AA03 - Filtration of Digester Blow-off - an Option for the Refinery Design of the Future

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Abstract

Rotary vacuum disc filters are successfully used in Alumina refineries since decades in seed deliquoring and wash applications. However, the limitation of the acting pressure difference to the conditions generated by vacuum pumps have restricted the field of applications. With the installation of these rotary disc filters in pressure vessels and the development of reliable solids discharge systems, the so-called hyperbaric filters have made their way into the Alumina refining process. At the moment they are used for Bauxite filtration if the bauxite is sent to the refinery through a pipeline as water/bauxite mix. This water must be removed as much as possible to keep the water balance in the process and to minimize the energy impact. But this may not be the only suitable filtration step for this filter technology. Bauxite residue is certainly a vital option although filter presses are state of the art technology at the moment. However, the discussion about the refinery design of the future always includes options for direct filtration of the digestor discharge that may replace the decanter and washers either partially or in total. The most appropriate filter technology for this application would be the hyperbaric filtration. It would allow to filter at high temperature of up to 200 °C and high pressure of up to 1000 kPa (10 bar). Backpressure operation could avoid flashing and moderate cake wash promises to eliminate washer in total. As the bauxite residue could be discharged with a moisture of 30 wt% or less, there would as well be no need for extra bauxite residue filters. The footprint of the Alumina refinery could be drastically reduced.

Keywords: Filtration, Bauxite Residue, Bayer, Hyperbaric, Digestion.

1. Introduction

Many production processes such as the Bayer process run at high temperature and high pressure to enable or improve specific reactions, to keep wanted or unwanted components in solution or to improve the process efficiency. Slurries from such processes have to be handled in a careful way. A drop of pressure and/or temperature would be associated with implications which have to be avoided such as boiling/flashing and evaporation of the liquid or product contamination due to unwanted reactions and/or crystallisation of unwanted by-products etc.

Such slurries should ideally be filtered at high temperatures and high pressures and the filtration process should meet the following challenging requirements:

- maintaining temperature and pressure at the low-pressure side (filtrate side) above a certain level to prevent flashing/boiling (T_b, p_b) of the filtrate
- continuous filtration with short residence time
- prevention of unwanted reactions and/or crystallisation/scalings in the filter cloth and filtrate pipe system
- applicability in corrosive, toxic or explosive atmosphere
- withstand high material stress
- filter sizes for small, medium and large (e.g. in alumina refineries) production rates
- reliable operation control with different sequences for heating procedure, start of operation, continuous operation and maintenance

Since no suitable filtration technologies were available that would meet the above requirements, the solid-liquid separation of such sludges is often carried out as a complex, multi-stage separation process with a number of individual steps in order to avoid or at least minimize the undesirable complications mentioned. Now, BoHiBar Filtration has made its way into the petro-chemical industry filtering the base components of polyester at high temperature of up to T > 200°C and high pressures of up to p_{abs} = 700 kPa and has shown its capability to operate in a reliable way under such challenging conditions in many reference applications.

The BoHiBar Filtration process can be performed with a high filtration pressure difference $\Delta p = p_1 - p_2$ (p_2 = atmospheric pressure) and as a counterpressure filtration process with high vessel pressure p_1 and a filtration pressure difference $\Delta p = p_1 - p_2$ with a back pressure p_2 at the filtrate side above the flashing/boiling point T_b, p_b of the flash curve ($p_{atm} < p_b < p_2 < p_1$). This allows the filtrate to be discharged at high temperature and pressure without flashing/boiling and crystallization effects and allows the hot filtrate to be further processed in hot downstream process steps.

