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ALUMINA CALCINATION: A MATURE TECHNOLOGY UNDER REVIEW FROM SUPPLIER PERSPECTIVE

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Abstract

Calcination is the last step in the production of alumina from Bauxite. In modern refineries this step is carried out in stationary calciners, such as Circulating Fluidized Bed (CFB), Gas Suspension (GSC) or Fluid Flash (FF) Calciners. These technologies have been available for over 40 years, and are thus very far matured. The technologies have developed substantially and many boundaries have been pushed, sometimes close to the theoretical limit. Yet the development has not stopped and new concepts and technologies are being explored. In this paper the authors discuss, from a supplier perspective, what was driving the design in the past, at present and possibly in the future, and also what the challenges typically encountered are.

Introduction

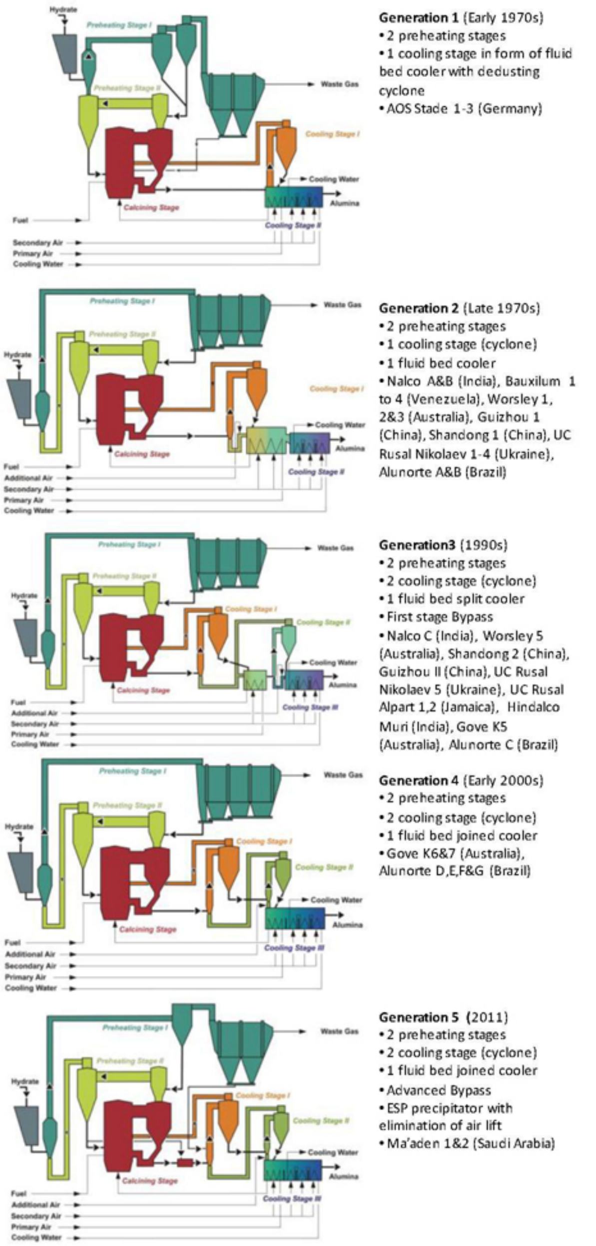
Since the first introduction of stationary calciners (CFB, GSC and FF) more than 40 years ago, the technology has undergone many improvements and constant development. The focal points and motivation for innovation has changed through the years with frequent changes in the market environment. In the following sections the past drivers for innovation in this technology is discussed as well as the current priorities and what future directions might be. The technology has reached a very high level of maturity, but some areas of improvement are still present.

Past Drivers for Technology Improvements

Alumina quality – the change from floury to sandy coarse alumina

One of the reasons for a change in alumina calcination technology in the past was the change in alumina quality demand – from floury to sandy. The change in alumina quality demand was driven by changes in smelting technology, namely the introduction of dry scrubbers and the use of break and feed systems. Dry scrubbers emerged in the 1960s as an answer to rising emissions concerns associated with the aluminium production process. Dry scrubbers make use of the high specific surface area and the reactivity of partially calcined alumina to capture the volatile fluorides emitted from the cryolite based electrolyte used to dissolve the alumina. Environmental requirements to enclose the cells as much as possible and the clear benefits of a more continuous way to feed the alumina into the electrolysis cells resulted in the development of so called Break and Feed systems, and eventually the today widely used Point Feeders, around the same time as the dry scrubbing process was introduced. The so called floury alumina was simply outperformed by the sandy type alumina.

