PROCESS OPTIONS FOR THE FILTRATION AND WASHING OF BAUXITE RESIDUE

Reinhard BOTT[1], Thomas LANGELOH[2]

[1] Managing Director, BOKELA GmbH, 76131 Karlsruhe - Germany
[2] Managing Director, BOKELA GmbH, 76131 Karlsruhe - Germany

rbott@bokela.com, tlangeloh@bokela.com

Abstract

After many years of theoretical discussions, the industrial re-usage of bauxite residue is now going to be realised in the more modern alumina refineries. The cost pressure caused by the disposal of red mud, by loss of caustic but also by loosing yield in alumina is the best argument for the application of superior filtration technologies. The main pre-condition for any industrial usage is a bulky behaviour of the red mud (i.e. very low moisture content) and a low caustic content (i.e. good washing out), which challenges for a superior filtration technology. During the establishment of various re-usage processes it became obvious, that not only the low moisture content (avoiding the sticky behaviour of red mud) but also the optimal washing out of the caustic content is a mandatory request for any industrial re-usage of the bauxite residue. In this process frame (separation/washing) the continuous pressure filtration (HiBar Filtration and HiBar Steam Pressure Filtration) is the most promising filtration technology whereas filter pressure technologies are mainly used for simple separation, when the red mud is disposed like in the past.

Introduction

Bauxite residue or red mud production in Al-refineries has steadily increased in the last years due to decreasing bauxite quality and increasing number of production facilities. Annual amount of bauxite residue production is estimated to some 120 million tonnes world-wide while globally some 2.7 billion tonnes are stored in disposal areas.[1] Numerous attempts have been undertaken by producers to improve the efficiency and safety of red mud disposal or to make it available for industrial re-usage. For decades major alumina producers have researched for alternatives to disposal and for product development to make bauxite residue available for re-usage in different industries. After many years characterised by more or less theoretical discussions, the industrial re-usage of bauxite residue is now going to be realised in the more modern alumina refineries due to cost pressure caused by the disposal by loss of caustic and yield in alumina. Depending on the bauxite feedstock usually 0.5 tonne to 1 tonne dry solids of bauxite residue arise per 1 tonne alumina produced and from some bauxites even 2 tonne residue solids result per 1 tonne alumina. Accordingly, for a 2 Mtpa refinery typically 1 to 2 Mtpa bauxite residue have to be processed and managed. So, it is evident from this that solutions for re-usage of bauxite residue require largescale consumers and current tendencies of re-usage strategies are focused on possibilities of utilisation such as:

- soil improvement,
- land reclamation for agriculture,
- regulator at cement production,
- sintering aids for iron and steel industry,
- etc.

For a further processing or a re-usage the bauxite residue to be made available by the refinery with a very low soda content and a non-thixotropic, non-sticky behaviour to ensure secure transportation and problem free handling. HiBar Steam Pressure Filtration is an innovative technology, which is capability to produce a dry, easy to handle material.

Product Characteristics of Bauxite Residues

The composition of bauxite residues varies in a wide range depending on the bauxite feedstock, the refinery's individual process design and the process conditions.[1] The most important and recyclable mineralogical constituents are iron oxide, titanium dioxide and silicon dioxide (see Table 1) of which the first is responsible for the color and the name of this waste material. Some bauxites are also known for their content of radioactive materials. Their concentration, however, is below critical values but can affect the public perception and acceptance of bauxite residue.

Table 1: Composition of bauxite residues – typical values[2]

Component	Typical Range [%]
Fe_2O_3	20 - 45
Al_2O_3	10 - 22
TiO_2	4 – 20
CaO	0 - 14
SiO_2	5 - 30
Na_2O	2 - 8

Not only the chemical composition but also the particle size distribution varies which both influence the residue characteristics with respect to filtration, washing and dewatering and consequently the residue behavior at disposal.