2. Historical Review of the Filtration of Digester Blow off

For alumina refineries the extraction yield of bauxite processing has been a major focus for decades and accordingly there have always been efforts to minimize the loss of extractable alumina in the process chain. Loss happens in the digestion reactor where extractable alumina (gibbsite) stays undigested, in the settlers and in the bauxite residue washers which sums up to a loss of about 6 % and is therefore a topic of economical relevance [1], [2]. As a rule of thumb [2], in the settlers up to 2 % gibbsite reversion is lost and 2 more percent points are lost during bauxite residue washing mainly due to the following reasons:

- cooling down of the liquor to less than 100 °C together with long residence time in the settler and bauxite residue washers with contact of the pregnant liquor with the bauxite residue (the liquid phase becomes oversaturated for aluminium hydroxide (gibbsite));
- precipitation of aluminium hydroxide (gibbsite) enhanced by the presence of seed;
- decreasing of the alumina solubility along with the decreasing caustic soda concentration due to the more diluted conditions in the bauxite residue washers.

If it was possible to separate the bauxite residue and wash it from the highly caustic and hot slurry quickly and directly just after digestion without cooling and with a short residence time, a lot of extractable alumina could be saved. In the early years of the Bayer process often plate and frame filter presses were used for the direct filtration of the blow off slurry and the cake was washed with condensate. Operational and maintenance cost, however, were immense especially due to cost for filter cloth wash water and manual efforts for cake discharge. In some refineries they were replaced by Kelly filters which showed a better separation performance and reduced maintenance and labour cost. But also Kelly filters could not establish for direct filtration due to the high loss of soluble soda and alumina.

In 1973 B. Schepers performed pilot scale testwork on direct filtration of the bauxite residue directly after the digestion reactor with continuous pressure filters in the Guilini Werk in Ludwigshafen, Germany [3]. The testwork was performed with an old vintage rotary pressure drum filter of 0.75 m² filter area. Maximum pressure that could be realized with this pilot filter was 3 bar, i.e. the filtration pressure difference was Δp = 200 kPa. Feed temperature of the slurry was 100 °C while the filtrate was drained off with a temperature of T = 60–70 °C. Solids concentration of slurry feed was 47 g/l, particle sizes were not recorded but it can be assumed that they were in the typical range of $x_{50} < 10$µm. The filter cake was washed with boiler feed water of 100 °C and discharged with a discharge roller. The filtrate performance was in the range of

0.5–0.6 m³/m²h, the washed bauxite residue filter cake was nearly free of soluble soda and had a low moisture content of mc = 22–33 wt% [3]. Although this testwork was performed on old-fashioned pressure filtration technology, it demonstrated both, the technical and economic feasibility of this direct filtration option.

With BoHiBar Filtration, nowadays, a most modern technology for continuous pressure filtration is available which is well proven in reference applications in several industries. BoHiBar Filtration is also applied for hot slurry filtration in many reference applications at high temperatures and high pressures with an individually adapted process and plant design.

3. Continuous Pressure Filtration Technology

3.1 Plant and Process Design

BoHiBar Filtration of BOKELA is the most advanced continuous pressure filtration technology. The basic principle is also known as hyperbaric filtration and is very simple: a continuous rotary drum or disc filter is installed completely in a pressure vessel filled with compressed gas (Figure 1). Thus, high process pressures up to 700 kPa (a) and high temperatures up to 200 °C can be realised. A pump feeds the suspension into the filter through in the pressure vessel. The filtrate flows through the filtrate pipes to the control head of the filter apparatus and from there to the filtrate separators. The filter cake is removed from the filter cloth by a reversed blast of compressed gas and discharged through a solids sluice from the pressure vessel.

The vacuum pumps used with a conventional vacuum filter are replaced by a compressor that supplies the necessary compressed gas/air to the vessel and for compressed gas/air blowback. The compressed gas/air from cake blowback also serves as process gas to maintain the overpressure in the vessel for the filtration process. Inside the vessel, the filter runs with a high differential pressure. The application of overpressure instead of vacuum ensures a high specific throughput and dewatering capability especially with filter cakes consisting of fine particles where high cake resistance and capillary forces in the cake have to be overcome.

