AA12 - The Hydrate Dryer Story – From Lab to Industrial Implementation

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Abstract

Metso Outotec's alumina calcination solution based on circulating fluidized bed (CFB) technology offers excellent performance in terms of product quality, plant flexibility and energy consumption. The two main heat losses in an alumina calcination plant is heat with the stack off-gas and heat with the cooling water circuit which is used to cool down the product alumina to safe handling temperatures. The total heat lost through the stack and with the cooling water can amount to more than 20 % of the overall energy consumption. To further reduce the heat loss and hence reduce the specific fuel energy consumption of the CFB calcination technology, Metso Outotec developed, designed and implemented the Hydrate Dryer, which can be integrated into calcination plants for additional efficient low temperature heat recovery. The Hydrate Dryer is designed as a stationary fluid bed, and is used for pre-drying a significant fraction of the total hydrate feed to the calciner by means of indirect heat transfer from the fluid bed cooler using a heating medium such as steam, pressurized water or thermal oil. In the paper, details regarding the development, design and functionality of the Hydrate Dryer, potential calciner flow sheet upgrade options as well as experiences from operating systems are presented. Furthermore, potential specific fuel and utility consumption savings will be discussed.

Keywords: Alumina calcination, circulating fluidized bed, hydrate dryer, specific energy consumption.

1. Introduction

The precipitated hydrate is extracted from the hydrate washing and filtration section of the Bayer process with a remaining free surface moisture of some 4-10 %. The motivation to externally remove this moisture by drying the hydrate is two-fold, depending on the subsequent use or processing of the hydrate:

Firstly, in the case of subsequent calcination to smelter/metallurgical grade alumina as the final step in the Bayer process: In the calcination plant, the surface moisture is usually driven off in the first preheating section. Here, pre-drying the hydrate before entering the calciner offers the possibility to reduce the specific energy consumption of the calciner by efficiently re-integrating waste heat streams (either from the calciner directly or from elsewhere in the refinery) in the energy balance. In a typical calciner, about ~ 11 % of the specific fuel energy is lost with the cooling water in the fluid bed cooler [1]. Part of this heat loss (in the first water-cooled chamber of the fluid bed cooler) happens at a temperature range suitable for hydrate drying, hence a use of this energy offers the aforementioned lower specific energy consumption in the calciner in combination with a significant reduction in cooling water consumption.

A second motivation for hydrate drying can be the direct sale of dry hydrate to the market, where it is used as e.g. fire retardant or in the pharmaceutical industry. Furthermore, the drying enhances the fluidizablility of the product and hence, facilitates transport and storage of this product. For these applications, the dry hydrate can directly be extracted from the calciner-integrated dryer, or a standalone hydrate dryer, independent from a calciner, can be used. When, in the latter case, existing heat streams (e.g. steam) are used, hydrate drying can lead a way towards a more economical energy balance in the refinery.

A further benefit from using a hydrate dryer is that similar fuel energy savings can be achieved as with dewatering chemicals. This can reduce or completely eliminate the need for expensive dewatering chemicals, which has two further positive aspects: 1) avoids contamination of the dried hydrate in case this is marketed as a product, and 2) reduces CO emissions stemming from partial decomposition / volatilization of the dewatering chemicals in the preheating stages of the alumina calciner.

In this paper, general design considerations regarding the development of Metso Outotec's Hydrate Dryer will be discussed together with potential applications and benefits for greenfield and retrofit calcination projects. Also, experiences from the operating industrial CFB alumina calciner with a hydrate dryer at AOS Stade [2] are discussed.

2. The Hydrate Dryer - Equipment and Process Design

Given the extensive experience in designing and operating fluidized beds and the well-known excellent heat transfer of immersed heat exchanger tubes in fluidized beds, Metso Outotec's hydrate dryer was developed as fluidized bed dryer [3].

In conjunction with the initial design of the dryer, testwork at the dryer test stand at Metso Outotec's R&D Center in Frankfurt, Germany (see Figure 1) was successfully conducted to determine and confirm fundamental design data of the future drying concept, such as optimum fluidization conditions, heat transfer coefficients between the immersed tubes and the fluid bed, optimum tube arrangement in the bed to allow for good material movement and the suitable combination of temperature and solid residence time required for a satisfactory drying result of the product. The extensive testwork confirmed the suitability of a fluid bed dryer for this application, as well as its robustness and flexibility.

