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Significant Improvement of Energy Efficiency at Alunorte's Calcination Facility

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Abstract

The Alunorte refinery produces 6.3 million t/a of alumina with seven Circulating Fluid Bed (CFB) Calciners. The calcination facility needs about 3 GJ per ton of alumina of the total energy of 8 GJ per ton for the refinery. Until the introduction of CFB Calciners by Outotec (formerly Lurgi) in 1960, rotary kilns were the standard technology for the calcination of alumina. Since then, stationary calciners such as CFBs are the preferred technology for new installations due to their superior energy efficiency and uniform product quality.

The CFB calcination system has implemented several preheating and cooling stages with cyclones for the separation of gas and solids. The inefficiency of these cyclones is leading to a reduction in the heat recovery and increased energy consumption.

The paper presents a procedure to improve the efficiency of these cyclones and the solid dust load significantly by using a new method of simulation technology. With the optimized process considerably lower energy consumption figures are achieved. The results of these improvements regarding fuel and electrical energy consumption, as well as return on investment are presented. Alunorte has installed the improvements already at two of their seven Calciners and has received the energy efficiency award 2010 from the German Energy Agency.

Introduction

Product quality is always a major focus for every industrial operation, with only production safety being on the same level or even more important. This applies to the production of alumina calcined from Aluminium Hydroxide with the same intent.

The calcination step is the last step in the chain of process steps to produce alumina from bauxite. Until the 1960s the calcination reaction was always performed in rotary kilns. In 1961 Outotec (then known as Lurgi) invented the circulating fluidized bed technology, and applied it to the calcination of alumina in CFB Calciners. With this new technology, energy consumption for alumina calcination was immediately cut by approx. 30% and fluidized bed has been the technology of choice ever since.

The new technology had quite some impact on product quality. While criteria such as LOI, BET, pick-up of iron and silica kept constant, the production of alpha alumina was significantly decreased while fines generation was increased. Although reduction of alpha alumina is basically considered to be an improvement in quality, increased fines is not. The mass fraction of particles smaller than 45µm is a common measure of fines content and should be as low as possible but certainly within the limits specified by the smelter customers.

To achieve significant lower energy consumption than rotary kilns, CFB Calciners utilize much more energetic means of gas-solids contact and gas solid separators (such as cyclones) with significantly higher velocities and hence strong mechanical stress on the particles. With rising energy prices it became also more favorable to increase the number of heat exchanger stages. The number of heat exchanger stages it is very important to have an efficient particle mixing into the gas stream [9]. Further a high separation efficiency of the cyclones in the heat exchanger stages is necessary to achieve low energy consumption.

The cyclone inlet velocity can be increased to achieve improved separation efficiency. However because of attrition, this leads to higher generation of fines in the process and has the result that the hydrate produced by the alumina refinery must be stronger and contain less fines in order to meet the final product quality specification. While this has certainly been achieved in many refineries, nevertheless, there are additional constraints placed on refinery performance indicators (e.g. yield) [11].

Since the introduction of CFB Calciners, a major part of Outotec's calcination research has been dedicated to reducing fines generation without compromising on energy consumption or other aspects of product quality (e.g. attrition index)[2].

While Outotec has been steadily improving its technology to reduce fines generation for many years, the latest installations represent a significant step improvement, with the result that the particle breakage in CFB Calciners has been reduced to only marginally higher than in rotary kilns and much lower than in earlier installations. Also the energy consumption has been reduced significantly and the latest alumina calciner installed in Alunorte has received the energy efficiency recognition prize at the industrial technology exhibition the Hannover Messe 2010 in Germany.

The following main improvements have led to the energy reduction in the calcination process:

- Improved Cyclone design to reduced the recirculation of fines and dust in the calcination system
- Improved Cyclone design to reduce the generation of fines
- Optimization of process stability for stable operating conditions

Improvements at Alunorte

Alunorte S.A. was founded in 1978. Production started in 1995 and since then its alumina production capacity increased continuously [14]. Currently Alunorte S.A. is the world largest alumina refinery with a total production capacity of 6.3 million tones of alumina per year.

