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Red mud pressure filtration for the alumina refinery's bauxite residue tailings disposal

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Abstract

Red mud waste residue management has been a consistent issue for review within alumina refinery operations. With 1 to 2.5 tons of red mud residue per ton of Al_2O_3 produced, the various options must be carefully considered. In light of the 2010 red mud pond dam failure at the Ajka refinery in Hungary, all eyes are on the problem and actions are underway at many producers to implement new strategies. Thickened underflows can be efficiently dewatered into high solids filter press cakes that can be safely stacked in dry storage areas to reduce the volume of waste material.

The results of pressure filtration testing demonstrates that, unlike traditional vacuum filters, standard design FLSmidth AFP IV™ filter presses can dewater red mud thickener underflows from initial concentrations of between 30–44 wt% to produce final cakes containing up to 80 wt% solids. We outline the various factors affecting the filtration rate and final cake solids concentration, such as feed solids concentration, slurry temperature, and feed pump delivery rate/pressure relationship, as well as the configuration of the filter plates.

This paper will detail the various flow sheets and equipment for efficient red mud disposal. Test results show variations by equipment type, geographic region, and different bauxite ore grades. Details will be presented on the selection criteria for the individual alumina refineries, including the main drivers; safety and environmental concerns, water and caustic recovery, storage volume, and waste area rehabilitation costs.

1 Introduction

Red mud bauxite residue management is a critical issue for alumina refineries. For every single ton of Al_2O_3 produced in the alumina refinery, as much as 2.5 tons of red mud residue must be handled. Depending on the bauxite ore grade and the geographic location of the alumina refinery, the amount of residue will vary. But in every case, the problem is significant. In recent years, much of the red mud has been stored in mud lakes, or impoundment areas; this has become common practice at alumina refinery plant sites around the world. When the dam wall ruptured at the Ajka alumina refinery in October, 2010, several thousand cubic meters of caustic red mud slurry flowed down the Hungarian countryside and into the neighbouring village, with devastating results (Bánvölgyi, 2010). The alumina industry, with a keen eye towards minimising such risks, has since invested heavily in the study and implementation of improvements to their red mud handling strategies. Many refineries are looking to pressure filtration to produce a red mud cake that would be high-solids, friable, and transportable by truck or conveyor.

The red mud resulting from the production of alumina is handled for disposal from the underflow off the bottom of the last washer at the end of a CCD circuit. Over forty years ago, flat-bottomed thickeners (Figure 1) were used in the Bayer process. Today this is mainly done using tank designs which achieve significantly higher specific settling rates and higher underflow solids concentration. These tanks incorporate sloped bottoms, significantly higher tank wall heights, and improved feedwell and rake designs (Figure 2).

Figure 1 Flat-bottom thickener

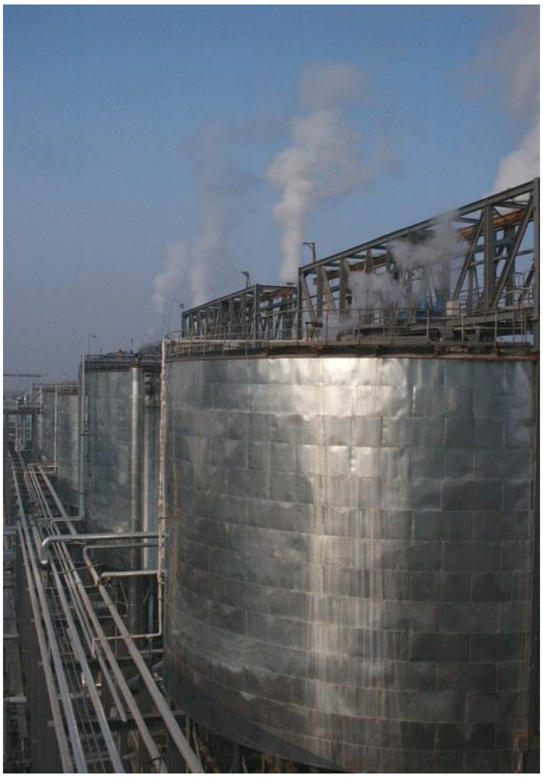

Figure 2 HiRate thickener

The washers are arranged in series to control and recover the amount of residual caustic in the mud discharged in the underflow of the final washer. These settler-washer units are arranged in series to facilitate a counter current decantation (CCD) circuit and provide maximum soda recovery for the plant at the highest achievable efficiency (Figure 3).

Slurries with good settling characteristics might produce underflow with more than 30% solids (Glenister and Abbott, 1989). Modern HiRate high density thickeners are specially designed to meet the demands of extremely large red mud tonnages, and are capable of producing underflows with solids content of 50% or higher (Avery, 2012). Thickened red mud slurry can be transported to the disposal area via pipeline utilising positive displacement pumps (Vlot, 2011) (Figure 3). Alternately, this slurry can be further dewatered using various types of filtration equipment.

