Design of the New Filtration Plant for the Storage of Bauxite Residues at Hydro's Alunorte Refinery

Lloyd Anthony Holliday[1], Rui Guilherme Medeiros[2], Marcelo Miranda de Castro[3], Vladimir Hartmann[4]

[1] Outotec Oyj, Dewatering Business, Filters, Espoo, Finland

[2] Alumina do Norte do Brasil S.A., Alunorte, Barcarena, Brazil

[3] Alumina do Norte do Brasil S.A., Alunorte, Barcarena, Brazil

[4] Outotec GmbH & Co. KG, Light Metals, Oberursal, Germany

Corresponding author: lloyd.holliday@outotec.com

ABSTRACT

Hydro Alunorte currently uses vacuum drum filters for red mud filtration and Giulini dry stacking technology for residue storage. Studies have been completed and Hydro is now implementing new technology with a new filtration plant using fast opening filter presses and changing to dry residue storage. The new system, now under construction, will increase the solids content of the residues to 78% w/w solids, decrease the caustic content in the residues, increase the recovery of caustic soda for reuse, reduce the ratio of washing water to red mud solids, significantly decrease the land area needed for residue disposal and lower the amount of surface water to be treated. The new technology is considered to be the most sustainable way forward for the industry.

Instead of using an independent engineering company, Hydro decided to draw on the proven expertise and experience of the filtration equipment supplier for the design and construction of the filtration plant. This paper will give an overview of the most important considerations when designing a filter press plant for red mud. Most important is personnel health and safety in operation and maintenance because the process is abrasive, corrosive, scaling and at high temperature. To achieve high plant availability the filter presses will have less and larger components. The logistics within the plant for storing and changing of filter cloths for the largest filter plates in the world (2.5m x 3.5m) will be important. The plant performance will be controlled by process optimisers.

1. INTRODUCTION

Located in Barcarena, State of Pará in Northern Brazil, Alunorte's alumina refinery is the largest in the world and is majority owned by Norwegian aluminum producer Norsk Hydro ASA. Production at Alunorte started in 1995 and after three expansions now has an alumina capacity of over six million tons per year [1]. The bauxites from Paragominas and Trombetas are refined into alumina producing around 4.4 million tons (dry solids basis) per year of bauxite residue, also known as red mud.

Norsk Hydro is recognised as an industry leader in corporate sustainability having been selected to the Dow Jones Sustainability World Index in 2014-15 for the 16th time [2]. Alunorte is certified by ISO 14001, OHSAS 18001, ISO 9001 and SA 8000 and operates with a high focus on health, safety, environment and sustainability [3].

The alumina industry has formulated the vision to manage bauxite residue in such a way that promotes/encourages use as a product and a resource for other industries and for all remaining residue to be stored in an environmentally acceptable form. The Alumina Technology Roadmap [4] strategy includes developing sustainable residue storage without the need for ongoing management, remediation of all residues and the reduction of soda trapped in the mud sent to residue storage. Studies have been completed and Hydro Alunorte is now implementing new technology supporting this strategy. The Dry Residue Storage Area 2 (DRS2) project is an expansion of its residue storage area which will use filter presses to decrease the caustic content in the residues and increase the solids content of the disposed residue thereby enabling a transition from dry stacking to dry storage. Furthermore, the increase in solids content reduces the space requirement of the residue storage area (RSA), extends the lifetime of the storage area, decreases the volume of collected rainwater to be treated, and decreases the disposal cost due to smaller footprint and no large perimeter dikes required [5].

Outotec is a leading technology provider of plant, equipment and service that support refineries for the entire life cycle of the process, including operation and maintenance. The company has developed many breakthrough technologies for metals and minerals processing, including for bauxite residue storage.

Outotec is also recognised as an industry leader in corporate sustainability being ranked 3rd in 2014 on the Global 100 List of the world's most sustainable companies by the World Economic Forum in Davos, Switzerland (ranked 12th in 2013) [6] and is selected to the Dow Jones Sustainability World Index. 87% of Outotec's order intake in 2013 comprised of environmental goods and services according to OECD criteria. Outotec is certified by ISO 14001, OHSAS 18001, ISO 9001 and ISO 3834 and is committed to sustainable quality, environment, health and safety excellence [7].

2. CURRENT RED MUD FILTRATION

Alunorte currently applies the dry stacking technology developed by the German company Giulini Chemie GmbH and reviewed by Alcan for bauxite residue storage. After washing of the red mud in five stages of counter current decantation (CCD) to recover caustic, the underflow slurry with suspended solids content 37 to 44% w/w is pumped to vacuum drum filters as shown in Figure 1 where it is further de-liquored and the filter cake is washed. The filter cake discharges with a solid content around 64% w/w into storage bins which, in turn, discharge into trucks for transportation to the deposition point in the RSA [3,5].

