FILTRATION MAP OF BAUXITE RESIDUES – FILTERABILITY OF RED MUD FROM SEVERAL BAUXITES AND POSSIBLE USE OF CONTINUOUS PRESSURE FILTRATION LIKE HI-BAR FILTRATION

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1. Introduction

Bauxite residue production in Al-refineries ranges to 100 million t/a world-wide and will further increase in future due to decreasing bauxite quality and increasing number of production facilities. 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.

Depending on the processed bauxite the thickening and filtration characteristics of red mud differ in a wide range. The lecture presents the results of comprehensive filtration test series with red mud from many bauxite sources all over the world. The evaluation of the test data allows a direct comparison of the filterability of the different bauxite residues. Based on these results the possibilities of continuous pressure and steam pressure filtration of red mud with Hi-Bar Filtration are presented. Hi-Bar Filtration has shown its capability to produce a really dry, easy to handle, bulk-like material for safe disposal or reusage. It is outlined by which adaptations standard Hi-Bar filter plants can be adapted with respect to plant and process design to different red mud characteristics and for producing residue qualities for different targets of disposal or reusage.

2. Characteristic Product Data of Bauxite Residues

The most important mineralogical compounds of bauxite residue are iron oxide, titanium dioxide and silicon dioxide 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. The composition of bauxite residue varies in a wide range depending on the origin of the bauxite, the individual process design and the process conditions of a refinery. 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 $\mathbf{x_{50} < 10\ \mu m}$.

An especially problematic characteristic of bauxite residue is the 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 a firm consistency is liquefied again and becomes sticky. This phenomenon leads to very poor bulk characteristics and complicates the handling significantly. Thixotropy disappears when the moisture content is reduced below a value of < 25 - 28 wt%.

3. Dewatering Characteristics and Disposal of Bauxite Residues

The treatment and disposal of bauxite residue influence production cost of alumina refineries. Numerous attempts have been undertaken to improve the efficiency of residue disposal or to make it available for industrial re-usage. For decades major alumina producers have undertaken research into alternatives to residue disposal and product development. These efforts have highlighted a large number of possible residue applications in different industries such as soil improvement, land reclamation for agriculture, regulator at cement production, sintering aids for iron and steel industry, catalyst for coal hydrogenation, top and bottom sealing of disposal areas, backfilling of underground mine etc. [3].

From an economic view these utilization possibilties are only feasible if bauxite residue complies with following requirements

- minimum soda content
- sandy material characteristic, i. e moisture content < 25 %
- problem-free handling and secure transportation.

Available methods of processing like deep cone thickeners or vacuum drum filters are not capable of producing a residue which meets these demands. The reasons for this unsatisfactory situation are special product characteristics which make filtration, washing and dewatering of bauxite residue a challenging task. This has to be seen against the background that thermal drying of wet bauxite residue is too energy and cost intensive and, therefore, not a feasible and profitable process alternative to produce dry bauxite residue for utilization.

Red mud filterability changes depending on the bauxite source but characteristic parameters can be given as below and shown in table 1:

- typical particle size distribution ($x_{50} < 10\ \mu m$)
- typical mineralogical composition consisting of Al_2O_3, Fe_2O_3, SiO_2, TiO_2 and others
- pH-value in the original red mud of pH = 10 – 12 (soluble soda content of some 60 g/l)
- serious dewatering problems

Table 1: Characteristic values of moisture content of dewatered bauxite residue for different dewatering technologies

Characteristic Data of Bauxite Residue		
Separation Technology	**moisture content**	**amount of water per t solids**
deep cone thickener	50 – 55 %	1,220 kg/ t solids
vacuum drum filter	35 – 50 %	540 kg/ t solids
Steam Pressure Filtration	< 28	330 kg/ t solids

4. Vacuum Filtration of Bauxite Residue

Since the early 1960's drum filters with roller discharge have been established as the leading technology for bauxite residue filtration. Typically, they are installed behind 3 to 4 wash thickeners and form the last step of bauxite residue washing and dewatering. The filter cake is only 1 - 3 mm thick and is washed with hot water via wash bars when emerging out of the slurry. If the wash water is distributed film-like it can help to prevent cake cracks. Cake discharge is usually performed with a discharge roller which removes the cake from the cloth.

