FILTRATION OF BAUXITE AFTER PIPELINE TRANSPORT: BIG CHALLENGES - PROPER SOLUTIONS

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1. Introduction

Transport of beneficiated bauxite via pipeline from mine to refinery is a very economic and environmental alternative to conventional transportation methods. Pipeline pumping of bulk materials such as kaolin or iron ore is not only a proven, but also a more economical and environmental method than ship, truck or railroad transport. Hydraulic transport of bauxite through pipelines, however, was thought to be very difficult or even impossible. This estimation has now been disproved by the first bauxite pipeline (24 inches in diameter) over 245km distance from Paragominas mine to Alunorte Alumina refinery of Vale (former CVRD), Brasil, which has been in operation for more than 1 year.

Normally, bauxite is delivered to the alumina refinery as dry material. Pipelined bauxite however, arrives at the refinery as slurry with some 50wt-% water which has to be removed as far as possible by appropriate dewatering facilities. This has to be seen as part of the transportation system. Therefore, it was a decisive condition for realising pipeline pumping of bauxite to have a feasible filtration technology available which is capable of handling the huge solids throughput, and of dewatering the slurry to a low moisture content in an economical way. Comprehensive investigations showed that continuous pressure filtration is the only filtration technology which is capable of coping with the specific product and process conditions, and which is capable of providing the required values of solids throughput and moisture content in an economic way.

2. Challenges of bauxite dewatering

Bauxite dewatering is a challenging task which is indispensable for realizing pipeline pumping since the dewatering facilities have to be seen as an integral part of the transportation system. For pipelining, the fine sized bauxite is pumped as slurry with some 50 wt-% solids which has to be dewatered at the refinery. Dewatering is essential to maintain the refinery's chemical and thermal balances and it is the target of bauxite dewatering to:

- minimise water input to the refinery (any surplus of water input to the refinery would influence the water and energy balance of the refinery in an unacceptable way)
- avoid sticky behavior, that is attain good handling characteristics
- enable blending of the dewatered bauxite with other bauxites.

The special product characteristics and process requirements listed below make bauxite dewatering a challenging task:

- small particle sizes with a large amount of fines below 10 µm require high pressure differences both for filtration and dewatering, especially if large throughput rates and low moisture contents have to be achieved
- a well defined low moisture content has to be reached which may not exceed mc = 12 to 15wt% (target moisture content mc = 12 %, maximal allowed moisture content mc = 15 %)
- bauxite is processed in large amounts which means that high specific throughput rates have to be achieved to limit the number of required filter units, that is keeping investment and operation costs to an economic scale.

These conditions require a high performance separation technology.

3. Determination of a viable bauxite dewatering concept for Alunorte

The first bauxite pipeline (24 inches in diameter) over 245km distance is in operation since 2006 from Paragominas mine to Alunorte Alumina refinery of Vale (former CVRD), Brasil [1]. This pipeline was built as part of the Alunorte refinery expansion 2 project which increased plant capacity from 2.5 to 4.3 million t/a. Remote location of the Paragominas mine and lack of alternative means of transportation motivated the experts of Vale to realize the first bauxite pipeline.

It was a decisive condition for realizing this pipeline to have an appropriate dewatering technology available which is capable of coping with the specific product and process conditions as listed above in an economic way. The dewatering concept designed by Vale was based on splitting the bauxite into a coarse (80 %) and fine fraction (20%) with dewatering of the coarse fraction on vacuum belt filters and the fine fraction on filter presses. Filtration test work performed by Vale showed that with the preliminary dewatering concept, the targeted moisture content of mc = 12 – 15 wt-% could not be reached even when using various, unwanted chemical additives like flocculants for increasing the solids throughput and detergents for reducing the moisture content. Neither filter press dewatering of the fines fraction nor belt filter dewatering of the coarse fraction could achieve the target moisture content. The mixed filter cake from the belt filter and from the filter press had a moisture content of mc = 18 – 20 wt%.

To find a viable concept for bauxite dewatering that is capable of achieving the requested performance with respect to throughput (500 t/h) and moisture content (mc = 12 – 15 wt%), Bokela was ordered by Vale to make a review of the preliminary dewatering concept, to recommend improvement measures, and to show alternative dewatering systems.