These developments also fuelled the development of alternative calciner technologies to the rotary kilns. The stationary, fluid bed, calcination technology was developed in the 1950s to 60s. The potential gains in fuel energy savings, increased production volumes, reduced maintenance etc. resulted in considerable research efforts into these technologies, and as a result variations of the fluidized bed technology emerged [1].



Generation 1 (Early 1970s)
- 2 preheating stages
- 1 cooling stage in form of fluid bed cooler with dedusting cyclone
- AOS Stade 1-3 (Germany)

Generation 2 (Late 1970s)
- 2 preheating stages
- 1 cooling stage (cyclone)
- 1 fluid bed cooler
- Nalco A&B (India), Bauxilum 1 to 4 (Venezuela), Worsley 1, 2&3 (Australia), Guizhou 1 (China), Shandong 1 (China), UC Rusal Nikolaev 1-4 (Ukraine), Alunorte A&B (Brazil)

Generation3 (1990s)
- 2 preheating stages
- 2 cooling stage (cyclone)
- 1 fluid bed split cooler
- First stage Bypass
- Nalco C (India), Worsley 5 (Australia), Shandong 2 (China), Guizhou II (China), UC Rusal Nikolaev 5 (Ukraine), UC Rusal Alpart 1,2 (Jamaica), Hindalco Muri (India), Gove K5 (Australia), Alunorte C (Brazil)

Generation 4 (Early 2000s)
- 2 preheating stages
- 2 cooling stage (cyclone)
- 1 fluid bed joined cooler
- Gove K6&7 (Australia), Alunorte D,E,F&G (Brazil)

Generation 5 (2011)
- 2 preheating stages
- 2 cooling stage (cyclone)
- 1 fluid bed joined cooler
- Advanced Bypass
- ESP precipitator with elimination of air lift
- Ma'aden 1&2 (Saudi Arabia)

Figure 1. 5 generations of alumina CFB calciners with main features and differences indicated, including references.

Reducing energy consumption

Increasing energy price (oil and gas) has been, and continues to be, one of the main drivers for technological developments in the Bayer process. For this reason also many of the new technologies introduced in the CFB alumina calciner were developed in order to reduce the specific fuel requirement. This has resulted in the following developments:

- **Hydrate bypass** [2]. A sub-stream of pre-calcined hydrate bypasses the furnace and is reacted to SGA utilizing the heat with the hot alumina discharged from the furnace in a purpose designed mixing pot.
- **More cooling stages.** In order to improve the heat recovery from the product alumina an additional cooling stage was included in the flowsheet [2]. This design change defined the 3rd generation of alumina CFB calciners.
- **New cooler concept.** A new cooler concept was developed to reduce the pressure drop, improve the solids flow and reduce dust entrainment with secondary air [3]. This development allowed the electrical energy to be reduced down from 20 to 18 kWh/t and the thermal energy by approximately 1%. As indicated in figure 2, in the older generation (generation 3) the second cooling stage (comprising of a lift duct and a cooling cyclone) was located between a fluid bed cooler for preheating of primary air for the furnace and a water cooled fluid bed cooler for final cooling of the product alumina to safe discharge temperatures. In the new cooler design (generation 4) the second cooling stage lift duct and cyclone is relocated upstream of the air cooled fluid bed cooler and the two fluid bed coolers are merged into one vessel. This leads to a better heat recovery from the hot solids by the secondary air.
- **Hydrate dryer**. The hydrate dryer utilizes heat from the fluid bed cooler (otherwise often wasted over the cooling tower) to pre-dry a sub-stream of wet hydrate before feeding this to the first pre-heating stage in the calciner. Although the conceptual design was made earlier the first industrial scale installation was in 2011 with very positive results demonstrating both the viability of the technology and the resulting advantages in terms of specific energy efficiency [4].
- **Fuel flexibility** (dual fuel). The dual fuel concept was developed to allow the switch-over and/or simultaneous use of both natural gas and heavy fuel oil [5].
- **New blower concept.** In recent installations large capacity centrifugal fans/blowers were used instead of positive displacement blowers for supply of primary and additional air. This can reduce the total amount of blowers down to 4 [3].