Figure 1. Red Mud Vacuum Filter at Alunorte

As mentioned earlier, the refinery has been expanded three times since starting production. Consequently there are four trains of red mud washing. The first two trains have conventional CCD washers and the last two trains have more modern Alcan deep CCD washers which produce the higher underflow solids content [8].

Although Alunorte has a total of 22 vacuum drum filters installed they are not equally distributed to each train because there is variation in train design capacity. Normally there are 19 filters in operation with 3 filters either undergoing maintenance or on standby. However if circumstances arise within one train where the filters are limiting the capacity of that train, the refinery is able to divert slurry to one of the other three trains. This point becomes particularly relevant when considering the most important design considerations for the new filtration plant.

3. NEW RED MUD FILTER PLANT

The DRS2 expansion project will use filter presses to de-liquor, wash and dry the red mud from the last washers enabling a highly sustainable transition from dry stacking to dry storage in the residue storage area.

Filter presses are particularly well suited to applications which have very fine particle size distributions. They are capable of operating to dewater red mud with and without cake washing. Alunorte's challenge has been to find the right filtration technology to achieve the desired process performance and to be able to successfully integrate the new technology within the process constraints of the existing refinery. The new red mud filter plant has to ensure that the current refinery performance is at least maintained because the vacuum drum filters will be decommissioned. The new filtration technology affects variously upon key operational parameters such as production capacity, caustic consumption, evaporation capacity, steam consumption, impurities returning to the refinery and water balance volumetric control. This is particularly relevant when filters operate with cake washing because all excess water entering to the refining process must be removed by evaporators which consume steam and energy.

There is some experience for red mud dewatering in the alumina industry reported in 2008 [9] using filter presses at Alteo, Gardanne (GAP) and Aluminium of Greece (AoG), Agios Nikolaos. The report concluded that the filterability of the AoG red mud was strikingly better than the filterability of the GAP red mud. The specific cake resistance at

6 bar pressure were determined during filtration trials to be 2.1 x 10^{11} m/kg and 1.8 x 10^{12} m/kg respectively. The report also concluded that chamber filter plates without membranes are not adaptable to red mud because of resulting high cake moisture and that membrane filter plates offer the flexibility of optimal performance when the feed slurry conditions vary.

The reported experience supports the importance of undertaking filtration tests in order to evaluate the performance of filter presses under different operating conditions. Not only does the filterability of red mud differ in every refinery, the process conditions such as slurry solids concentration, temperature, caustic concentration, and wash water temperature among other conditions influence the filter performance. The filter cake produced at different moisture contents can also be evaluated for reliable conveying or transportation to the storage area and for proper geotechnical design of the disposal area.

For the expansion project, Alunorte invited several filter press suppliers to undertake pilot scale filter tests to establish the filtration performance. After completing various studies Alunorte decided for its refinery that the new red mud filter plant process should optimally:

- Increase the solids content of the residues to 78% w/w when considering the Amazonian climate
- Decrease the caustic content in the residues compared to the vacuum drum filters thereby increasing the recovery of caustic for reuse
- Reduce the ratio of washing water to red mud solids compared to the vacuum drum filters thereby saving energy in evaporation.

In the early stages of the project Hydro requested proposals for the supply of filtration and auxiliary equipment. There are many different filter press designs in the market. Some of the main areas of differences are:

- Designing to safety standards and higher
- Technical time (dead time) – fast opening/closing filter press (FFP) versus packet plate shifting
- Membrane filter plates (MFP) versus chamber filter plates (CFP). MFP can be either mixed or combination plates
- Size of filter plates range from standard DIN sizes up to 2m x 2m versus proprietary designed plates around 2.5m x 2.5m from Outotec and other companies, and 2.5m x 3.5m, the largest filter plate in the world from Outotec.
- Filter plate support from overhead beam versus support from side bars
- Number and size of feed, filtrate and other channels or ports and whether they are exchangeable
- Exchangeable membranes versus welded membranes and compressed air versus high pressure water for cake squeezing
- Filter cloth shaking versus filter plate shaking for cake discharge
- Systems for filter cloth washing
- Systems for plate pack sealing, opening/closing and plate shifting
- Operating pressure and temperature limitations
- Control systems for process optimisation and redundancy

Hydro also recognised that the differences between the various filter press technologies impacts significantly on the design of the filter plant and, in turn, onto the capital and operating cost of the expansion project. The cost of the filtration equipment does not necessarily reflect the total cost of the filter plant. Hydro's studies also revealed that some filtration equipment suppliers have extensive experience in design and construction of filter plants in many applications. Consequently instead of using an independent engineering company, Hydro decided to draw on the real experience of the filtration equipment supplier and selected Outotec for the DRS2 expansion project filter plant.