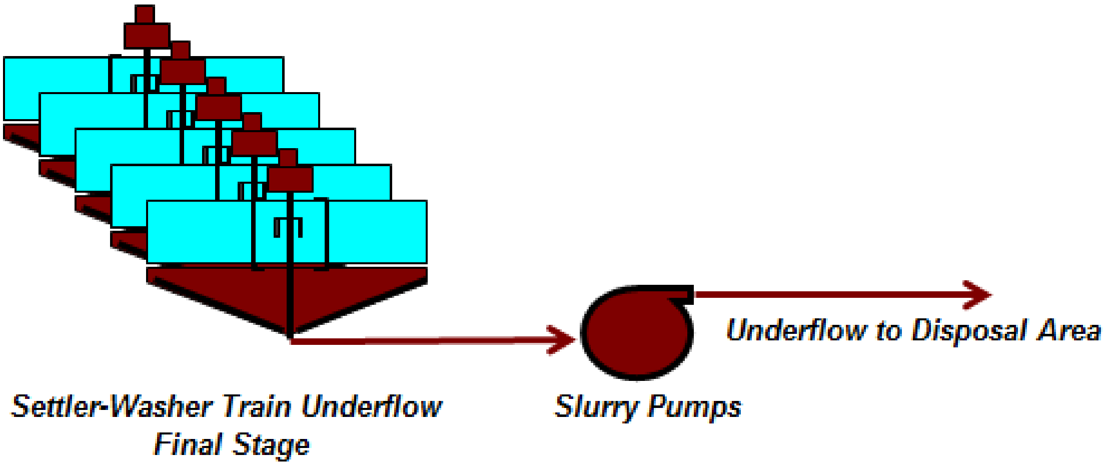

Figure 3 CCD circuit, settler-washer train with thickener underflow to disposal

For more than 40 years, rotary drum vacuum filters (RDFV) (Figure 4) have been traditionally used for red mud filtration and washing after the final washer. Coming off the final stage of the CCD settler-washer circuit, filtration is completed using a vacuum to form a semi-dry filter cake. Additional cake washing is accomplished on the RDVF by applying wash liquor via precisely positioned spray headers. Vacuum filters are continuous in operation and fully automated.

Figure 4 Rotary drum vacuum filter

The red mud filters typically produce a filter cake for discharge with 50 to 65% solids. This thixotropic cake is generally solid by appearance, but through shear-thinning in an agitated vessel, the cake becomes liquefied and may be pumped.

Many alumina refineries are seeking solutions for lower moisture content filter cakes to reduce volumes of residue in red mud disposal sites. Pressure filters can produce very dry cakes. Filter presses offer efficient cake washing for caustic recovery. With modern filter presses, fully automatic operation is offered.

As an alternative approach to transportation and distribution of the thickened red mud slurry to a dry stack area, the alumina refinery may consider using automated pressure filters (Figure 5) rather than the old mainstay for dewatering, the red mud rotary drum vacuum filter.

Figure 5 Automated filter press – 1,000 m^2

Automated pressure filters offer considerable advantages, mainly that the highest solid-content cake (Figure 6) achieved on a pressure filter is no longer thixotropic in nature and yields less volumetric mass; thus, it allows for more material to be deposited in a given waste mud disposal area.

Throughout the processing industries and over the course of many decades, when a liquid-solid separation process requires dewatering with the absolute highest degree of liquid removal and as dry a filter cake as possible, laboratory and/or pilot testing often leads to the conclusion that a pressure filter will be best suited to the task. High-pressure filter press units can be operated at up to 15.3 bar to meet these needs – much higher pressure than the 0.5–0.8 bar that can be achieved on a vacuum filter. Additionally, specific design features of these latest generation units allow for efficient cake washing which can lead to additional soda recovery or a reduced number of thickener stages required in the settler-washer train (Bach, 2011).

Due to the variations in materials at various refinery sites, when considering a pressure filter, the review team will typically evaluate variables, including feed pressure/feed rate, cake thickness, filter plate type (i.e., recessed chamber versus membrane squeeze type), air blow pressure/time, and cake washing efficiency if applicable.

A variety of different configurations are available within the range of filter presses currently offered. Some are fitted with indexing mechanisms to shift plates one or two at a time. Filter cloth washing can be done with 100 bar wash pressures.