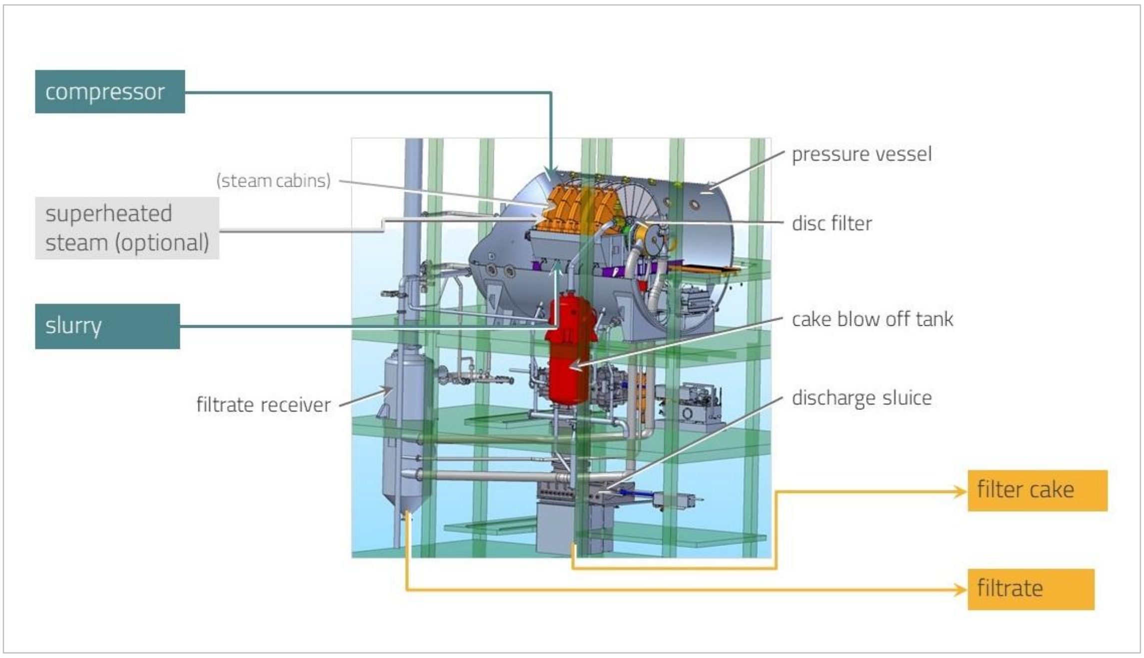

Figure 1. Principle flow sheet of BoHiBar Filtration

The laws of continuous cake filtration still apply for the continuous pressure filtration and the following equation derived from the Darcy Equation describes the solids throughput of a cake-forming filtration on rotary filters as a function of the relevant process, product and machine parameters.

$$\dot{m}_S = \rho_S(1-\varepsilon) \cdot \sqrt{\frac{2}{\eta_L r_C}} \cdot \sqrt{\kappa} \cdot \sqrt{\Delta p} \cdot \sqrt{n} \cdot \sqrt{\frac{\alpha_1}{360^0}} \tag{1}$$

where:

$\dot{m}_S$	specific solids throughput, kg/m²·h
ρ_S	solids density, kg/m³
ε	filter cake porosity
η_L	filtrate viscosity, kg/ms
r_C	cake resistance, m^{-2}
κ	solids concentration parameters
Δp	differential pressure, kPa
n	filter speed, min^{-1}
α_1	angle of cake formation, °

Equation 1 clearly shows that the solids throughput $\dot{m}_S$ increases proportionally to the square root of the differential pressure Δp and to the square root of the filter speed n. A higher filtration pressure with otherwise unchanged filter setting (i.e. unchanged angle of cake formation α_1) increases solids throughput according to equation 1 since thicker filter cakes are formed which then allow to increase filter speed n. Since increase of filter speed also increases solids throughput, the total throughput increases linearly with the differential pressure within a wide range. The limiting factor for speed increase is cake removal from the filter cloth by compressed air blowback which requires a filter cake of a certain minimum thickness. Provided that the hydraulic system and cake blow off of the filters are properly designed then the continuous pressure filtration with a filtration pressure difference of e.g. Δp = 3 bar leads to a six-fold higher mass throughput compared to a conventional vacuum filter that runs with Δp = 0.5 bar. In other words, with the same filter area, the six-fold throughput can be achieved.