Typical apparatus data and average operational data of bauxite residue vacuum filters are given in table 2 while table 3 shows results of running rotary drum filters from different refineries processing different bauxites. An essential weak point of vacuum filtration, which can not be overcome, is the low filtration pressure difference which is limited under technical conditions to some Δp = 0.7 bar. During bauxite residue filtration this low pressure difference reduces even more since bauxite residue is filtered with a high slurry temperature of about 85°C. At this temperature the filtrate has a vapor pressure of 0.58 bar which means that the theoretically available pressure difference by vacuum is only 0.42 bar. So, the efficiency of washing and dewatering on vacuum drum filters is limited, the content of soluble soda Na_2O in the cake of 6 – 12 g/kg is high whilst the moisture content is 35 % - 50 % (see table 3) and the discharged cake has a thixotropic behavior.

In many filter revamping projects BOKELA has upgraded red mud vacuum drum filters from many OEM's. The main improvement targets are increasing the filter capacity and reducing the soda content in the cake whereby cake washing and cake discharge are main weakpoints of running vacuum filters. By upgrading measurements and design modifications the filter performance can be improved often up to 100 %.

Table 2: Apparatus data and typical results of red mud vacuum drum filters (see also table 3)

Filter Size		Operation Data	
filter area	up to 100 [m²]	solids throughput	150 – 300 [kg/m²h]
drum diameter	up to 4.2 [m]	cake moisture	35 – 50 [%]
drum length	up to 7.6 [m]	content of soluble Na_2O	6 – 12 [g/kg]

5. Continuous pressure filtration technology - plant and process design

Hi-Bar Filtration of BOKELA is the most advanced continuous pressure filtration technology (also known as Hyperbaric Filtration) that includes also the patented steam pressure filtration process. Hi-Bar Filtration is realised on rotary drum or disc filters which are installed in a pressure vessel. Thus, process pressure values of 15 bar (Hi-Bar Oyster design) and filtration pressure differences up to 6 bar and even higher (Hi-Bar Oyster design) are realised. For this purpose the filtrate pipes of the rotary filter 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 – in case of red mud filtration of up to Δp = 6 bar. 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.

The first hyperbaric filter started operation in 1986 for dewatering of coal concentrate. Nowadays, this economic high performance technology is well established and wide spread on the market. Typical applications are found in coal preparation, in copper, zinc and iron ore beneficiation, in starch production, in the fine chemicals industry and for filtration and purification of PTA with the Hi-Bar Oyster Filter.

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

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

m_S	specific solids throughput	[kg/m²h]
ρ_S	solids density	[kg/m³]
ε	filter cake porosity	[-]
η_L	filtrate viscosity	[kg/ms]
r_C	cake resistance	[1/m²]
κ	solids concentration parameters	[-]
Δp	differential pressure	[kPa]
n	filter speed	[1/min]
α_1	angle of cake formation	[°]

Equation 1 clearly shows that the solids throughput 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 (see equation 1) the total throughput increase is linear 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 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 e.g. $\Delta p = 3$ bar leads to a sixfold higher mass throughput compared to a conventional vacuum filter that runs with $\Delta p = 0.5$ 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.