Figure 6 High-solids filter press cake

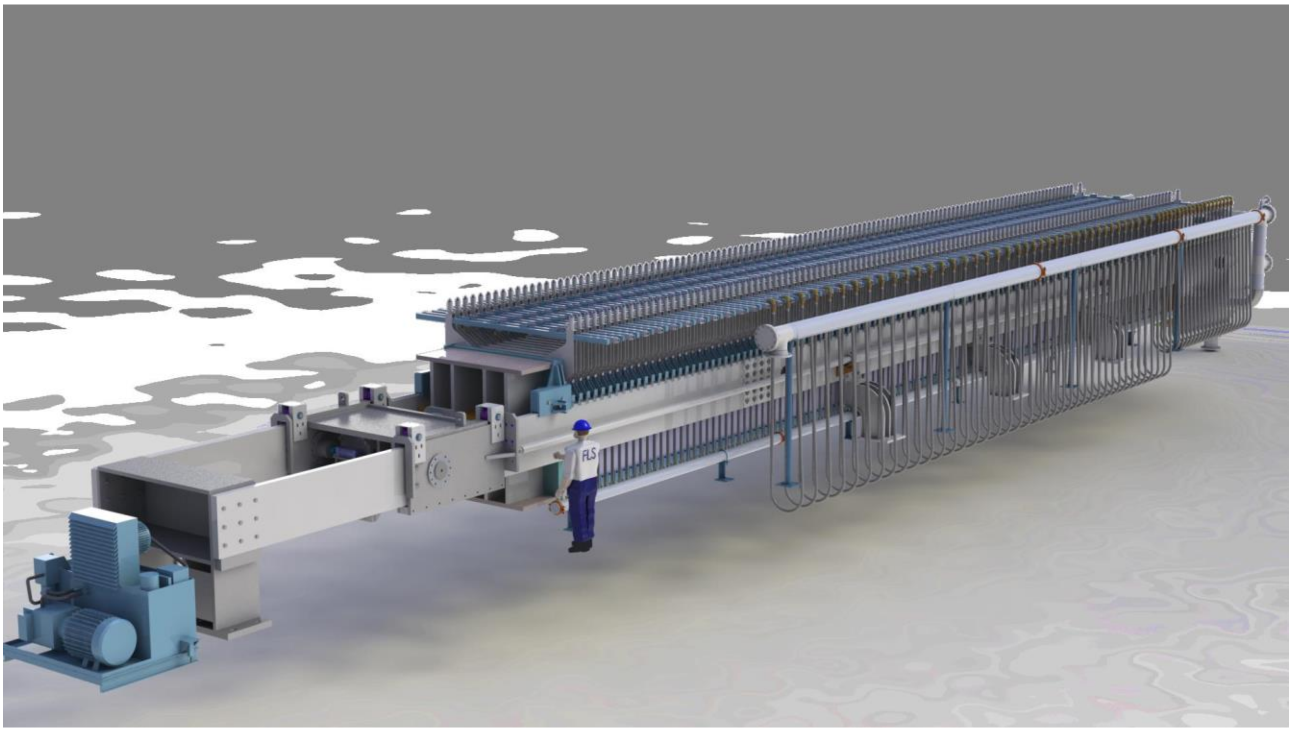

Figure 7 Fast cycling AFP IV™ filter

Others, such as the AFP IV™ shown in Figure 7, minimise downtime by opening the entire filter plate stack, discharging the filter cake, washing the cloth, and closing up ready for another cycle in a matter of just a few minutes. This quick-cycling approach allows for smaller filter, or fewer units installed, as more online time is achieved. These filters require a mechanical time of just three minutes total to open, discharge, close, and prepare for the next filtration cycle and they offer true hands-free automated operation, minimising manpower requirements.

The flow sheets for the following processes are shown in Figures 8, 9, and 10:

1. Thickener underflow to filtration with washing, re-slurry, and pumping to dry stacking areas.
2. Rotary drum vacuum filter cake transported by truck *or* re-liquefied & pumped.
3. Automatic filter presses producing high solids filter cake, which is transported by conveyors and automated mobile stackers.

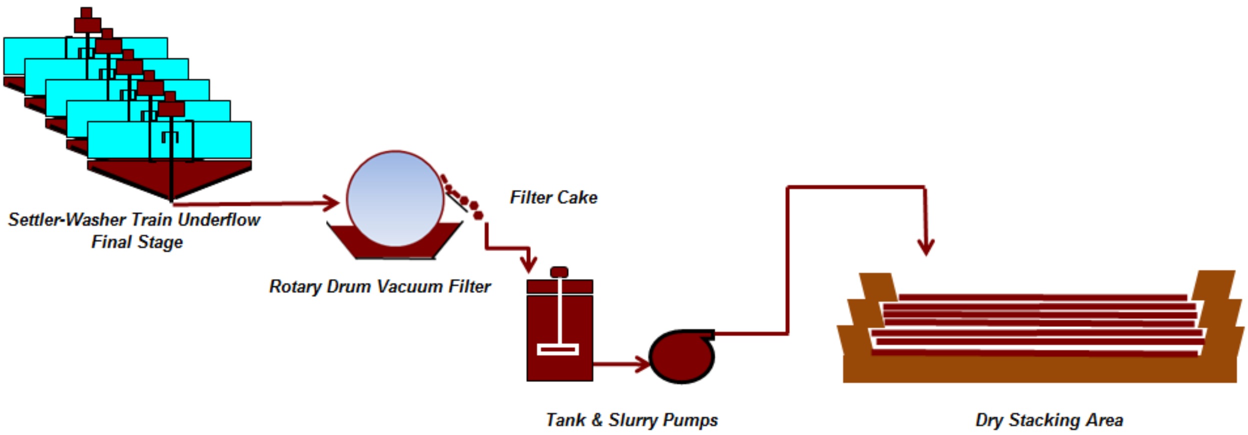

Figure 8 Thickener underflow to filtration with washing, re-slurry, and pumping

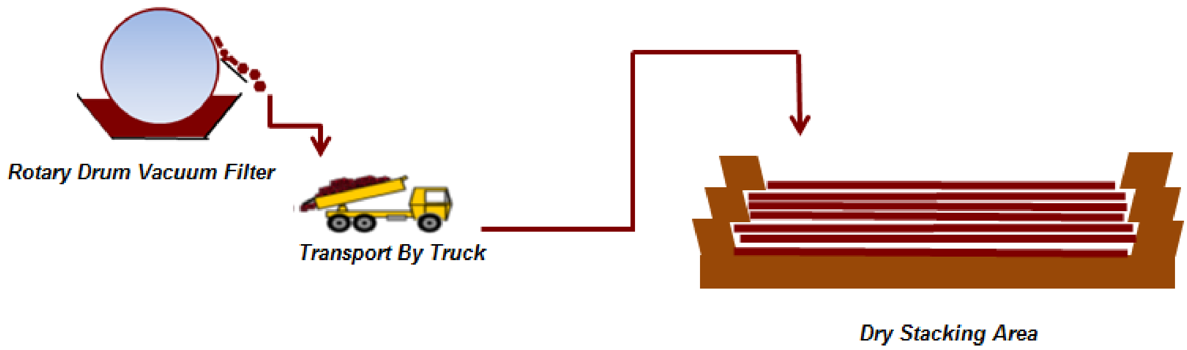

Figure 9 Rotary drum vacuum filter cake transported by truck to dry stacking area

