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Flash- and CFB Calciners, History and Difficulties of Development of Two Calcination Technologies

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Abstract

In the last 40 years, stationary calciners have permanently replaced rotary kilns in existing alumina refineries and are being installed in all new Greenfield alumina refineries producing smelter grade alumina.

In the 1960's two separate and different approaches to stationary alumina calciners were going through research and development. Alcoa developed a fluid flash system and VAW, together with Lurgi (today Outotec) the Circulating Fluid Bed (CFB) calciner. Both developments had the same targets, but took different approaches to create more efficient calcination systems. Without any joint effort, the industrial stages of both developments were introduced to the industry at the same time.

This paper describes the significant steps of the development that both calcination systems went through to reach an industrial stage and the risks and failures that both took. Furthermore the differences and common goals of both approaches are analyzed and described.

Introduction

At the time that stationary alumina calciners were being developed, different product qualities were required in the US and in Europe. In Europe the alumina producers were requiring a floury alumina with high angle of repose and high alpha content, while up to 70 % of the US producers required a sandy coarse alumina with low alpha content. These different market demands influenced the development. The independent but common goal of both developments was to create a new calcination system to replace rotary kilns with all their disadvantages. Both groups focused on stationary calcination systems where the refractory lifetime could be improved and energy consumption could be significantly reduced. Furthermore mechanical moving parts could be reduced to a minimum. Alcoa did the development by itself; VAW used an engineering company as supplier and partner, but both developments were started and completed within the alumina industry and were not an outside of the industry development.

ALCOA Fluid Flash Calciner Development

First Fluid Bed Developments

Alcoa Research became interested in fluid bed technology after the first commercial application of a fluid bed system was introduced in a fluid bed catalytic reactor at the Esso Refinery in Baton Rouge in 1942. At that time, rotary kilns producing calcined alumina used 9.3 GJ/t (4000 BTU/lb). The first application of the new fluid bed technology was in the use of fluidized coolers on the discharge of alumina kilns to preheat combustion air and that brought the energy consumption down to 4.9 GJ/t (2100 BTU/lb). This value, however, was more than 2.5 times the theoretical heat requirement needed for calcining alumina but was thought to be approaching the practical limit of rotating kiln design.

Research studies had shown that alpha alumina could be produced at 500°C. in a high-pressure steam atmosphere. The possibility of calcining alumina trihydrate in a steam-fluidized bed electric calciner was briefly investigated. That effort was dropped, however, because of the design requirements of feeding and constructing such a unit operating at 3450 kpa (500 psi).

First Alcoa Fluid Bed Alumina Calciner Design

Alcoa Research began bench and pilot plant studies in 1946 on a fluid bed alumina calciner. In 1951, a proposal was made to install an 8-foot diameter calciner at the East St. Louis Refinery as a prototype unit. It developed that material shortages caused by the Korean conflict prevented building the experimental unit at East St. Louis. At this same time, however, the new Bauxite Arkansas Works had already been authorized and design work was underway for that refinery plant. A decision was then made to install three untried, full-sized fluid calciners at Bauxite.

The new Bauxite Works was to be a combination plant utilizing the sinter process. The basic rotary kilns and coolers to be used in the sinter plant were to be exact duplicates of alumina kilns. Since the sinter plant would not be expected to reach full-scale operations for nearly a year after the start of the Bayer plant, it would be possible to use one or more of the sinter kilns as alumina kilns for an interim period during testing and startup of the new fluid bed calciners. The target was that one digester unit would be completed in August of 1952 with the second digester unit completed at the end of the year. The first calciner was scheduled to be completed by June of 1952 and the other two by the end of the year.

In Bill Fish's 1974 TMS paper [1], a description is given of the design of one of these units and the design is shown in Figure 1 [1]. The units "incorporated two stages of heat exchange at the feed end, two combustion zones and five stages of alumina cooling by direct contact with combustion air. Free moisture was reduced in a drying filter followed by a fluid bed preheating stage where 50 - 60% of the combined water was removed".

"The high rate of heat transfer in the fluidized bed provided practically instantaneous water removal. The partially calcined alumina entered the first combustion fluid bed where again instantaneous water release was achieved. In order to minimize velocity, this combustion zone was operated at the lowest practical combustion temperature (1400°F), which was also sufficient to remove essentially all of the combined water. The second combustion zone was supplied with only that fuel and

combustion air required to supply the sensible heat to raise the essentially anhydrous alumina to the temperature required for the desired properties. Cyclones were supplied in the zones handling the highest vapor volumes to permit fluidization velocities in the range of high entrainment. To achieve increased capacity in economically sized units, the calciners were operated under pressure".