A simplified block diagram of the new dry residue storage project and scope of the filter plant is shown in figure 2

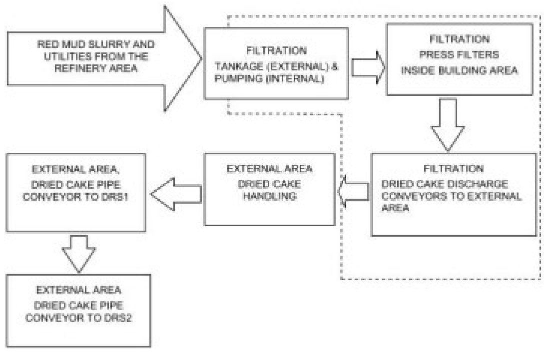

Figure 2. DRS2 Dry Residue Storage Project

Outotec's turnkey plant delivery to the project includes eight fully automatic Outotec Larox FFP3512 fast opening filter presses as shown in figure 3. Each filter will have 992m^2 filtration area and operate with a total cycle time around 16 minutes. The plant design capacity will be 597 tph with the filter cakes being washed with up to 0.77kg condensate per kg dry red mud solids.

Figure 3. Outotec Larox FFP3512

The particle size distribution of the red mud measured with the Malvern Mastersizer 3000 is typically around:

- D_{90} 35 microns
- D_{50} 4 microns
- D_{10} 1 micron
- D[4,3] 16 microns

Outotec's FFP3512 has design patented membrane filter plates (MFP) made from polypropylene material formulated by the company for high temperature operation. All feed, filtrate and other channels or ports are external of the cake forming filtration area and detachable from the base plate. All ports are equipped with flexible lip seals which require much lower sealing force than in any other filter press. The FFP3512 has four large feed ports for fast filling at an acceptable velocity and to ensure even cake distribution for good cake washing and successful air drying. The filter cloths hang freely from support bars above the filter plates and are connected to the cloth shaking system which enhances cake discharge. The filter cakes which completely discharge onto heavy duty conveyors beneath the filters in approximately 20 seconds are metered to cross conveyors. The filter cloths are designed to be shaken and washed every cycle with recycled liquor and with minimal affect on the total cycle time. Washing ensures cloth and plate sealing surfaces are free of solids before commencing the next filtration cycle.

Outotec's automation system with visual user interface automatically adjusts for process changes and includes diagnostics for fast troubleshooting. The design patented weighing system uniquely weighs only the filter plates and cake for consistent performance, not the entire filter weight.

The filtration cycle consists of a sequence of steps. After closing and sealing the chambers, the filter is fast filled with red mud slurry and further pumped under normal pressure to recover mother liquor filtrate. In the next step the membranes are pressurised with air to de-liquor the filter cakes without overly compressing them. Then condensate wash water is pumped through the cake from one side to the other to further displace and recover caustic mother liquor. On completion of cake washing, membranes are pressurised with high pressure air to compress the filter cakes while simultaneously blowing compressed air through the cake solids to promote removal of residual cake moisture. Then the filter opens and in one stroke the cake discharges from all chambers, the cloths are shaken and washed before commencing the next cycle.

4. MOST IMPORTANT FILTER PRESS PLANT DESIGN CONSIDERATIONS

Although the design of the FFP3512 filter press is important and has been earlier described, the purpose of this paper is to give an overview of the most important considerations when designing the filter plant for red mud.

Even though it has been done for many other applications, Hydro Alunorte's DRS2 expansion project is the first time that a filtration technology supplier is constructing a turnkey filter press plant for red mud in the world as shown in figure 4.

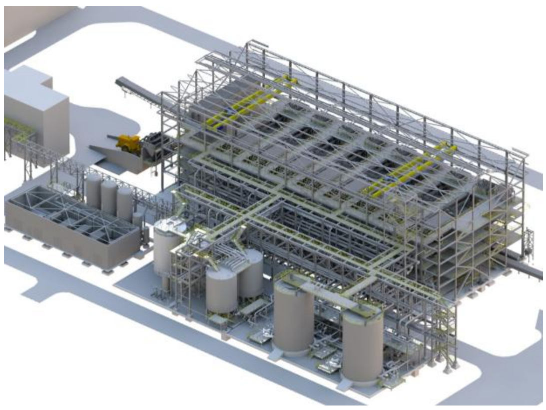

Figure 4. 3D model of the Alunorte Filter Plant

It is a requirement that the filters will achieve the specified process parameters at least for capacity, cake moisture and caustic recovery and this should be assumed for this paper.

