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Technology comparison of red mud filtration: assessment of washing and de-liquoring performance of vacuum drum filters versus filter presses

Karolin Schröder [a,*], Dirk-Eckhard Keller [a]

[a] ANDRITZ Separation GmbH, Germany

Abstract

Bauxite residue, commonly called red mud after its colour, is the main byproduct of making alumina by the Bayer process. The quantity and quality of red mud, as well as the volume and the caustic content of the adherent liquor, differs widely in various refineries. Alongside the essentially non-soluble constituents of bauxite, such as iron and titanium minerals, red mud also contains some undissolved soluble alumina minerals and other compounds such as sodium aluminium hydrosilicates which are formed during processing.

Common methods for red mud filtration include filter presses and vacuum drum filters – technologies with very different operating principles, investment costs and impacts on the end product. This paper compares these commonly used red mud filtration technologies, considering general operating principles, washing and de-liquoring efficiency, as well as the residual moisture achieved. The theoretical comparison of the operating principles and their impact on the red mud is illustrated with practical examples from both laboratory tests and operational experience.

The objective of this paper is to outline the optimal approach to obtain red mud with the lowest amount of adherent liquor and the lowest concentration of solutes.

Keywords: *red mud filtration, vacuum drum filter, filter press, technology comparison, vacuum filtration, hyper-baric operation, washing efficiency, de-liquoring efficiency*

1 Introduction

Invented in the late 1800s by Karl Josef Bayer, the Bayer process has become the most widely used process for refining bauxite ore into pure alumina (Al_2O_3) which is then converted into aluminium. While the common Bayer process is primarily designed for alumina production, most refineries handle significantly more red mud than alumina, leading to serious technical, economic, and environmental challenges.

The rheological nature of red mud and its disposal poses a constant risk as shear forces and heavy rain might trigger uncontrolled movement and groundwater contamination by caustic liquor. A prominent example is the rupture of the residue reservoir at the Ajka aluminium plant in Hungary which Day (2010) describes as an ecological catastrophe. An estimated 1 Mm^3 of red, poisonous sludge, depicted in Figure 1, was released, resulting in multiple casualties, injuries and contamination of rivers and lakes.

[*] Corresponding author. Email address: karolin.schroeder@andritz.com

Figure 1 Ajka 'red sludge' alumina plant accident (Kormányzati Kommunikációért Felelős Államtitkárság 2010)

Consequently, the separation of red mud from the liquor is considered a distinct and critical operation. In the standard Bayer process, as shown in Figure 2 schematically, the red mud will be settled, thickened and washed by a counter-current decantation (CCD) circuit from the underflow of the bottom of the last washer.

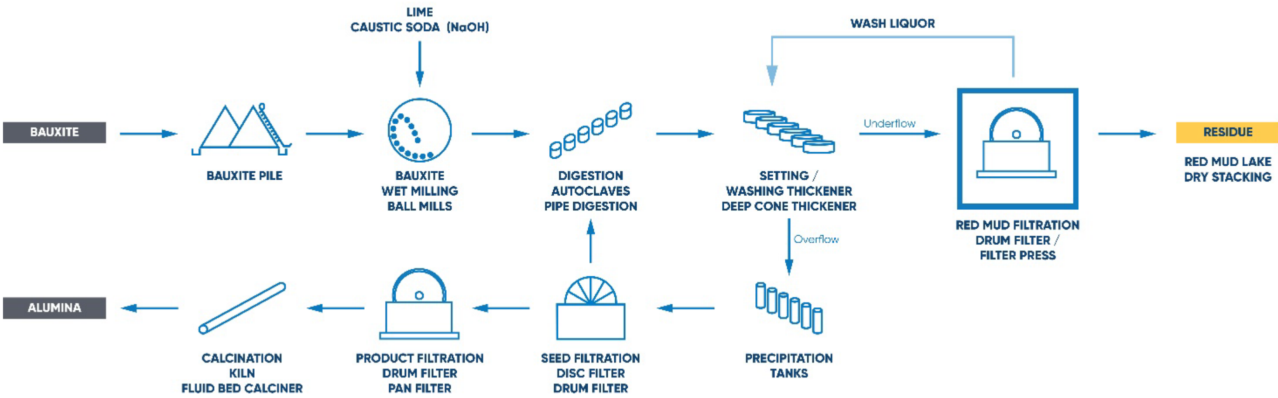

Figure 2 Simplified processing flow chart of the Bayer process

The settling and thickening of such fine particles in combination with the viscous alkaline liquor at ambient temperatures makes the process more difficult leading to large settling areas and a high number of washing stages. The downstream red mud filtration enhances both the plant performance and overall process efficiency.