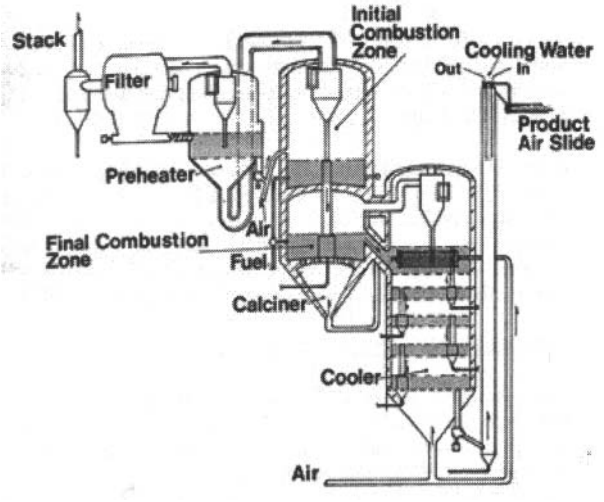

Figure 1: 1951 Fluid Bed Calciner Design

"The capacity of the fluid calciner was set by the quantity of fuel that could be burned within the fluid beds in the two combustion zones. Higher fuel input resulted in after-burning with excessive temperature in the disengaging zone and cyclones above the bed. For the 12 ft dia. Unit, capacity was limited to about 12,000 lb/hr at atmospheric pressure and 25,000 lb/hr (300 ton/day) with pressure operation." Under pressure operation the units were to operate at three atmospheres. Ceramic hearths were used for fluidization in the two calciner sections and perforated stainless steel plates used for the fuidizing grids elsewhere.

A number of factors, including a steel strike, delayed completion of the first fluid calciner until January 1 1953. The 6-month's shakedown period was gone before a calciner was ready to run. To make matters worse, the pressure filters, which were being fabricated by Eimco, were further delayed by higher-priorities on filters being built for the Atomic Energy Commission. As a consequence, the first pressure filter was not ready for operation until the end of April 1953. To assist the now overloaded rotary kiln it was decided to operate two of the fluid calciners as atmospheric calciners. The first calciner was started at the end of 1952. Operations during these few months of atmospheric operations were quite encouraging.

Real trouble in operating the units began, however, when the pressure filters were installed in early May 1953. The pressure filter was a rotary drum in a pressure-tight casing. Feed slurry pumped onto the surface of the rotating screen drum was to dewater immediately. Hot gases from the fluid calciner entered the filter housing and passed directly through the cake on the filter drum. In passing through the cake these gases give up their heat, dried the cake, and at the same time deposited any entrained dust on the surface of the cake. The dried cake then discharged from the drum rather close to the feed point and fell into the bottom of the filter housing where it was picked up by a screw conveyor and conveyed to the first stage of the fluid calciner. Considerable difficulty was initially encountered with sealing the rotating shafts of the filter drum and the conveying screws but these difficulties were ultimately solved. The real filter problem, which was never completely solved, was the blinding of filter screens. This resulted in short-circuiting of slurry that at times resulted in cake moisture content in excess of 60%. It is estimated that the average feed moisture to the calciner was between 10 and 15%.

In early 1955, the pressure filters were abandoned. A request for funding for $50,000 was prepared to further modify the units to increase their capacity at atmospheric pressure up to 300 t/hr with an expected heat consumption of 3.3 GJ/t. Alcoa's top management had had enough! Management turned down the request and the calciners were shut down in September of 1955. Research was able to prevail and have one complete calcining unit maintained intact in the hope of completing the development program on fluid calcination.

Fluid Flash Calciner Design

Research studies on alumina calcination next turned to dispersed phase contacting systems, which showed the promise of avoiding the capacity limitations of the fluidized bed process. Dispersed phase or "flash calcination" became the catch phrase to use with upper management and at all times the term "fluid bed", that was associated with the failed units, was to be avoided.