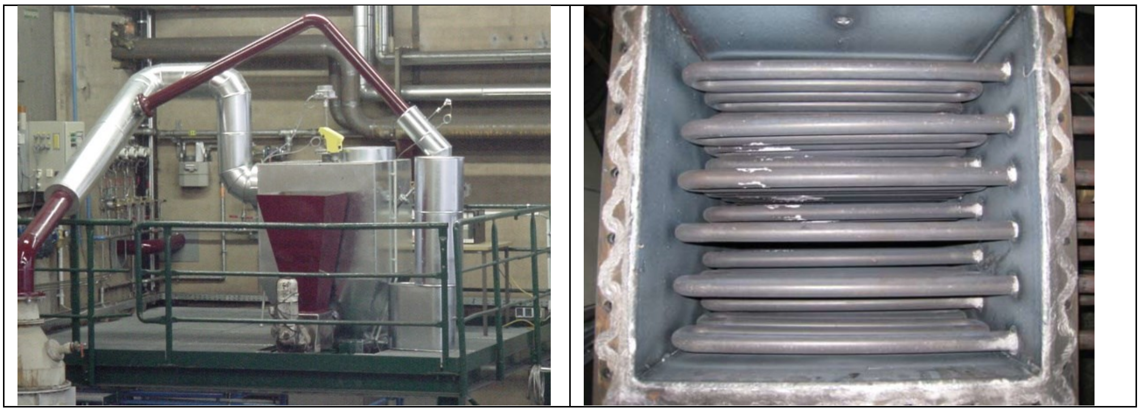

Figure 1. The Fluidized Bed Dryer Test Facility at Metso Outotec's R&D Center.

The main driver for the development of a hydrate drying solution was the constant demand to increase the efficiency and competitiveness of our CFB calcination process [4] by using what is usually a waste heat stream from the fluid bed cooler to optimize the energy balance of the process. Hence, the hydrate dryer solution presented hereafter (see Figure 2) follows this application but can be adapted to serve as a standalone drying solution.

A feed screw is used to feed the wet hydrate from the feed bin to the fluid bed dryer. The wet material is fed above the bed, passes through the immersed tube bundles and the dry product is discharged at the lower part of the unit. Fluidizing air to the dryer is supplied by a separate blower in sufficient quantity to keep the stationary bed fluidized to ensure good mixing and efficient drying. The off gas from the dryer (including the released water vapor) can be dedusted separately or fed back to the calciner when integrated into the calciner flowsheet.

In order to regulate the discharge of the dry hydrate from the dryer vessel, a seal pot is directly connected to its outlet. The desired level in the fluid bed (measured as the differential pressure along the bed) is controlled by solid mass flow through the seal pot, which is controlled by the fluidizing air flow to the seal pot. This way, a constant bed level and a homogeneous low output hydrate moisture can be achieved. The discharged material is then either fed into the preheating stage of the calciner or is transported to a storage facility for dry hydrate.

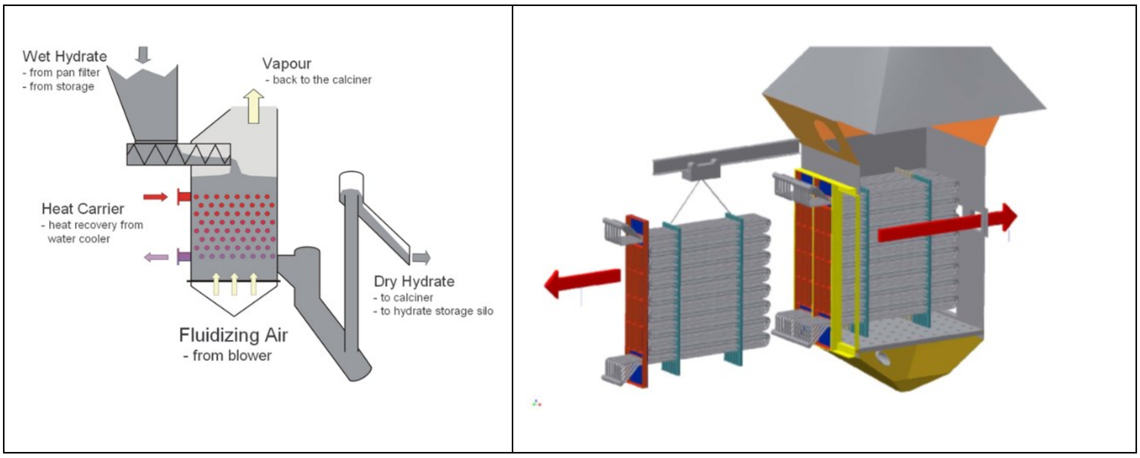

Figure 2. The Hydrate Dryer System integrated in the CFB calciner process.