The investigations of BOKELA described in [2] showed that bauxite classification and dewatering of single product fractions is not a viable concept. Only the formation of a homogeneous and thin filter cake with the original unclassified product, and the application of filtration pressure differences of up to Δp = 6 bar provides the required values. This can only be realized with the Continuous Pressure Filtration (see section 4). In filter presses a minimum cake thickness of only 16 mm can be achieved and a minimum moisture content of some 16 wt% is reachable with the Paragominas bauxite. Cake dewatering with compressed air leads to very long cycle times and consequently huge filter areas up to 3,000m² would have been necessary. In automated filter presses, thin filter cakes can be realized but then long idle times and long cycle times and large filtration areas are necessary.

The investigations also influenced bauxite preparation at the mine to ensure that granulometry of the bauxite, including a large fines content, satisfies requirements both of pipeline pumping and of dewatering. This led to a PSD of 40 – 47% < 44 µm [1].

The continuous pressure filtration is capable of providing the required values of solids throughput and moisture content in an economic way, that is with a reasonable filtration area or number of filter units, respectively. With Hi-Bar steam pressure filtration, even moisture contents of mc < 12 wt-% are possible.

The continuous pressure filtration offers the necessary production flexibility to compensate in a fully automatic way, variations in filtration behavior which may occur due to

- variations in daily production
- variations in solids concentration due to intermittent pipeline flow (water/slurry)
- change in granulometry of the bauxite and particle size distribution of the solids to be filtered.

4. Plant and process design of the continuous pressure filtration technology

The development of continuous pressure filtration (known as Hyperbaric Filtration and Hi-Bar Filtration) started at the University of Karlsruhe in Germany in the early 1980s. It was the aim of this development to combine the advantages of continuous rotary vacuum filters, such as drum and disc filters, with the advantages of a high filtration differential pressure to allow filtration and dewatering of slurries with fine solids. For this purpose, a conventional filter is installed in a pressure vessel (Figure 1). The filtrate pipes are connected to the environment and the suspension is pumped by an appropriate pump into a pressurized vessel. The filter cake is removed from the filter cloth by compressed air blowback and discharged from the pressurized zone through a sluice system. The vacuum pumps used with a conventional vacuum filter are replaced by a compressor that supplies the necessary compressed air to the vessel and for compressed air blowback. The compressed air from cake blowback also serves as process air to maintain the overpressure in the vessel for the filtration process. Inside the vessel, the filter runs with a high differential pressure of up to Δp = 6 bar.

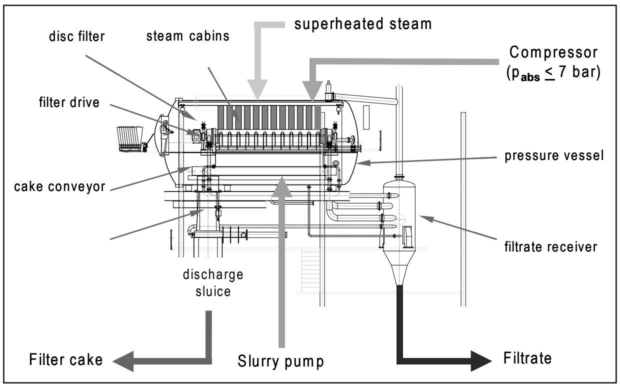

Figure 1. Schematic view of a Continuous Pressure Disc Filter with steam cabins for steam pressure filtration

The first hyperbaric filter started operation in 1986 for dewatering of coal concentrate. Nowadays, this economic high performance technology is well established and widespread on the market. Typical applications are found in coal preparation, in copper, zinc and iron ore beneficiation, in starch production and even in the fine chemicals industry for which BOKELA has developed the Hi-Bar Oyster Filter. The most advanced continuous pressure filtration process and plant design is the Hi-Bar Filtration technology of BOKELA that includes also the patented steam pressure filtration process.