Foremost in the list of important plant design considerations are:

- Plant safety in operation & maintenance
- Plant availability
- Plant logistics
- Support services
- Other considerations

4.1 Plant Safety

The Outotec FFP filter plant layout is designed with five floor levels;

4th: Operating floor level with control room

3rd: Filter floor level

2nd: Swivel plate floor level

1st: Cake discharge conveyor floor level

GF: Tanks, pumps, and Alunorte's cross conveyors

Because the operating floor level is on top of the filters, Outotec's plant design is uniquely safer for operating personnel. As shown in figure 5 the floor plan is totally open with high visibility thereby making it much easier for communication between operators with reduced risk of accidents by miscommunication. It favours convenient inspection of slurry feeding shoes, cloth washing and shaking, and cake discharge.

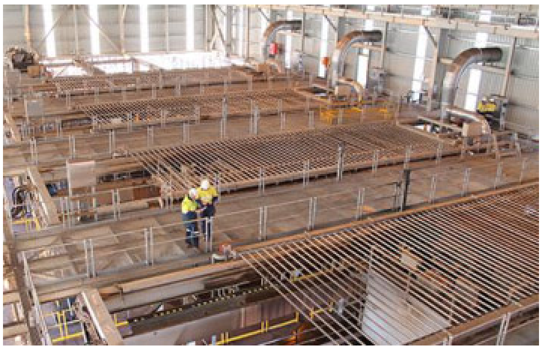

Figure 5. Example of Plant Operating Floor

At the 1st, 2nd and 3rd levels the filters and the area beneath them are enclosed by locked floor to ceiling side screens to physically protect O&M personnel from leakages and heat radiation. The screen enclosures are connected to ventilation systems to draw in air from the operating floor level and exhaust hot air and steam outside of the building. This is important because the process operating temperature during certain times can be up to 90 ºC and reducing O&M personnel exposure to heat, vapours and fatigue will dramatically reduce accidents. The side screens are movable on track rollers for carrying out preventative maintenance.

The operating floor level is serviced by travelling cranes for exchanging cloths and is enclosed with roof and walls to reduce the risk of accidents caused by tropical winds and rain whereas the lower floors are without walls to promote ambient ventilation.

As mentioned earlier the Outotec filter cloths hang freely from support bars above the filter plates and this design is much safer than designs where the cloth is attached to the filter plate at the feed port. With freely hanging filter cloths it is not necessary to either remove the entire filter plate to change the cloth or for personnel to treacherously get in-between the plates to perform inspection at the feed port. The filter plant is designed to rapidly and safely exchange up to 10 filter cloths to/from storage racks located adjacent to each filter on the operating floor level as shown in figure 6.

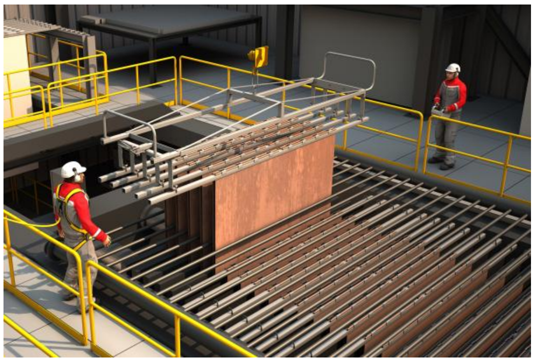

Figure 6. Exchanging 10 cloths (FFP3512)

4.2 Plant Availability

Currently the refinery has four trains of red mud CCD with vacuum filters. If circumstances arise within one train where the filters are limiting the capacity of that train, the refinery is able to divert slurry to filters in the other three trains to maintain refinery capacity.

The new filter plant design will be a single train to minimise capex and opex, and has to ensure 24/7/365 operation otherwise there will be a risk of reduced alumina production. Consequently, high plant availability will be very important. The new filters are sized for the design capacity with the redundancy philosophy being one additional filter maintained off-line according to preventative maintenance work orders and then placed on standby. Filter presses are batch operating processes and do not continuously need auxiliary services so most of the auxiliary equipment will be shared between several filters. The auxiliary equipment is also sized for the design capacity while non-sequenced filters could have overlapping cycles and be simultaneously demanding auxiliary services. However in circumstances where multiple auxiliary equipment should fail the redundancy philosophy of the control systems is defined so that filters move to sequenced operation and the process continuing with little or no reduction in production capacity.

