AA23 – Carbon Footprint Reduction in Alumina Calciners

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Abstract

This paper outlines several design changes in the Gas Suspension Calciner. The design changes presented include: 1) a change in cyclone dimensions with the aim to lower the gas velocity to thereby reduce pressure drop & wear on vortex finder and to reduce particle breakdown, 2) improved refractory design to minimize radiative heat losses, thereby reducing the thermal energy consumption and, 3) other improvements in the calciner such as an optimized hot vessel design, start-up burner relocation and a plant layout with a lower building height. Also keeping with our Mission Zero goals, the introduction of these latest technologies, and aided by digital solutions, help customers move towards greener processes by reducing thermal energy and power consumption as well as CO_2 emissions.

The paper also presents some details of hydrogen firing for alumina calcination following a research and development program.

Keywords: Alumina, Calciners, Thermal energy consumption.

1. Introduction

FLSmidth has experience with Gas Suspension Calciners (GSC) over the past 40 years from different hydrate sources calcined in both pilot and full-scale Gas Suspension Calciners of various design and capacity.

Calcination is the final step of the Bayer process where alumina is produced from aluminum trihydroxide (Hydrate, Gibbsite). After calcination, alumina is sent to a smelter where pure aluminum is produced.

In 1976 FLSmidth had commissioned the first industrial Gas Suspension Calciner (GSC) technology for the pre-calcination of raw meal (~70 % limestone fines) in a new 4600 tpd cement clinker production line in Japan. The pre-calciner operating temperature was about 950 °C with few seconds of solid retention time.

Since the basic research and development work and prototyping of the gas suspension calcination technology was developed and done for cement raw meal it was relatively straight forward for FLSmidth to adopt this calcination furnace/reactor technology for alumina production (in 1976).

The timing of this technology spin-off was very fortunate as FLSmidth had lost its dominating world market position for supply of rotary kilns for production of sandy or floury alumina when the last rotary kiln for alumina was contracted in 1974.

Ten years after FLSmidth started the development with pilot plant testing in 1976, the first GSC unit with a calcining capacity of 1000 tpd and calcination furnace temperature around 1050 °C for Smelter Grade Alumina (SGA) was commissioned at Hindalco [1], India in 1986, replacing three old FLSmidth rotary kilns.

2. Gas Suspension Calcination (GSC)

The First GSC technology had a vertical arrangement (refer to Figure 1) and comprised of the following main sections:

- Drying and Pre-heating/Pre-Calcination of feed material in cyclones
- Calcination Furnace and Furnace Cyclone
- Direct Heat Recovery from alumina by cooling with Air in Four (4) stage Cyclone cooler.
- Indirect alumina cooling with water in a Fluxo Cooler.

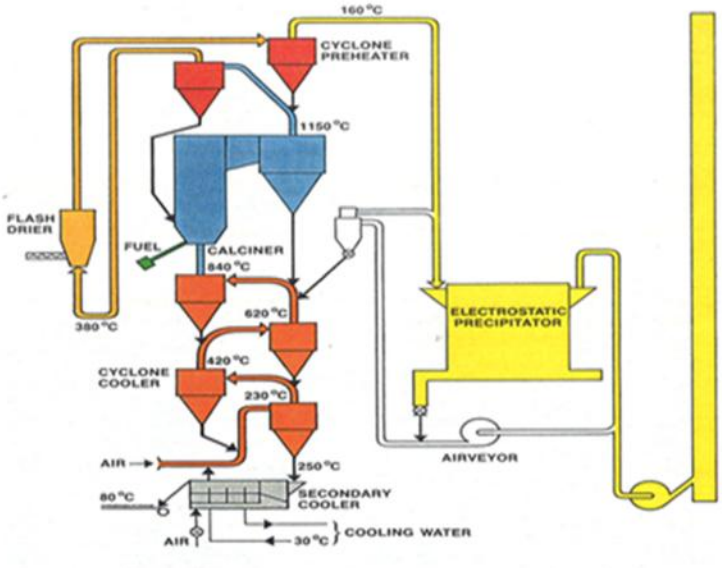


Figure 1. Gas Suspension Calciner vertical arrangement.

In 1986, Eurallumina, Italy, decided to retrofit one of three Ø3.95 × 107 m long rotary kilns producing 900 tpd sandy alumina with an oil fired GSC unit to produce 1550 tpd SGA. The specific energy consumption was reduced to 3100 kJ (LHV) per kg SGA from about 4100 kJ (LHV) per kg with the kilns. The alpha-phase content was reduced from about 18% to 2–5% in the SGA for the same SSA, furthermore the LOI (300–1000 °C) was reduced from 0.8% to 0.55–0.65 wt%.

