all alumina refineries depend on optimizing the precipitation process. The dual aim of the precipitation process is to maximize productivity and to improve product quality. The yield and strength of hydrate precipitated are dependent on process parameters and to some extent on certain impurities. The important parameters are temperature profile of precipitation circuit, initial alumina to caustic ratio (RP or A/C), concentration of pregnant sodium aluminate liquor, seed ratio, precipitation time, impurity level of input seed hydrate and aluminate liquor. The attrition of alumina can occur during precipitation and/or calcination where the latter is more prominent and dependent on the precipitation conditions. The strength of alumina is determined by the term of attrition or attrition index (breakdown of particles) of alumina during calcination. Not only the mode of calcination influences the breakdown of alumina to some extent, but also the strength of the crystal of hydrate plays a greater role. All parameters which influence the precipitation yield and the strength of crystals are very much dependent on the precipitation process and the liquor quality which is again dependent on the chemistry and mineralogy of bauxite and its processing technology. This paper describes the different methodologies adopted to maximize the productivity as well as improve the product quality.

2. Liquor Productivity (Yield) Increase Options Adopted by Refinery

The liquor productivity for the refinery was running very low at 68–72 gpl during the past years. This was very low as compared to the design. The increasing recirculation load of the refinery was leading to high energy costs as well as reducing throughput from the refinery. The Figure 1 shows the liquor productivity for a period of 10 months wherein the average productivity was 68 gpl.

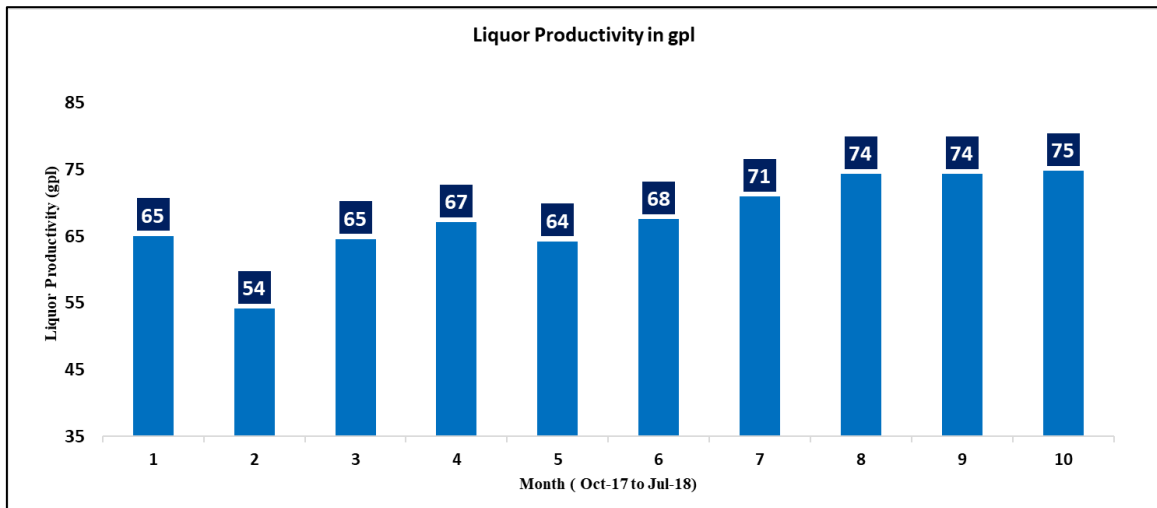


Figure 1. Liquor productivity graph.

The following options were analyzed for the possibility of an increase in the yield:

1. Targeting optimum temperature profile across precipitation by increasing availability and performance of Inter stage coolers. To increase availability of Interstage coolers (ISCs) , the refinery took the following steps:

- Replacement of new ISCs instead of existing damaged ISCs: The refinery had operated ISCs almost in the range of 7–8 years despite a design life time of around 4–5 years (typical life time expectancy of tank bottom mounted coolers).
 - Provision of caustic cleaning facility for ISC cooling water side: Analysis showed the gibbsitic scaling in cooling side which was a resultant of previous plate leakages.
 - Provision of acid cleaning facility of ISC cooling water side: The cleaning facility for cooling media side was not available as a design fault causing poor heat transfer due to lime scales.
2. Improving availability of coarse seed filtration (CSF) unit (for reduction in recycle spent liquor in the circuit and improve residence time in precipitation):
- The turnaround time for each filter reclothing was very high due to high fumes in the area. The design of the filters is such that the cake chutes open up to common slurry tanks where in hot aluminate liquor is being used for repulping leading to high fumes. Provision of exhaust system in each filter hood was given.
 - Provision of screen facility at the inlet of each filter feed pump: Absence of screening facility at the pumps feeding to the filters were leading to intermittent trough and dump line blockages and filter outages
 - In house engineering and provision of chemical cleaning facility for filters barometric legs: The design of the filters did not incorporate any chemical cleaning facility of filtrate/barometric system
 - CSF reslurry pumps capacity upgradation (along with change in pump model to facilitate higher solids conc handling)
 - Design change of Quick Bleeding Valves to incorporate AFR (air filter regulator) along with surge vessel.
 - Bypass line for coarse seed filtrate for 48TK0002 (filtrate tank in fine seed unit) to allow scheduled outage of coarse seed filtrate tank for annual cleaning.
 - Feeding system redesigning (provision of flow control valve with flow element) to allow flow control to each operating filter along with filter speed control linked to trough level
 - Agitator capacity upgradation (design change in gear box, motor and impeller system) for handling higher solids concentration in reslurry tank.
3. Precipitation solids (for higher seed surface area for enhanced precipitation):

The precipitation of alumina from supersaturated aluminate solution is highly dependent on the solids concentration in the precipitators. The higher the solids, the higher the growth on the new agglomerates resulting a higher yield. The average precipitation solids of the refinery were low at 330 gpl despite the target of ~450–470 gpl. The main reason for the lower solids in precipitators is the higher hydrate production at the downstream to avoid any disturbance in alumina supply chain without considering the equivalent cut down alumina production from aluminate solution. This leads to the eventual depletion of precipitation solids. A detailed SOP for the control of precipitation solids was formulated which involved the adjustment of finished product alumina production as per target solid concentration across precipitation with respect to the red side hydrate production. This led to an improvement of precipitation solids up to ~460–470 gpl which increased the seed charge to agglomeration tanks by 17 % and to growth tanks by 9 %, resulting an increase in yield as shown in Figure 2.

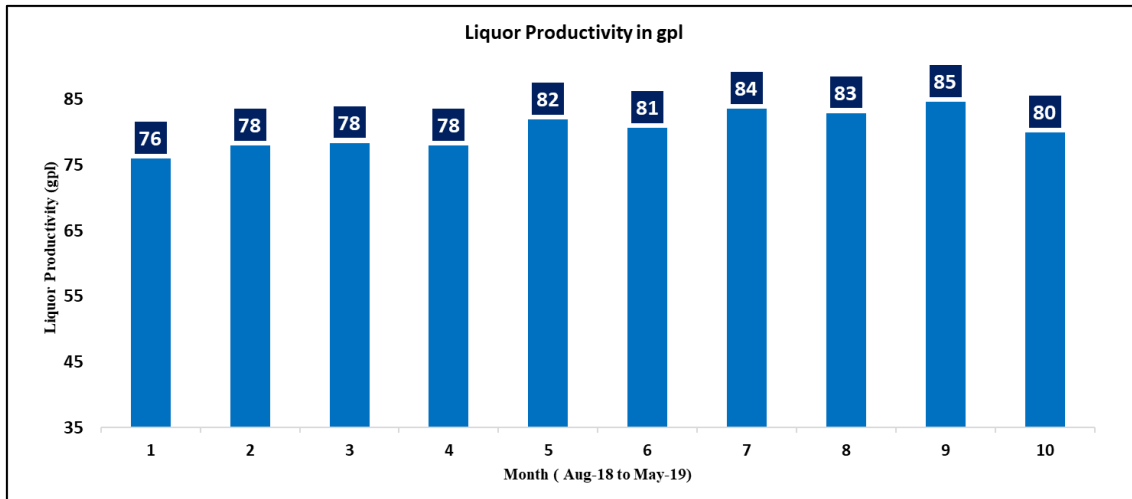


Figure 2. Liquor productivity graph after improvement.

3. Hydrate Strength Increase Options Studied by Refinery

Lanjigarh Alumina Refinery is designed to produce smelter grade alumina with alumina fines specification, -45 microns size within 10 % for its customers. An important issue for the optimization of the Bayer precipitation section is the constraint to sustain a delicate balance between increasing the yield whereas controlling particle size and strength. Increasing the yield would also mean increasing the seed charge which could also lead to high fine particle generation, poor size control and particle breakage in calciners resulting higher fines in final product. Figure 3 shows the SEM image of typical alumina produced by Lanjigarh Refinery.