The heat of the heating medium is transferred through tube bundles, offering excellent heat transfer. The bundles can easily be removed for maintenance from the side of the dryer (see figure 2). The overall size of the dryer vessel together with the number of tube bundles can be adapted to cater for different capacities and material properties.

Due to the versatile design of the hydrate dryer, media like water, condensate, steam or thermal oil can be used as a heating medium. With the hydrate dryer being part of the alumina calciner, water will in most cases be used as the heating medium. In this case, the hot water is pumped in a closed-circuit loop from the fluid bed cooler to the hydrate dryer to provide the heat for drying the wet hydrate through tube bundles, as shown in the typical calcination flow sheet with hydrate dryer in Figure 3. The available amount of heat extractable from the fluid bed cooler at the suitable temperature level will then determine the maximum dryer capacity and the fraction of the total calciner feed to be fed to the dryer. The temperature of the transferred heat shall be as high as possible to enable efficient heat flux in the tube bundle, but is must be below the onset temperature of the calcination reaction. Hence, 150-200 °C has been determined as a suitable temperature range of the heating medium.

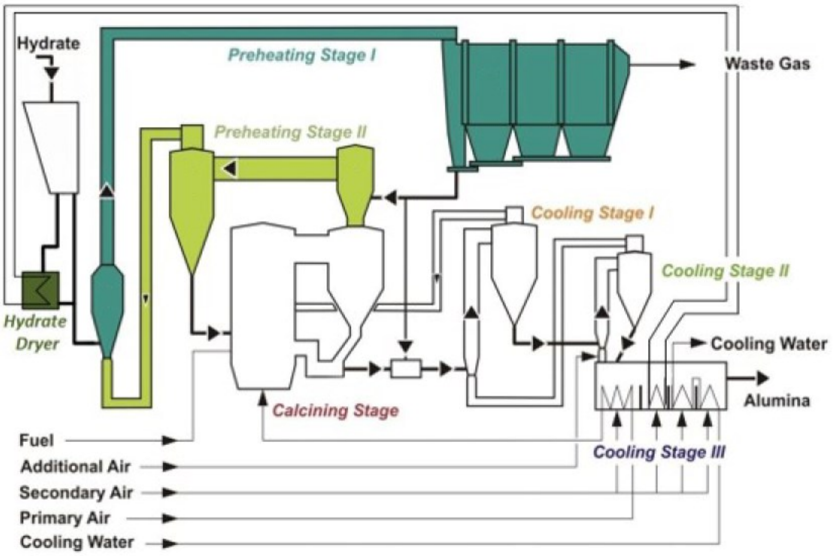

Figure 3. The Preheating Section with a hydrate dryer in a typical CFB calciner flowsheet with mixing pot.

3. Calciner 2 at AOS Stade – Metso Outotec's Benchmark Calciner with Hydrate Dryer

Calciner 2 at the AOS Stade alumina refinery in northern Germany (originally commissioned in 1973) has been successfully upgraded to a modern CFB calcination flowsheet in 2012 [2]. With the hydrate dryer forming an integral part of these modifications, the specific energy consumption of the calciner improved to below an unprecedented 2.7 GJ/t [2]. The hydrate dryer has a capacity of 20 t/h of dry hydrate production, enabling the plant to pre-dry up to ~40% of the total plant feed. Ever since the commissioning, the hydrate dryer system, including the dryer fluidized bed vessel, the seal-pot for discharge and the water circuit for heat transfer from the fluid bed cooler, is characterized by very stable, reliable and safe operation. A sophisticated control concept facilitates plant operation, including e.g. the automatic bed level control in the dryer, as well as automatic temperature and pressure control in the water system.

