Production of Ceramic and Smelter Grade Alumina in Outotec's Dual Purpose CFB Calciner

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Abstract

Special grade alumina are commonly used in a range of application, such as ceramics, refractories, glasses and polishing agents. The production of these materials require calcination at higher temperatures that what is used to produce Smelter Grade Alumina (SGA), and often also the use of mineralisers. Particularly for small or mid-sized alumina refineries tapping into alternative revenue streams is an attractive option in case there is additional capacity in the upstream refinery processes. In 2014, Outotec was engaged by ETİ Aluminyum Inc. to design a calciner capable of producing both Smelter Grade Alumina for use in their own smelter as well as Ceramic Grade Alumina (CGA). This required a dual purpose-built plant to cater for the required wide range of processing conditions to produce these very different alumina qualities. This paper explores some of the design challenges, provides solutions that Outotec developed to overcome these, and also discusses the performance of the plant after commissioning.

Keywords: Alumina Calcination, Ceramic Grade Alumina, Circulating Fluidised Bed, Alumina Quality, Smelter Grade Alumina.

1. Introduction

Special grade alumina are commonly used in a range of application, such as ceramics, refractories and polishing agents. The production of these materials require calcination at higher temperatures than what is used to produce Smelter Grade Alumina (SGA), and often also the use of mineralisers. By adjusting calcination parameters, mainly calcination temperature and retention time some of the key properties can be controlled. Particularly for small or mid-sized alumina refineries tapping into alternative revenue streams is an attractive option in case there is additional capacity in the upstream refinery processes.

In 2014 Outotec was engaged by ETİ Aluminyum Inc. to design a calciner capable of producing both Smelter Grade Alumina for use in their own smelter as well as Ceramic Grade Alumina (CGA). This required a purpose-built plant to cater for the required wide range of processing conditions to produce these very different alumina qualities. The success of the challenging project was only possible through a very close cooperation between Outotec and ETİ Aluminium in all stages, from design and engineering, through to construction and commissioning. Most importantly, focusing on getting the design aspects right in the early stages of the project was a key to the success. In this the experience of both parties was crucial.

Implementation of the project comprised understanding of the functional target of the plant over the definition of engineering aspects to be re-engineered and reinforced. This involved interaction of all disciplines, process, plant layout, equipment design, materials, instrumentation, programming, controls, operation and maintenance. This paper explores some of the design challenges, provides solutions that Outotec developed to overcome these, and also discusses the performance of the plant after commissioning.

2. Process Parameter

Establishing the required process parameters to obtain products with the desired characteristics was one of the most important activities in the early stages of the project. This defines not only the design parameters of the main vessels but also the sizing of several key vessels. It is well known that calcination time and temperature impacts on the alumina properties [1], and this is also utilized in the calciner control, for example by adjusting the furnace temperature to achieve the target SGA properties.

Several chemical and physical properties such as loss of ignition (LOI), specific surface area (BET) and alpha alumina are related to each other. A typical relationship as derived in Circulating Fluid Bed (CFB) calcination, is shown in figure 1, in which BET and LOI are represented with blue and green lines, respectively, and alpha alumina with a red line. As can be seen in the relatively narrow temperature range (used for SGA production) the BET and LOI appear to follow an almost lineal trend inversely proportional to the temperature. Alpha alumina formation, on the other hand increasing exponentially with calcination temperature. Impurities and mineralisers can further enhance/catalyse or inhibit this phase transformation reaction. As an example, fluoride which is often used as a mineraliser has a strong influence in catalyzing the conversion to alpha alumina.