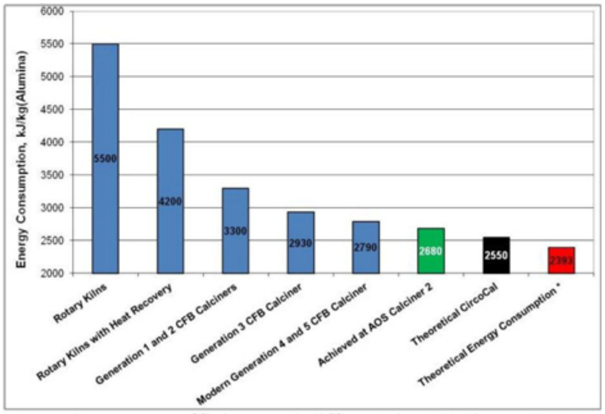


Figure 2. Energy efficiency at different installations. *) Note that the theoretical energy consumption does include 6% surface moisture but does not include any heat losses and assumes all energy is used for the calcination reactions.

As a result of these changes the specific fuel energy requirement has progressively decreased (see figure 2) and recently set the current benchmark of 2.7 GJ per ton alumina [4]. It should also be noted that this was achieved in a 40 year old plant by retrofitting and upgrading the plant to a more modern configuration including both a hydrate bypass and a hydrate dryer.

Plant Arrangement and Specific Weight Reduction

As discussed elsewhere [2] one of the most significant shifts in design paradigm was the changeover from a tower design to a flat arrangement going from generation 1 to 2. This effectively halved the required height of the plants (figure 3) and significantly reduced the structural steel requirement thus lowering the capacity specific investment cost. Since then a further gradual decrease in the specific weight has been achieved. This reduction is not only the result of the increased capacities but also of the more efficient use of construction materials.

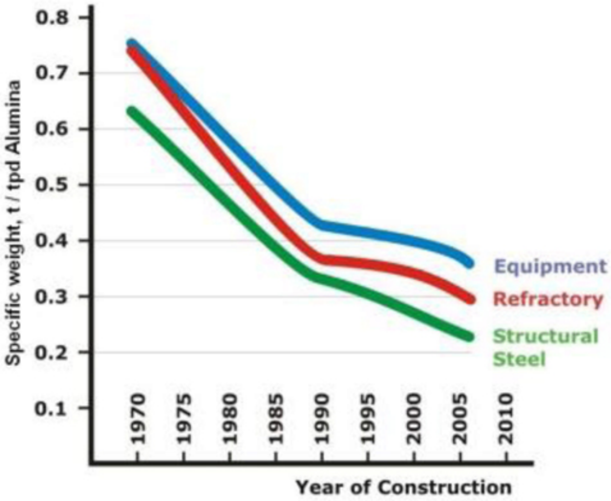


Figure 3. Reduction in specific weight (by item) for selected references.

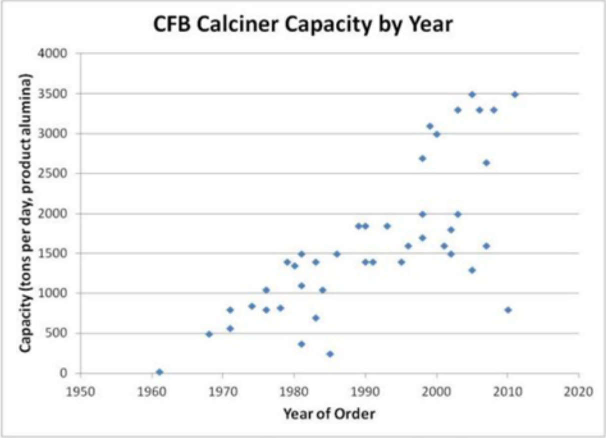


Figure 4. Calciner capacity by year of order (including upgrades)

Larger capacity plants

Another industry trend driving the development of calciner design has been the shift towards larger capacity refineries, and thus the need for increased capacity in calcination. This is illustrated in figure 4 where the CFB calciner capacity is plotted by year of order.