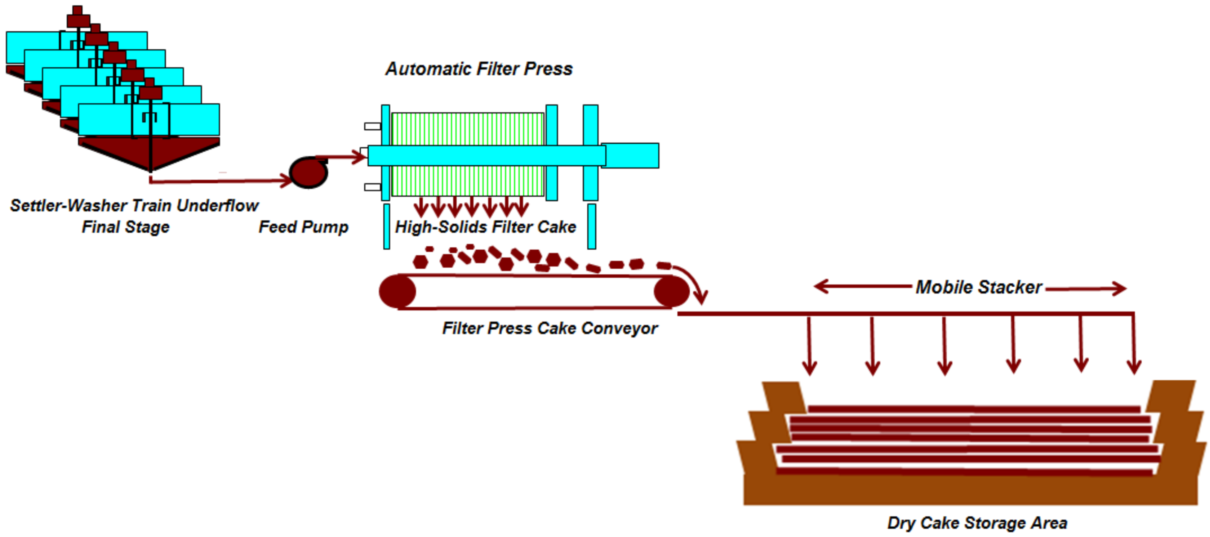

Figure 10 Automatic filter presses producing high solids filter cake, transported by conveyors (red mud cake may be distributed with automated mobile stackers)

2 Red mud pressure filtration testing

Bench scale and pilot scale testing is performed to evaluate the feasibility of using pressure filtration to dewater the red mud. The objective of the pressure filtration testing may include study of the following typical variables:

- Bauxite ore red mud variations.
- Feed pressure/feed rate.
- Plate type: recessed versus membrane squeeze chambers.
- Slurry feed concentration.
- Air blowing of the filter cake.
- Cake washing for caustic recovery.
- Cake thickness (Figure 11).

Figure 11 Measuring filter cake

With the test data results at hand, the equipment selection can begin. The configuration of the equipment required to meet the targets will be identified and the test data used to calculate the size of filters needed to process the plant tonnage.

2.1 Test equipment

Initial red mud filtration tests may be performed using a bench-scale pressure filter. Bench-scale testing is always recommended before pilot unit testing. Bench-scale testing can test a wide variety of filter configurations and zero in on the best configuration to test on the pilot scale. However, the best results will be attained by testing with a pilot unit, preferably located at the refinery site, where fresh washer-settler underflow may be fed directly to the filter press.

2.1.1 Bench-scale filter press units

The bench-scale filter press test unit (Figure 12) may be utilised to gain some initial experience on the material to be tested. After careful characterisation of feed slurry, laboratory tests are performed at varying feed pressures, trying various cake thicknesses, with and without membrane squeeze, and with varying air blow times. Additionally, different styles of filter media may be tested to select the best fabrics for the application.

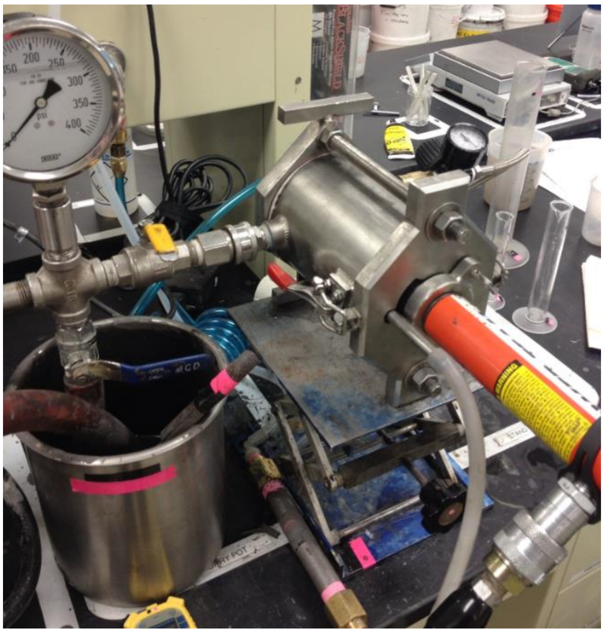

Figure 12 Bench scale pressure filter

2.1.2 Pilot filter presses

Pilot filter presses (Figure 13) with plates ranging in size from 470 to 630 mm^2 are supplied, and fitted out with a variety of filter plate configurations (i.e.; recessed chamber type and/or plates capable of membrane squeeze). During the pilot testing program, filter chambers can be switched out to study the results within a limited range of cake thicknesses.