The moisture of the dry hydrate leaving the dryer was confirmed to < 0.02 wt.% for different loads and inlet moisture levels [2]. Furthermore, as it is operated as a bubbling fluidized bed, there

Figure 4. The calcination plant and storage silo at AOS Stade (left) and the hydrate dryer vessel installed at Calciner 2 (right).

was no significant impact on particle size measured when pre-drying the hydrate. In other words, the hydrate dryer does not contribute to particle breakdown across the calciners due to the low to moderate design velocities.

With its proven contribution to the outstanding energy consumption at the AOS Stade refinery, the hydrate dryer continues to demonstrate the large potential it can offer as a retrofit option in other calcination plants as well.

4. Hydrate Dryer Applications – Integrated Calcination Solutions & Stand-Alone Operation

The hydrate dryer can either be integrated in existing calciners as a retrofit upgrade option or included from the start in the design of new greenfield calcination plants to reduce the specific fuel energy consumption with a reasonable increase in plant complexity and capital expenditure. Alternatively, the hydrate dryer can be used as a stand-alone drying plant.

As an enhancement upgrade of Metso Outotec's established CFB calcination plant generations 4 (see figure 3, e.g. Alunorte Calciners F & G) and 5 (e.g. Al Taweelah Calciners 1 & 2), a reduction of the specific energy consumption down to below 2.7 GJ/t of alumina is viable, while customers can profit from established and standardized calcination equipment and plant arrangement concepts.

In order to profit from the maximum reduction of the fuel consumption in conjunction with the use of the hydrate dryer, the CircoCal process concept [5] can yield specific energy consumption figures below 2.6 GJ/t of alumina. The additional equipment required, such as a third preheating and cooling stage, increases the relative plant weight and thus capital investment cost for such a plant configuration [6] however the reduced operating cost does give a reasonable payback time.

Also, as a retrofit option, the hydrate dryer system will decrease energy consumption and cooling water demand at the calcination plant. The typical and most economical upgrade for a typical generation 4 or 5 CFB calciner requires both, new additional equipment to be installed as well as modifications to existing equipment (see figure 3 for a typical flowsheet for a generation 4 CFB calciner with hydrate dryer). Additional equipment includes:

- the hydrate dryer fluid bed vessel itself with a dedicated feed screw
- a seal pot to discharge the solids from the dryer into the existing calciner (venturi preheater stage 1)
- An additional blower to provide the fluidizing air for the dryer and the seal pot
- The heating water circuit, to transfer heat from the first water cooled fluid bed cooler chamber to the hydrate dryer, incl. pumps, heat exchanger, compensation vessel
- Additional valves and instrumentation

The major modifications of existing equipment comprise the following:

- A separate hydrate feed bin for the dryer, or an optional modification of the existing feed bin to allow for an additional feed stream to the hydrate dryer
- Connection from hydrate dryer seal pot to existing venturi preheater stage 1
- Vent duct from hydrate dryer to the duct from venturi stage 1
- Adjust the cooling water circuit to reflect new heating water circuit to hydrate dryer

The additional rotating equipment (mainly the blower for fluidization air and the pump for the water circuit) will impose a minor increase in the electrical energy consumption, estimated to approx. 0.5-1.5 kWh/t of alumina for a typical 1500-2000 t/d alumina calciner, depending on feed properties like moisture and particle size distribution.

To showcase the potential saving of such a hydrate dryer retrofit, typical values for the specific energy consumption of different CFB calcination plant generations (based on [4]) with and without the hydrate are presented in Figure 5. The results confirm an efficiency increase the range of up to ~ 90 kJ/kg throughout different plant generations. In case of a calciner with a production capacity of 3500 t/d, assuming typical fuel compositions, this translates to savings of up to 2600 tonnes of fuel oil or 2900000 Nm³ of natural gas per year.