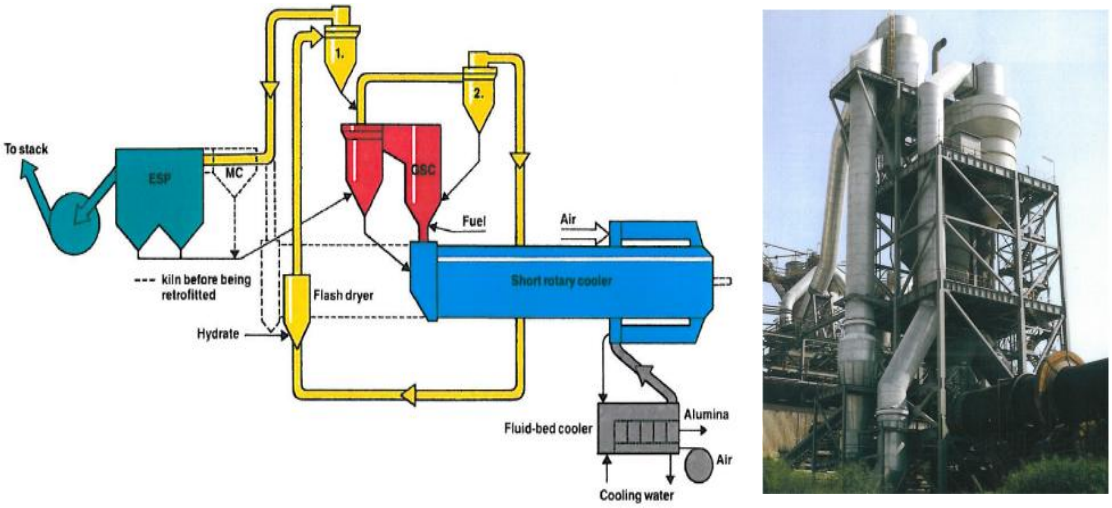


Figure 2a. GSC retrofit converting rotary kiln to rotary cooler, Eurallumina, Italy.

In the global alumina market rotary kilns were replaced with new stationary calciners, but some were retrofitted to more energy efficient operation and higher production capacities (refer to Figure 2a).

In 1989, an integrated GSC and filtration arrangement was developed and supplied to Sherwin Alumina, in the USA. This new arrangement also reduced the height of the GSC structure (refer to Figure 2b).

Figure 2b. Integrated GSC with reduced tower height, Sherwin alumina.

In 2001, FLSmidth collaborating with Alcoa further developed a semi vertical GSC arrangement using a Hot Air Lift (HAL) and also introduced a Fluid bed cooler (FBC) replacing the fluxo cooler. With this technology, FLSmidth supplied the world's largest stationary calciners 3 × 4500 tpd GSC units to QAL, Australia (refer to Figure 3).

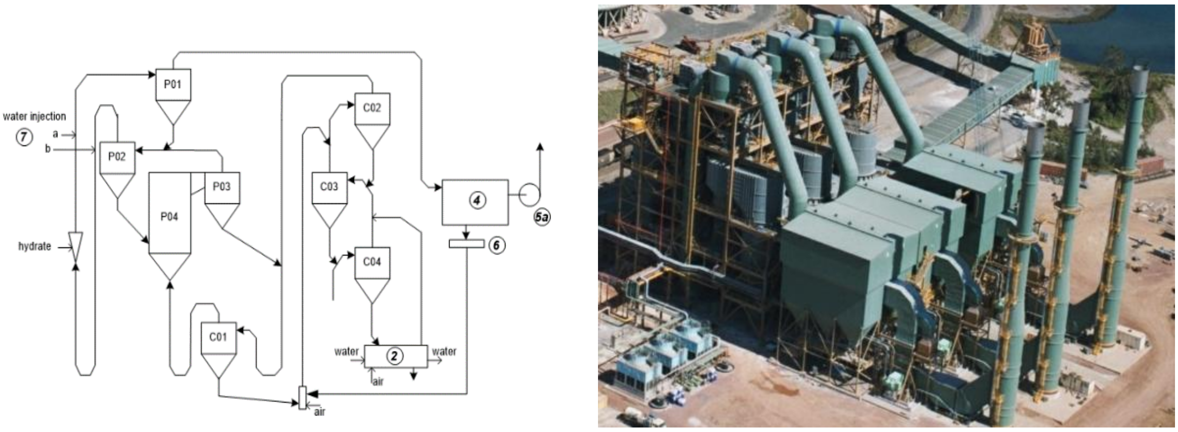


Figure 3. GSC with HAL and FBC, without HV QAL, Australia- 3 × 4500 tpd GSC Unit.

The most modern GSC design, which was implemented in Yarwun, Australia in 2007, and has four main process stages [2, 6] (refer to Figure 4):

- Drying and pre-heating/pre-calcination (PO1/PO2)
- Calcination furnace (PO4), furnace cyclone (PO3) and hot vessel (HV)
- Direct heat recovery (by direct air cooling, CO1-CO4)
- Indirect heat recovery (by water cooling in a fluidized bed cooler, FBC)

The Hot vessel (HV) increases the retention time and ensure that the reactions have time to proceed to a desired degree in order to meet product specifications and provides significant energy savings as the temperature in the furnace is reduced and the reaction time is prolonged in this process stage. As Wind et al. remark, higher temperature is substituted by longer retention times [3].