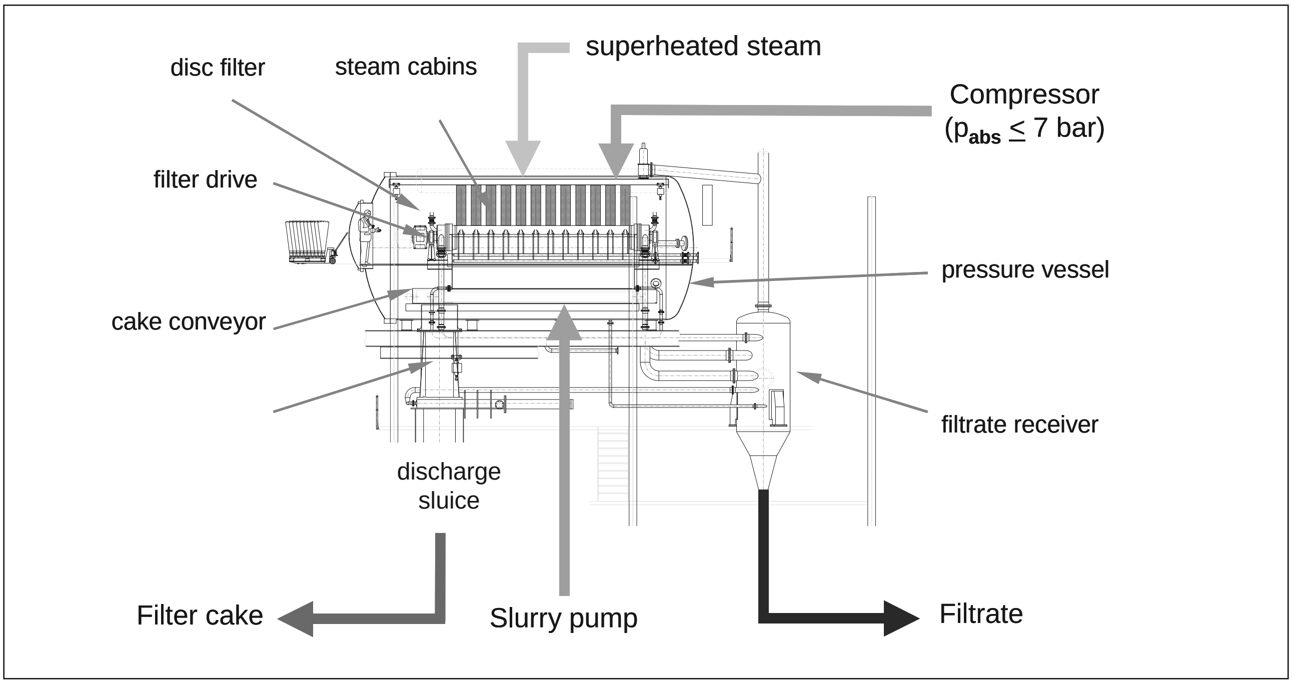

Figure 1: Schematic view of Continuous Pressure Disc Filter with steam cabins for steam pressure filtration

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 bauxite residue which do not dewater on vacuum filters high pressure differences are necessary for cake. Figure 2 shows the cake moisture versus solids throughput for different values of pressure difference and filter speed.

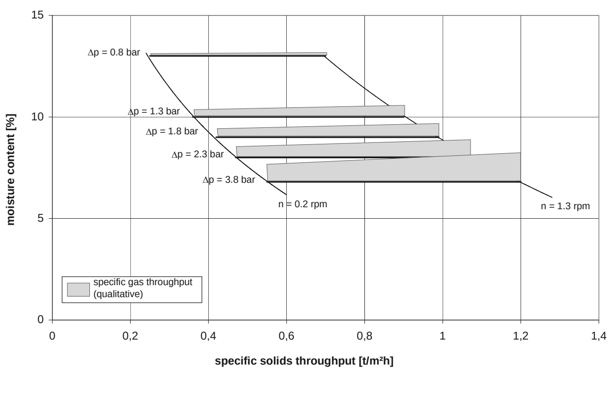

Figure 2: Residual moisture content versus specific solids throughput for different values of pressure difference Δp and filter speed n (zinc ore)

5.1 Hi-Bar Steam Pressure Filtration

The most innovative variant of the Hi-Bar technology is steam pressure filtration. Contrary to the 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 phenomenon take place which can be described by the model of the "condensate front" (figure 3):

- The steam condenses on the cold cake surface and a homogeneous condensate layer is 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 up completely to steam temperature. At this point the cake leaves the steam cabin.
- Now compressed air passes the pre-dewatered and hot filter cake causing a very effective thermal drying which leads to extreme low cake moisture contents.

These thermal/mechanical phenomenon inside the filter cake lead to a nearly homogeneous and therefore to a highly intensive cake washing and cake demoisturing without pressure and energy loss by a "fingering". Compared to cake demoisturing with pressurized air the use of steam under Hi-Bar conditions improves the demoisturing to a far extent. The synergy by the "condensate front" effects in many cases that 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 100 kg/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 (fig. 1). All other components, e.g. the pressure vessel, filter with feed trough or sluice with discharge system, match those of a continuous pressure filter. Moreover, it is important that only the steam supply system must be insulated as steam is only fed into the steam cabin. Hi-Bar steam pressure filtration enables very low moisture contents and allows production of dry bauxite residues with moisture content mc $\leq$ 25 wt-% which enables re-usage of bauxite residue.