In 1960, the revised calciner shown in Figure 2 [1] was put in operation. The upper hearth of the prior unit was removed and the internal cyclone was replaced with an external refractory lined cyclone returning to the combustion vessel. The single combustion zone was operated well above conveying velocities and the control of solids density in the dispersed phase was set by the rate of alumina withdrawal. In this manner, the entire vessel volume was available for combustion. Operating at atmospheric pressure, the capacity was 300 ton/day.

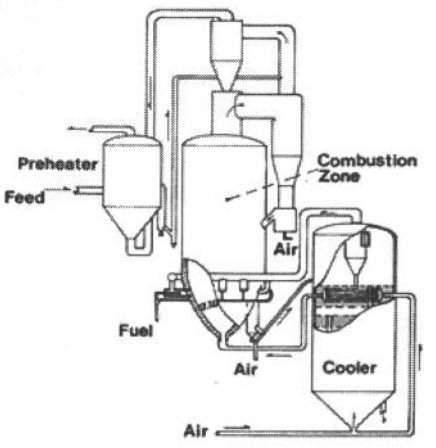

Figure 2: Fluid Flash Calciner design

Continuing studies resulted in the 1962 design shown in Fig. 3 [1]. The combustion zone was been further simplified by eliminating hearths entirely. The furnace took the shape of a vertical cylinder with conical top and bottom. Heated combustion air enters at the bottom of the furnace. Fuel, gas or oil, was introduced at several points around the periphery of the lower portion of the cylindrical section, partially calcined alumina from a cyclone heat exchanger was fed to the combustion zone through an inclined conduit aimed to spout the alumina into the central portion of the furnace. The calcined alumina and combustion products left the top of the furnace and entered a cyclone where the solids separated from the gas stream and fell into a fluidized bed in the lower portion of the cyclone vessel. Fluidizing grids through out the unit were now replaced with fiberfax cloth membranes compressed between two perforated stainles steel plates.

Complete combustion and maximum calcining temperature were achieved in the dispersed phase (flash) calcination stage. The holding period in the fluid bed, at calcining temperature (or slightly below due to losses to radiation and fluidizing air), provided control of L.O.I. and surface area.

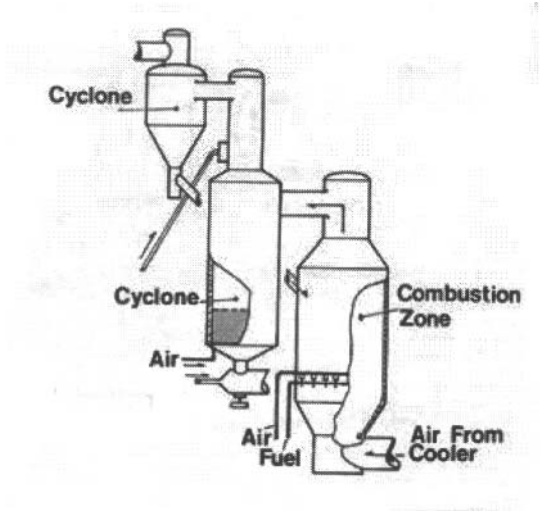

Figure 3: 1962 Fluid Flash calciner design

That unit, named Mark I with a capacity of 300 t/d, became the forerunner the Alcoa "fluid-flash" calciners, With further modification and an initial capacity of 600 t/d Mark II fluid-flash calciners were installed in Suriname in 1965 and Kwinana, Australia in 1966. In 1971, the first of the Mark III fluid-flash calciners were installed in Point Comfort, Texas and Clarendon, Jamaica with an initial capacity of 1200 t/d.
The design of the Mark III is shown in Figure 4 [2]. Moist filter cake from table filters is conveyed into and contacted by hot combustion gases and water vapor in a flash drying section. The dried hydroxide is held in a fluidized bed dryer, to provide a holding time to allow for feed variations and insure dryness of the hydroxide. The dry hydroxide is conveyed from the dryer to the calcining section at a controlled rate to maintain constant calcining temperature, Calcined alumina leaving the combustion zone is retained in a fluidized bed for the desired period of time by control of bed level. The combination of calcination temperature and retention time determines the physical characteristics of the product alumina, The calcined alumina is first cooled by direct contact with combustion air in a series of cyclone heat exchangers and finally in a two deck fluid bed cooler. A tubular heat exchanger in the upper deck heats air for the fluid dryer, and water-cooled tube bundles provide the final cooling in the lower deck. Alcoa continues to use this Mark III base design for the ever-increasing design capacities that have followed.