Figure 1: Alunorte S.A. 6.3 million tons per year alumina refinery

Figure 1 shows the alumina refinery of Alunorte S.A. located in Barcarena, Brazil. With its latest expansion Alunorte S.A. added two alumina calcination plants from Outotec each with a name plate capacity of 3300 tons per day (tpd).

Figure 2: View of the seven CFB calciners at Alunorte S.A.

In figure 2 the seven alumina calcination plants of Alunorte S.A can be seen. The wet aluminium trihydrate is conveyed by belt conveyors to the hydrate feed bin of the calcination plant. From the hydrate feed bin, the hydrate is discharged by a screw feeder, which delivers the material into the venturi preheater of the first preheating stage. There, the solids are mixed with the waste gas, which leaves the cyclone of the second preheating stage. The heat contained in the waste gas evaporates the entire surface moisture of the hydrate.

Then the preheated hydrate entrained with the waste gas is conveyed into the two-stage electrostatic precipitator (ESP). The solids precipitated in the ESP are conveyed to the venturi preheater of the second preheating stage. The conveying air is dedusted in the airlift cyclone and delivered via ducts to the secondary air cyclone and used finally as combustion air.

The hydrate entering the venturi preheater of the second preheating stage is mixed with the hot waste gas leaving the recycling cyclone and is dehydrated by the heat contained in the hot gas. In the cyclone, which is arranged downstream of the venturi preheater, the flow of gas and solids are separated.
From the cyclone the pre-calcined alumina is delivered into the fluid bed furnace through the material feeding line. The waste gas leaving the cyclone of the second preheating stage is conveyed to the first preheating stage where it assumes the above-mentioned function.

The final calcination of the preheated and partly dehydrated hydrate takes place in the fluid bed furnace as shown in figure 3.

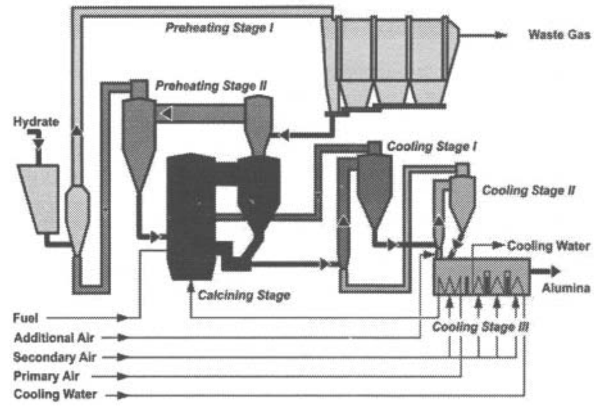

Figure 3: CFB Calciner Flowsheet of recently installed calcination plants at Alunorte S.A.

The required heat for calcination is generated by direct combustion of fuel oil in the fluid bed. Part of the air required for combustion is introduced through the nozzle grate as primary air, and the remaining air is added above the grate as secondary air. Due to the intensive mixing and heat exchange that takes place in the fluidised bed, the furnace temperature adjusts itself as a mixed temperature between the combustion temperature and the solids temperature, and is kept steady at a pre-set level. In the lower furnace zone, between the grate and the secondary air inlet, a fluid bed of high solids concentration is adjusted. It favors the combustion of the fuel and increases the mean retention time in the calcining furnace. In the upper furnace zone the internal recirculation of the solids causes a continuous reduction of solids concentration until a relatively low concentration is reached. With this solids concentration, the hot gases enter the recycling cyclone where they are separated from the solids. The hot alumina, which is separated in the recycling cyclone, passes through the seal pot and re-enters the fluid bed furnace [12],[13].

The recirculation of the solids leads to uniform and practically identical product and gas temperatures in the entire calcination stage, which consists of the fluid bed furnace, recycling cyclone and seal pot.