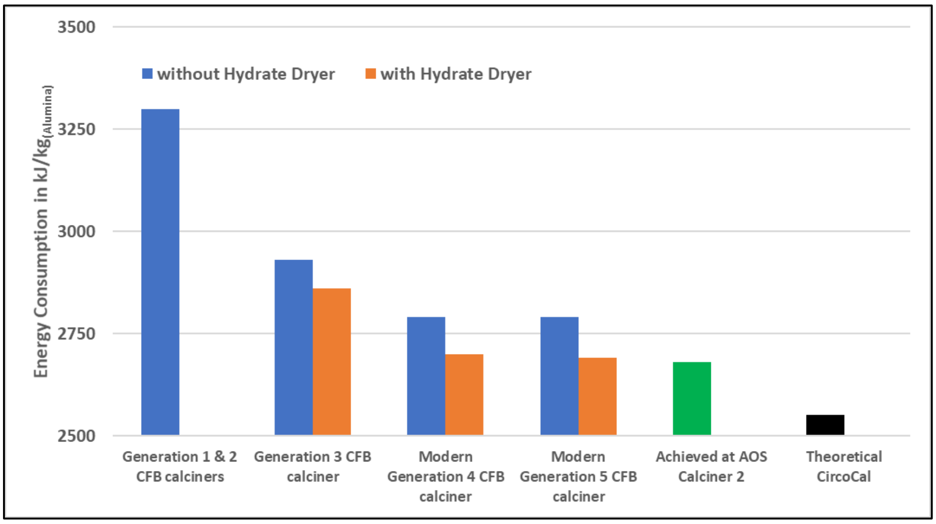

Figure 5. Specific energy efficiency at different CFB calciner generations (see also [1]) with and without a hydrate dryer retrofit.

As the heat for drying the hydrate is taken from the fluid bed cooler (FBC) in case the typical flowsheet (Figure 3) applies, the cooling water demand is reduced. In Figure 6, a typical fluid bed cooler schematic for 1500-2000 t/d CFB calciner is shown. The calcined alumina enters the FBC from the upstream cooling cyclone. In the first chamber, the high temperature alumina is used to preheat the primary air for the fluidized bed furnace via a set of air coils/bundles. The remaining heat is extracted in 3 consecutive water-cooled chambers, were cooling water is typically used to bring the alumina temperature down to below 80°C at the discharge. In case of heat re-integration for hydrate drying, the first water cooled chamber is typically viable to extract the required heat. Here, the temperature level is suitable for hydrate drying and the heat flux is sufficient for drying a significant fraction of the total feed. About 50 % of the total cooling water consumption is required in this section (see figure 5). If the total heat is used for drying, the remaining cooling water requirement in the last 2 water-cooled chambers correspondingly reduced to only ~ 50 % of the previous demand without the hydrate dryer. This substantial reduction of a major utility flow in an alumina refinery will translate into additional cost savings.

The hydrate dryer integrated into the calcination flow sheet uses waste heat to reduce the moisture of a partial feed stream. Therefore, apart from improving the energy efficiency in the calcination unit, it can also open the potential to reduce the requirement of dewatering chemicals, which are widely used in the hydrate washing and filtration section of alumina refineries to reduce the residual moisture in the wet hydrate filter cake.

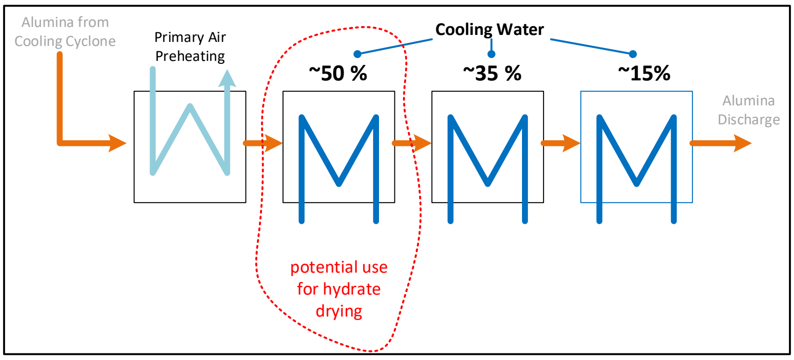

Figure 6. Typical fluid bed cooler for a CFB calciner. Indicated cooling water requirements and potential heat source for hydrate drying.