Closing Remarks

In closing I would like to pay tribute to Bill Fish. With his undefeatable attitude and engineering ingenuity, he was the single person most responsible for the development of fluid-flash calcination within Alcoa. I was truly honored to have known him as a colleague, mentor and friend

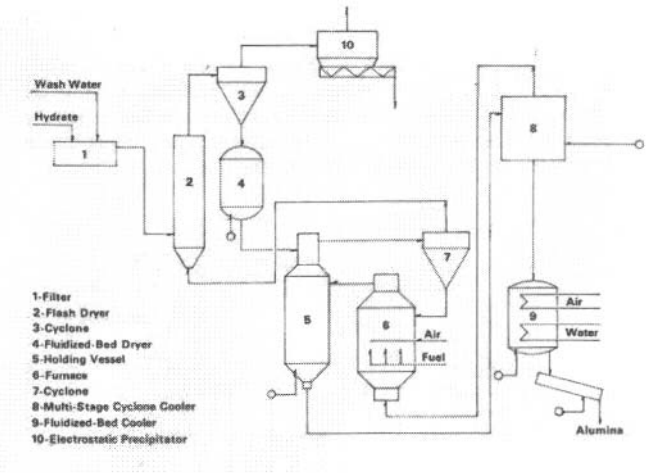

Figure 4: Mark III Fluid Flash Calciner Design

Lurgi - Outotec Circulating Fluid Bed (CFB) calciner Development

As mentioned in the Introduction, when VAW started the joint undertaking with Lurgi for a fluid bed calciner, the demand for alumina quality in Europe was floury alumina with high alpha content. The original target of the joint undertaking was the production of a higher purity alumina without the SiO_2 contamination that was coming from abrasion of the refractories used in rotary kilns. The stationary calciner should reduce abrasion significantly and Lurgi with its experience in fluid bed technology was the chosen partner for VAW. The beginning of the joint undertaking started in 1958.

Because of the fine particle size of floury alumina – around 30% less than 45 micron, it became very clear in the beginning that a classical fluid bed with defined surface between gas and solids where the particles are in equilibrium would not allow an economic upgrade for industrial units. (This was the major reason why Alcan stopped a development in the 50's that they had started together with Dorr Oliver). Therefore a circulating fluid bed was chosen which allowed higher velocities and provided a feasible option for an upgrade to an industrial unit.[3],[4].

Based on laboratory test work in a small (100 mm diameter) unit, a pilot plant was built in 1962 in the VAW's Lippewerk in Luenen [5]. Figure 5 shows the first design of pilot plant.

This plant was erected merely to confirm the applicability of the CFB principle and had a capacity of 24 tpd. Heat utilisation was not emphasized. The plant consisted of a fluid bed furnace with recycling cyclone, one preheating stage with venturi and a heat exchanger to recover the remaining waste gas heat to preheat combustion air. The entire heat content of the alumina was transferred to the cooling water of a water-cooled screw.

Although satisfactory alumina qualities were obtained very early the work had many reverses and needed a number of improvements in the equipment. A major problem was the recycling of the solids back into the furnace which required a number of modifications before a continuous operation of ten weeks could be achieved. In addition, the high calcination temperature of more than 1100°C caused problems in initial material and equipment design. It was certainly a fortunate coincidence for the new development that alumina had extremely good fluidising behaviour. A more difficult type product would have made the development difficult, if not impossible.

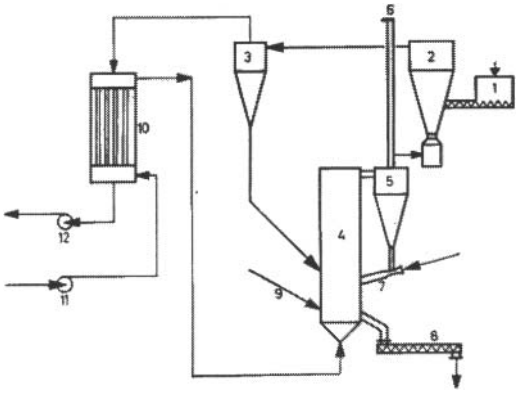

Figure 5: First design of pilot plant at VAW Lippewerk

The excellent fluidising behaviour of the alumina contributed very much to solve the core problem of the system – a continuous operation with a consistent acceptable product.