3.2 Filtration of Bauxite Ore after Pipeline Transport with Hyperbaric Filtration

Hyperbaric filtration is the chosen technology for the dewatering of the worldwide first pipeline transported bauxite at an Alumina refinery of Alunorte (Alumina do Norte do Brasil S/A) in Brazil.

When Vale was designing the mining and beneficiation of the Paragominas mine, it was to decide by which means the bauxite should be supplied to the Alumina refinery. Beside ship, truck, railroad or conveyor transport the most feasible option was pipeline transport of the bauxite, considering the local landscape as well as the local conditions. In this case the cost for pipelining is lower than any other transport option. At the refinery, however, the slurry has to be dewatered and it is a decisive condition for realizing pipeline transport of bauxite to have a feasible filtration technology available which is capable to dewater the arriving slurry to a low residual moisture content in an economical way. This intensive dewatering step must guarantee a very low moisture content below a critical moisture of 14 wt% due to the following reasons:

- the amount of water entering the refinery process must not exceed a critical point
- above a certain moisture the bauxite filter cake becomes sticky and has difficult handling and processing characteristics (very similar to bauxite residue)

- different bauxite grades need to be mixed which requires a dry and mixable filter cake
- the portion of fines may vary due to variations of the mine operation/location

Analogous to the bauxite residue (red mud) the fine milled bauxite is difficult to dewater. After extensive analysis by Alunorte, BOKELA and other expertised groups, the continuous pressure filtration was preferred over filter presses because these filters achieve better moisture content and require lower investment and operating costs. BOKELA designed a process flow sheet which ensured that the continuous pressure filters achieve the required moisture content below 14 wt% which can be improved by application of the BOKELA Steam Pressure Filtration Technology to a moisture in the range of 10−12 wt%. The engineering and supply of these filters was managed by a consortium of Andritz AG, Graz (Austria) and BOKELA based on a comprehensive feasibility study done by BOKELA [4]. Meanwhile 13 pressure disc filters of 168 m² each are in operation.

4. Filtration of Digester Blow off

The red side of the alumina refining process comes into focus when new developments are discussed. The considerations of reducing the physical plant footprint and increasing the process efficiency both have put the focus on the treatment of the digester blow off. An alternative to the mud decanter and washer train would be the filtration of the digester blow off. Filtration would occur within minutes, while standard settling in a decanter takes anywhere from one to several hours. This time reduction would minimize the loss of alumina to the red mud and has the potential to replace approximately 50−100 % of the red mud washing train. However, to implement this process option, filters with the following design features are required

- operating temperature of 140−200 °C
- operating pressure of 400−1 000 kPa
- operation with back pressure on the filtrate separators to prevent flashing
- ideally filters that allow moderate cake wash

Figure 2. BoHiBar Drum Filter with open pressure vessel for purified terephthalic acid (PTA) filtration

BOKELA is already operating filters under these conditions (160 °C, 550 kPa filtration pressure, 400 kPa back pressure) in the filtration of the base material for polyester fibres and PET bottles. For these applications even a three-stage counter current wash is performed on the filter, which reduces the amount of wash liquid to < 50 % compared to filters with single stage wash. Figure 2 shows such a filter with open pressure vessel and 18 m² filtration area.

In addition, BOKELA has developed disc filters that enable cake washing and are already being used successfully in aluminum refineries, as can be seen in Figure 3.

Figure 3. BoVac Disc Filter for Al-hydrate filtration with cake wash

The combination of both process options - carrying out the filtration as continuous pressure filtration with BoHiBar disc filters at 140–200 °C inlet temperature and back pressure on the filtrate separators as well as using disc filters with 8 times the filtration area per unit and perform a moderate cake wash - results in an ideal filter design for the filtration of digester blow off. Especially in processes with digesters working at pressure > 6 bar. The digester blow off slurry would first be fed to a flash tank at 400–1 000 kPa and from there to the filter. Some of the steam from the flash tank would serve as the driving gas for the filtration process. Thus, no air is required which would suite one of the targets of this new separation step – no contact with air.

