APPLICATION OF OPTIMIZED ENERGY EFFICIENT CALCINATION CONFIGURATION TO AOS STADE CFB CALCINERS

Perander L[1], Lalla A[2], Klett C[1*], Reeb B[1], Petersen B[2], Missalla M[1], Guhl E[2]

[1] Outotec GmbH, Oberursel, Germany
[2] Aluminum Oxid Stade GmbH, Stade, Germany

Abstract

AOS Stade is one of the most energy efficient alumina refineries in the world. The low energy consumption is due to the application of highly efficient technologies, such as the tube digestion units and the Circulating Fluidized Bed (CFB) calciners, both installed from the beginning of production in the early 1970s.

However, since the AOS CFB calciners were started, some significant advances in the technology have been made and several calciners with more modern layouts have been built. With every new installation the energy efficiency has been improved. Prior to the most recent upgrade, the AOS calciners' energy consumption of 3.15 GJ/t was at the upper end of the range.

To improve the fuel consumption and hence also the operating costs at AOS Stade, Outotec has in a joint effort with the refinery, changed one of the existing calciners according to the most modern CFB calcination flowsheet, and have thus been able to decrease the specific energy to the 2.7 GJ/t mark.

The modifications enabling this unprecedented energy efficiency included implementation of a second cooling stage and a hydrate bypass, which made the configuration comparable to the latest Outotec CFB calciners. Furthermore, the addition of a hydrate dryer and a third preheating stage advanced the configuration to Outotec's latest developed flowsheet CircoCal™ and reduced the energy efficiency to a world record low.

In this article the modifications, achievements and experiences are discussed, with implementation potential for other plants also outlined.

1. Introduction

1.1 Development of the Fluidised Bed Calciners for AOS

The three 650 tpd calciners at AOS were first started in 1974. Although some CFB calciners had been installed and commissioned earlier (at refineries in Lünen and in Nabwerk), Stade was the first Greenfield refinery equipped with the recently developed CFB calcination units. The nuclear power station in Stade had been started a few years earlier and was supplying electrical energy to the integrated alumina refinery and aluminium smelter located nearby. Although power was relatively affordable at the time, gas and oil prices were of concern. The calciners were therefore designed for optimum fuel efficiency with high availability/reliability equally important. From design, natural gas was selected as the fuel source. This presented some design challenges as the prior installations had been oil fired. However, by controlling the primary and secondary air flows as well as the natural gas feed, good fuel consumption and gas-solids mixing as well as low emission levels could be ensured.

Originally the calciners were designed to produce so called floury type alumina, with relatively high alpha alumina content and fine particle size. Due to customer demand, the refinery later switched, first to 'semi sandy' and later to sandy alumina. This had some impacts both for the precipitation operation as well as for the particle breakage in the calciners. An extensive programme was then initiated to reduce the particle breakage by optimisation of the calciners (for example by reducing the gas and solids velocities and installing new gas and air lances and nozzles) with very successful outcomes. Further reduction in particle breakage was achieved by coarsening the gibbsite feed and later by converting the last two precipitators into classifiers allowing the overflow to be used as seed in precipitation [1].

Figure 1. Calciners and alumina storage silo at AOS.

1.2 Description of Outotec's Circulating Fluidised Bed Calciner

The main components, in both the original and current layout of the Circulating Fluidised Bed calcination process, are: two preheating stages, a calcining stage and one cooling stage. The CFB calciner makes use of a multi-stage venturi preheating system to recover the waste gas heat by preheating and drying the gibbsite feed prior to reaction. Moist gibbsite is an excellent heat sink; and most of the energy in the decomposition of gibbsite to transition alumina is used below 300°C. The main calcination reaction is carried out in the CFB reactor. The energy for the calcination process is supplied by direct combustion of either oil or gas. Energy in the hot alumina is also recovered in the cooling system (which includes one or several additional cyclones and a fluidised bed alumina cooler).
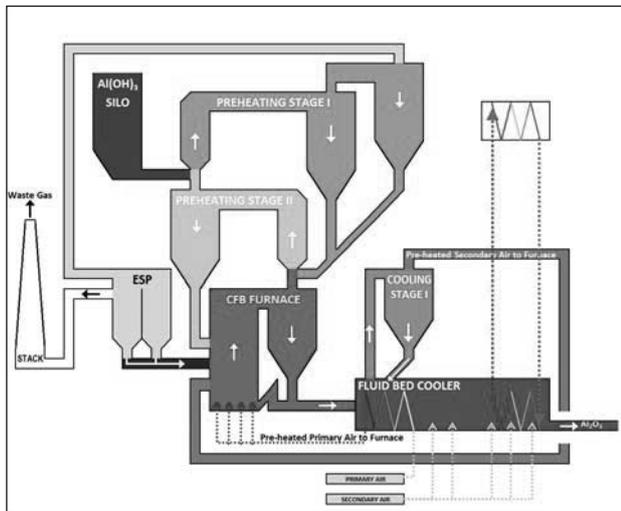
Figure 2. Original flowsheet of the CFBs at AOS.