After a stable operation of the CFB principle could be demonstrated, numerous factors were considered to improve the heat economy of the system. This improvement was done in several steps.

- Installation of a second preheating stage and replacement of the heat exchanger in the waste gas.
- Implementation of a fluid bed cooler to recover the heat from the discharged alumina by preheating the two combustion air flows - primary and secondary air.

Figure 6 shows a flow diagram of the improved plant. The calcination temperature was between 1100 °C and 1150°C, depending on the product quality to be achieved. The waste gas was cooled down to approx. 150°C and at the same time the wet hydrate introduced in the system was predried and partly dehydrated before entering the fluid bed furnace.

The furnace was fired with heavy fuel oil that was directly injected into the fluid bed. The principle of the CFB furnace can be seen in Figure 7.

The combustion air was separated into a primary and secondary airflow. The major reason for this split into two airflows was to balance the solids distribution over the furnace height. The area which was fluidised by the primary air flow provided a higher solids concentration compared with the section with secondary air and higher velocities.

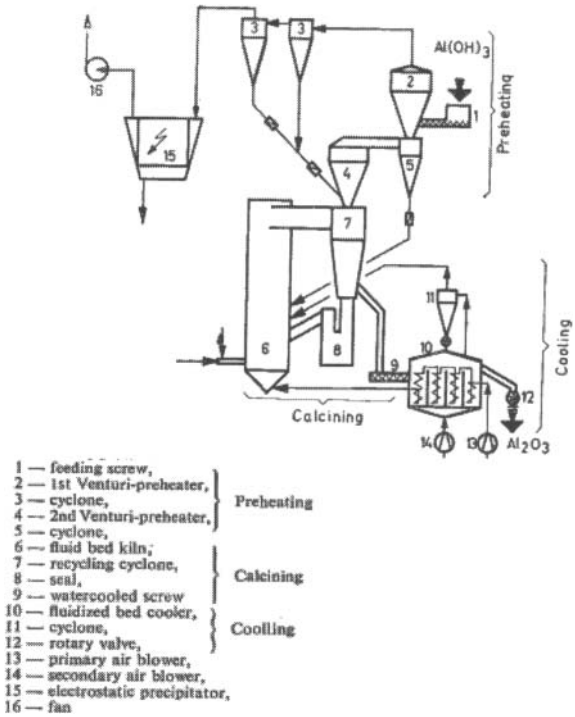

Figure 6: Flow sheet of improved calcining plant

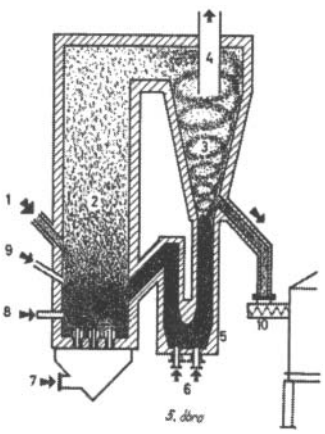

Figure 7: Circulating fluid bed calciner with direct fuel injection

The distribution of the solids is shown in figure 8. The suspended concentration of solids is dependent on the primary air velocity w_p and total fluidising velocity $w_G = w_p + w_s$. It is important for a stable operation of the circulating fluid bed, that the solids distribution in the furnace is constant. The discharge of the hot alumina from the circulating fluid bed was made with a water-cooled screw, which transported the hot alumina to the fluid bed cooler. The cooler was subdivided into several chambers that were equipped with heat exchanger bundles. The primary combustion air was preheated indirectly in the heat exchanger bundles by cooling the solids. The secondary air was preheated directly by fluidising the individual cooler chambers and after separation of the fine particles, the secondary air flow was introduced as combustion air above the calcination furnace. The alumina was discharged from the cooler at 200°C.