Improving automation and control

In terms of automation and process control the trend and driving force for product development has been the demand for increased automation and improved process stability to improve availability and a reduction in manpower for process control related tasks and field adjustments. This has resulted in advances in process control, allowing for example pre-heating, gas and solids purging, start-up and shut-downs to be fully automated. In addition the development of more advanced control loops, taking the multivariate nature of the process into account, has allowed the performance and stability (temperature, pressure) and product quality (LOI, BET and alpha alumina) related parameters to be maintained within specification during activities like capacity load changes and process upsets. [5, 6]

Equally important, plant safety has been and continues to be a leading driver for development both in terms of plant layout and process control philosophy. For these reasons automation expert systems such as the Outotec® SmartFeed were developed that controls feed and fuel automatically thus keeping the furnace temperature stable and oxygen content in the off-gas at safe levels. At the same time, Outotec's BMS has been designed to reduce the downtime of the calciner and to allow maintaining the temperature in the CFB furnace during shutdowns by keeping the pre-heat burner in operation continuously. The advantages are that the revised operating and interlock philosophy improves the operability, availability and safety of the calciner and also allows for faster restarts after plant trips [7].

Alumina quality – Reducing particle breakage

One of the main focal points for Outotec's development programs has been the reduction of particle breakage in CFB alumina calcination. These research efforts have culminated in the latest CFB calciner units (late generation 4 and generation 5) in which the following main measures were taken in order to reduce the overall particle breakage:

- Optimization of velocity profile
- Optimization of fluidization technology (SF Nozzle™ and improved bubble caps)
- Improved position for fuel injection
- Reduction in calcination temperature
- Improved automation for stable operation

These improvements and their impact on the alumina quality have been presented and discussed in recent years [3, 5-6]. Particularly noteworthy are the achievements at Alcan Gove where the particle breakage could be compared between rotary kilns, older generation CFB calciners and the newer generation with the above mentioned measures incorporated in the design. In figure 5 the particle breakage relative to rotary kilns is compared for the old and new generation CFB calciners. It can be seen that the measures taken have effectively reduced the particle breakage to a level approaching that observed with rotary kilns. It should be stressed that the results in figure 4 are from the same refinery where all three calciner technologies were running in parallel using the same hydrate.

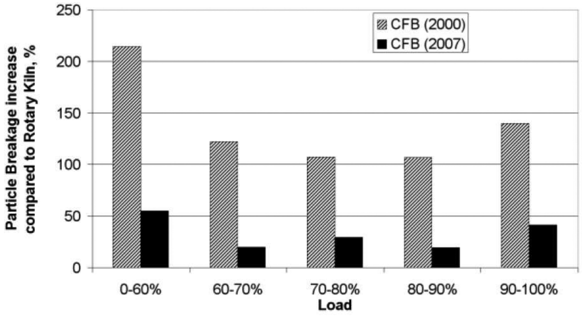


Figure 5: Particle Breakage of CFB Calciners compared to rotary kilns

Current Trends and Drivers for Alumina Calciner Design

In the following section current trends and drivers are discussed. It is notable that further increase in plant capacity seems to not of further interest as for current "typical" refinery sizes of ~2 MTPA a 2x3500 tpd calciner capacity is optimal both from a maintenance and production perspective as well as capital investment costs (engineering, construction). The operational flexibility (large turndown ratio, down to 25-30 % of nominal capacity) of the CFB calciner is favoring the 2 x 3500tpd over 3 times smaller units..