Key to the high energy efficiency (apart from the circulating fluidised bed) is the cyclones used in the system as the heat recovery is achieved by the counter current solid gas heat transfer. This requires solids and gas to be separated, a task for which cyclones are the ideal choice. The cyclone design therefore becomes critical to achieve high separation efficiency, low breakage and thus obtain high energy efficiency [2].

With the introduction of an additional pre-heating and cooling stage and the implementation of a hydrate dryer and hydrate by-pass as well as through optimised cyclone design according to latest design knowledge [3] AOS has been able to achieve energy values around 2,700 kJ per kg of alumina. The required modifications are however not trivial; upgrading an almost 40 year old plant to the most modern flowsheet presents some significant engineering challenges. In this paper the details of the modifications and the experiences during the calciner upgrade at AOS which enabled this unprecedented low energy level are discussed.

2. Modifications to Calciner 2 at AOS Stade

2.1 Second Cooling Stage

The original CFB calciner design at AOS had two pre-heating stages and one cooling stage (as outlined in the schematic in figure 2). To improve the heat recovery an additional cooling stage was introduced in the recent upgrade. In the new configuration cooling stage 2 takes the air from the fluid bed cooler and uses this to both to transport the alumina to cooling stage 1 (see figure 3) and to recover heat from the material. The solids and gas are separated in a cyclone, from which the now significantly warmer air is used in cooling stage 1 to recover more heat from the solids. Gas-solids separation is again carried out in a cyclone. The pre-heated air is used as secondary air in the CFB furnace.

2.2 Hydrate Bypass

The objective with the hydrate bypass, as developed by Outotec, is to use the heat in the discharged material from the CFB furnace to react part of gibbsite. Typically the gibbsite is bypassed after the last pre-heating stage [4]; however, due to the arrangement at AOS the second pre-heating stage was selected. At AOS the bypassed solids (from the second preheating stage) are mixed with the hot alumina from the CFB discharge and allowed to react in a so-called mixing chamber. The mixing chamber is designed to allow sufficient residence time for the reactions. The hydrate bypass has two main benefits: 1) some of the heat from the discharged alumina is directly used for the calcination reactions rather than for heating the combustion air and 2) it reduces the amount of material needed to be heated to the reaction temperature in the furnace.

At AOS, the first cooling chamber (out of six in the original design) in the fluid bed cooler was converted to a mixing chamber. A hydrate bypass sealpot was introduced after the second pre-heating stage (see figure 3). This allows for a part of the dry gibbsite to be fed directly to the mixing chamber, where the heat from the material discharged from the furnace will transform the gibbsite into alumina. This has the effect of lowering the temperature of the material going to the cooling stages, which results in lower secondary air temperatures as well. By controlling the fluidisation air volume in the hydrate bypass sealpot the amount of material being bypassed can be regulated and hence the secondary air temperature controlled.
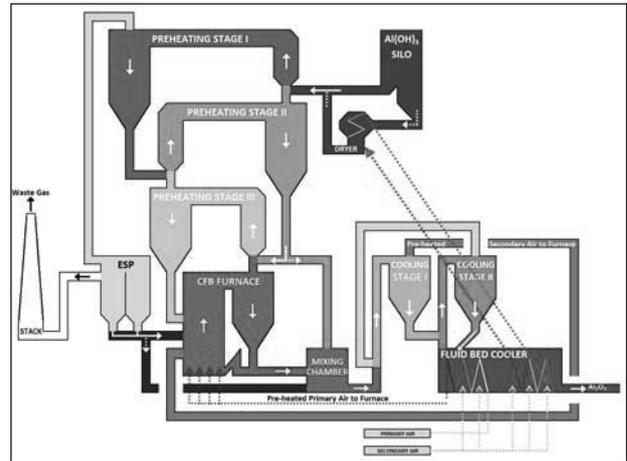

Figure 3. Revised flowsheet after the modifications (CircoCal™).

2.3. Hydrate Dryer

The hydrate dryer used at AOS utilizes the waste heat from the fluid bed cooler to pre-dry a part of the feed material. This hydrate dryer is based on a bubbling fluidized bed (similar to the fluid bed cooler) in which heat transfer bundles are submerged. The heat transfer is done using water as a medium and in a closed circuit with the fluid bed cooler. See figure 4 for a schematic illustration and a photograph of the fluid bed dryer. Note that the bundles can be designed to easily be removed from the side for access to the dryer and for maintenance or replacement of the bundles (not implemented at AOS).