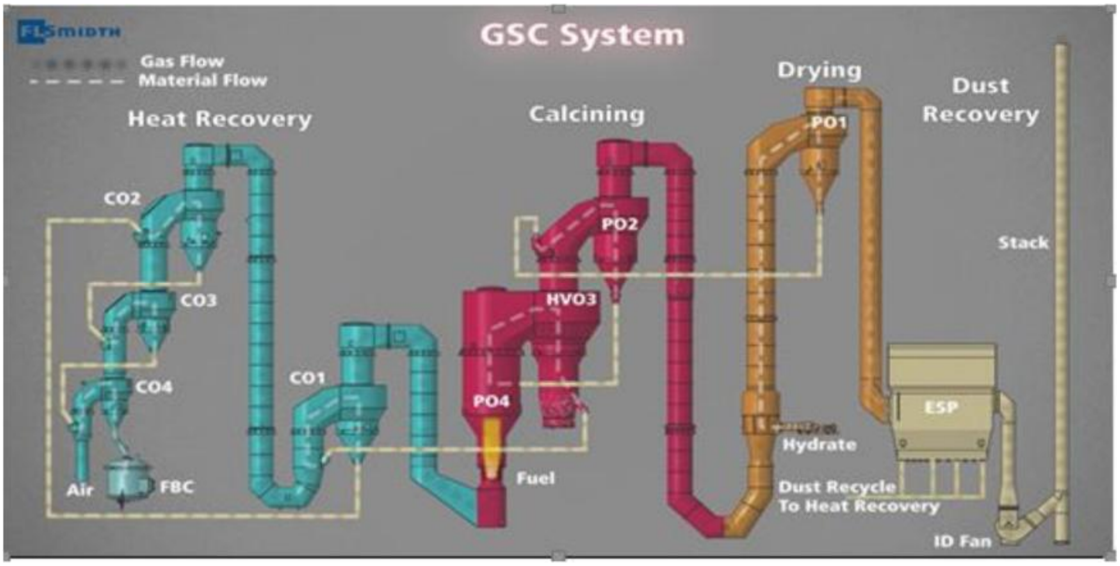


Figure 4. Gas Suspension Calciner with Hot vessel.

3. Recent Developments in Gas Suspension Calciner

This section will present and describe the latest design improvements of the GSC calciner technology. The design changes are based on the experience gained from the calciners supplied in 2009-2013.

3.1 Redesign of Riser Ducts in GSC

FLSmidth R&D work has shown that Particle Break Down (PBD) happens due to internal and external thermomechanical forces acting on the alumina particles during cool down. CFD modelling has shown that there is a high degree of in the existing riser duct RBO3-RCO1 to the CO1 cooler cyclone from which has a potential of increasing particle break down.

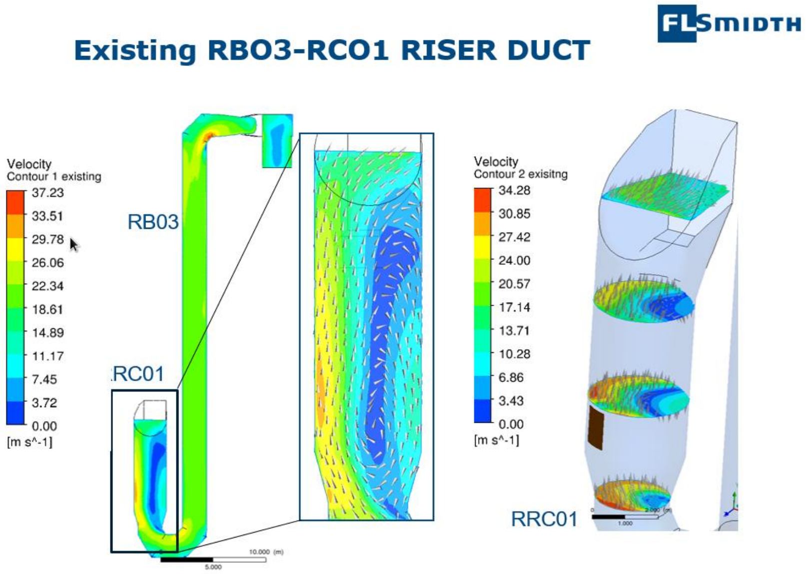


Figure 5a. RCO1 Riser Duct Existing (a).