The major benefits of red mud dewatering can be summarised as follows:

- Lower caustic content in the red mud cake improves de-liquoring efficiency, reduces disposal costs, and facilitates possibilities for industrial re-use.
- Reduced moisture levels in the cake leads to smaller volumes and consequently lower transportation, storage, and disposal expenses while also improving mechanical stability.

Together, these improvements facilitate safer and more streamlined handling of red mud, whether for disposal or potential re-use, such as in newly designated residue deposit areas. These aspects will be discussed in detail in the following sections.

2 Red mud dewatering: technology comparison between rotary drum filters and filter presses

Similar to other tailings applications, a variety of mostly mechanical separation technologies have established themselves in red mud dewatering. This paper provides a detailed discussion of the 2 most commonly used technologies in the field: rotating vacuum drum filters (Figure 3a) and filter presses (Figure 3b). Furthermore, this paper also presents trial data from pressurised drum filters which are considered uncommon in typical red mud treatment operations.

The following subsections provide an in-depth examination of caustic reduction through improved cake washing efficiency, as well as the decrease in cake moisture content achieved by applying these technologies.

(a) (b)

Figure 3 (a) Rotary vacuum drum filter; (b) Sidebar filter press in red mud operation

In continuously operating vacuum drum filters, the rotating drum is covered with a filter cloth. A vacuum applied inside the drum draws the liquid through the cloth, while solids accumulate on the outer surface forming a filter cake. Krauss-Maffei, nowadays known as ANDRITZ, has delivered more than 130 large vacuum drum filters for red mud dewatering, which are typically in the size range of 45–100 m^2.

Filter presses, in comparison, are batch-operated systems for the solid–liquid separation of suspensions by applying pressure to a slurry, forcing the liquid through a filter medium and leaving the solids behind as a filter cake. They are known for their ability to achieve high separation efficiencies and low residual moisture.

2.1 Technology comparison: reduction of the caustic content in the red mud cake (g/l Na_2CO_3)

The first step in comparing the technologies involves using a standardised evaluation method to assess washing performance. This method specifies the reduction of caustic content in the cake which is calculated using the formula shown on the following page.

The caustic concentration, $C_{caustic}$, is measured in the liquid phase and is expressed as Na_2CO_3. The cake washing efficiency, ε_{wash}, is calculated using Equation 1:

$$\varepsilon wash = \frac{Cfeed - Ccake}{Cfeed} \quad (1)$$

where:

C_{feed} = caustic concentration in the feed liquor (expressed as Na_2CO_3)

C_{cake} = caustic concentration in the liquid phase of the filter cake

ε_{wash} = washing efficiency (dimensionless, often expressed as a percentage).

Figure 4 displays the results regarding washing efficiency based on trials and installations in the field.

- The rectangular data points correspond to results obtained from a filter press operated by Alunorte (2011), showing the caustic concentration of the filter cake and wash efficiency as a function of the specific wash water consumption for a feed slurry caustic concentration of around 90–100 g/l Na_2CO_3.
- The dotted blue line represents the caustic concentration of vacuum drum filters at Δp = 600 mbar and a residual moisture of approximately 30.0–34.0 wt/wt% H_2O, as described in an ANDRITZ test report for CBA Brazil conducted and described by Keller (2011).
- The dotted orange line indicates the tendency of the caustic concentration of pressurised rotation filters at p_{abs} = 2.5 bar and a residual moisture of 31.0–32.0 wt/wt% H_2O, described by Steinlechner et al. (1996).