Figure 13 FLSmidth 500 mm pilot membrane filter press

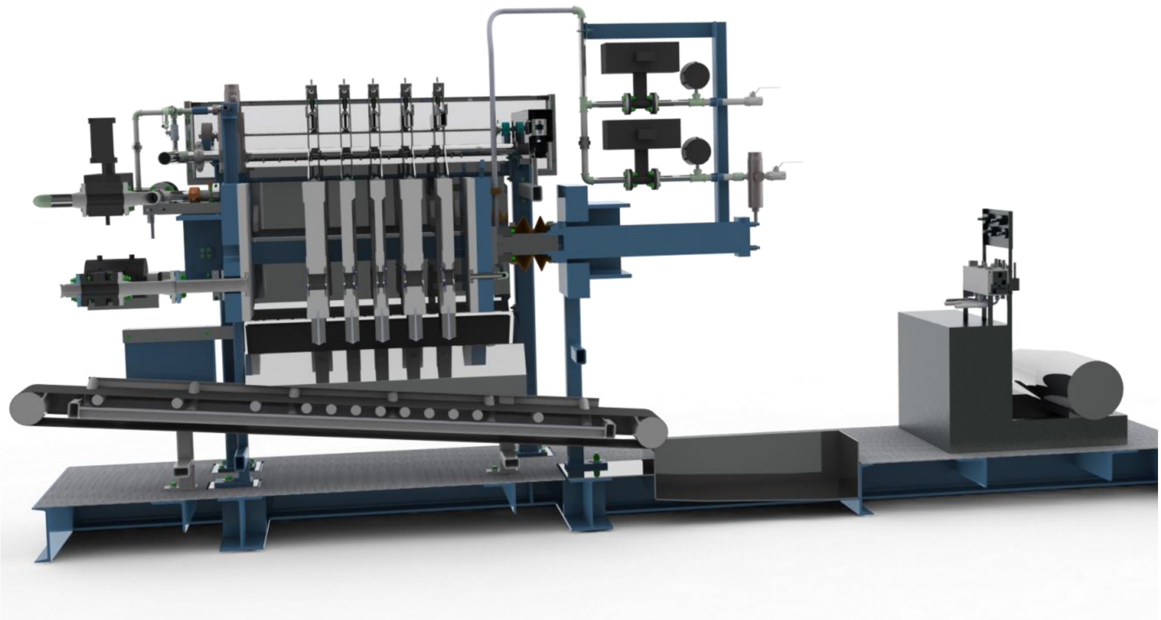

Figure 14 FLSmidth 630 mm AFP IV™ automatic filter press – pilot skid

A fully automatic pilot filter press, as shown in Figure 14, can be trailer mounted and brought into a refinery site for testing. All required ancillary pumps, compressors, etc., are already fitted and prewired to simplify the pilot equipment program start-up. FLSmidth's automatic pilot filter press is furnished complete with pneumatically actuated process valves and all required instrumentation and controls for fully unattended operation. Instrumentation provides for easy data logging for system optimisation and the acquired filtration cycle parameters are utilised for precise scale-up to production units.

3 Pressure filtration – results of red mud test programs

Each individual alumina refinery has its own unique set of objectives for their testing programs. Due to the variety of bauxite ore types, the red mud to be filtered will be quite different from one site to the next. Presented here are several case studies.

3.1 Red mud Case 1

The client's testing objective was to process the red mud slurry material to produce a cake that would be friable and transportable by truck or conveyor with a cake of 70–75 wt% solids.

The results of pressure filtration testing demonstrated that a standard design FLS AFP IV™ filter press can dewater this red mud from initial feed concentrations of between 30 and 44 wt% and produce final cakes containing 67–70 wt% solids. Various factors affect the filtration rate and final cake solids concentration, including feed solids concentration, slurry temperature, feed pump delivery rate/pressure relationship, and the configuration of the filter plates. The results are presented for different bauxite grades. Additional testing was performed to obtain filter cakes containing 75 wt% cake solids by evaluating high-pressure filtration at 30–60 bar using both recessed plate and membrane plate configurations. The tests demonstrate that high-pressure filtration above 30 bar can produce 75 wt% solids (Bach, 2011).

3.1.1 Red mud Case 1 – filtration time

The filtration time during the Case 1 tests varied from 7 to 20 minutes. The reasons for the variations include the filtration temperature (related to the liquor viscosity) and the feed solids concentration. The effects of temperature/viscosity are shown in Table 1. The effects of feed concentration are shown in Table 2. By keeping filtration time low, the highest rate can be achieved on a production filter. This plays an important part in keeping production equipment size and/or number of filters required to a minimum.

Table 1 Feed temperature comparison

Feed temperature	°C	+35	20–30
Filtration time	min	7	12
Discharge time (AFP IV™)	min	3	3
Total cycle time	min	10	15

Table 2 Feed concentration comparison

Feed concentration	wt%	41	35
Cake solids concentration	wt%	69	69
Liquid volume removed	kg/kg solids	0.99	1.41
Filtration time	min	7	10
Discharge time (AFP IV™)	min	3	3
Total cycle time	min	10	13

3.1.2 Red mud Case 1 – filtration pressure

The feed pressure affects the rate at which the liquid passes through the cake. When the filtration pressure is greater, a higher filtration rate and shorter filtration time occurs. The relationship is nearly inversely proportional to the filtration pressure, only subject to differences in the cake resistance being formed at the different pressures. Basic relationships may be understood by reviewing Equation 1, which is the basis for the filtration theory.

$$\frac{1}{A}\frac{dV}{d\theta} = \frac{\Delta P}{\mu\alpha\omega V / A + R_m} \tag{1}$$

Where:

V = filtrate volume.