Generally, bauxite residue consists of very fine, lamina-shaped particles in the range of $x_{50} < 10$ µm. The pH-values of bauxite residues are in the range of pH = 10 – 12 (soluble soda content of some 60 g/l). An especially problematic characteristic of bauxite residue is its thixotropic behavior which impairs the possibilities of utilisation. Under mechanical stress, which may occur e.g. by shaking during the transportation, bauxite residue which seems to be of firm consistency is liquefied again and becomes sticky. This phenomenon affects very poor bulk characteristics and impedes handling significantly. Thixotropy disappears when the moisture content is reduced below a value of < 25 - 28 wt%.

Status-quo of Bauxite Residue Dewatering

Red mud filterability changes depending on the bauxite feedstock and mineralogical composition but generally red mud is a product which is difficult to filter and to dewater due to the very fine, lamina-shaped particles in the range of $x_{50} < 10$ µm (see pos. 2). Equipment in use for bauxite residue dewatering like deep cone thickeners or vacuum drum filters are not capable of producing a residue which meets the demands for re-usage i.e. an dry and good washed product with low moisture content and low soda content. Vacuum drum filters which are the established and only available continuous filter technology for bauxite residue are limited in their dewatering capacity and produce thixotropic filter cakes with moisture contents of mc = 35 – 50 wt%. The high liquid content in the cakes and the poor wash results also effect that bauxite residues possess a high amount of soluble soda of some 6 – 12 g/kg. Thus, a further processing or direct utilisation of the bauxite residue is not feasible neither technically nor economically.[4, 5, 6]

Targets of Bauxite Residue Filtration – Dry Bauxite Residue

New methods of bauxite residue treatment must be capable to improve the product characteristics of this residue to such an extent that utilisation becomes a real alternative to disposal and loss of valuable content is minimised. This requires a significant improvement of the bauxite residue washing and dewatering by feasible filtration technology which is capable to produce a dry bauxite residue (DBR).[6] The main targets are:

- reducing the moisture content down to mc = 25 – 28 % by an improved filter cake dewatering in order to achieve a non-thixotropic and non-sticky product with sand-like bulk characteristics, good transport and handling characteristics,
- reducing the content of soluble Na_2O far below the actual values of 6 – 8 [g/kg] by an improved washing for minimising the loss of soluble soda, for achieving better product quality for bauxite residue utilisation possibilities

Options for Improved Dewatering and Washing of Bauxite Residue

The production of a dry bauxite residue (DBR) which is a precondition for making re-usage feasible requires improved filtration, washing and dewatering of red mud by a filtration technology which enables (preferably continuous) operation with high pressure differences and good capability for effective cake wash.

Filter presses

Filter presses are one of the most used solid-liquid separation machines for discontinuous cake filtration and for demoisturing of difficult to filter suspensions. Filtration takes place discontinuously and as driving force overpressure is applied delivered by a pump. Cake wash can be performed but distribution of the wash liquor and wash results are limited. The oldest design is the filter press where the filtration chamber is formed by perforated plates alternating with frames. Solids discharge has to be manually performed by breaking the cake out of the frames. A more automated operation of cake discharge was introduced with the chamber filter press which today is the most common filter press design comprising two neighboring recessed filter plates facing each other to form the filter chamber. Discharge of the cake can be executed more beneficially and simpler than from frame filter presses. However, filter cakes of a certain thickness i.e. of a certain weight are necessary to ensure that cake falls out by gravity. Typically, cake thickness in filter presses range from 20 mm to 40 mm and even more and often long cycle times take up to several hours are required. The membrane filter press – a further development - allows for cake squeezing in the filter chamber from one side by a rubber membrane. Filter plates and membrane plates alternate with each other. Advantages of this design are that slurry feed pressure can be kept low and a high pressure pump is not needed since the filter cake can be uniformly compressed by the membrane. A more detailed description of filter presses is given by Sutherland K.S.[3]

For handling large volumes filter presses contain hundreds of plates with up to 2.5 m in size and have areas of up to 1,000 m^2. They are operated with pressures of up to

16 bar while in some applications high-pressure filter presses are applied with up to 60 bar. Depending on the filtration properties of the slurry a filter cycle (filling, dewatering, sometimes washing and cake discharge) can take few minutes up to several hours leading to large required filter areas. Reduction of cycle time to achieve higher solids throughput requires the use of membrane filter presses. Automated operation requires large number of valves and instruments. Nevertheless, manual check of cake discharge is necessary leading to a steady and high personnel demand. To ensure that feed lines remain operational a cleaning system with many cleaning and flushing steps is needed.