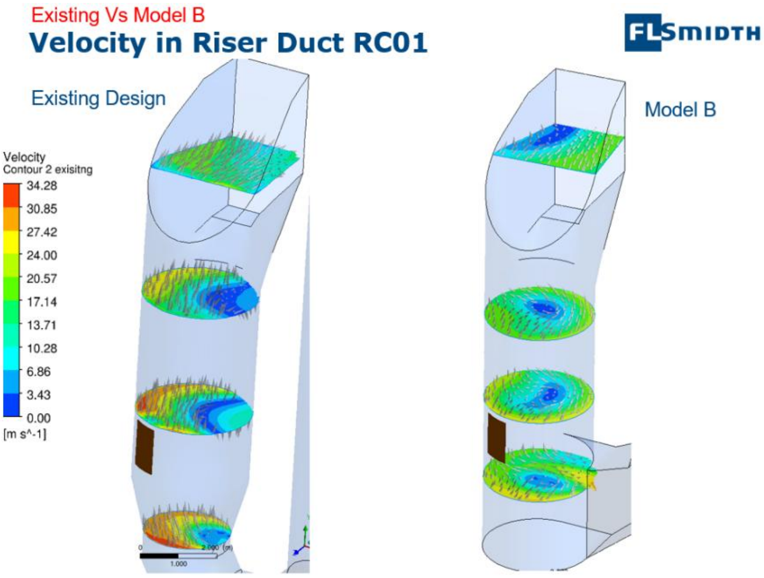


Figure 5b. New design Model B (b).

Comparative CFD analysis of the existing RCO1 Riser duct and the Model B redesign (refer to Figure 5) clearly indicates a reduction in peak velocities and thus a corresponding expected reduction in Particle Break down. The re-design of RCO1 has the potential to reduce not just Particle Break down, but also the pressure drop & wear [5]. These design changes have been implemented in Utkal Alumina India Line-3.

3.2 Improved Refractory Design

Refractory engineering is done with a primary design objective to provide a long service life of the process vessel. In consideration of energy saving, ideally all the heat added to the calciner system should be used to heat and react the feed material but in practice, a lot of heat is lost in several ways: energy losses through the cyclone, ducts and chutes at steady state operating condition and heat storage loss during transient condition. The heat loss through refractory wall during steady state condition depends on the thermal conductivity "K" of the refractory materials, the wind velocity, ambient air temperature, surface temperature, emissivity factor and the operating temperature (reference). In general, materials with high porosity and low thermal conductivity reduce the service life of the refractory lined vessel due to lower strength and lower resistance towards chemical attack. In contrast, high density refractory materials have higher thermal conductivity and therefore require a multilayer design with lower conductivity materials to reduce the energy loss through the refractory wall.

Refractory also serves to protect the steel shell from corrosion and erosion, provides thermal insulation and provides a thermal barrier between the hot medium and the shell of the processing vessel.

A multi-layer lining with optimized performance of layers in the specific operating environment, and proper installation, improves the energy efficiency of a furnace and can contribute to saving specific fuel energy.

In many of the existing alumina calciners, the refractory design is often of two layers i.e., one insulation layer and a hot face dense refractory layer. Operational experience with FLS calciners has shown that the radiation losses through the walls of the cyclones is high, resulting in higher specific thermal energy consumption.

A detailed study was done on the lining materials and their thickness. Thermal calculations were done to optimize the refractory thickness so as to improve the energy efficiency. Based on the detailed calculations, the insulation thickness and materials were changed. Instead of a two-layer lining, a multi-layer lining was introduced.

Refractory lining design and materials shall be selected to:

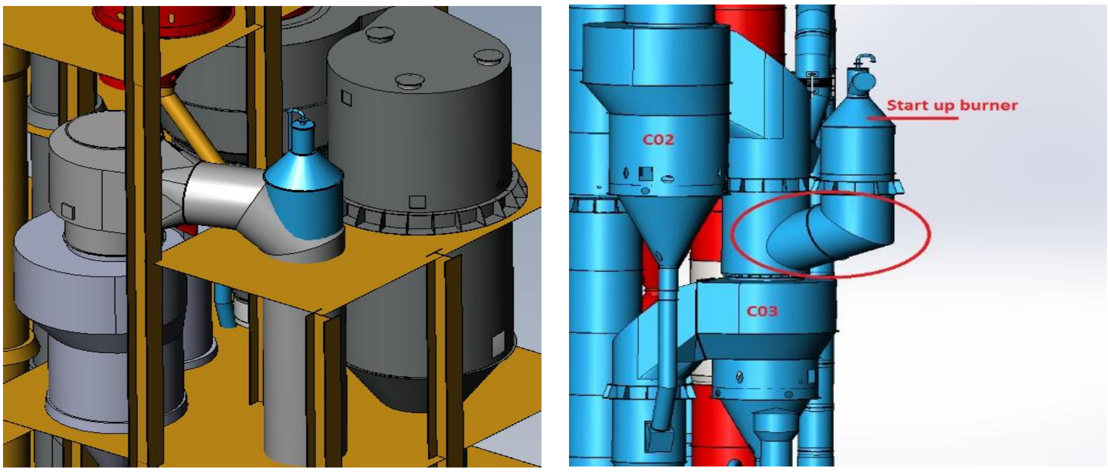
- Be capable of withstanding thermal shock during emergency start up and shutdown or trips (BMS/DCS) of the calcination unit without significant decrease in refractory service life.
- Be capable of withstanding cold and hot abrasion from solids in gas suspension without significant decrease in refractory service life.
- Provide for reliable long service life and cost-efficient maintainability.