θ = cake formation time.

ω = weight of solids per unit volume of filtrate.

α = average specific cake resistance.

μ = liquid viscosity.

R_m = resistance of media or other system resistance.

Generally, filter press recessed chamber plates can be fed at pressures up to 15 bar. Filtration pressures between 7–15 bar were evaluated in the Case 1 tests. The effect of increasing the feed pressure, and the associated feed rate, is to increase the cake solids and reduce the filtration time (Figure 15).

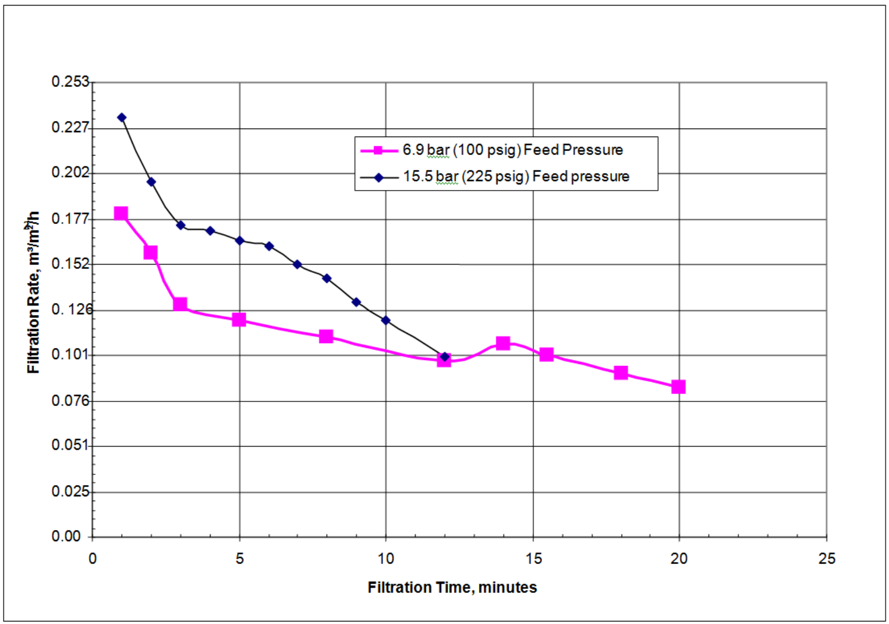

Figure 15 Filtration rate versus pressure

Evaluations of recessed and membrane plates were made during this study. Recessed plates rely on the feed slurry pump to push liquid through the filter chamber while retaining the solids to compact the solids and produce the final cake solids. Membrane plates allow for reduction of feed pumping time through a preliminary separation of liquids and solids followed by compacting the solids using an inflatable diaphragm attached to the plates.

In Figure 16, we see how the formed filter cake is compacted by expressing the flexible diaphragm incorporated within the membrane plate, using pressurised water. There is a slight increase in the cake solids due to higher pressures from the slurry feed pump and also from membrane squeezing. The higher cake solids will result in a slightly higher solids density; thus, lower filter volume is required at the higher pressure. For this case, the impact on cake solids is an increase of about 1–2 wt% in the final cake solids content. This is attained by increasing the feed pressure from 7–15 bar for a specific bauxite ore. Figure 17 shows the data for all ores tested.