Lower Specific Fuel Consumption and Use of Hydrate Bypass

Lower specific fuel consumption continues to be one of the main drivers for improvements in alumina calcination. Two of the new developments of particular interest for reducing fuel energy consumption are: the hydrate bypass and the hydrate dryer (discussed elsewhere [4]). The latest generation of CFB calciners features a 2nd stage hydrate bypass. The hydrate bypass technology was originally developed in the 1990's as a way to reduce specific fuel energy consumption. Since then the hydrate bypass has been installed in 12 CFB calciners worldwide. In all installations the alumina quality targets / specifications have been achieved while enabling significant energy savings (typically around 3-5% corresponding to 0.10-0.15 GJ/t alumina product).

The hydrate bypass functions as follows: a sub-stream of partially reacted hydrate bypasses the CFB furnace using a sealpot as a variable mass flow control device. The mix pot temperature is kept at a setpoint by varying the amount of bypassed material. In the mixing chamber (mix pot) the bypassed material (at approx 300-350°C) is mixed with the hot alumina from the furnace (at approx 950-1000°C). The heat with the hot alumina from the furnace is used to react the partially calcined bypassed material. Optimum heat transfer and sufficient residence time is ensured by the mix pot design having an underflow weir forcing the material streams to fully intermix.

Since the calcination is an endothermic reaction the temperature of the product coming out of the mixing pot is considerably lower than the temperature in the furnace. The resulting temperature in the mix pot depends on the amount of bypassed material (for example, with approximately 15% hydrate bypass the resulting mix pot temperature is around 720°C). The amount being bypassed is controlled by the adjustable seal pot so that the product LOI and BET specifications are consistently met. No moving parts (i.e. rotary valves) are required for control of the hydrate bypass flow.

Operation of the hydrate bypass has a minor influence on the overall alumina product quality that can be controlled by adjusting the furnace operating parameters (temperature and differential pressure). As the material being bypassed is calcined at a lower temperature in the mixing chamber the LOI and BET surface area of that material will be higher than the material calcined in the CFB furnace at higher temperatures. Note that at the lower temperatures encountered in the mix pot, no alpha alumina will be formed. When operating at high hydrate bypass levels (i.e. low mix pot temperatures) the furnace temperature (and possible also the furnace differential pressure) may need to be raised slightly to maintain product quality within specifications (with regards to BET surface area, LOI and alpha alumina content). This could for example be required to temporarily run the plant at overload capacity to reduce the hydrate level in storage after a major overhaul on one calciner.

Based on operation of the hydrate bypass in several CFB calciner plants the following impact on product quality has been observed:

- No gibbsite detected in any product samples with hydrate bypass operation
- Typical LOI and BET values achieved with hydrate bypass:
  - LOI = 0.69 wt-% (typical spec < 1.0 wt-%)
  - BET = 73.5 m²/g (typical spec 75 m²/g +/- 5 m²/g)
  - Alpha alumina = 4.2 wt-% (typical spec < 10 wt-%)
- A slight decrease of particle breakage has been observed with the use of hydrate bypass
- A slight broadening of pore size distribution due to lower temperature calcination in mix pot when operating with hydrate bypass has been observed

As mentioned above the LOI and BET values of the product alumina are kept within SGA specifications by adjusting the furnace temperature and pressure accordingly. As not only the specific surface area, but also the pore size, is of importance for effective dry scrubber performance in the aluminium smelter [10-11], the impact of utilizing the hydrate bypass on the pore size distribution has been investigated as well.

As can be seen from the figures below the pore size distribution in CFB calciners without hydrate bypass is uniform with an average pore size around 7-9 nm. With normal level of hydrate bypass a slight broadening in the pore size distribution is seen (in the 2-5 nm range, green oval). The average pore size distribution is also shifted slightly higher, to 8-10 nm.