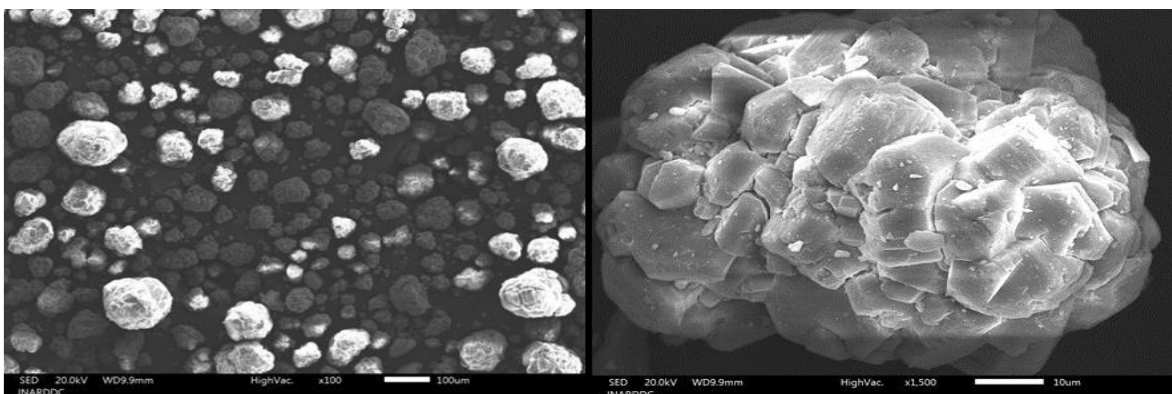


Figure 3: Typical SEM image of sandy alumina grains produced by Lanjigarh Refinery.

Figure 4 shows the normal distribution of fines (-45 μm) in alumina (final product output from calciner) and hydrate feed (hydrate feed to calciner) for the period of phase 1 & phase 2. During phase 1 period, in 80 % of the time, -45 μm particles in alumina has been less than 10 %. This is considered as a good performance. Around phase 2 period, refinery noticed an increase in -45 μm particle generation in the calciners with a concern of further increase in particle breakage, particularly occurring parallel with increasing calciner throughput, which may lead to the difficulties of the maintaining product quality within the specifications. Figure 5 describes the analysis of the particle breakage with the available data. It was studied to understand the root cause for such a change and further actions to be taken to reduce the breakage to make the final alumina product less vulnerable in terms of meeting the spec of -45 μm .

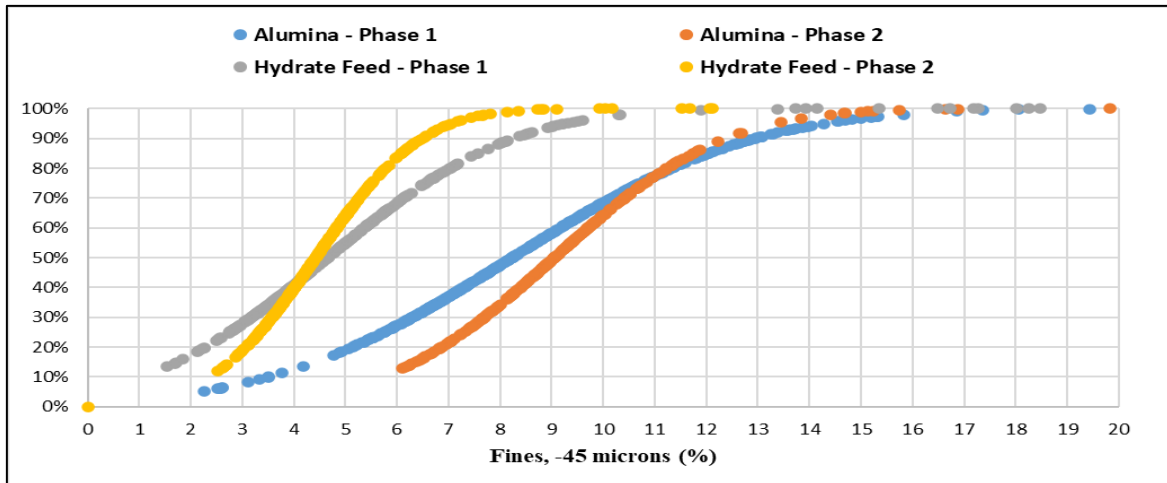


Figure 4. Normal distribution of fines in alumina and hydrate feed (Phase 1 and Phase 2).