A small example: In a typical alumina refinery, dewatering aid is used to reduce the moisture from 7 wt.% down to 4 wt.%. In the same refinery, in a realistic scenario with a typical CFB calciner, the implementation of the hydrate dryer can be designed to fully pre-dry up to ~ 40 wt.% of the total wet feed (at 7 wt.% moisture) to the calciner. This effectively reduces the total amount of moisture with the combined feed (from dryer and regular wet feed) from 7 wt% down to 3.5-4.0 wt%. Hence, the absolute total moisture removal potential by retrofitting a hydrate dryer is of a similar magnitude as with the usage of dewatering chemicals. Besides that, avoiding the use of dewatering agents will not contaminate the dried hydrate and is also expected to reduce the CO being generated from the partial breakdown and volatilization of the dewatering chemicals in the preheating stages of the calciners. With increasingly stringent emissions limits in many places such measures can be important for the reduction of harmful emissions. This small comparison shows that the investment of a hydrate dryer system as a retrofit can offer significant savings of up to several hundred thousand euros in operational cost for dewatering chemicals; and still offer the aforementioned reduction of the cooling water requirement.

Retrofitting the hydrate dryer is in principle also viable for older plant generations and not limited to CFB calciners. In any case, the detailed flowsheet, impacts on the process conditions and the operation of the calciner will be evaluated in depth for each specific case, as it also depends on factors like e.g. hydrate properties, fuel type and the details of the existing plant arrangement.

The fluidized bed dryer can also be used to produce dry hydrate, independent from any calciner operation. In that case the operating principal is the same, however the heat recovery is not integrated into the calciner flowsheet. The heat for drying can be provided from other sources, such as surplus steam, surplus hot condensate or alternatively generated within the drying facility for example by a small boiler operated on fossil fuel (gas, oil, syngas etc.) which produces steam or heats thermal oil which is pumped in a closed loop to the dryer. With such a boiler configuration the typical operational cost is ~ 303 kJ/kg of dried hydrate (with wet hydrate entering at 30 °C and with an initial moisture of 8 wt.%).

The hydrate dryer size for the stand-alone application can be adapted to the available heat. Furthermore, the fluid bed vessel provides flexibility for frequent start-ups and shut-downs, as the available heat (e.g. steam) might only be available temporarily on a low cost-level, as for example during maintenance periods of major steam consumers. For example, a dryer with a capacity of 20 t/h of dry hydrate production requires approximately 2.5 t/h of saturated steam (at inlet moistures of 6 %). The solid discharge can be directly connected to the dry hydrate conveying system or a truck. A dedusting system is also required to clean the off gas before being released to the atmosphere, the recovered dust can be mixed with the dryer product.

In general, also a flexible solution is viable, with the hydrate dryer being integrated in the calcination plant, but also allowing for dry hydrate production in parallel to the calcination. This requires a separate discharge line from the hydrate dryer vessel.

Based on the positive experiences with the operation of the hydrate dryer, Metso Outotec has also explored applying the hydrate dryer in other mineral, concentrates and ore processes. Testwork in the lab and studies were conducted for these purposes, in principal fully confirming the feasibility to apply the concept also to the drying of bauxite ores. The only limitation observed so far with the dryer is on the particle size of the material to be dried, as the dryer is based on a fluidized bed principle and the material needs to be fluidizable. Therefore, typically a maximum particle size applies, which is normally in the range of several mm (depending on the density of the solids). The minimum particle size to be treated in the fluid bed dryer is usually limited by increased dust entrainment and unfavorable fluidizing behavior of very fine particles.
With a pre-crushed and ground bauxite ore with a size in the mm range it is highly likely that the dryer would be suitable. Testwork and validation to derive design and scale-up parameters, can be conducted in the pilot plant facilities in Metso Outotec's laboratories in Frankfurt.

5. Conclusions

Through specific fundamental testwork in our R&D center and the vast experience in fluidized bed design, Metso Outotec has developed a solution for efficient hydrate drying based on stationary fluidized bed technology. The successful engineering, construction and commissioning of the hydrate dryer system at AOS Stade pushed the specific energy consumption to a record low of < 2.7 GJ/t of alumina, and we see great potential in applying this energy saving technology in existing and new plants.

The hydrate dryer, whether implemented in a greenfield project from the start or as a retrofit option for existing calcination units, offers proven substantial savings in operational cost for utilities such as fuel, cooling water and dewatering aid. Furthermore, the fluidized bed dryer is suitable for stand-alone dry hydrate production and can also be applied to other minerals, concentrates and ores, such as for example bauxite drying.

6. References

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