Bánvölgy et al. reported about the use of filter presses for red mud dewatering[4] in two alumina refineries. Filter cakes with low moisture contents of some 28 wt% and good handling properties were achieved. The drawbacks are the discontinuous operation, relatively low throughput leading to large required filter units and poor results of cake wash. The effectivity of cake wash on filter presses was restricted due the thick filter cakes (typically cake thickness ranges from 20 mm to 40 mm) and due to the poor distribution of the wash liquor. Feeding of wash liquor in filter presses was done via one feeding point which was located either on top of the filter plate or in the center. Accordingly, distribution of the wash liquor in the filter chamber was inhomogeneous and large areas of the filter cake did not get in contact with the wash liquor, thus, were kept nearly unwashed.

HiBar filtration - continuous pressure and steam pressure filtration

HiBar Filtration of BOKELA is the most modern technology of continuous pressure filtration also known as hyperbaric filtration.[5] HiBar Filtration enables low moisture contents, high specific solids performance and efficient filter cake wash in continuous operation if fine grained, difficult to filter products have to be processed. Lowest cake moisture contents are achieved with HiBar Steam Pressure Filtration.

Plant and process design of HiBar Filtration

HiBar Filtration is realised on rotary drum or disc filters which are installed in a pressure vessel (Figure 1 and 2). Thus, process pressure values of up to 7 bar,abs (with HiBar Oyster design even 15 bars) and filtration pressure differences up to 6 bar and even higher (HiBar Oyster design) are realised. The application of overpressure instead of vacuum ensures a high specific throughput and dewatering capability even with filter cakes with fine particles such as filter cakes of bauxite or bauxite residue where high cake resistance and capillary forces in the cake have to be overcome.

HiBar steam pressure filtration

Lowest cake moisture contents are achieved with HiBar Steam Pressure Filtration. With this hybrid separation process the filter cake is treated with steam immediately after emerging from the slurry. In a specially designed and patented steam cabin covering only part of the filtration area, the filter cake is only partially exposed to steam, which accelerates and intensifies the dewatering process. For many products the dryness of the filter cakes significantly improves quality, handling and transport of the product which often is also a pre-condition for reusage. At filtration of bulk materials such as bauxite residues, iron ore concentrates etc. these are decisive criteria.

Dewatering of Various Bauxite Residues with HiBar Filtration and HiBar Steam Pressure Filtration

HiBar Filtration has shown its capability to produce a non-thixotropic, really dry and easy to handle, bulk-like bauxite residue. Lowest moisture contents and soda contents are achieved with the innovative steam pressure filtration. The treating of the red mud cake with steam immediately after cake formation leads to moisture contents of mc $\leq$ 25 wt% and low soda content which enables re-usage of this residue. Bott et al.[8] report on results of red mud filtration (vacuum filtration, continuous pressure and steam pressure filtrtation) of different refineries with bauxites from different feedstocks. Generally, it can be seen that continuous pressure filtration achieves moisture contents in the region of 25 – 30 wt% and HiBar steam pressure filtration achieves moistures < 25 wt% in the region of 22 – 25 wt%.[8]

First HiBar Filtration Plant for Bauxite Residue Dewatering

Figure 1 shows the first HiBar steam pressure filtration plant for the dewatering of a fine bauxite residue (x_{50} = 1.9 µm). Two HiBar disc filters of 70 m² each are installed with one unit in operation and one filter as stand-by unit.

The refinery operator decided in favour of HiBar Steam Pressure Filtration in order to achieve dry bauxite residue (DBR) with lowest moisture content. Required value of moisture content is mc $\leq$ 28 wt% to go below the thixotropic point for improving residue handling and ensure high yield stress of the bulk. The dry HiBar filter cake will both improve residue handling and residue disposal. The dryness and high yield stress of the filter cake ensure steeper dumping slopes i.e. reduced disposal area and improved safety of the disposal site. Commissioning of this first HiBar Steam Pressure

Filtration plant for bauxite residue dewatering was in September 2014. Operational results are shown in Table 2.