Anchor systems shall be of an appropriate design to allow vertical and horizontal support of the refractory while allowing refractory movement due to thermal expansion. The anchor system design shall also ensure safe removal of refractory during repairs.

The refractory and anchor design around all bull-noses shall consider horizontal and vertical forces applied to the bull-nose apex. Attention shall be paid to the long wall movement especially for temperatures greater than 800 °C.

The same was implemented in Utkal Alumina India Line-3 and has been in service for 2 years satisfactorily with lower fuel consumption. The external heat losses were reduced by about 45 %, thereby achieving lower specific thermal energy consumption. As stated by Raahauge [5] improved refractory design can significantly reduce the specific thermal energy consumption in the GSC units.

3.3 Start/Preheat Burner Location Change



Existing location **New location**

Figure 6. Change of Start/Preheat burner location.

In GSC the start burner is located at the outlet of cooling stage three. However, this arrangement has a few disadvantages:

- Higher thermal load to cooling cyclone (CO2) second stage and its riser duct (RCO2) which leads to damage in RCO2 refractory lining.
- Refractory failure in start burner combustion chamber.
- Since the start burner is located in RCO2, preheating of PO4 is not possible above 750 °C.

In the latest GSC arrangement FLSmidth has addressed the above issues by relocating the start burner to RBO4 (inlet to PO4), (refer to figure 6) with the following expected benefits:).

- This new design location will reduce the risk of refractory failure in start burner combustion chamber, because the RBO4 duct volume is used as a burning chamber.
- Faster ramp up – preheating of PO4.
- PO4 inlet temperature can be preheated above 750 °C.
- Reduced thermal load on Cooling cyclone (CO2) second stage and its riser duct (RCO2)

These changes were implemented in Utkal Alumina India Line-3.

3.4 Optimization of Hot Vessel (HV)

As mentioned in the introduction the primary function of the Hot Vessel is to increase the residence time of the calcined alumina at high temperature, thereby allowing the furnace to be operated at a lower temperature. However, the current Hot Vessel design provides a too long residence time which leads to over calcination, and also creates dead zones (areas without fluidization where the material is stagnant) in the Hot Vessel.

To overcome the above issues, the HV design has been optimized based on the CFD simulations. See below.

Advantages are:

- More reliable fluidization
- Less risk of dead zones in HV
- Less risk of over calcination
- Lower thermal impact to HV refractory

These design changes were implemented in Utkal Alumina India Line-3 and the plant is running efficiently since the last 2 years.

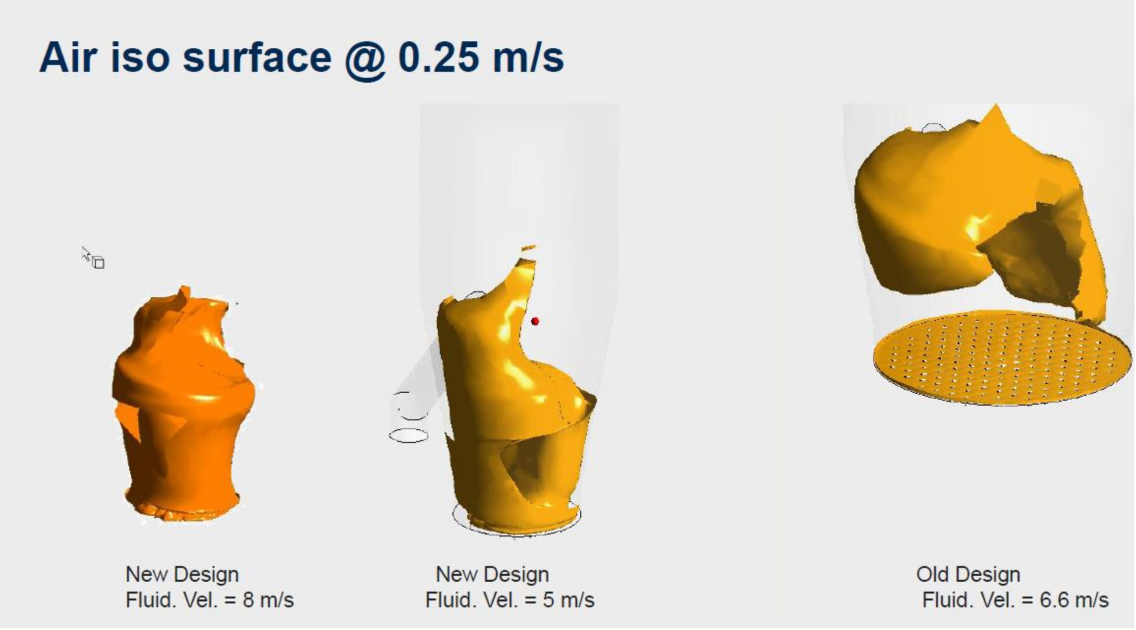


Figure7. Hot Vessel CFD.