The laws of continuous cake filtration still apply for the continuous pressure filtration. 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

$$\dot{m}_s = \rho_s (1-\varepsilon) \cdot \sqrt{\frac{2}{\eta_L r_c}} \cdot \sqrt{\kappa} \cdot \sqrt{\Delta p} \cdot \sqrt{n} \cdot \sqrt{\frac{\alpha_1}{360^0}} \qquad (1)$$

m_s	specific solids throughput	[kg/m²h]
ρ_s	solids density	[kg/m³]
ε	filter cake porosity	[-]
ηL	filtrate viscosity	[kg/ms]
r_c	cake resistance	[1/m²]
κ	solids concentration parameters	[-]
Δp	differential pressure	[kPa]
n	filter speed	[1/min]
$\alpha 1$	angle of cake formation	[°]

Equation 1 clearly shows that the solids throughput mS 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 $\alpha 1$) increases solids throughput according to equation 1, since thicker filter cakes are formed which then allow an increase in filter speed n. Since increase of filter speed also increases solids throughput (see equation 1), the total throughput increase is linear with 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 minimal 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 say Δp = 3 bar leads to a sixfold 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, or for a required throughput only a sixth of the filter area is needed compared to vacuum filtration.

The residual cake moisture content of a product reduces if higher differential pressures are applied, which is described by the capillary pressure curve of the product. The higher the differential pressure the smaller capillaries of a filter cake can be dewatered by the compressed air. Particularly for fine solids such as pipelined bauxite, which do not dewater on vacuum filters, high pressure differences are necessary for cake dewatering because such filter cakes have small sized cake pores with high capillary pressures. Figure 2 shows the cake moisture versus solids throughput for different values of pressure difference and filter speed.

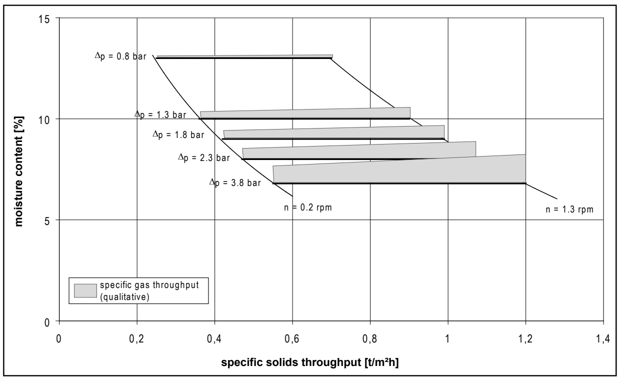

Figure 2. Residual moisture content versus specific solids throughput for different values of pressure difference Δp and filter speed n (zinc ore)

4.1 Hi-Bar Steam Pressure Filtration

The most innovative variant of the Hi-Bar technology is steam pressure filtration. Contrary to conventional steam filtration, the Hi-Bar steam pressure filtration uses pure steam instead of compressed air for dewatering, washing and cake drying. A filter cake which is formed at the low temperature of the feed slurry enters a specially designed steam cabin immediately after emerging from the slurry in the filter trough. Here, a superheated steam atmosphere exists and the following phenomena take place which can be described by "condensate front" model (Figure 3):

- The steam condenses on the cold cake surface and a homogeneous condensate layer formed moves through the cake in a piston-like flow ("condensate front").

- The moving "condensate front" replaces nearly 100% of the mother liquor.
- When the "condensate front" reaches the filter cloth, the filter cake is heated completely to the steam temperature. At this point the cake leaves the steam cabin.
- Now compressed air passes through the pre-dewatered and hot filter cake causing a very effective thermal drying which leads to extremely low cake moisture contents.

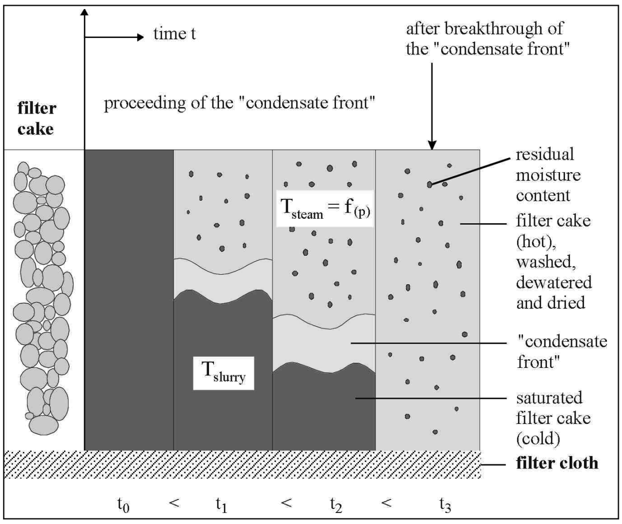

Figure 3. Steam Pressure Filtration: model of the "condensate front"