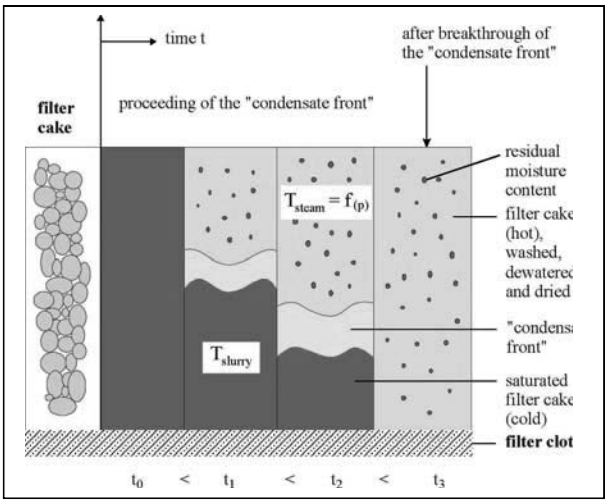

Figure 3: **Steam Pressure Filtration: model of the "condensate front"**

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6. Results of Bauxite Residue Dewatering with Hi-Bar Filtration and Hi-Bar Steam Pressure Filtration

Hi-Bar Filtration has shown its capability to produce a non-thixotropic, really dry and easy to handle, bulk-like bauxite residue (figure 4). Lowest moisture contents and soda contents are achieved with the innovative steam pressure filtration [4]. The treating of the red mud cake with steam immediately after cake formation leads to moisture contents in the region of 25 wt-% and below.

Table 3 shows the results of red mud filtration of different refineries with bauxites from different sources. The vacuum results in table 3 are results from running rotary drum filters, the results for Hi-Bar pressure filtration and Hi-Bar steam pressure filtration are results from lab and pilot tests. Some more tests with red mud from further bauxite sources have been made but have not been evaluated yet and some further tests will be performed. Tests with the red mud from refinery 12 (table 3) will be performed to investigate further options and potential for improved dewatering of this special red mud. Generally it can be seen from table 3 that continuous pressure filtration achieves moisture contents in the region of 25 – 30 wt-% and Hi-Bar steam pressure filtration achieves moisture contents below 25 wt-% in the region of 22 – 25 wt-%. An important parameter in table 3 with respect to Hi-Bar steam pressure filtration is the ratio t steam/t1 which is the ratio of time for steam treatment on a rotary filter to the cake formation time t1. A very small value of this ratio (see refinery 12 in table 3) means that no real steam pressure filtration with formation of a condensate front was possible due to serious crack formation in the filter cake. Currently BOKELA along with academic partners started a comprehensive R&D project to investigate very promising approaches to prevent or to handle the formation of cracks in filter cakes from products such as red mud but also other fine products.

Generally red mud filtration with Hi-Bar Filtration can be performed in different variants. The filtration can be performed as "first filtration" which means the replacement of red mud vacuum drum filters by Hi-Bar drum filters for filtration and washing of the last washer underflow. Another variant is the "second filtration" which means the filtration (without washing) of reslurried filter cake from vacuum drum filters by a Hi-Bar (disc) filter. The "second filtration" method enables filtration without washing of the filter cake, because the bauxite residue has already been washed on the vacuum drum filters. This allows the usage of disc filters instead of drum filters what leads to an increase of the specific throughput as consequence of a bigger cake formation angle of disc filters. Another conceivable option could be the "direct filtration" which means the filtration and washing of the first settler underflow by Hi-Bar filters, thus replacing the wash thickeners.

With Hi-Bar Filtration and Hi-Bar Steam Pressure Filtration bauxite residue can be converted to a non-thixotropic, really dry and sandy product which meets future demands and opens new possibilities for re-usage of this residue.

Table 3: Results of red mud filtration of different refineries with different bauxite sources; results of running vacuum drum filters and results of Hi-Bar Pressure Filtration and Steam Pressure Filtration (lab & pilot test results)

Refinery		Refinery 1	Refinery 2	Refinery 3	Refinery 3	Refinery 4	Refinery 5	Refinery 6	Refinery 7
Bauxite/Country of origin		Australia 1	Australia 2	Brazil 1	Brazil 1 (Lab)	Brazil 2	China	China	Guinea/ Australia
							1st stage	2nd stage	
Vacuum results for rotary drum filters (operational results of running filters)									
pressure difference	[bar]	0,6	0,6	0,4	0,6	0,5	0,4	0,4	
specific solids throughput	[kg/m²/h]	150 - 250	60 - 150	160 - 270	335 - 600	300 - 350	300	450	
moisture content	[wt%]	31 - 33			30 - 35	34 -36	40 - 44	40 - 44	
Hi-Bar Pressure Filtration (disc filter)									
filtration pressure	[bar]	3			5,5	5,5	5		
specific solids throughput	[kg/m²/h]	300			350 - 450	1500 - 2500	500 - 600		
moisture content	[wt%]	25 - 27			29 - 32	25 - 27	29 - 30		
Hi-Bar Steam Pressure Filtration									
filtration pressure	[bar]					5,5			4 - 6
specific solids throughput	[kg/m²/h]					1500 - 2500			250 - 450
t-steam / t_1 (*)	[-]					0,1 - 0,5			0,3 - 0,8
moisture content	[wt-%]					22 - 25			22 - 25