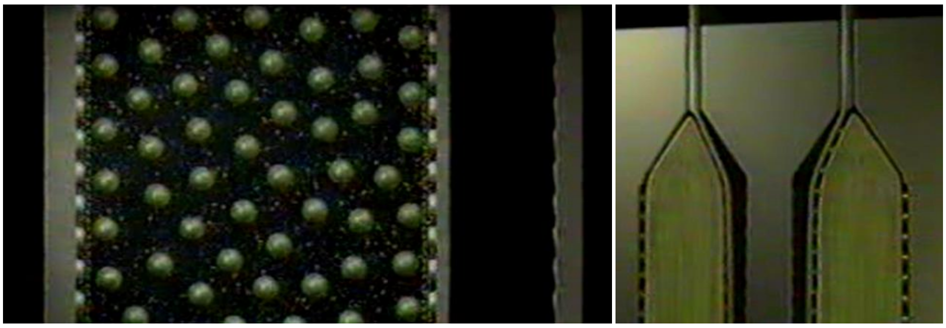

Figure 16 Cake consolidated with high-pressure squeeze

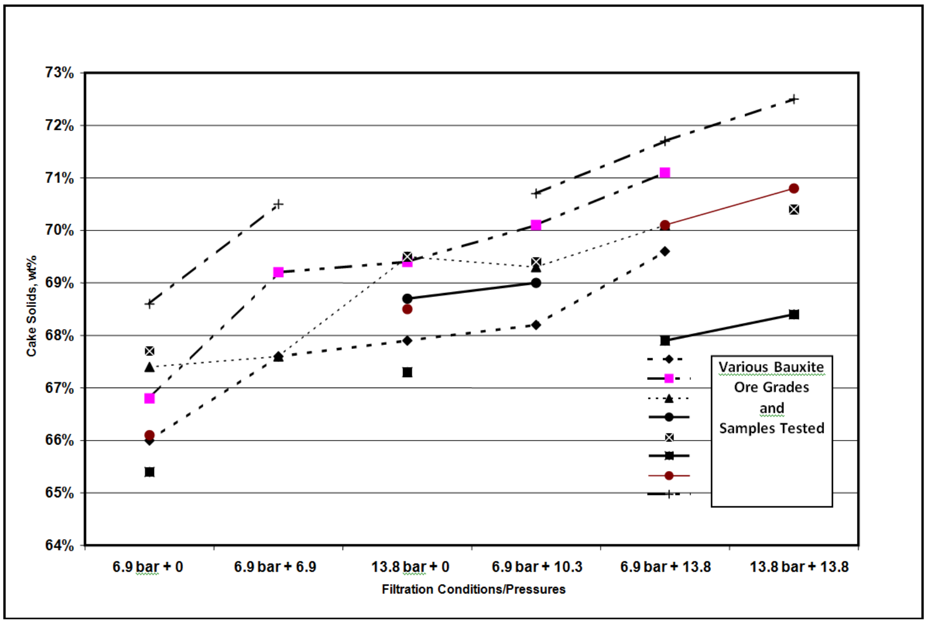

Figure 17 Filtration pressure comparative results (slurry feed pressure + membrane squeezing pressure)

3.1.3 Red mud Case 1 – conclusions

The red mud in this case can be dewatered with an FLSmidth AFP IV™ filter press to produce a final cake containing 68–71 wt% solids using a 15.5 bar filtration pressure. The filter size can be minimised by ensuring a feed solids concentration of at least 40–44 wt% and maintaining filtration temperature at 35°C. The plate type comparison and basic design conditions are listed in Tables 3 and 4.

Table 3 Plate comparison

		Recessed plate filter	Membrane plate filter
Filtration time	min	7	6
Membrane time	min		5
Discharge time	min	3	3
Cycle time	min	10	14
Cake solids concentration	wt%	69	69.5
Wet cake density	t/m³	1.8–2.0	1.8–2.0
Dry cake density	t/m³	1.29	1.29
Cake density (filter volume)	t/m³	1.29	1.25

Table 4 Design summary

		Best case	Worst case
Feed concentration	wt%	40–44	35
Feed temperature	°C	30–40	20–30
Filtration time	min	7	14
Discharge time (AFP IV™ only)	min	3	3
Cycle time	min	10	17
Dry cake density	t/m³	1.29	1.29
Wet cake density	t/m³	1.84–1.92	1.84–1.92
Cake solids	wt %	67–70	67–70
Filter volume required for a feed of 1,000 t/day dry solids	m³	5.37	9.12

3.2 Red mud Case 2

In the Case 2 study, the client objectives were to replace existing rotary drum vacuum red mud filters with technology that reduces final cake moisture and loss of caustic salts (Na_2CO_3 and NaOH). The alumina refinery's existing vacuum filters yield about 65% cake solids with a consequential loss of approximately 20 g/L causticity in the waste filter cake. The vacuum filter cakes can be sticky and difficult to handle. The higher solids concentration filter cake would reduce volume and extend the life of the red mud residue disposal areas.

3.2.1 Red mud Case 2 – pressure filtration

The results of pressure filtration testing demonstrate that a standard design FLS AFP IV™ filter press utilising membrane filter plate technology can dewater red mud from initial feed concentrations of between 42–46 wt% and produce final cakes containing 75–80 wt% solids. Subsequent cake washing tests showed that the ultimate causticity losses can be limited to less than 14 g/L. A typical cake moisture versus time curve is shown in Figure 18, wherein the membrane squeeze in combination with air blowing of the cake yields the desired result.

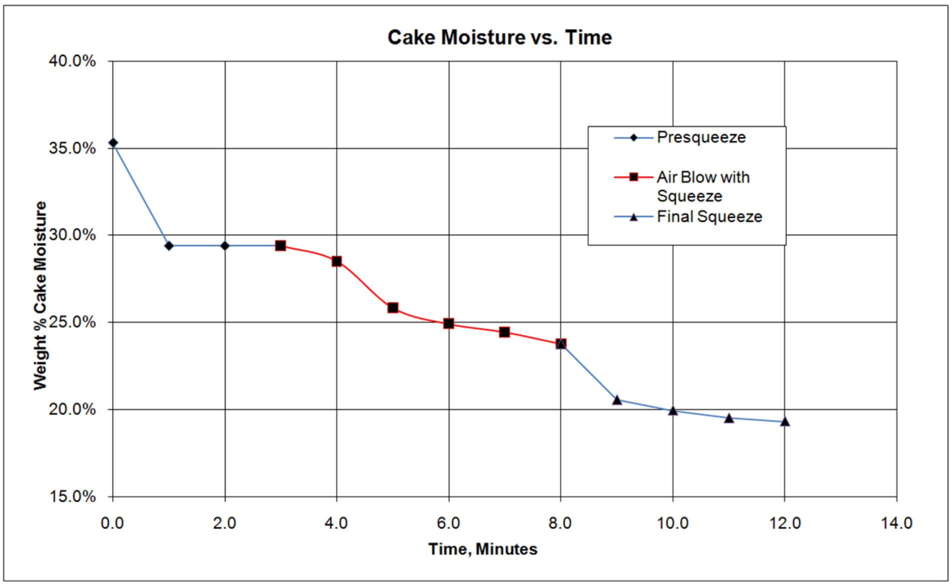

Figure 18 Cake moisture versus dry time

3.2.2 Red mud Case 2 – cake washing for caustic recovery

Valuable caustic salts are entrained in the residual liquor trapped in the filter cake. Minimising the amount of that liquor will serve to reduce the caustic salts lost with the cake. But the cake can also be washed to replace the caustic salt containing liquor with water before finishing the filter press cycle. In the filter press, the wash water is pumped to alternating plates. This water enters the cake from just one side, passes through the cake, and then exits the opposite plate. This thorough washing technique maximises distribution of the wash water and ensures that the most efficient washing is performed.