At AOS the moist gibbsite is fed into a feed bin which has two separate bottom discharge screw feeders. One of the screw feeders is feeding the gibbsite directly into the venturi of preheating stage 1 and the second screw feeder is transporting material to the hydrate dryer. The dryer screw feeder is controlled by a temperature measurement in the fluid bed in the dryer. This ensures that material is only fed into the dryer, when the temperature is above 100°C which guarantees that the fluid bed is always dry and readily fluidised. The rotation speed of the feed screw is controlled to maintain a stable dryer temperature and to ensure that all the heat available from the heat carrier is used.

Discharge from the hydrate dryer is by means of a seal pot. The seal pot also regulates the bed height in the fluid bed dryer, which ensures that the heat exchange bundles are sufficiently covered.

The vapor from the hydrate dryer is added to the off-gas of preheating stage 1, from where it leaves the calciner through the ESP and stack together with the combustion off-gas. Although not used at AOS, the water from the off-gas could potentially also be recovered if required.
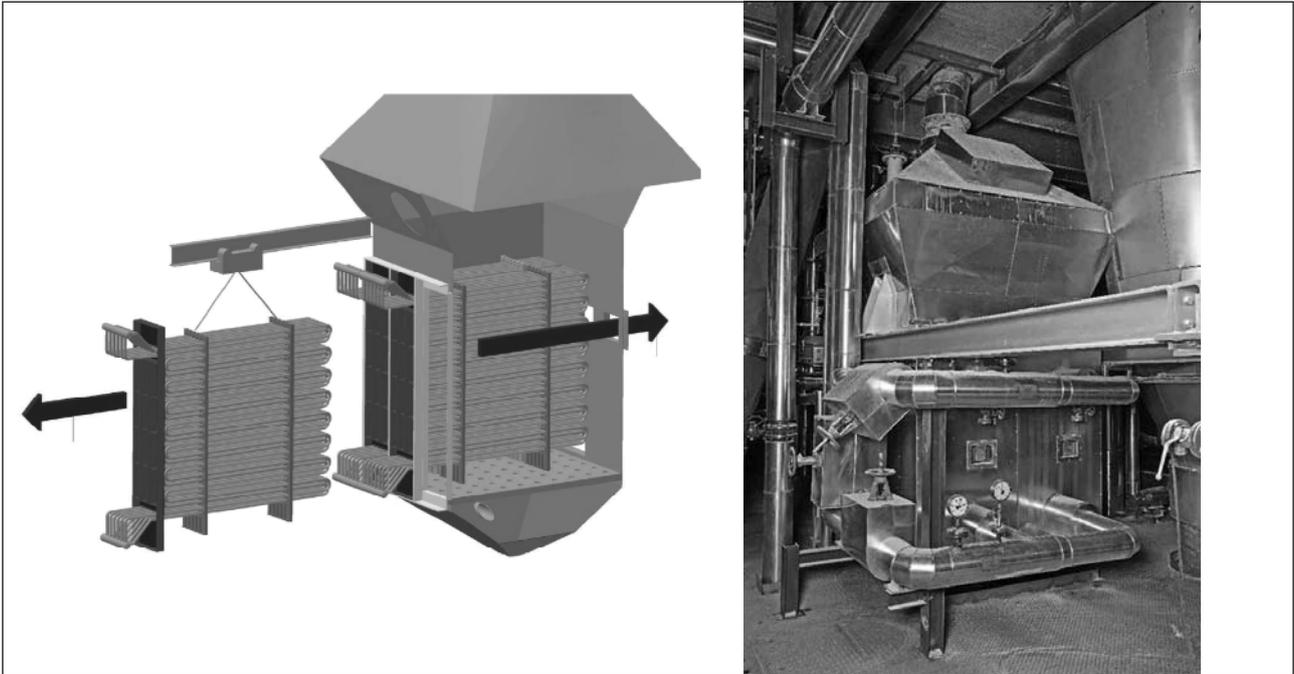
Figure 4. Schematic overview of the hydrate dryer (left) and a photo of the installed dryer (right). Note that the hydrate dryer installed at AOS does not have the optional removable water bundles.

2.4. Third Pre-heating Stage

An additional pre-heating stage was also build as part of the upgrade. Originally the calciner had 2 pre-heating stages. In the original design, the first venture pre-heater utilized the hot gases from the material cyclone (see figure 2) to pre-heat the gibbsite. The solids were then separated from the gas in two cyclone stages from which they entered the second venture pre-heating stage via a rotary valve. The second pre-heating stage used the hot gas from the furnace recycling cyclone to further heat the gibbsite. In the new flowsheet an additional venturi pre-heater was added and one of the two cyclones in the first pre-heating stage in the original design was converted to the second preheating stage. The original second pre-heating stage thus became the third pre-heating stage in the new flowsheet (see figure 3).