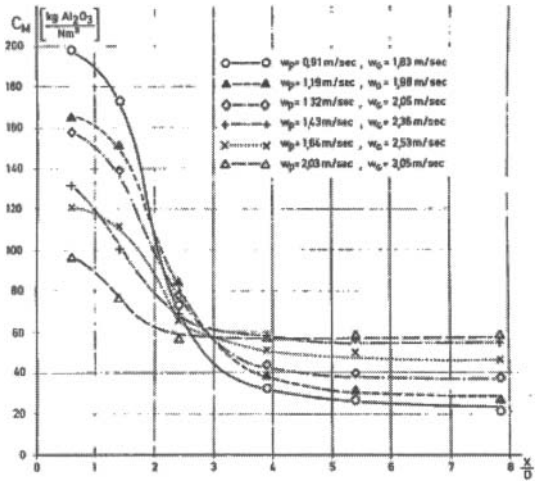

Figure 8: Solid distribution of the furnace height

Although the "semi industrial" unit had several difficulties, VAW decided to built a commercial unit with 500 t/d alumina production.

First 500 tpd CFB calciner unit

The scale up from 24 to 500 tpd was based on data and experience gained in the pilot plant. Particular experience regarding the material quality was considered. The basic flow diagram was only slightly modified compared with the pilot plant. The first preheating stage used two cyclones to clean the waste gas before entering the ESP and the fluid bed cooler had two additional water-cooling stages.

The hot alumina was discharged from the furnace with a water cooled screw, which was replaced very soon by a discharge lance which had the function of a cone valve.

The unit was started up in 1970 and had major difficulties before it achieved continuous operation. The major difficulties and problems occurred in the following areas:

- Material of mechanical equipment
- Process stability
- Continuous operation

As all three areas affected each other success could only achieved when they were solved together. The most difficult task was to achieve a steady continuous operation of the circulating fluid bed, which demanded a constant steady feed and a constant steady discharge of the CFB system. Furthermore the alumina quality, with a high alpha content, required high calcining temperatures. The primary problem during the start up period was the damage caused by overheating of non-refractory equipment such as nozzles, heat exchanger bundles, etc., caused by a non-continuous mass flow.

An optimised control system for feed, discharge, furnace pressure and calcining temperature made a continuous operation possible. Once that was in place, the material problems could be resolved. Nozzles and heat exchanger bundles were replaced and for safety reasons, the tube bundles in the first chamber of the fluid bed cooler were removed.

It took almost one year to overcome all difficulties, but then the unit was performing well and operated with a specific heat consumption of 3.400 kJ/kg Al_2O_3. During the period when the major problems were being resolved the development was sometimes very questionable, but thanks to the excellent team effort, the final target was achieved.

Alcoa and Lurgi/Outotec

Lurgi and VAW published the process first in 1969 at Icsoba in Budapest[5] and in 1973 at the TMS in Chicago[6]. Lurgi offered the technology to other alumina producers and it was a great surprise when they realised that at the other side of the Atlantic Ocean a similar process was developed in the alumina industry. Alcoa offered its process as well to the market at the same time.

Both process developments had similar difficulties to overcome and because of the difficulties experienced were close to having the developments dropped and called a failure.

The two processes have common features, and common basic principles, even though they are using different solutions. In both processes the waste gas heat is used to preheat the product and the enthalpy of the hot alumina is utilised to preheat the combustion air. A fundamental difference between the two processes is the method used to achieve product quality:

- Alcoa uses a holding vessel and determines the product quality through retentention time at almost constant temperature

- Lurgi/Outotec uses the Circulating Fluid Bed and determines the product quality through temperature at constant retention time.

Heat input is very similar and both systems using direct fuel injection with either fuel oil or gas.

From the time that both systems were offered to the alumina industry, no further rotary kilns have been built for smelter grade alumina. Over the years both processes have been steadily improved to meet customer demands and competition. Rotary kiln suppliers originating from the alumina and cement industry, have since introduced flash calciners to the market, similar to the Alcoa principle, but without holding vessel.

A number of publications in TMS and other conferences have been made over the years describing the latest developments of both the flash calciner and Circulating Fluid Bed calcination technology.

Although both processes have started with different requirements for product quality- floury and sandy coarse- today each calciner system supplies products at international standard specification for smelter grade alumina. Today the world market share of stationary calciners producing smelter grade alumina is more than 80%, with the rest being produced in rotary kilns that are still in operation.

Conclusions

The foundation of the aluminium industry was the development, over a century ago, of the Hall-Heroult smelting cell technology. As shown in this paper, the development of the stationary alumina calciner has the similarity that like that earlier development, two simultaneous and independent efforts on opposite sides of the Atlantic, started development and brought to commercialization competing, but similar designs, for a major improvement in alumina calcination. This development, like the Hall-Heroult cell, has won universal commercial approval.

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