We measure the washing efficiency by plotting the value R as a function of N (ratio of kg wash water applied to kg liquor in the formed but unwashed filter cake). If the cake solids were packed into a cake of perfect spheres, and the wash water flowed through the cake in a plug-flow or piston-like manner, it might be expected that the application of one wash ratio (N=1) would remove all the salt-laden liquor and replace it with the wash water. However, imperfections in the cake due to non-uniform particle sizes and imperfect solids stacking cause the formation of non-uniform pores or channels in the cake structure. The wash water tends to take the path of least resistance, following the most open channels in the cake. This leads to a loss in washing efficiency. Although the easiest to remove liquor gets washed out well, liquor in hard-to-reach areas of the packed solids does not get washed out. The law of diminishing returns takes over, and increasing the volume of wash water does not lead to a proportionate decrease in salt content of the cake.

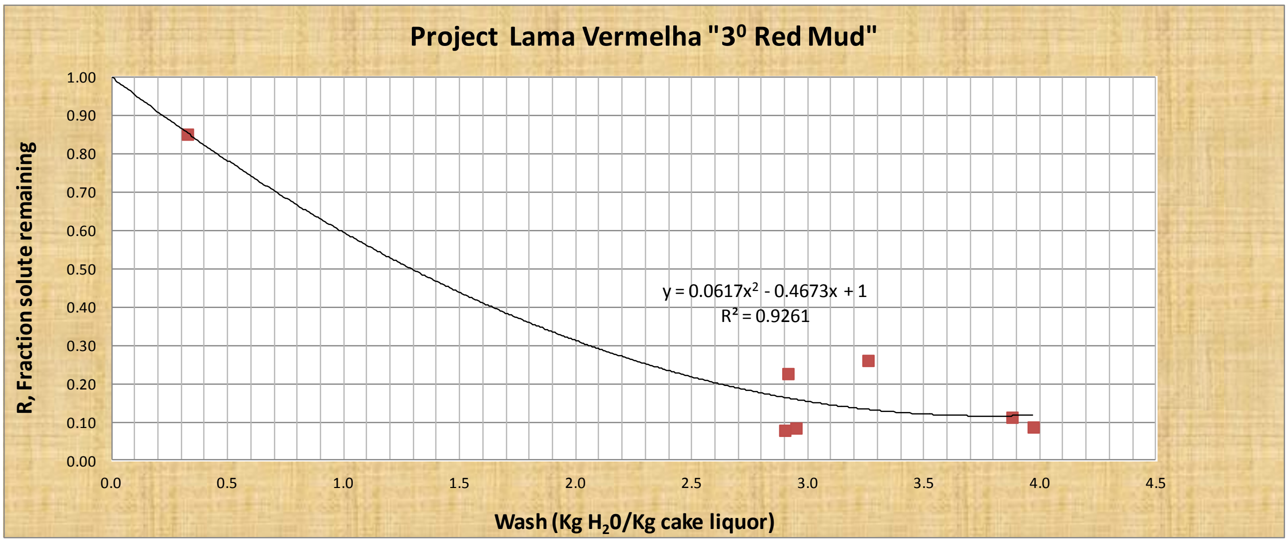

Figure 19 Cake washing efficiency

A filtration and cake washing study using a filter press pilot unit was performed on the Case 2 material at this alumina refinery site. Cake washing of both CCD final stage and earlier stage underflows was studied. A typical cake washing curve is shown in Figure 19, where 80% of the residual causticity in the unwashed cake was removed with 2.5 to 3.0 displacements of wash water. Only 10% more was removed by increasing the wash ratio to 4.0. This red mud exhibited rather good filtration characteristics, yielding 78% dry solids content in the washed cake (22% liquor content). The client's target was <14 g/L NaOH in the waste red mud cake liquor. These tests showed that 2.8 displacement volumes of the liquor could achieve that goal, meeting the target ratio for wash water/kg dry solids in the cake.

4 Conclusions

Red mud disposal management, and possible re-use of residues, continues to be studied by alumina refineries worldwide. The main drivers are safety and environmental concerns, water and caustic recovery, and rehabilitation costs. The options available will vary by geographic region, ore type, environmental regulations, community acceptance, and other factors. Capital equipment cost and operational cost must be studied in detail for each case to determine the best path for the refinery to choose. Key to the future success of the industry is finding safe and affordable long-term solutions for red mud management.

FLSmidth recommends laboratory and/or pilot testing to study the specifics of each case:

- Filtration steps and cycles times may vary considerably.
- Depending on material, >80% cake solids may be achievable.
- Cake washing efficiency for caustic recovery may be studied.

The information FLSmidth has developed on red mud filtration suggests that filter press technology is a viable and economical substitute for other technology such as mud impoundments and vacuum filtration. Filter cakes produced from filter presses are much easier to transport and stack, have less entrained caustic values, and require less attention after final disposal.

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