These thermal/mechanical phenomena inside the filter cake lead to a nearly homogeneous and therefore highly intensive cake washing and cake de-moisturing without pressure and energy loss by "fingering". Compared to cake demoisturing with pressurized air the use of steam under Hi-Bar conditions improves the demoisturing to a great extent. The synergy by the "condensate front" means that in many cases with 1 kg steam more than 1 kg of mother liquor is displaced which otherwise would have to be removed by thermal drying. Thus, extremely low moisture contents and a high efficient cake washing is attained. Typical steam consumption rates range between 60 and 100kg/t (dry substance) and depend on the properties of the solid material.

Differences in the design of a steam pressure filter and a standard pressure filter are additional steam cabins and pipes necessary for steam supply (Figure 1). All other components, the pressure vessel, filter with feed trough or sluice with discharge system, match those of a continuous pressure filter. Moreover, it is important to note that only the steam supply system must be insulated. As steam is only fed into the steam cabin, insulation of the entire pressure vessel is not necessary. However, the higher thermal stress as well as the different coefficients of expansion must be taken into consideration at all points where different materials come into contact, such as at the control head at the filter cloths and at the cake discharge. Hi-Bar steam pressure filtration enables very low moisture contents of pipelined bauxite (mc < 12%) as shown in Figure 2. Hi-Bar steam pressure filtration also allows production of dry bauxite residues with moisture content mc < 25 wt-% which enables re-usage of red mud [3].

4.2 Realization of a continuous pressure filtration plant for bauxite dewatering at Alunorte

As a result of the investigations and technology screening described in section 3 and in [2], Bokela was asked by Vale to carry out the basic engineering for a continuous pressure filtration plant for a solids throughput: MS = 500 t/h and a moisture content of mc = 12 – 15 wt-%.

For this successful project, a consortium of Andritz AG and Bokela was formed for the engineering, supply and commissioning of the first 5 hyperbaric disc filters of 168m² filter area each (Figure 4). Award of order was in February 2005 and commissioning was in March 2007. Bokela was responsible for basic and detail engineering, filter scale up, specification of components and process automation. Andritz was responsible for manufacturing and supply of the disc filters, pressure vessels and discharge sluices. A second, identical filter plant has been ordered in August 2006. Start-up is scheduled in 2008.

4.3 Operation results of the continuous pressure filtration plant at Alunorte

The bauxite slurry from the pipeline feeds three tanks of 6,700 m³ each. Two serve for storage of the bauxite slurry and one for storage of the water that is pumped through the pipeline between any bauxite batch. From here the slurry is pumped to Alunorte refinery by two pumps (957 m³/h nominal capacity) to an intermediate slurry tank which feeds the 5 hyperbaric disc filters. The cake discharged from the filter cloth by means of compressed air blowback is collected by a chain conveyor inside the pressure vessel and discharged from the vessel to atmosphere by means of a discharge sluice (double knife valve design). The sluiced cake is collected by a belt conveyor system and transported to dewatered bauxite storage with a total capacity of 64,000 t dewatered bauxite or to bauxite bins to feed the repulping tank. The filtrate with a solids content less than 4g/