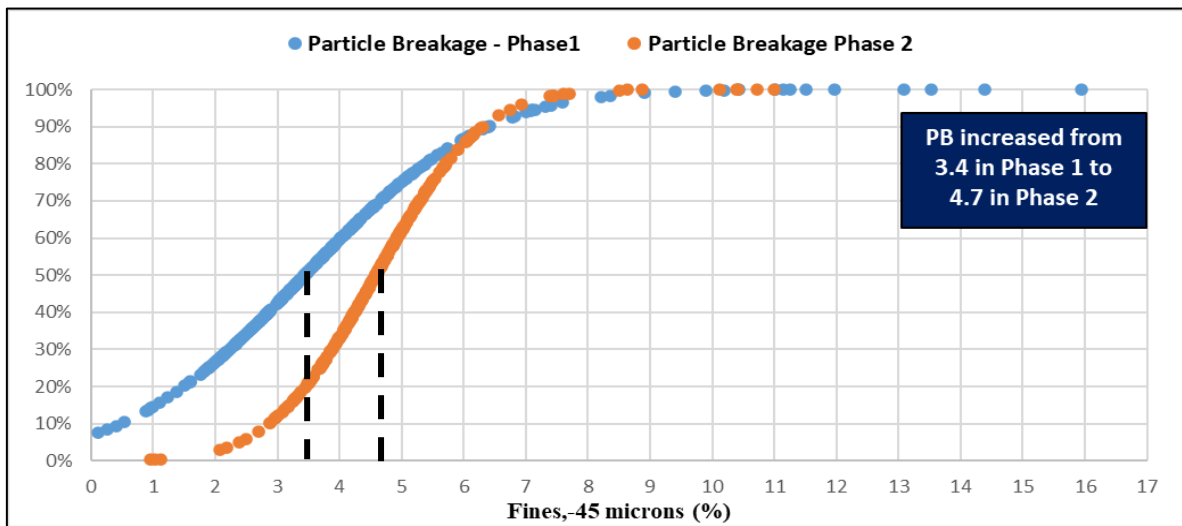


Figure 5. Particle breakage (PB) distribution during Phase 1 and 2.

It was suspected that the phase 2 product strength was impacted by a combination of different factors. The study that was done examined the following factors to screen and identify the potential reasons for the higher breakage and finer alumina product using the long-term data from both the phases.

- Impact of hydrate feed rate (tph) to calciners on the apparent breakage
- Impact of calcination process conditions (P04 temperature) and alpha alumina content on the alumina breakage
- Impact of precipitation conditions on hydrate strength and calcination breakage:
 - Agglomeration conditions and performance
 - Growth conditions
 - Hydrate classification performance

3.1 Impact of Hydrate Feed Rate

According to literature [1], particle breakage in calciner is proportionate to the square of hydrate feed rate, tph (hydrate feed to calciners in tonnes/h). Figure 6 shows the studied data during the entire phase. The data shows two distinct correlations for two groups of hydrate with different strength. For weaker hydrate, the breakage increases more significantly with the feed rate. For

stronger hydrate, the correlation is less significant. For example, the breakage is about 2.0 % at a feed rate of about 117 tph ($117^2 = 13\,689$) and increases to about 5.0 % at the maximal feed rate of about 210 tph ($210^2 = 44\,100$). From the period between phase 1 to phase 2, the average hydrate feed increased from ~180 to ~192 t/h (~6.8 % increase), and total breakage increased from ~3.5 to ~4.4 (~27 % increase). Though hydrate feed rate impacts the particle breakage, we cannot say the step change in apparent breakage was caused by just the hydrate feed rate. If we examine closely the trending on Figure 7 (blue bar is from where phase 2 was started), there seems a step change on particle breakage although there was no step increase in hydrate feed.