Alumina bed is more packed in new design with fluidisation velocity of 5 m/s. But with 8 m/s fluidization velocity in the new design, the bed is not as densely packed (refer to Figure 7).

3.5 Redesign of Distribution Box

Heat transfer in a GSC results from several stages of mixing gas and solids prior to separating them again to move to the next heat exchange stage. If the mixing of the gas and solids is not sufficient there will be a significant difference between the exit temperatures of both streams leading to lower thermal efficiency. Attention to detail in this area through the design and application of appropriate “Distribution Box”, enables effective mixing and low temperature differentials therefore might reduce particle breakdown and hydrate bypass.

The purpose of the distribution/spreader/feeder box (RPO2) is to evenly distribute the dried hydrate feed into the gas stream of RPO2 in order to maximize the heat transfer between gas and material. The existing conventional spreader box in some of the GSC's were experiencing a bypassing of hydrate. This is a phenomenon that occurs when the dried hydrate that discharges from the spreader box splits into two streams, one that is transported to PO2 cyclone and the other known as "Hydrate Bypass" passes through the gas stream down in PO3/HVO3 (Cyclone / Hot Vessel). This results in un-calcined material mixing with the final product and has a detrimental impact on the quality of the SGA product. Based on CFD results to address this issue, an aeration type RPO2 spreader box was designed (refer to Figure 8) to provide uniform distribution of dried hydrate into the gas stream of RPO2 and to minimize the hydrate bypass. The same was implemented in Utkal Alumina India Line-3 and is working successfully since start-up 2 years ago.

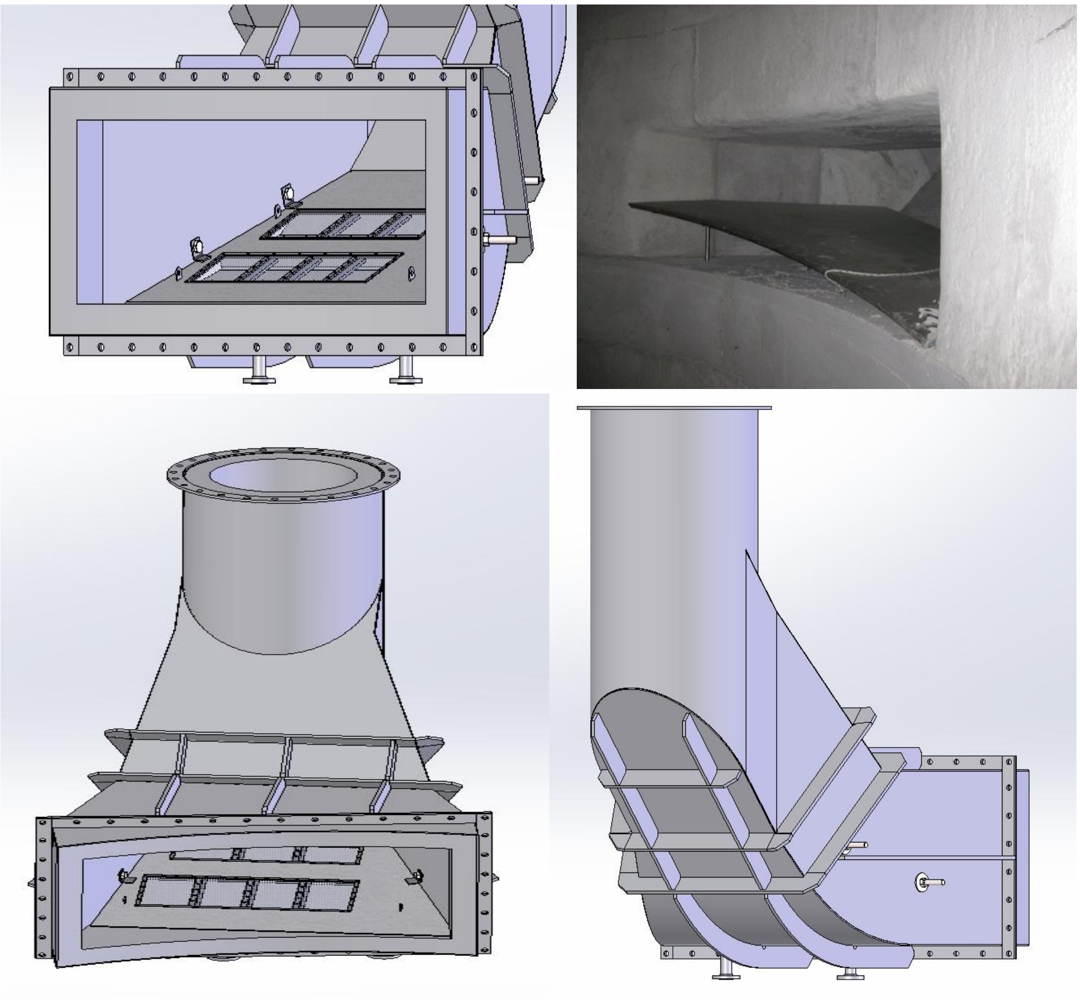


Figure 8. RPO2 Aeration Spreader box.