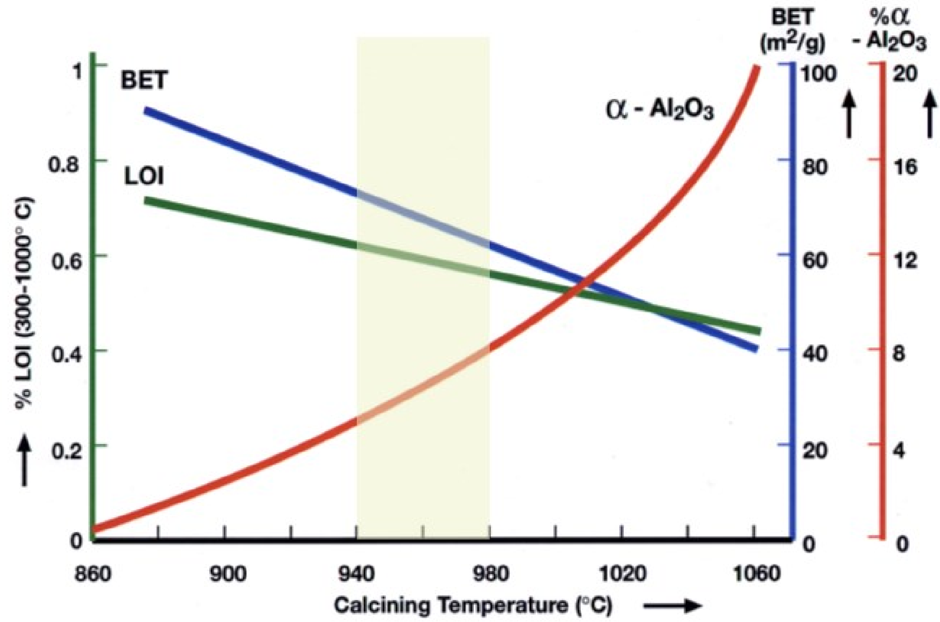

Figure 1. Development of BET, LOI and alpha alumina as a function of calcination temperature in a CFB (at fixed residence time). Typical range for SGA production indicated in the shaded area.

However, these relationships are highly idealized as the development of alumina microstructure and properties are influenced also by other factors [2]. Most notably for a Bayer refinery would be the hydrate quality in terms of particle size, shape and impurity content and distribution. Therefore, finding out the required process parameters for a specific hydrate requires test work, which in the case of a brownfield refinery is easily facilitated by using existing hydrate.

A series of testwork was carried out to determine optimal operation temperature for target alumina qualities, referred to as SGA and CGA. The test work was carried out in a pilot scale CFB reactor, where the heat and mass transfer mechanisms and kinetics are comparable to industrial CFB calciners. It has been shown that also the quality of the alumina produced in terms of crystallographic order (and disorder) and microstructure is comparable in such pilot scale calcination to industrially produced samples [3]. The test work was mainly focusing on the formation of alumina as a function of time and temperature, thereby allowing to derive reaction kinetics. Other quality parameters were measured, but the discussion of those are outside the scope of this paper, as alpha alumina is the lead indicator for the CGA product quality.

The alpha alumina formation as a function of temperature at several residence times is shown in **Error! Reference source not found.**. This data is the basis for temperature set point for o peration, design temperature of main vessels and required residence time (vessel size), and for evaluating and determining margins for control response time for scenarios such as plant upsets/trips. Not surprisingly, the curves reveal that the alpha-alumina conversion is driven by the temperature. In the range of 1000 to 1050°C the alpha-alumina content is almost the same or within the analytical error margin. At temperatures above 1100°C the conversion rapidly increases and thus the retention time start to play an important role. Based on this test work the set point for the production of CGA and the operation of the plant was selected between 1100 and 1150°C. At upper temperature the conversion is extremely rapid, in case of temperature deviation during plant operations the α-alumina content may exceed production targets not only causing product quality variation but also causing operational issues and production downtime.

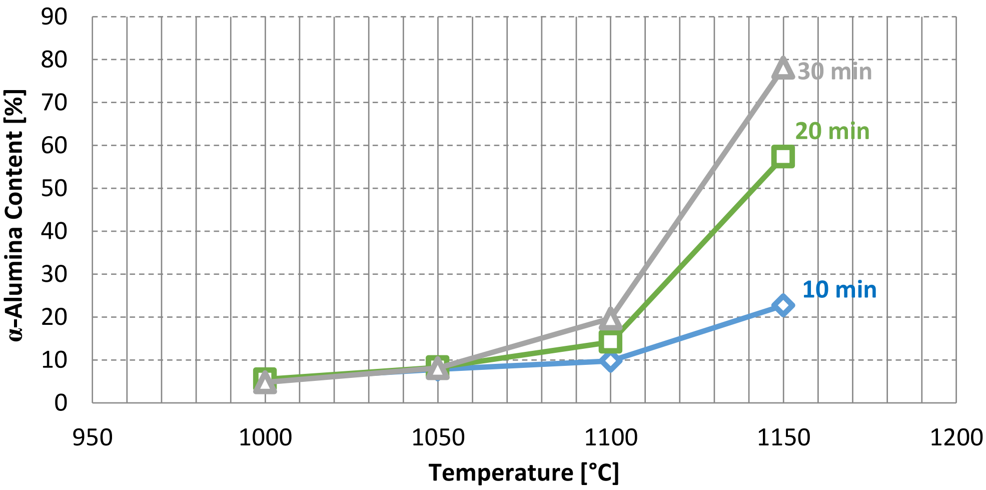

Figure 2. Alpha alumina content vs. Temperature.