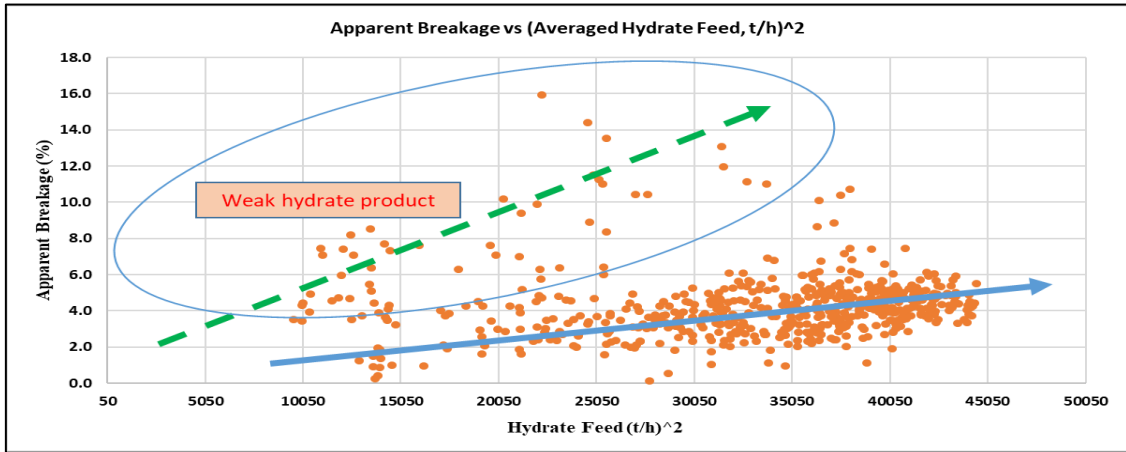


Figure 6. Trending of apparent breakage and hydrate feed rate².

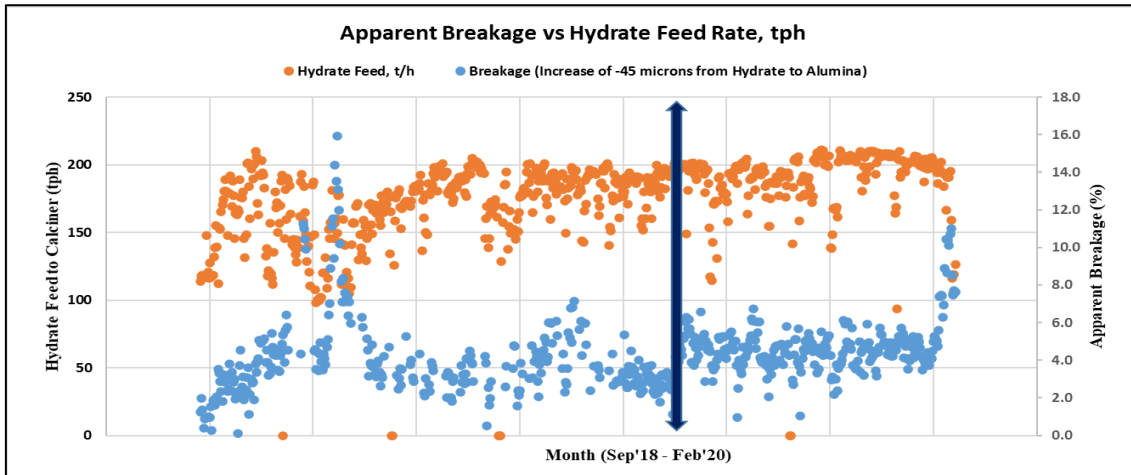


Figure 7. Trending of apparent breakage and hydrate feed rate to calciner (both phases).

To analyze the impact of other factors, we normalized the apparent breakage to the maximal feed rate of about 211 tph which the refinery has produced in the duration of both the phases. The calculation formula used for the normalized breakage is:

$$\text{Normalized Breakage} = (211, \text{tph})^2 \times ((-45 \mu\text{m in Alumina}) - (-45 \mu\text{m in Hydrate Feed})) / (\text{Hydrate Feed, tph})^2 \quad (1)$$

By the above equation, the impact of the feed velocity (or production rate) on breakage is eliminated, and as shown in Figure 8, the normalized breakage is no longer a function of the hydrate feed rate.