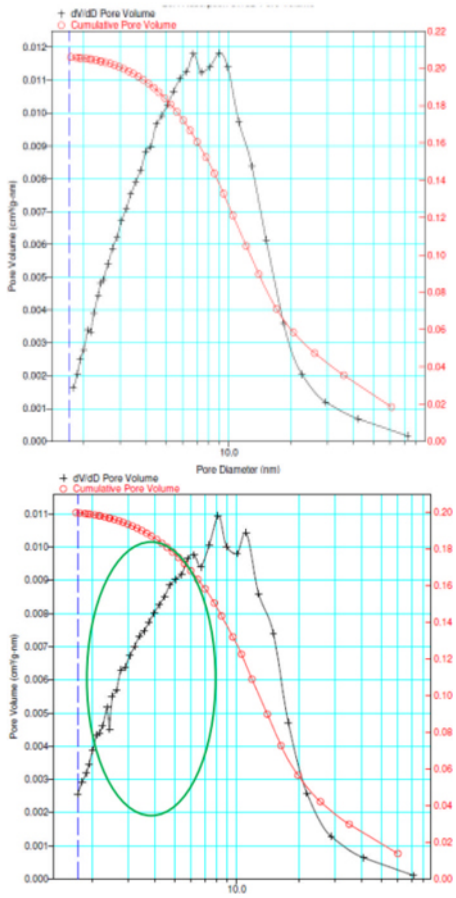


Figure 6. Influence of hydrate bypass on product alumina pore size distribution. Top: no hydrate bypass, Bottom: typical hydrate bypass level (note the green oval indicating a slight increase of pores in the 2-4 nm range),

To explore the limits of the hydrate bypass and to investigate what the impacts on quality and fuel consumption are some further industrial trials were conducted (figure 6). It was observed that only with extreme hydrate bypass utilization (mix pot T below 700°C) a significant broadening of the pore size distribution in the 1-4 nm range (figure 7) is occurring. The average pore size is still however in the 9-11 nm range. The increased contribution of the pores < 3 nm to the total cumulative pore volume is insignificant (refer to the red line in the figure above) and does not influence the performance of the alumina in the dry scrubber for which pores > 3 nm has been found to be ideal [11]. Note that all samples were obtained from the same calciner with the same hydrate quality.

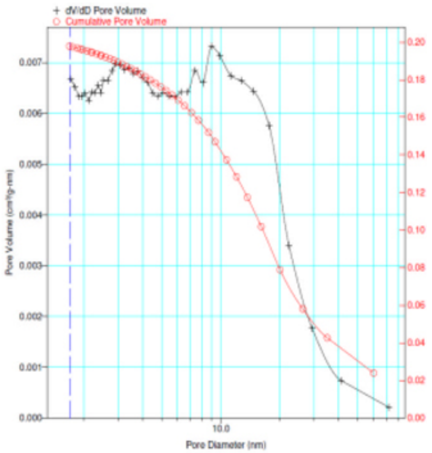


Figure 7. Pore size distribution with extreme utilization of hydrate bypass.

<u>Lower spec. electrical energy consumption</u>

One of the main changes between generation 4 and 5 is the elimination of the airlift. This has three main advantages: 1) the ESP footprint becomes smaller as the whole product is not cycled over the ESP, and 2) the elimination of the airlift and the smaller ESP reduces the electrical energy consumption, 3) reduced particle breakage as the whole product stream does not have to be conveyed with relatively high velocities over the airlift. These changes combined with the previously mentioned improved cooler concept reduces the specific electrical energy consumption to less than 15 kWh/t [8].

<u>Upgrades and retrofits of old calciners</u>

With an installation base of over 50 calciners, some over 40 years in operation, a recent trend has been the modernization and upgrading of older units. In recent years several 20+ year old plants have been upgraded in terms of fuel efficiency, capacity, safety, automation etc [4, 8-9]. Although this is a very challenging undertaking from an engineering perspective, due to the fact that the refinery and other calciners are often operating in parallel and also because of space and access limitations in older plants, it has been demonstrated that there are clear benefits in terms of capacity and fuel efficiency improvements.

<u>Environmental requirements</u>

Another significant environmental issue is dust in the form of flue gas emissions and as fugitive emissions from the calciner equipment. In recent years, the stack dust emission concentrations acceptable to our customers has been reduced by more than 50%, with some sites now targeting emissions below 20 mg/Nm^3(wet). Also for NOx the emissions limits are being tightened. Due to the staged combustion in the CFB calciner and the uniform temperature distribution and low temperature very little NOx is formed or emitted compared to other calcination systems utilizing burners that may result in high local temperatures which increased the formation of thermal NOx.