3. Operational Experiences

Generally, the operational experiences with the hydrate dryer are very positive, and hydrate moisture levels of less than 0.05 wt-% can reproducibly be achieved at a range of operating conditions (feed level and hydrate moisture content). It is important to keep the inventory of the hydrate dryer stable, in order to keep the bundles submerged to ensure good heat transfer. This is achieved by having a differential pressure measurement across the fluid bed height which is indicative of the solids level in the fluid bed dryer. This differential pressure is then controlling the fluidizing air to the hydrate dryer seal pot, which discharges the dry gibbsite directly into the venturi of the preheating stage 1 (where also the moist gibbsite is introduced). With the mixture of wet and dry gibbsite the utilization of the available heat in the heat carrier and thus in the fluid bed cooler is maximized. This reduces the specific energy consumption to around 2,720 kJ/kg alumina. The experiences at AOS also demonstrate that an empty dryer can reliably be put into operation, by controlled introduction of the wet hydrate.

The additional heating and cooling stages (comprising of venturi pre-heaters and cyclones) work mostly automatically and require little intervention in terms of control or maintenance. As discussed elsewhere, the additional stages may also cause more particle breakage, this is however to some extent alleviated by the hydratebypass [5]. As more material is passed through the bypass less material is passing through the furnace and recycling cyclone which in effect decreases the total particle breakage (or generation of fines). The material bypassing the furnace is also calcined at a lower temperature which decreases the brittleness of the material thus resulting in less breakage. This offsets the additional increase in breakage which occurs due to the increase in furnace temperature needed to keep the LOI value within specifications.

The upgrades at AOS allowed the production capacity to be increased by more than 10 % to over 840 tonnes per day. It is important to note that this production increase was made possible while keeping the airflows and gas consumption at a similar level as before. Therefore the energy consumption was improved. Additional gains in energy consumption were made possible through the efficient utilisation of waste heat from the fluid bed cooler through the hydrate dryer. As can be seen below in figure 5 the specific energy consumption could be reduced to an unprecedented 2,720 kJ/kg with potential for further reductions.
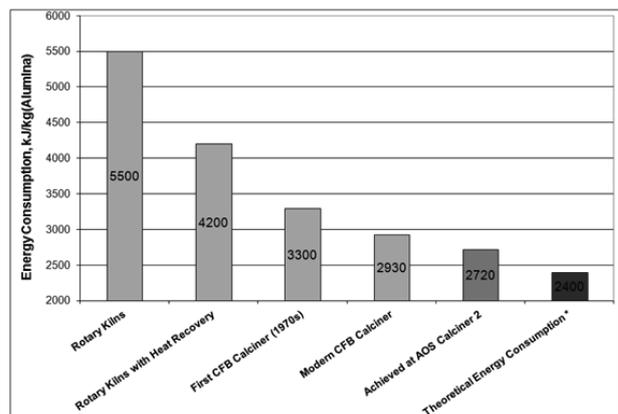

Figure 5. Energy efficiency at different installations and at AOS. *) Note that the theoretical energy consumption does not include any heat losses and assumes all energy is used for the calcination reactions.

4. Conclusions and/or Recommendations

In this paper the calciner upgrade and performance at AOS have been discussed. By converting existing process vessels (such as the pre-heating and cooling cyclones) to new process stages the investment costs for the upgrade could be kept to a minimum. It was demonstrated that the upgrade could reduce the energy consumption to a world record low and that the impacts on product quality were minimal. These upgrades have great potential for retrofitting in other installations as well.

With this Modification Outotec has continued their efforts in reducing energy consumption further to the also recently awarded energy efficiency award for the results at Alunorte in 2010 by the German Energy Agency

The experiences with the hydrate bypass indicate that for new installations, a reduction in fuel consumption can be expected and it would also allow designing the preheating stages, CFB stage and cooling stages smaller (meaning less construction material required in new installations). In retrofitted installations, such as AOS, the bypass allows to increase the production capacity.

References

[1] E. Guhl, R. Arpe, "Nearly 30 years of experience with Lurgi Calciners and Influence Concerning Particle Breakage", TMS Light Metals (2002)

[2] C. Klett, B. Reeb, M. Missalla, "Methods to Reduce Operating Costs in Circulating Fluidized Bed Calcination", TMS Light Metals (2011)

[3] M. Missalla, "Calculation Method for Highly Loaded Cyclones", Ad.libri Hamburg, Dissertation Technische Universität Braunschweig (2009)

[4] M. Missalla, H-W. Schmidt, J. Ribeiro Alves Filhio, R. Wischnewski "Significant Improvement of Energy Efficiency at Alunorte's Calcination Facility ", TMS Light Metals (2011)

[5] C. Klett, M. Missalla, R. Bligh, "Improvement of Product Quality in Circulating Fluidized Bed Calcination", TMS Light Metals (2010)