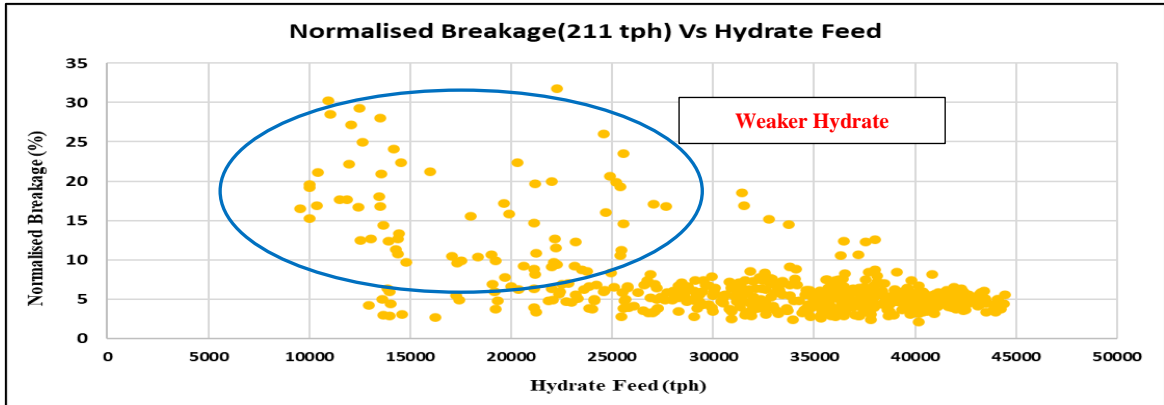


Figure 8. Trending of the normalized breakage and the hydrate feed rate to calciner².

3.2 Impact of Alpha Alumina (Calciner Temperature)

Higher PO₄ (calciner furnace) temperature in calcination tends to produce slightly higher alpha alumina in the product. We control PO₄ temperature normally above 1 065 °C to avoid any soot particles in the alumina when the calciner produces above 2 800 tpd (~179 tph hydrate feed). However, this leads to a relatively higher alpha alumina, currently 3.0 to 3.5 %. We could not find any significant correlation between the normalized breakage and the alpha content. It is therefore concluded that the high PO₄ temperature did not noticeably contribute to more particle breakage during calcination, even if slightly higher alpha alumina is produced.

3.3 Impact of Hydrate Strength

Particle strength of hydrate and alumina is a function of several factors, related to precipitation, production classification and calcination conditions.

3.3.1 Correlation Between Na₂O Content and Attrition Index (A.I.) with The Alumina Product

It has been shown in the literature [2] and [3] that the A.I. of hydrate and alumina is related to wt. % of Na₂O. The stronger hydrate or alumina is normally associated with the higher wt. % of Na₂O content. The mechanism for this is related to alumina supersaturation. At a higher supersaturation, hydrate tends to incorporate a higher content of Na₂O due to a higher growth rate. The increase in breakage from phase 1 seems a sharp “stepwise” from ~3.0 to ~6.0 %, following a step change in Na₂O from 0.350 to ~0.330 %. However, the long-term average shows the current normalized breakage is still around 5.0 %. To further demonstrate this, each of the 10 data points were clustered from low Na₂O to high Na₂O and plotted in Figure 9 with normalized breakage as a function of Na₂O content in alumina.

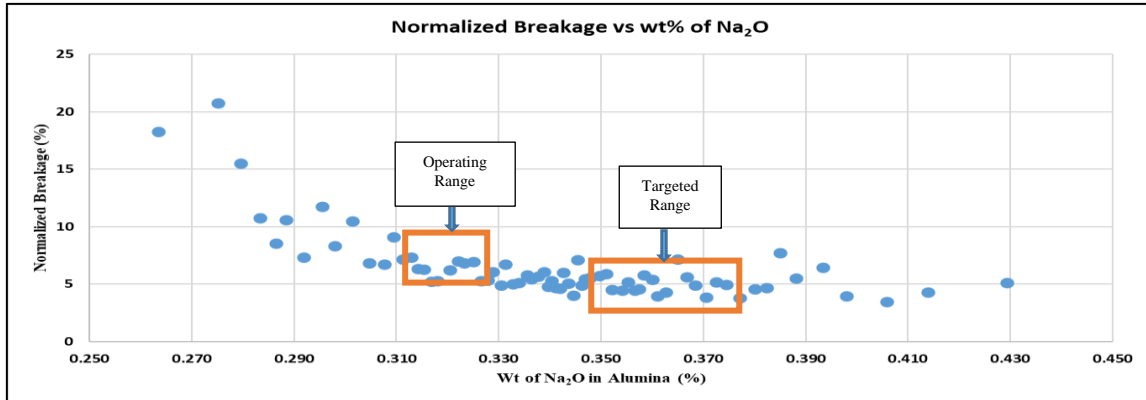


Figure 9. Correlation between normalized breakage vs wt. % of Na₂O in alumina (typical operating range vs targeted range post analysis).