The process control system is also using redundancy protocol ring technology so that if one element is down, the signal to the rest of the system is secured. The control system is also secured by an UPS.

Larger filters with larger filter plates and very short technical times mean less filtration equipment, less filter plate components, less auxiliary equipment, less maintenance time and less risk of reduced production capacity, in addition to saving capital and energy. For example, the time to exchange 10 filter cloths is about 5 minutes assuming the replacement cloths are stored in the cloth racks next to the filter, as shown in figure 6.

With all feed, filtrate and other ports being on the side of the filter plate and not within the chamber filtering area the design promotes easier inspection and facilitates quicker maintenance of the main wearing parts. Having the screens around each filter also saves time and increases plant availability because they eliminate the need to set up temporary screens when undertaking preventative maintenance on an adjacent filter. All ports are bolted to the base plate and replaceable without removing the filter plate from the filter.

Generally the hydraulic systems are highly reliable and do not require much maintenance except after many years of operation.

The operating floor level is equipped with travelling crane lift wells at both ends of the building to facilitate easier movement of parts in and out of the building more quickly and easily.

Because the filters are large and designed for fast filling, the slurry pumps and angle valves are also large and designed with overhead monorails to facilitate maintenance more quickly and easily

With the plant designed for short preventative maintenance times it ensures equipment is quickly returned to standby status to ensure the production capacity of the refinery is not reduced.

4.3 Plant Logistics

The temptation to minimise capital cost by minimising the plant size and layout would impact on preventative maintenance logistics. With this in consideration the filter plant operating floor level is designed with enough operating space for the control room and office with sanitary facilities. Most importantly it is also designed with enough maintenance space for storing spare cloths in racks adjacent to each filter, storing some spare membrane filter plates, storing wearing components and for large tables to carry out plate maintenance such as replacing membranes. Being able to carry out the majority of the maintenance in the immediate vicinity of the filters will reduce downtimes.

Because of the remote location of the refinery and the long lead times for delivery of spare parts, Alunorte will also be carefully considering the options for local inventories. The plant will be using new technology and some components such as membranes will be imported because of the specialised manufacturing process and the need to use quality components. Industrial textiles for filter cloth are also typically imported to Brazil so customs and delivery logistics will also be carefully considered.

4.4 Support Services

The implementation of new technology for red mud will mean that the supplier's experience working in alumina refineries and with the starting up and handing over will be critically important. The new technology will require Alunorte's O&M personnel to learn new skills and it is expected some people will be highly motivated by the opportunity. It is planned to commence training very early in support of Alunorte establishing its internal work procedures.

Outotec also offers expert services for on-site and remote web based technical support to Alunorte. The value of this will be studied by Alunorte and the important consideration is that it is available now and in the future to ensure a smooth running of the filter plant.

4.5 Other Considerations

Each filter and the filter plant will be optimised for process performance. The Outotec weighing system is important because it controls the pumping of slurry to each filter until the contents of the filter chambers reach a set point weight. The weighing system will compensate for changes in feed slurry concentration, particle size distribution and viscosity of the liquor, the latter being a function of temperature and caustic content. The system delivers better performance than using cycle timers for pumping of slurry because when the filter cake mass and cake thickness are reasonably constant from one cycle to the next, it means that the other steps in the cycle can be constant including the metered volume of cake wash water and the cake drying air volume. Overall the system will deliver consistent cake moisture content for conveying and disposal.

The weighing system also allows non sequenced faster filtering filters to overtake slower filters thereby ensuring the higher plant capacity.

Turbidity meters will be provided to monitor the filtrate quality and detect damaged cloths.

Another important design consideration is the recycling of liquids within the plant or refinery for flushing of the slurry feed channels and for cloth washing.

5. CONCLUSION

Hydro Alunorte has contracted Outotec to design and construct the filter plant for the DRS2 dry residue storage expansion project. Dry residue storage is considered to be the most sustainable way forward for the industry. Filter presses are well suited to de-liquoring and washing of red mud residues and Outotec's fast opening filter press (FFP) technology has been chosen to increase the solids content of the residues to 78% w/w solids, decrease the caustic content in the residues, increase the recovery of caustic soda for reuse, reduce the ratio of washing water to red mud solids, significantly decrease the land area needed for residue storage and lower the amount of surface water to be treated.

The two most important design considerations apart from process performance are plant safety in O&M and high plant availability to ensure the refinery capacity is at least maintained.

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