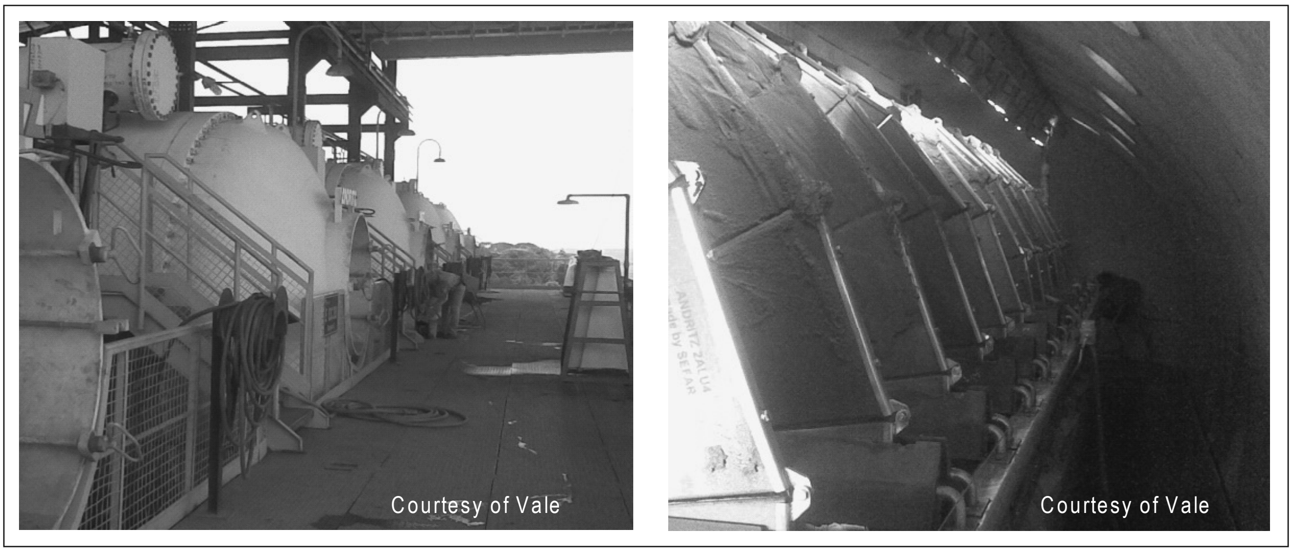

Figure 4. View of the filter plant with five continuous pressure disc filters (168m² filter area each, 12 discs and 240 sectors i.e.20 sectors per disc) (left); view into a pressure vessel (right)

L is sent to a thickener and then further treated. A more detailed description of this plant design is given in [3].

With the correct granulometry, which was the basis for filter scale-up, the filter plant provides the same values of solids throughput and moisture content as calculated by Bokela (Figure 5). After commissioning in March 2007, the hyperbaric filters run with the required nominal slurry feed. Operation results are as follows [4]:

- Solids throughput per filter: 125 t/h
- Average moisture content: 14.3 wt%
- Filtrate solids content : < 4g/L.

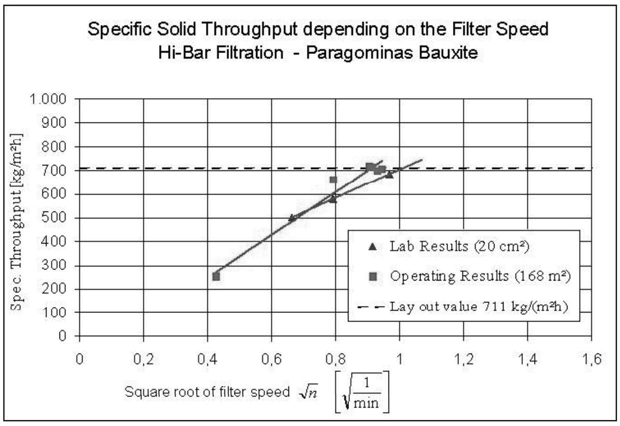

Figure 5. Specific solids throughput of the hyperbaric filters in operation compared to scale-up throughput value calculated by BOKELA (same granulometry of real slurry and test material)

4.4 Dewatering results with other bauxites

In Figures 6 and 7, results of dewatering tests and filter layout are shown for a bauxite with a particle size x50 = 15 µm and x90 = 138 µm. The test results shown were carried out with a filtration pressure difference Δp = 5.5 bar and with a slurry temperature of T = 30°C. Target value for the cake moisture content is mc < 12 wt% and required specific solids throughput is ms = 680 kg/m²h, which is necessary for dewatering the yearly solids throughput on two Hi-Bar disc filter plants with 168m² filter area each.

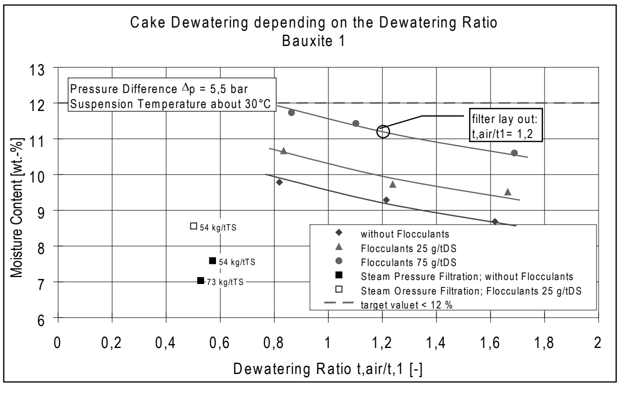

Figure 6. Moisture content as function of the dewatering ratio t2/t1 (t2 = dewatering time, t1 = cake formation time) for a pressure difference Δp = 5.5 bar