The average Na₂O content changed from 0.358 to 0.330 % while the normalized breakage changed from ~4.9 to ~5.5 % (~12 % increase). If Na₂O is reduced from 0.325 to 0.300 % (0.025 % reduction), the breakage increases to above 7 %. Figure 9 demonstrates the fact that soda value close or below 0.300 % (bound soda 0.26 %) should be avoided otherwise, particle breakage will be high.

3.3.2 Trending of Na₂O vs Supersaturation:

Soda incorporation in hydrate during precipitation is a function of supersaturation as shown by [4] & [5]:

$$d\text{Na}_2\text{O}/d\text{Al}_2\text{O}_3 = \alpha (A-A^*)^2 \quad (2)$$

Where “ α ” is function of liquor composition

We did a comparison of Na₂O concentration with alumina supersaturation in both agglomeration and growth tanks as an approximation and found a strong correlation. The higher caustic concentration of pregnant liquor (PGL) tends to generate lower Na₂O content in hydrate as the circuit supersaturation is reduced with higher caustic concentration, if A/C ratio is not increased. The dependency of Na₂O concentration on growth condition is stronger than on the agglomeration condition, indicating that higher degree of growth in the growth stage is more efficient to strengthen the hydrate than one in agglomeration. Reduction of Na₂O content in product was mainly caused by the lower supersaturation in agglomeration, which was again the result of higher agglomeration temperature, lower A/C ratio and higher caustic concentration input to agglomeration. The below findings explain the causes of lower supersaturation.

Root cause of lower supersaturation:

Lower alumina supersaturation is mainly caused due to factors like changes in aluminate liquor flow, alumina content (RP or A/C ratio), temperature conditions, seed charge etc. The details of white side process parameters were studied and analyzed for a period (both when particle breakage was low and during the period when breakage was high). Key findings between these two periods were:

- Increased PGL flow from phase 1 to phase 2.
- PGL temperature at the HID (heat interchange department) exit increased due to decreased overall heat transfer coefficients (U factors) in all three HID units (77 to 80 °C) (refinery has been installed with 3 HID units and all of them remain in service during 3-digestion trains are in operation).

- Supersaturation in agglomeration had decreased by 9 g/L because of increased agglomerator temperature and reduced agglomeration A/C (52.7 to 43.7 in A-A*).
- Reduced A/C ratio and increased caustic concentration across agglomeration stage were observed mainly caused by high seed charge with no change in PGL A/C ratio.

Control for increasing supersaturation - Tschamper Ratio:

In the design phase of Lanjigarh Refinery, Tschamper Ratio control has been given as a tool/guide for precipitation size control. This ratio represents the first agglomeration tank input condition defined as:

$$\text{g/L of Al}_2\text{O}_3 \text{ supersaturation per m}^2\text{/L of fine seed charge} \quad (3)$$

According to the original design, TR in the first agglomeration tank should be kept around 10. In the last agglomeration tank, it should be higher than 7. TR as low as 5 is not good for product strength. The TR in the last agglomeration tank was compared with the product soda content which showed a correlation in the similar way as supersaturation has. It was found that a TR of 7–13 was the desirable range to be operated for better size control.

Avoiding over coarsening in agglomerator:

The absolute increase in +120 µm fraction in agglomeration is a good indicator of over-agglomeration.

3.3.3 Impact of Increase in Organic Content (Oxalate) in The System

From around late of FY20, refinery has started witnessing an increase of oxalate content in liquor due to higher organics input in the system, taking into account of change in bauxite source. Figure 10 shows the increase of high organic content bauxite consumption and the consequent increase of oxalate levels in liquor.