As only thin layers of solids are built on the filter fabric and discharged, the residence time in the filter would only be some minutes. This is important for the efficiency of the digestion, because as soon as pressure and temperature are reduced, there is a reverse reaction and precipitation of aluminum compounds, which are then lost into the red mud. The faster the red mud is separated, the lower the loss of aluminum compounds in the red mud. The following simplified process flow sheets gives a first idea of the integration of a rotary pressure disc filter (Figure 4).

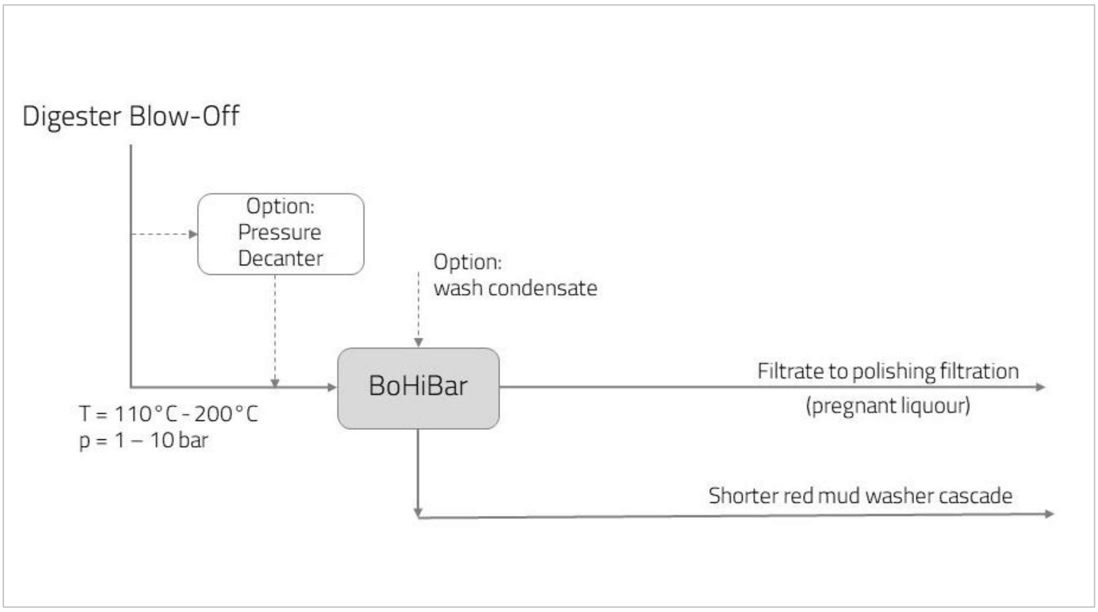

Figure 4. Flow sheet of digester blow off filtration with one filtration stage

The digestor blow off would be fed from the flash tank at 400–1 000 kPa to the filter. A value of 100 g/l can be assumed as a typical solids content. BoHiBar filters typically produce a filter cake with a porosity of 50 % (50 % void volume between the solid particles). This means that only about 3 % of the digestion liquid remain in the filter or and 97 % of the liquid is already removed with this first filtration step.

In addition, there is the option to wash the filter cake with condensate to further remove digestion liquid from the red mud. According to current experience the amount of wash water is limited on disc filters to around 0.2 kg wash liquid per 1 kg of solids. However, this would improve the removal of pregnant liquor to almost 99 % and it would significantly reduce the size/length of the remaining washer train.

The low feed solids in the digester blow off would require a quite large filtration area. This area could be reduced by factor 3–5, if a pressure decanter is used to thicken the filter feed. And this expected be the most attractive process flow sheet in terms of CAPEX. Finally, the filtered solids have to be re-slurried and released to the final mud wash stage. The re-slurrying could be performed in the discharge box of the filter inside the pressure vessel and the pressure in the vessel would be the driving force to get the slurry to the first washer.