Figure 1: HiBar disc filter (70 m²) with steam cabins in the vessel for steam pressure filtration of bauxite residue (left) and filter building with both units (right)

Table 2: Operational results of HiBar disc filter (70 m²) during commissioning – steam pressure filtration of bauxite residue

HiBar Steam Pressure Filtration of bauxite residue - Operational results during commissioning		
Moisture content	≤ 28 wt% ≤ 25 wt%	with operation in pressure filtration mode during commissioning with steam pressure filtration for hot operation later
Solids throughput	10 t/h 32 t/h	with restricted speed and restricted filter area (only 3 discs in operation) due to limited feed slurry later
Filter speed	0.3 rpm (up to 1.2 rpm)	
Cake height:	9.5 mm	
Pressure difference	pressure difference	

Figure 2: A heap of dry and flowable **DBR** after discharge from the HiBar disc filter plant

Future Process Options

Direct filtration of bauxite residue in the Bayer process from the caustic, hot slurry

For alumina refineries the extraction yield of bauxite processing has been a major focus for decades and accordingly the loss of extractable alumina in the process chain has to be minimised as far as possible. 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 of economic relevance.[4,5] As a rule of thumb,[6] 2 % gibbsite reversion is lost in the settlers and 2 more percents are lost during bauxite residue washing mainly due to cooling down of the liquor to < 100°C together with long residence time in the settler and residue washers, precipitation of aluminium hydroxide (gibbsite) enhanced by the presence of seed and decreasing of the alumina solubility along with the decreasing caustic soda concentration due to the more diluted conditions in the bauxite residue washers.[9] Separation of the bauxite residue and washing it from the highly caustic and hot slurry quickly and directly just after digestion without cooling and with a short residence time would save a lot of extractable alumina.[9]

In the early years of the Bayer process often plate and frame filter presses were used for 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 could also not establish due to the high loss of soluble soda and alumina. In 1970s B. Schepers[10] and H. Loss[11] performed pilot scale testwork on direct filtration of the residue directly after the digestion reactor with continuous pressure filters. This testwork was performed on old fashioned pressure filtration technology but both the technical and economic feasibility of the direct filtration option were demonstrated.

With HiBar Filtration a most modern technology for continuous pressure filtration is now available. HiBar Filtration is applied for hot slurry filtration in many reference applications at high temperatures and high pressures with a specially and individually adapted process and plant design. HiBar Filtration has the capability for direct filtration of the hot pregnant liquor slurry within a very short residence time of some minutes at the temperature and pressure of digestion: T ≈ 145-150 °C, p ≈ 4-5 bar. The filtrate can be drained off with somewhat lower but still fairly high temperature of e.g. 140 – 145 °C. This way, loss of extractable alumina in the settlers and the bauxite residue washers, which sums up to about 4 %, could be minimised to approximately 0.5 – 1 %.

Direct filtration of hot slurries in the ILTD process

The ILTD (Improved Low Temperature Digestion) Process is a modification of the Bayer process that has been developed by G. Bánvölgyi to retrofit existing refineries or to be implemented in new alumina refineries. This process is assigned for Al-hydroxide production from gibbsitic bauxites. It has been tested and proven on a laboratory scale with various bauxites.[12] At the ILTD process the digestion is carried out with the total dissolving capacity of the digestion liquor and with maximum extraction of the gibbsite. The consequences and main benefits such as 9-13 % reduced material and energy cost per ton of alumina, 5 – 20 % higher digestion capacity, 30 – 90 % savings in the chemically combined NaOH losses, desilication product (DSP) of high purity, bauxite residue with extremely low soda content etc. are reported as follow[12, 13]. The ILTD process contains two decisive separation steps where separation technologies such as HiBar Filtration are of crucial importance because of their capability to process hot, fine particulate slurries under extreme conditions such as temperature and pressure of digestion: T = 145-150 °C , p = 4-5 bar.[12, 13]

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