Figure 6 shows the moisture content as function of the ratio t2/t1, which is the ratio of dewatering time t2 to cake formation time t1 on a rotary filter. The curves show results for flocculant doses of 25g/t DS (dry substance), 75g/t DS and results without flocculants. Figure 6 also shows results of Hi-Bar steam pressure filtration with 25g/t DS flocculants and without flocculants. It can be seen that the target moisture content of mc < 12 wt% can be reliably reached with and without flocculants for dewatering ratios t2/t1 > 0.8. For steam pressure filtration, shorter dewatering times are required so that the target moisture is reached for smaller values of t2/t1 > 0.5. Flocculants are required to improve the filtration behavior and solids throughput but it can be seen from Figure 6 that flocculants hinder the dewatering and increase the moisture content both for pressure and steam pressure filtration. The very low moisture content of mc = 7 wt% is achieved of course with Hi-Bar steam pressure filtration without flocculants.

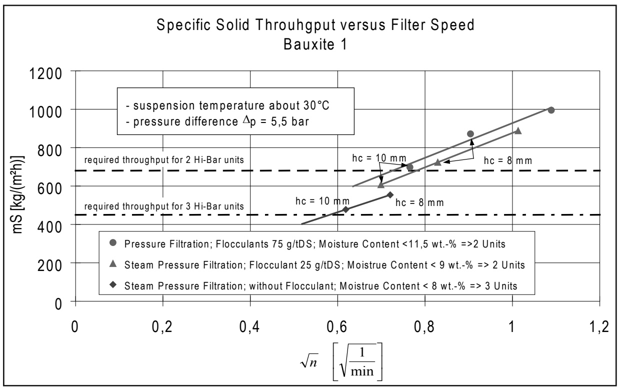

Figure 7. Specific solids throughput as function of square root of the filter speed (filter layout for moisture content mc < 11.5 wt%)

Figure 7 shows the specific solids throughput as a function of the square root of filter speed. As can be seen the specific solids throughput increases linearly with the square root of filter speed. This means that scale-up calculations based on the filtration theory according to equation 1 (ms ~ n0.5) are valid for this bauxite product. For filter layout a dewatering ratio t2/t1 = 1.2 has been chosen (see Figure 6). Since gas throughput for this product is low, this ratio of dewatering time to cake formation time is necessary to ensure that during filter operation the dewatering time is long enough that all filtrate can leave the filtrate pipes. This is necessary to prevent the filter cake being re-wetted during cake discharge. Figure 7 shows three options for filter layout:

- Option 1 means standard pressure filtration with a flocculant dose of 75g/t DS. In this case the specific solids throughput ranges to ms > 680 kg/m²h which means that only two filter units are necessary. The cake moisture content for this layout is mc = 11.5 wt%, the thickness of the filter cake ranges from 10 to 8 mm, which ensures a reliable cake discharge.
- Option 2 means steam pressure filtration with a flocculant dose of 25g/t DS. For this option the specific solids throughput ranges from 600 kg/m²h to 900 kg/m²h which also means that only two filter units are necessary. The cake moisture content for this layout is much lower and ranges to mc < 9 wt%. Steam consumption in this case is about 54 kg steam/t DS.
- Option 3 means steam pressure filtration without flocculants. For this option an extremely low cake moisture content of mc < 8 wt% is achieved for which a steam consumption of about 73 kg steam/t DS is necessary. The specific solids throughput however is below 600 kg/m²h which means that three filter units are necessary.

Summary

The continuous pressure filtration is a high performance technology which is capable of coping with the challenging product and process conditions of filtration and dewatering of pipelined bauxite. The first plant has been realized at Alunorte alumina refinery, Brasil. The successful start up and one year of operation show that this technology provides the required values of moisture content and solids throughput in a reliable operation. Tests by BOKELA show that with his technology other bauxites also can be successfully dewatered in an economic way. The application of Hi-Bar steam pressure makes possible even extremely low moisture contents of the dewatered bauxite.

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