Another option is to feed the red mud that has been resuspended to a second stage rotary pressure filter according to the following process flow diagram (Figure 5). This filter would have two duties:

a) reduce the pregnant liquor content to the final target
b) reduce the moisture of the red mud to a value that allows for dry stacking

If the second-stage rotary pressure disc filter were to achieve both goals, which is a reasonable assumption, the entire red mud washing plant would disappear from the process flow diagram and the plant's physical footprint would be two-thirds of its current value.

As the filtrate of the rotary pressure filters contains more than 1.0 g/l solids the polishing filtration of the pregnant liquor would still be required and would have to deal with an even higher solids load more in the range of 1–5 g/l.

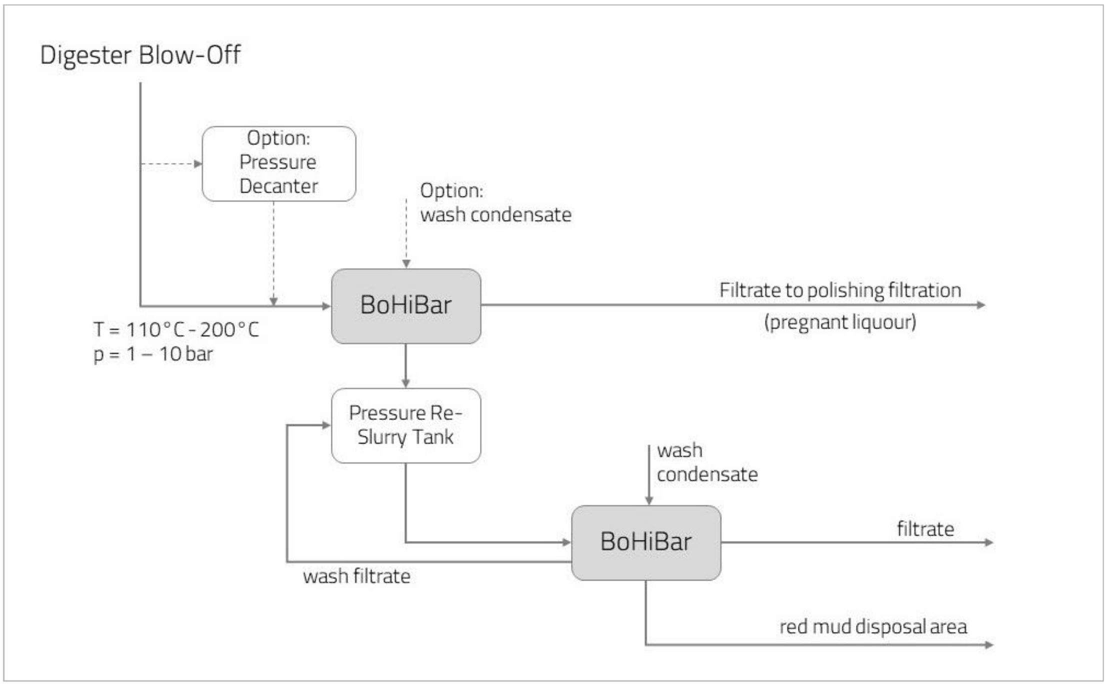

Figure 5. Flow sheet of digester blow off filtration with two filtration stages

The filter operation at temperatures in the range of 140–200 °C of the digester blow off is a challenge for the materials of construction as well as for the operation of the filter, but also a challenge for the filter fabric. The temperature in combination with the high pH-value is a bigger challenge than the abrasive nature of the solids is. The possible success of this technology is certainly linked with the operation and maintenance procedure and strategy. The filters already in operation at high temperature and pressure are running well because preventative maintenance strategy is in place with a strict adherence to the given maintenance schedules in combination with a smart sequence of how to cool the filter before servicing. It would be great to see this change to digestor blow off filtration in the next years and to contribute with this technology to the CO_2 emission reduction, the safety of the bauxite residue storage facilities and the efficiency of the refinery process.

5. References

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