3.6 Cyclone Design Optimization

The cyclone dimensions are adjusted to lower the gas velocity, to reduce the pressure drop and wear on vortex finder and to minimize the risk of particle breakdown. Also, by reducing the cyclone cylindrical height, based on CFD modelling, the overall building height can be reduced by 4 m. The Pan filter building height is thereby also reduced by 3.6 m (refer to Figure 9).

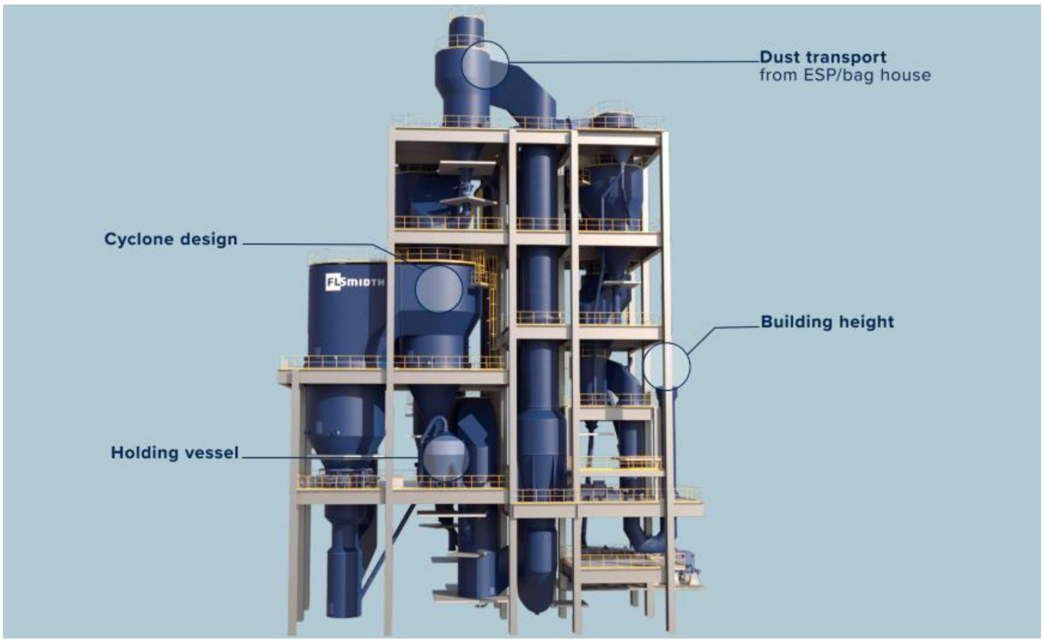


Figure 9. Latest GSC Building based on reduced height.

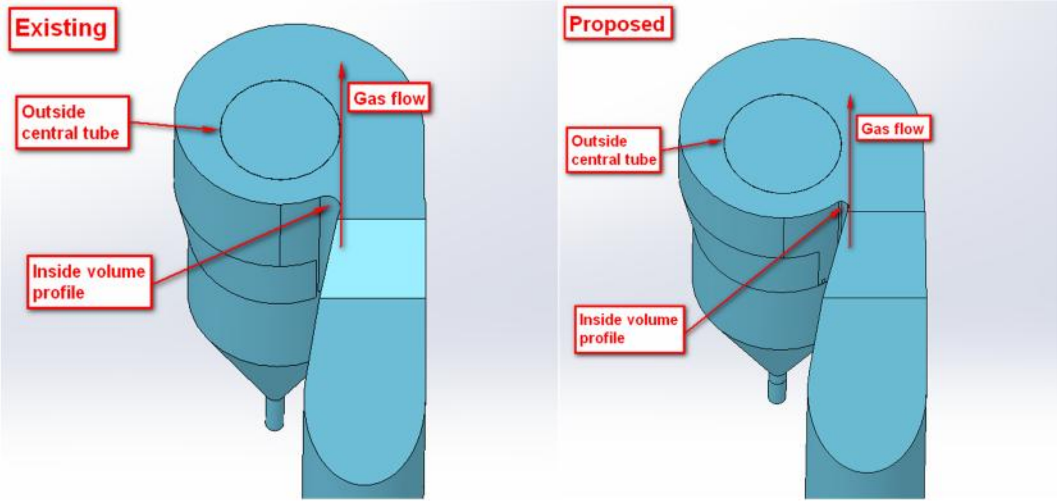


Figure 10. Cyclone design optimization.