The alumina, which is discharged from the calcining stage is cooled in two direct cooling stages each of which consists of a liftduct and a secondary air cyclone. The third cooling stage is designed as a fluid bed cooler and mainly relies on indirect heat transfer. The alumina coming from the calcining stage is first mixed with pre-heated air in the liftduct and conveyed into the secondary air cyclone 1. At the same time, the air is heated from the temperature of the second cooling stage to the temperature of the first cooling stage. This air is routed from the outlet of the secondary air cyclone 1 to the CFB system as secondary air and used for combustion. The same applies for the second direct cooling stage.

In order to achieve low specific heat consumption during the calcining process, there is further heat recovery in the air-cooled part of the fluid bed cooler. Primary air is pre-heated by indirect heat exchange in a counter-current flow to the alumina. Secondary air is also preheated by direct contact with the alumina. Further heat recovery occurs in the water-cooled section of the fluid bed cooler as secondary air is preheated in the air-cooled section. Any part of the heat content of the alumina, which cannot be utilized for preheating of air or liquid media is removed by means of cooling water.

With the process described above the specific energy consumption at Alunorte has been reduced to 2790 kJ/kg Alumina.

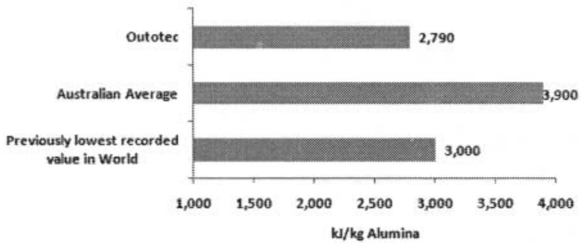

Figure 3: Specific energy consumption according to CSIRO National Framework for Energy Efficiency, 2007 including Alunorte S.A. calciner.

In Alunorte S.A. the outstanding performance with respect to the specific energy consumption was reached by improved design of the cyclones which are used for the separation of the solids from the offgas and the combustion air as described above. Furthermore, the process stability was improved significantly which also contributed to the reduction in specific energy consumption.

Cyclone improvement

Cyclones are firstly named in 1886 in a patent of Knickerbocker Company, USA [5]. Since then the design and calculation of cyclones have been improved significantly. Basically cyclones are used to separate particles from a fluid or gas by centrifugal force. Therefore the dust loaded gas stream is fed into the cyclone where a rotary motion is induced. The solid particles, due to their higher density, are separated to the wall of the cyclone and flow downwards to the solid exit, while the gas leaves the cyclone via the vortex finder. The flow field in a cyclone is highly complex and can be differentiated in:

- Inlet flow
- Main flow with
  - Tangential velocity
  - Redial velocity
  - Axial velocity
- Secondary Flows with
  - Top Secondary flow
  - Vortex Finder Secondary Flow
  - Wall Secondary Flow
- Vortex Finder Flow

To calculate the grade efficiency curve for a cyclone, a model was used which is shown in figure 4. The cyclone is divided into different separate regions which are:

- Inlet region e
- Separation region 1 and 11
- Secondary Flow regions at the top d and at the vortex finder tr
- Separation region 2 and 4
- Re-entrainment region 3

For the above mentioned regions, differential particle mass balances are solved to calculate the grade efficiency curve for the cyclone. The model considers the different separation efficiencies for the main flow V and the secondary flow V_{sek} over the top and the wall of the vortex finder. In the model the re-entrainment of already separated particles at the solid outlet is also considered at the re-entrainment region 3.