Refinery		Refinery 8	Refinery 9	Refinery 10	Refinery 11	Refinery 12	Refinery 13	Refinery 14	Refinery 15
Bauxite/Country of origin		Guinea	India 1	India 2	Indonesia	Jamaica	Kasachstan	Montenegro	Turkey
Vacuum results for rotary drum filters (operational results of running filters)									
pressure difference	[bar]	0,5	0,3	0,6		0.6	0,2	0,2 - 0,3	0,5
specific solids throughput	[kg/m²/h]	70 - 160	250 - 350	80 - 150		34 - 122	30 - 50	100	170 - 310
moisture content	[wt%]	40 - 45	36 - 41	39 - 42		39 - 43	45 - 50	45 - 50	44 - 46
Hi-Bar Pressure Filtration (disc filter)									
filtration pressure	[bar]				5,5	6,0			
specific solids throughput	[kg/m²/h]				500 - 800	115			
moisture content	[wt%]				27 - 28	33			
Hi-Bar Steam Pressure Filtration									
filtration pressure	[bar]				5.5	6.0			
specific solids throughput	[kg/m²/h]				500 - 800	115			
t-steam / t_1 (*)	[-]				0,1 - 0,2	0,05			
moisture content	[wt-%]				23 - 27	28 - 30			

(*) t-steam/t_1: ratio of time for steam treatment on a rotary filter to cake formation time t_1

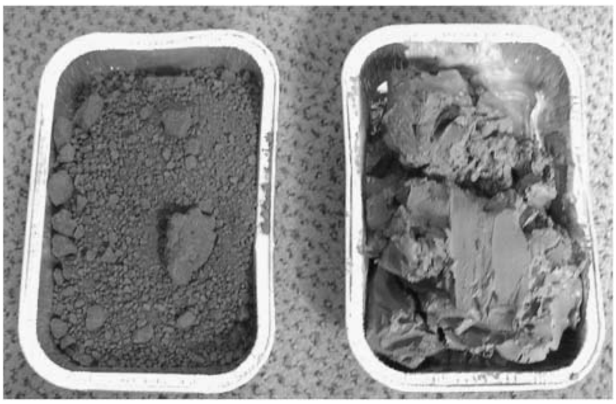

Figure 4: Filter cakes of red mud: pasty and sticky with a moisture content of 35 wt-% (vacuum filter) and sandy material with mc = 23 wt-% from Hi-Bar Steam Pressure Filtration

The Hi-Bar and Hi-Bar Steam Pressure Filtration offer new process possibilities for improved handling, improved disposal or sustainable use of bauxite residue such as:

- reducing the moisture content remarkably below the thixotropic point leading to:
  sand-like bulk characteristics (easy mixable with sand, soil or other bulk materials)
  good transport and handling characteristics
  improved disposal
  a high utilization potential
- reducing the content of soluble Na_2O by an improved washing for:
  minimized loss of soluble soda i.e. additional cost savings
  achieving a better product quality for bauxite residue re-usage for re-cultivation, street or dam building or other applications
- ensuring an economical process by avoiding or reducing crack formation in the filter cake by a minimum input of thermal energy.

7. First Hi-Bar Filtration Reference Plant for Bauxite Residue Dewatering

BOKELA has received order for delivery of the first two Hi-Bar Filters for the dewatering of Bauxite Residue. The Hi-Bar disc filters will be operated with an pressure difference of $\Delta p = 6$ bar and will produce a firm filter cake with a moisture content of < 28 wt.% and high yield stress. The dry Hi-Bar filter cakes will improve residue handling and residue disposal with steeper dumping slopes i.e. reduced disposal area and improved safety of the disposal site.

Since the filters are prepared for an upgrade to Hi-Bar steam pressure filtration the production of bauxite residue with a much lower moisture content is possible if required.

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