3. Process Layout

Outotec's latest CFB calciner flowsheet, generation 5 [4], was selected as the basis for the plant design and layout and specific equipment adapted for the capacity and duty, see figure 3. Equipment/vessel heights and widths (and thus velocities) were carefully selected to assure flowability of the material throughout the plant at any production mode and capacity. An improved hydrate bypass was integrated in the layout, to bypass preheated hydrate the circulating fluid bed furnace and calcine it at the mixing pot with the heat of the fresh calcine alumina coming out of the furnace by smelter grade alumina production mode. The hydrate bypass was introduced in the CFB calciners in the 1990's [5] and has since been implemented in some 15 plants. The hydrate bypass allows significant fuel energy consumption savings, by utilizing the heat with the hot discharged alumina from the furnace to calcine the bypassed hydrate in a purpose designed mixing vessel. The improved hydrate bypass allows to bypass a fixed amount of hydrate without the use of rotating devises in the solids flow, thus improving plant reliability. Furthermore, the hydrate bypass was strategically designed to allow to swap the bypassed preheated hydrate to the second preheating stage when the plant is operated in the ceramic grade alumina mode to ensure that the target alpha alumina content can be continuously achieved.

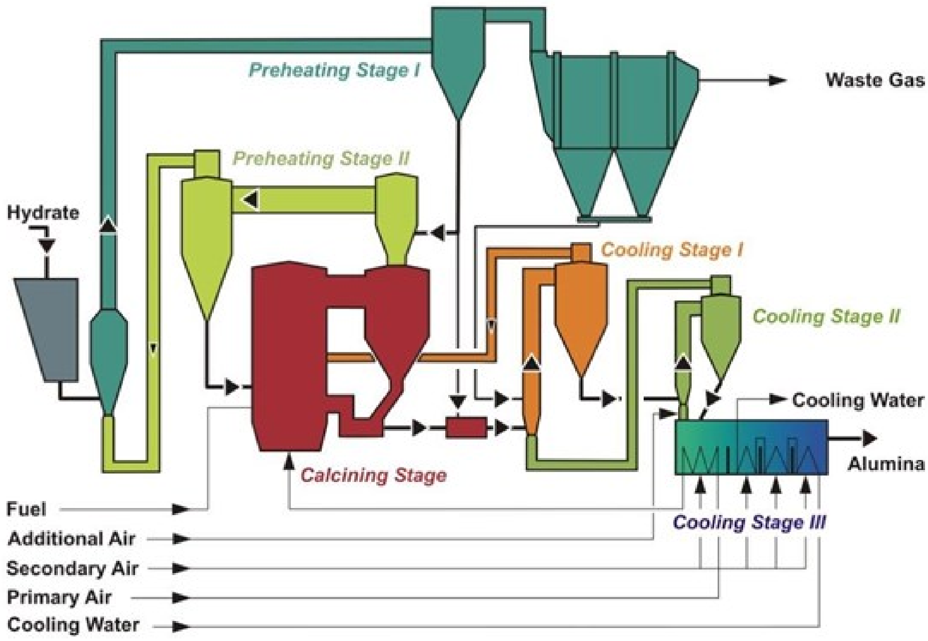

Figure 3. Outotec generation 5 CFB calciner flowsheet.

The presented plant comprises all the equipment and vessels typically used in a 5th generation CFB calciner. In the design phase, the equipment, vessels and ducts were evaluated against typical design criteria to determinate the design basis as applicable for a dual production calciner. In some equipment or part of the plant, computational fluid dynamics, CFD, modelling was employed to make more detailed evaluations. Particularly attention was made in determining the design velocities, and pressure profile, to ensure the solids transport and flowability at any production mode and production rate. Theoretical temperature profiles of both operational modes (SGA and CGA mode) are outlined in Figure .