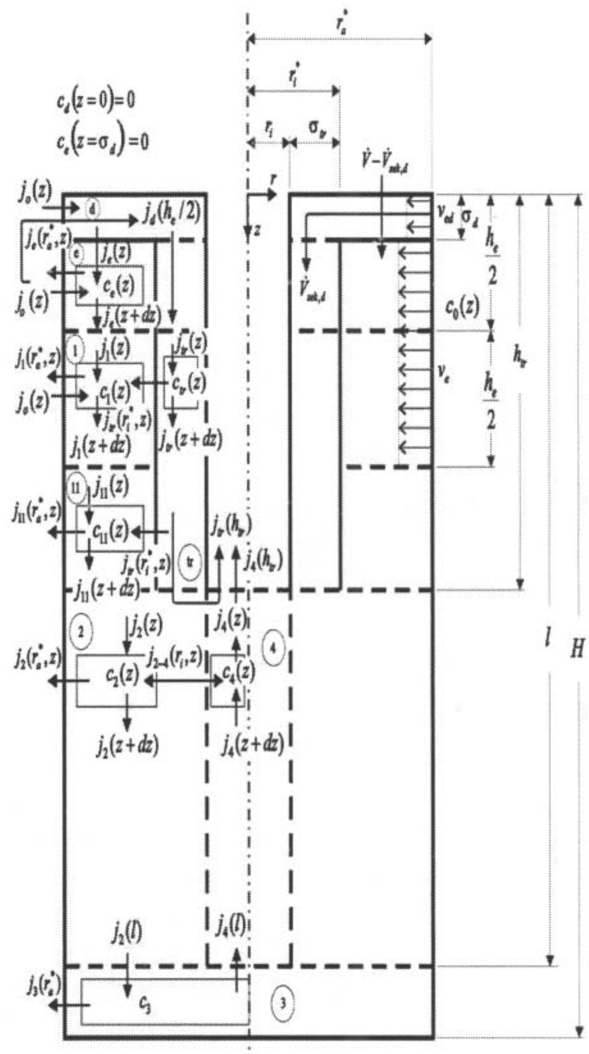

Figure 4: Model for calculation of the grade efficiency curve of a cyclone [8]

In CFB calciners as well as in flash calciners the typical solid loading in the preheating and cooling cyclones inlets is high. Due to the very high solids concentration, it dominates the flow field in the cyclone. It has been found that with higher solid loading the tangential velocity decreases significantly in a cyclone [8].

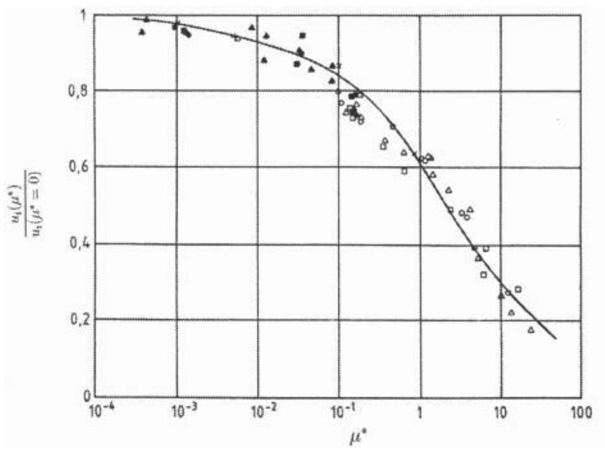

Figure 5: Relative tangential velocity of a loaded to an unloaded cyclone as function of the solids loading μ* in the inlet stream

Figure 5 shows that the tangential velocity of a cyclone with high solid loads in the inlet drops significantly. A cyclone with a solid load of μ*=1 in the inlet has just 60 % of the tangential velocity of a cyclone with no solid load (μ*=0) in the inlet. Thus it becomes very difficult to separate fine particles since the tangential velocity is reduced substantially. Muschelknautz [10] showed that the separation in high loaded cyclones is mainly driven by the strand formation. Figure 6 shows the effect of the formation of strands in the inlet of a cyclone. It can be seen that increasing the load in the inlet of the cyclone enhances the separation due to the formation of strands.