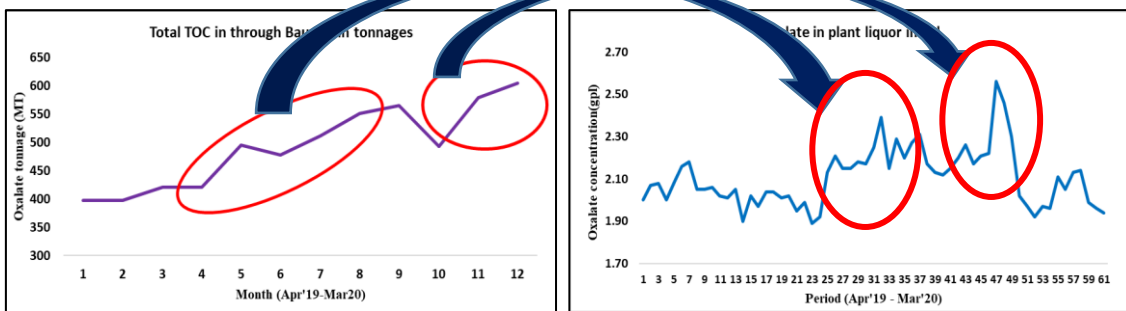


Figure 10. Oxalate tonnage input vs COC increase.

Figure 10 explains the bulging of oxalate towards COC (critical oxalate concentration) and the correlation between the total OC (organic carbon) tonnage input to the plant (converted to oxalate) and the trend of oxalate gpl in plant liquor.

Due to sudden increase in plant oxalate concentration which leads plant liquor to reach to the critical oxalate level, oxalate precipitation took place and oxalate moved towards the solid phase of the hydrate slurry. The solid phase oxalate levels increased 18–20 times than that was being maintained before this event. This situation adversely impacted the circuit fines and eventually product alumina fines.

4. Summary of Findings and Conclusion

Increase in apparent breakage in calcination was caused by:

- Increased production rate in calciner.
- Weaker hydrate strength due to reduced supersaturation in agglomeration and initial growth tanks and over-agglomeration.
- Reduced supersaturation caused by increased agglomeration temperature as well as 1st growth temperature (mainly caused due to poor HID performance).
- Weaker particle strength due to increased over-agglomeration (as indicated by +120 μ m increase in agglomeration).
- Slightly weaker hydrate growth ring strength due to reduced supersaturation in growth.
- Though the agglomeration index has been steady on long term basis, it was increased for a while during the phase 1 and 2 (sharp increase of +120 μ m in agglomeration output), but it was returned to normal in the later end of phase 2. Such increase partially contributed to the weaker hydrate.
- Increased organics in the system due to bauxite source change resulted an increase of oxalate levels in the circuit causing oxalate outbreak and impacting precipitation seed size disturbances.

Actions taken for improving the hydrate particle strength:

- Debottlenecking of HID for temperature reduction and control in agglomerator and 1st growth tank through installation of additional HID system.
- Targeting bound soda content in agglomerated product to control the soda content of product in the range of ~0.35 % with a minimum cap of 0.32 %.
- Inclusion of the sizing analysis of +120 microns particle size in agglomeration to monitor and control over agglomeration.
- Introduction of Tschamper Ratio control in DCS to monitor and control TR on real time basis (target 10-13 g/m²).
- Measurement of the hydrate and alumina attrition index in house to monitor trends.
- Reduction of the precipitation tank solids to avoid / reduce oxalate precipitation.
- Increase of the end tank temperatures of precipitation circuit to reduce oxalate precipitation.
- Start-up of the seed washing unit and ensuring the optimum caustic concentration and temperature for effective oxalate wash.
- Oxalate destruction unit operation for oxalate conversion from liquor phase to solid phase by lime dosage and disposed of through mud.

5. Acknowledgements

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6. References

1. Wind S., Jensen-Holm C. and Raahauge B., Development of particle breakdown and alumina strength during calcination. *Proceeding of the 9th International Alumina Quality Workshop*, 18-22 March 2012, Perth, Australia, 308-315.
2. L., Armstrong et al., Alumina attrition - investigation of hydrate structure, *Proceeding of the 4th International AQW (Alumina Quality Workshop)*, 2-7 June 1996, Darwin, Australia, 239-249.

3. Wijayaratne H. and H. M., Balancing sodium impurities in alumina for improved properties. *Metallurgical and Materials Transactions B*, Oct 2018, Vol. 49, Issue 5, 2809-2820.
4. J. V. Sang, Factors affecting residual Na₂O in precipitation products, *Proceeding of 117th TMS annual Meeting*, 25-28 January 1988, Phoenix, Arizona, USA, *Light Metals 1988*, 147-156.
5. Chris Vernon et al., Soda incorporation during hydrate precipitation, *Proceeding of 134th TMS Annual Meeting*, 13-17 February 2005, San Francisco, California, USA, *Light Metals 2005*, 191-196.