The cyclones in the FLS GSC calciner have been redesigned with the aim to reduce direct impingement of dust laden gas on the vortex finder (refer to Figure 10) where it can be seen how the proposed new design directs the gas flow slightly away from the vortex finder. This new design is expected to:

- Reduce vortex finder wear and increase the life of the vortex finder
- Reduce the particle breakdown by avoiding/reducing direct impingement on the vortex finder.
- Increase solids separation efficiency.

3.7 Reduction in Power Consumption by Elimination of Dense Phase Conveying System with Bucket Elevator System for ESP Dust

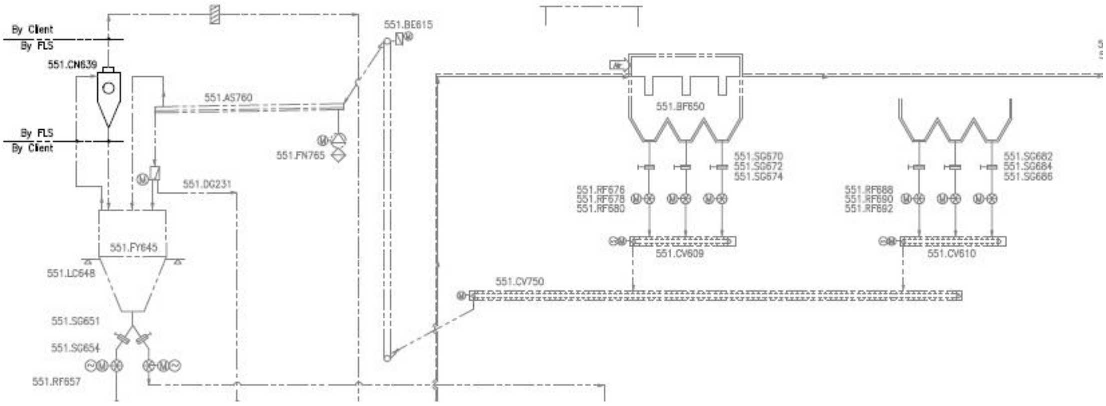


Figure 11. ESP Dust return System by bucket elevator.

Refer to Figure 11 for an illustration reflecting the mechanical conveying arrangement with bucket elevators as an alternative to a pneumatic conveying system.

Replacing the pneumatic conveying system with a bucket elevator requires:

1. Two (2) drag chains below ESP hoppers.
2. Two (2) RALs (Rotary Air Lock) on exit of ESP drag chain.
3. One (1) drag chain below RALs.
4. One (1) bucket elevator
5. One (1) air slide with blower, vent filter (1) & dedusting fan (1)
6. One drag / belt conveyor between item 3 and item 4 to meet the layout requirement.

The difference in power consumption is 280 kWh (Pneumatic system) vs 62 kWh (Bucket Elevator system).

3.8 Evaluation of Alumina Hydrate Flash Calcination Using an Oxyfuel (Hydrogen) Fired Flash Calciner with Steam Transport Medium

The test results obtained during this pilot program strongly suggest that it is viable to convert a commercial alumina gas suspension flash calcining system from air-based operation with natural gas firing to steam-based operation with hydrogen firing and oxygen injection without compromising system stability and alumina product quality. It is also expected that no major commercial calciner modifications will be required to support this mode of operation. The main focus will be on how to manage the operating and BMS safety logic to allow for the transition from air-based operation to steam-based operation, followed by the transition from natural gas firing to hydrogen firing.

Key observations:

Hydrogen burned very effectively in the flash calciner and resulted in an improved overall flash calciner temperature profile that contributed to an increased level of alumina calcination relative to natural gas firing. Residual hydrogen levels at the flash calciner exit remained near zero throughout most of the hydrogen firing trials.

The use of a steam atmosphere and thus a high partial pressure of water vapor in the pilot calciner had no measurable impact on the degree of alumina decomposition relative to operation using air.

The use of oxygen to allow for operation at lower flash calciner velocity levels while maintaining the production rate did result in stable operation, a reduction in the fuel consumption and a reduction in the < 45 microns fines content in the alumina product.

There was no evidence of moisture condensation or bag cleaning issues in the jet pulse bag filter at any time during the pilot program. The bag filter was cleaned with compressed air at ambient temperature.

A significant reduction in NOx emissions were observed during steam-based calciner operation versus NOx emissions measured during air-based operation.

Based on the successful trials, FLSmidth has engineered a plant (Confidential Client) which is expected to be commissioned shortly.

4. Conclusions

This paper has presented details on some key design changes introduced to the FLS GSC to improve performance and reduce energy consumption and particle breakdown. The main improvements described were:

- Redesign of riser ducts in GSC
- Improved refractory design
- Optimization of hot vessel
- Redesign of distribution box
- Cyclone design optimization

These design changes are expected to have the potential to lower the specific fuel energy consumption to 2650 kJ/kg. Most of these changes were implemented in Utkal Alumina India Line-3 and have been running satisfactorily since the last 2 years.

Based on pilot testwork FLS is ready to supply calciners based on hydrogen firing.

5. References

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