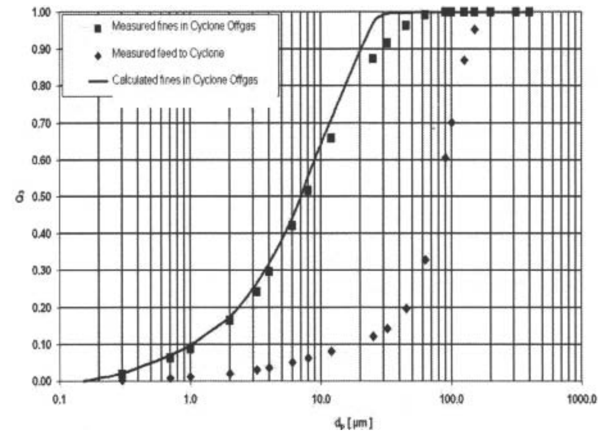

Figure 7: Calculated and measured particles in the offgas of a cyclone at the Alunorte calciner

Figure 7 shows the measured particle size distribution in the inlet as well as in the offgas of a cyclone in the Alunorte calcination plant. It can be seen that the measured particle size distribution fits quite well with the calculated curve from the model, thus allowing the optimization of the cyclones.

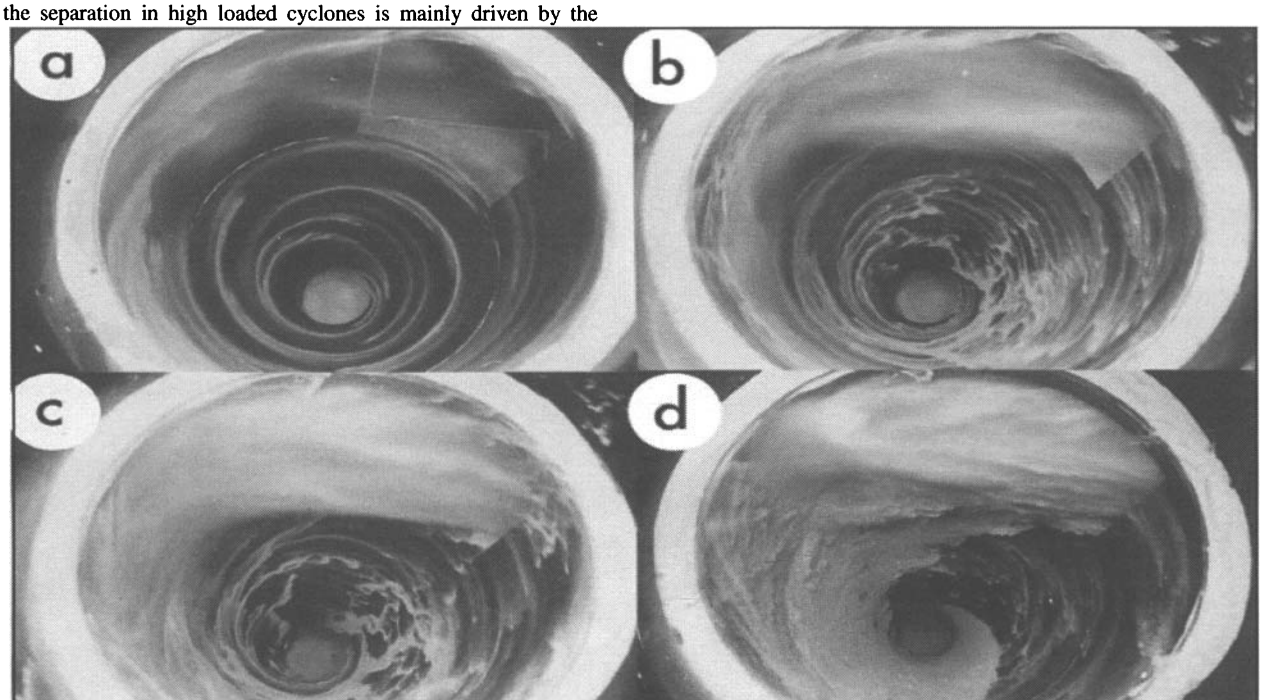

Figure 6: Formation of Strands in a cyclone at different inlet loads: a) μ*=0,01 b) μ*=0,1, c) μ*=1, d) μ*=10 [10]

The process flowsheet shown in figure 3 has four cyclones of which one is in the preheating stage for the hydrate, one is in the CFB and two are in the preheating stages for the combustion air. The integration of the ESP in the overall CFB process ensures that all dust is collected and returned to the process. In other stationary calciner systems the dust returns to the fluid bed cooler [9]. The disadvantage of the latter method is that it cannot be ensured that all the hydrate is completely calcined.