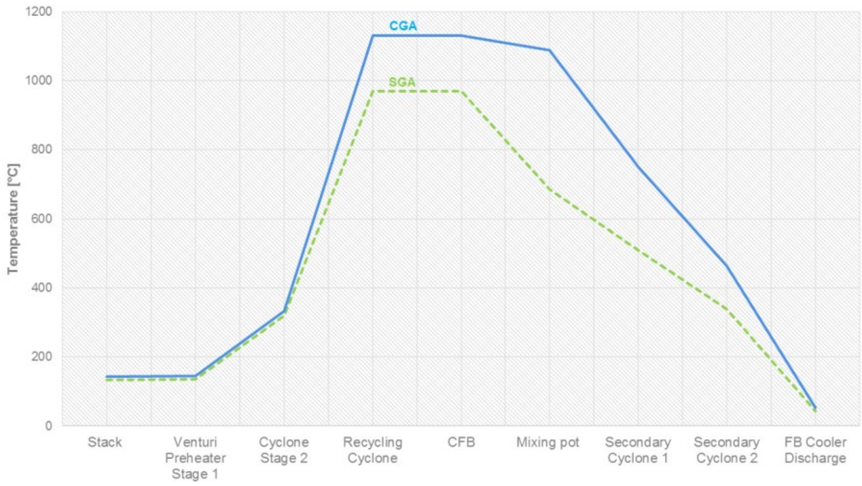

Figure 4. Temperature profile of SGA and ceramic grade alumina CGA.

4. Equipment Design

At the core of the CFB alumina calcination technology lies the furnace group, comprising of the furnace the recycle cyclone and furnace seal pot. This is one of the most critical equipment in the plant and ensures a stable production and uniform alumina quality while also facilitating the combustion reactions which provide the heat for the calcination. Figure 5 provides a model of the CFB group in the dual purpose calciner. Due to the high temperatures and temperature difference at the circulating fluid bed system, the recycling cyclone vortex finder was replaced by a smart arrangement with an inlet ramp into the vessel. The inlet ramp was implemented keeping sufficient distance between inlet and outlet. With the objective to restricts flow bypassing the recycling cyclone, the material flows inside the vessel in 29° angle with respect to top. The top of the cyclone was formed as a dome, so that the flow exists the vessel in an angle of 6° with respect to the inlet. Hanging parts were omitted to avoid exotic materials for the construction and its installation.

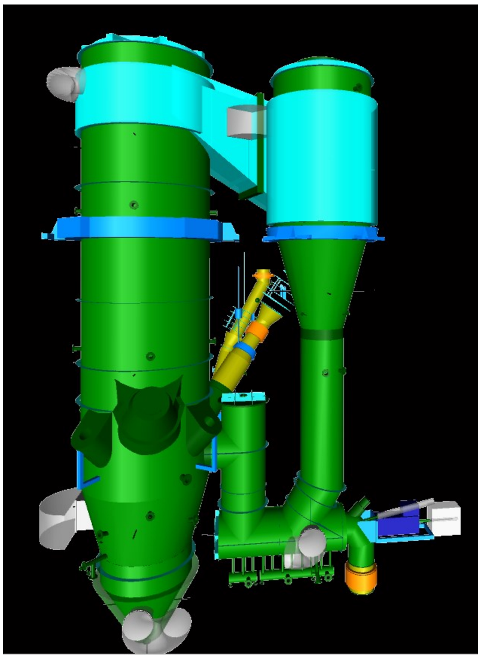

Figure 5. Model of the CFB furnace group for the dual purpose calciner. The use of a ramp design in the recycle cyclone eliminated the need for a vortex finder.

Another critical equipment was the fluid bed cooler (figure 6), in which the final product cooling down to temperatures safe for further handling takes place. The challenge with the design of this equipment was the large temperature difference the solids would have when entering the vessel in the two different operating modes. When the plant is used in SGA mode and the hydrate bypass is in operation the solids would have the lowest temperature when entering (typically around 300 °C), see figure 4. Whereas, when operated in the CGA mode (with the hydrate bypass disabled to ensure high alpha alumina conversion) the maximum material temperature is observed (up to 500 °C). In the fluid bed cooler further heat recovery takes place, both directly by heating part of the combustion air (the fluidising air for the cooler) and indirectly by heating the primary air which is used for fluidization of the CFB furnace. To allow the fluid bed cooler to handle the two very different operating modes compacted bundles with smart design for easy accessibility and maintainability of the chambers were installed and special attention paid to refractory design.