Towards a Standardized CFB Calciner

Now where calcination technologies are approaching a level of maturity and reaching the limits of what is physical possible, costs and project execution are getting even more in the focus as they have already been. When it comes to cost and schedule efficiency then instantly standardization is being thought of.

Both from a supplier and client perspective a standardized plant with standardized plant components would be preferred. This would greatly reduce engineering effort in all stages of a calciner project. It would allow to reduce delivery time significantly. In most refinery projects calcination as a long lead item is usually awarded first. Further it would simplify and reduce costs for operation, maintenance and spare part management during the operational lifetime of the plant.

However a few items are limiting the extent to level of standardization which could be achieved. Whereas the basic flowsheet, process design, sizing and geometry of main equipment and basic arrangement can surely be standardized by each vendor the following aspects only have limited potential for standardization.

Site conditions, like ambient temperature, pressure and wind loads and seismic conditions, etc. can have significant influence on refractory thickness, blower sizing, equipment protection from environment, steel structure, etc.

Further although many stand for environmental protection and safety are nearly globally harmonized by now, there are still local and even more so client and EPCM standards and specifications which need to be complied with. These standards can vary quite significantly between projects and have strong influence on

- Accessibility guidelines
- Further safety requirements beyond regulatory requirements
- Isolation requirements
- Operability requirements
- Piping arrangement
- Equipment clearance
- etc

The industry is not harmonized on these aspects and therefore each project requires quite some engineering effort to adjust the overall plant design to comply with specific project requirements. Further it also feeds through to sub-suppliers as they are asked to comply with different requests each project and limits their ability to standardize their equipment. Further it also requires additional effort on client and EPCM side to review and ensure compliance and schedule. Being able to standardize has the potential to reduce delivery time by several months and reducing costs on vendor's, but also client and EPCM side significantly.

However some things as said above can be done. Outotec has structured their calcination product in several components as shown in figure 8. Besides the basic design the client can choose further components to be added. These components allow customization in terms of operability, availability, energy efficiency, fuel flexibility or even further benefits such as utilization on waste heat in other parts of the refinery. This way the cost- benefit structure can be defined by the client and allow the vendor to streamline his offering for project execution and cost.

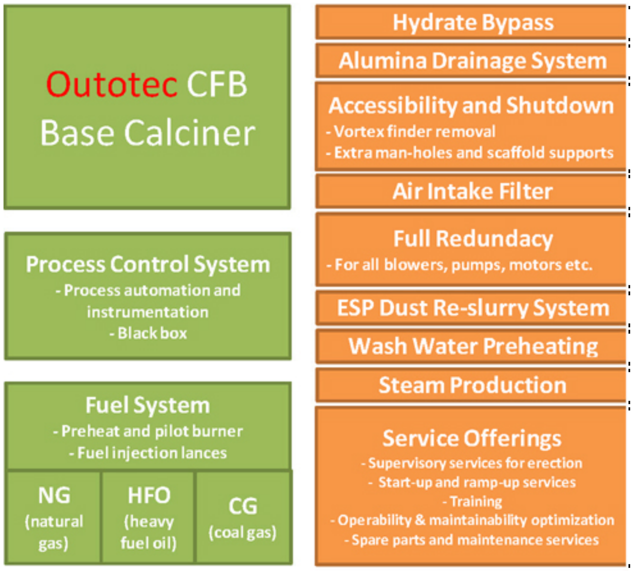


Figure 8. Outotec CFB Calcination Product Structure

Conclusions

In the presented overview the authors have presented and discussed past and current trends and directions in the development of CFB calcination. Many aspects were always the same like energy efficiency, operability, product quality and plant capacity. As plant capacity only had one trend towards bigger and bigger plants to take advantage of economy of scale it seems to have leveled at approx. 3500tpd.

Other criteria have changed in their priority over time. The energy efficiency of CFB calcination has by now achieved nearly 95% of thermal efficiency. Only little can be further gained. So product quality and operability are now in the main focus.

Further cost pressure was always high, but with maturity of technology will only grow and lead the efforts in development. However this is not an effort which is best done by vendors alone, but also influenced by clients and EPCMs requirements. An industry wide harmonization of specific standards and requirements would have huge potential to influence costs and projects execution efficiency.

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