According to the grade efficiency curve of a cyclone, certain fractions of a specific particle size will not be separated. Assuming two cyclones in series, as in the flowsheet in figure 3 for the secondary air cyclones, the fine particles not separated by the second secondary air cyclone serve as additional solid feed for the first secondary air cyclone. So the first secondary air cyclone is fed with the fresh solid feed from the CFB and with the fine particles from the second secondary air cyclone. Thus the efficiency of the first is reduced.

Applying this logic further, then due to the fines in the offgas, the other upstream cyclones are reduced in their separation efficiency. In table 1 a comparison between CFB systems with two and three cyclone cooling stages with different total cyclone separation efficiencies η_{tot} is made. A total separation efficiency of η_{tot} =100 % means that no particles are leaving the cyclone with the offgas while η_{tot} = 90 % means that 10 % of the particles been fed to the cyclones are leaving it with the off gas.

Table 1: Specific energy consumption normalized to the system with the highest energy consumption

Number of Cooling Stages	Furnace Temp. °C	η_{to} $\%_t$	Normalized Energy Consumption
2	950	100	**95.3%**
		90	96.1%
3	950	100	92.4%
		90	93.4%
		80	**94.8%**

The results in table 1 show that cyclone efficiency is of utmost importance to reduce recirculation in the process and thus the energy consumption. Comparing a CFB system with two cooling stages and a η_{tot} =100 % with a CFB system of three cooling stages with not optimal total cyclone separation efficiency of η_{tot} =80 % the result for the specific energy consumption is almost the same.

With the model as described in figure 4 the optimum vortex finder length can be found to increase the separation of fine particles. With increasing height H of the cyclone its separation efficiency is improved. Finally also increased recirculation of fines in a calcination process leads an increased amount of alpha alumina in the system. Due to its stickiness, this type of alumina can lead to process fluctuations which finally affect the separation efficiency of a cyclone negatively.

The energy efficiency of a calcination process does not only depend on the number of cooling stages but also on its total separation efficiency. An investment comparison of the different system can only be done when the weights of the cyclones are known.

Operating Stability

In order to achieve the best results for the separation in a cyclone the operating stability of the process becomes more and more important. Over the last few years, [3] [4] the stable operation of CFB calciners has been in focus and great improvements have been made up to the point of complete automation of the plants.

Figure 8 shows the ability to maintain calcination temperature in the furnace under all circumstances. The modern automation approaches enable the operators to change the load of the plant in a flexible manner and also to keep the furnace temperature within a range of +/- 10 to 15°C.

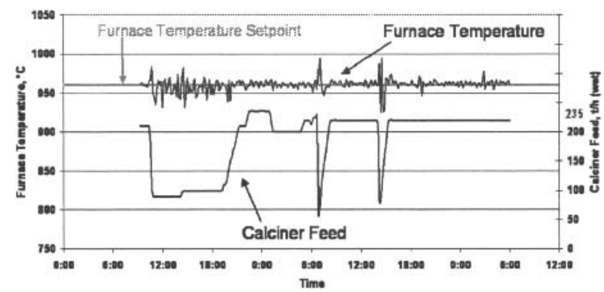

Figure 8: Operation stability of CFB calciners during rapid load changes

The temperature stability in the CFB calciner is very important for the separation efficiency of heat exchanger cyclones in the flowsheet, since the separation efficiency is negatively affected by increasing temperature. Also an increase in particle breakage due to higher furnace temperatures can be observed [2]