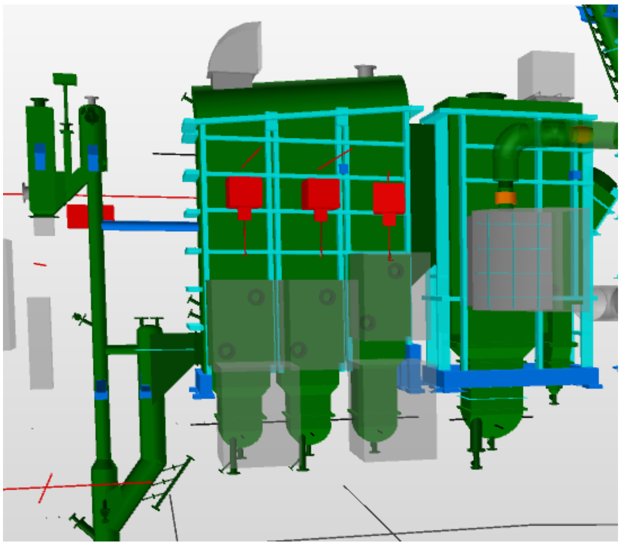

Figure 6. The purpose designed fluid bed cooler, capable to operate at two very different modes.

One important aspect of the design for the two operating temperatures was the refractory, particularly in those areas with higher temperature and higher temperature differences (ref to figure 4). The refractory design involved the selection of the material for the refractory itself, the material for the joints or mortices and the anchors for support. For the dual calcination plant a custom-made concept were developed, this deviate from nowadays Outotec smelter grade alumina calciner standards. This concept is indicated in figure 7 where the vessel on the left is an example of a “standard” refractory design for smelter grade alumina plants and the vessel on the right the specially designed refractory for the dual purpose calciner. In the standard configuration concrete castings are used, this a proven design that guarantee its function and provides advantages for logistic, installation, repairs and demolition. In the dual purpose calciner the upper part of the vessel is lined with brick and the lower part a combination of brick and monolithic with ceramic anchors. The decision on what material to use was based on the heat transfer from bottom to the top with temperature above of 1050 °C.

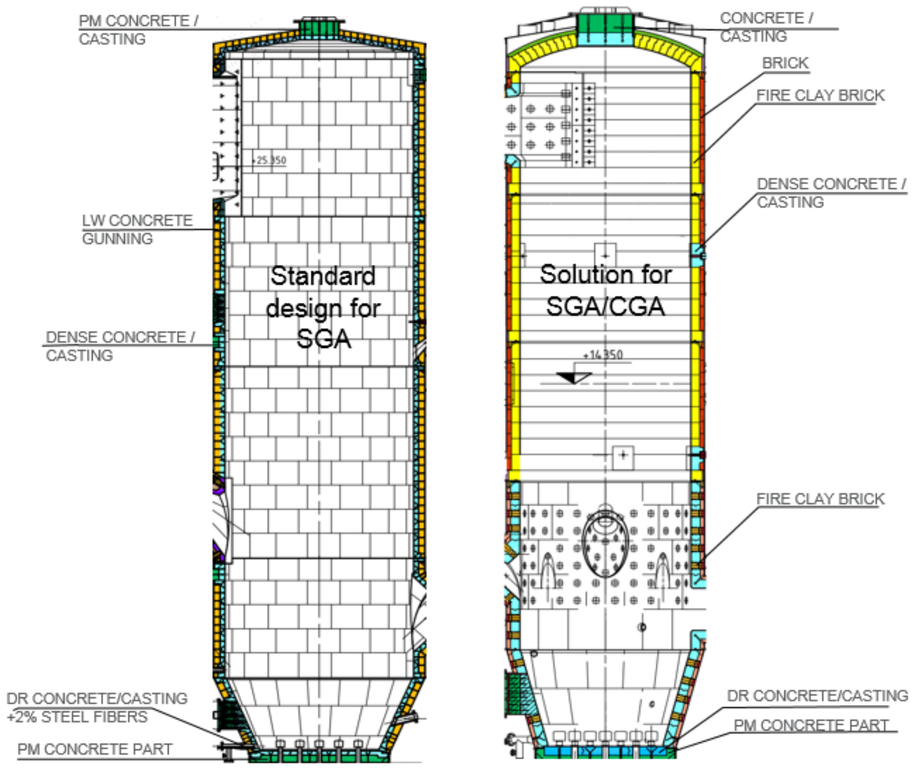

Figure 7. Refractory design for "standard" furnace used for SGA production (left) and new design for the dual purpose calciner (right).

5. Process Performance

After mechanical completion the plant hot commissioning commenced in December 2017. The plant hot commissioning was carried out by ETİ Aluminyum Inc. under the guidance of Outotec's process and commissioning experts, and was a true collaborative effort. After initial trials and adjustments ramp up to nominal production capacity could be achieved. During the plant operation the performance was carefully monitored and evaluated in both operating modes. The table below provides a summary of operational, quality and consumption figures achieved in either operating mode.

It can be seen that the plant design capacity could readily be achieved in both operating modes. The operational parameters are typical only, and mainly included to indicate the wide range of operating conditions the plant was designed for. As mentioned earlier in the CGA mode the procedure is not to use the hydrate bypass (as this would decrease the alpha alumina content in the product) but instead route the bypassed hydrate to the second preheating stage. Furthermore, testifying to the cooler design the alumina discharge temperature is well below safe handling limits for typical equipment used in the transport of alumina.

The product quality parameters are reflecting the furnace temperature setpoint (and to some extent the furnace inventory, which is not included here). In the SGA mode a low LOI well under the typical limit of 1.0 wt-% is readily achieved. In CGA mode, the LOI is typically around 0.1 wt-%. The BET was measured to be approx. 80 m²/g in SGA mode and typically only 30 m²/g in the CGA mode. A lower BET can be produced in the SGA mode, buy increasing the furnace temperature setpoint, should that be desired. In SGA mode very a low content of alpha alumina was detected, typically only 1-2 wt-%, whereas in CGA over 30 wt-% is achieved. These figures correspond well with the design predictions at the different temperatures, as derived from the test work conducted in the design stage and also described in this paper. In either operational mode, no gibbsite is detected in the alumina product under normal operating conditions.

The consumption figures are not disclosed here, only the relative consumption CGA mode compared to SGA mode (normalized to 100 %). It may be seen that both electrical and fuel energy consumption is higher in CGA mode. The higher specific fuel energy consumption in the CGA mode is a result of higher heat losses, both due to a slightly higher shell temperature and due to a high stack temperature when the plant is operated at close to 1150 °C in the furnace. Similarly, and as predicted in the process modelling, the electrical energy consumption is also increased in the CGA mode. This is due to the higher velocities at the higher temperature in the CGA case, which results in increased pressure drop throughout the plant. This increased pressure drop is translated to higher electrical energy consumption for the blowers.

Table 1. Summary of key performance indicators.

	Parameter	Units	SGA	CGA
Capacity	Design	tpd	500	500
	Achieved		529	518
Operational	Top furnace T	°C	960	1140
	Hydrate bypass	-	In use	Not used
	Alumina discharge T	°C	47	52
Alumina Quality	LOI	wt-%	0.58	0.11
	BET	m^2/g	80.9	Not applicable (typically ~30 m^2/g)
	Alpha alumina	wt-%	1.3	31.3
	Gibbsite in Product	wt-%	Not detected	Not applicable
Consumption	Specific Fuel	Normalized to SGA at 100%	100%	107%
	Specific Power	Normalized to SGA at 100%	100%	126%

6. Conclusion

This paper presented some of the main design challenges in developing a new type of CFB calciner suitable for the production of two distinct alumina qualities, namely Smelter (or Metallurgical) Grade Alumina, SGA, and Ceramic (or Commercial) Grade Alumina, CGA. These two alumina qualities require calcination at markedly different temperatures, which has to be catered for in the design both in terms of process parameters and mechanical equipment as well as refractory design. This required careful evaluation of basic design assumptions, and also involved test work in Outotec's pilot plant facilities to derive some of the required design parameters. This had consequences for the design of some of the main equipment, which had to be designed specifically for this plant. Furthermore, a unique refractory design was developed for the CFB furnace group to cater for the required high temperature in CGA mode.

A key to the success was the close cooperation between Outotec and ETİ Aluminyum Inc. throughout the project, and in particular during construction and commissioning. The plant is in operation since early 2018 producing alumina meeting the required quality specifications for either type of product. This endeavor is a good example how small refineries (or refineries with surplus hydrate production capacity) can create additional value by tapping into different types of products and new revenue streams.

7. References

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