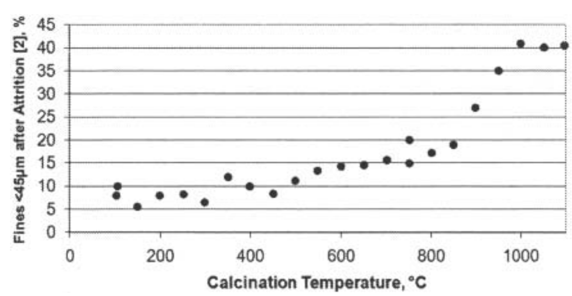

Figure 9: Friability of alumina calcined at different calcining temperature.

From Figure 9, between 800 and 1000°C the particle breakage changes approx. 1.2% for every 10°C increase. With a value of 40% in the Saatci Test [2] at 1000°C this means a ratio of 3% on the actual breakage. For a plant with a normal particle breakage of 3.5% this would correspond to a variation of 0.1% for each temperature variation of 10°C. To control the particle breakage means to control the stability of furnace temperature.

However the dependency could also be more than proportional, which would mean a disproportionate increase of breakage with increasing temperatures. In this case the fluctuations of calcination temperature around the set-point would be a disadvantage to the overall breakage, as every increment of temperature would cause more damage than a decrease could compensate. The effect of increased particle breakage in the calciner and thus the generation of more fines is an increased specific energy consumption due to the negative effect on cyclones performance.

Future Developments

Beside designs for low fuel consumption [6], [7] the existing plants can be further improved by adding a Hydrate Bypass as shown in figure 9.

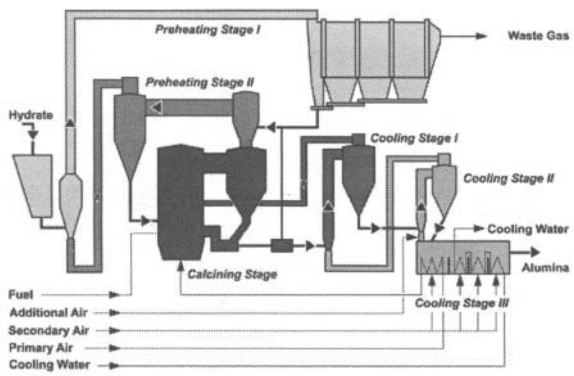

Figure 10: CFB Calciner Flowsheet with Hydrate Bypass

Figure 10 shows a CFB Calciner Flowsheet as it is installed at Alunorte S.A. but with the addition of a Hydrate Bypass. The upgrade with a hydrate bypass will further decrease the specific energy consumption of the already for its lowest consumption awarded plant. With the hydrate bypass pre-dried hydrate from before preheating stage 2 will be bypassed around the CFB to a mixing pot. In the mixing pot the hydrate is calcined with by the hot alumina leaving the CFB. Beside using the energy from the CFB the efficiency of the cooling cyclones is improved since they are operating with decreased temperature.

However, the by-pass is a major part of the energy saving methodology and can operate to up to 15% of the total dry hydrate flow. As a result, a few effects happen simultaneously. Firstly, only the remaining part of the hydrate flow will actually pass through the CFB and undergoes breakage there. Secondly the recombined flows of alumina originating from the furnace material and from the by-pass material have now been calcined at different temperatures. According to the temperature effect from above, the by-pass material is significantly less brittle and will lead to a reduction of breakage in the cooling stages. This effect is even large enough to compensate for any temperature increase in the furnace to achieve the target LOI. The specific energy consumption is improved by approx 3-5%

Conclusions

With the recent research activities and developments Outotec has made a significant effort to understand cyclone design, process stability and particle breakage in CFB Calciners. The recent success with the latest CFB Calciners Outotec has received the energy efficiency award 2010 from the German Energy Agency. It demonstrates Outotec's capabilities to design optimum calcination technology for energy efficiency and product quality.

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