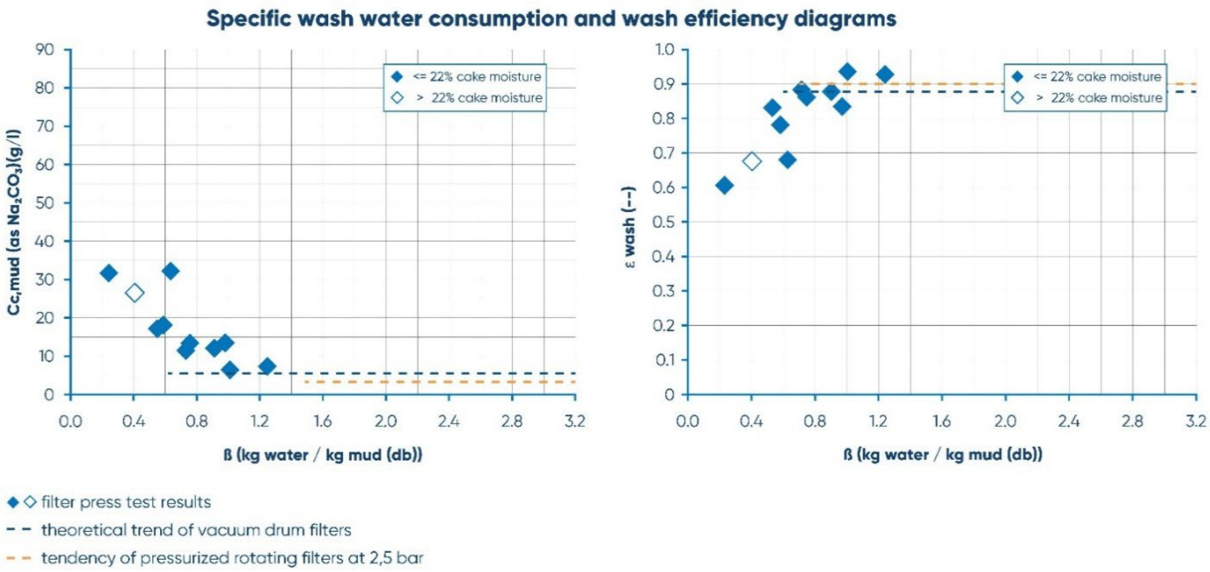

Figure 4 Comparison overview of washing efficiency per technology

Riemer et al. (2000) explain in their patent that for rotary drum filters, a wash water quantity of 0.5 m³ per metric tonne of dry mud is usually sufficient. Moreover, washing efficiency can be further improved when using pressurised hot water over 100°C. Their chart also shows that for rotary drum filters, when the wash ratio exceeds 1:1 (kg/kg dry basis), the wash quality remains nearly constant with a slight increase in wash efficiency from 0.88 to 0.93.

Summarising the results on washing efficiency, rotating filters produce much thinner filter cakes and allow a more homogeneous feeding of the wash liquid towards the cake surface. This enables the washing fluid to penetrate the capillary system of the red mud more effectively, resulting in improved cake washing and higher washing efficiency in drum filters compared to filter presses.

Rousseaux et al. (2008) describes the use cases of the alumina plants of Gardanne and AdG, where the red mud will be dewatered only by means of filter presses, while the cake will not be washed, resulting in a highly alkaline product.

2.2 Reduction of the water content in the red mud cake (residual moisture)

To achieve lower residual moisture in the filter cake, a higher differential pressure is required, which can only be attained through overpressure operation. Figure 5 illustrates the influence of operating pressure on the residual moisture content of red mud filter cakes produced on rotary drum filters, being nearly independent from the rotation speed of the drum, leading to high production capacities. Particular attention should be given to the following aspects:

- The rectangular data points represent results obtained from testwork conducted at ANDRITZ, which were validated by a vacuum drum filter operating in the field under a differential pressure of approximately 600 mbar. This setup achieved residual moisture levels in the range of 35.0–40.0 wt/wt% H_2O.
- The dotted orange line indicates the tendency of the residual moisture of pressurised rotating filters at p_{abs} = 2.5 bar in the range of 31.5–33.0 wt/wt% H_2O described by Steinlechner et al. (1996).
- The dotted blue line reflects the theoretical trend of the residual moisture of pressurised rotating filters at $p_{abs} \geq$ 4.5–5.0 bar of approximately 25.0–27.5 wt/wt% H_2O described by Steinlechner et al. (1996).

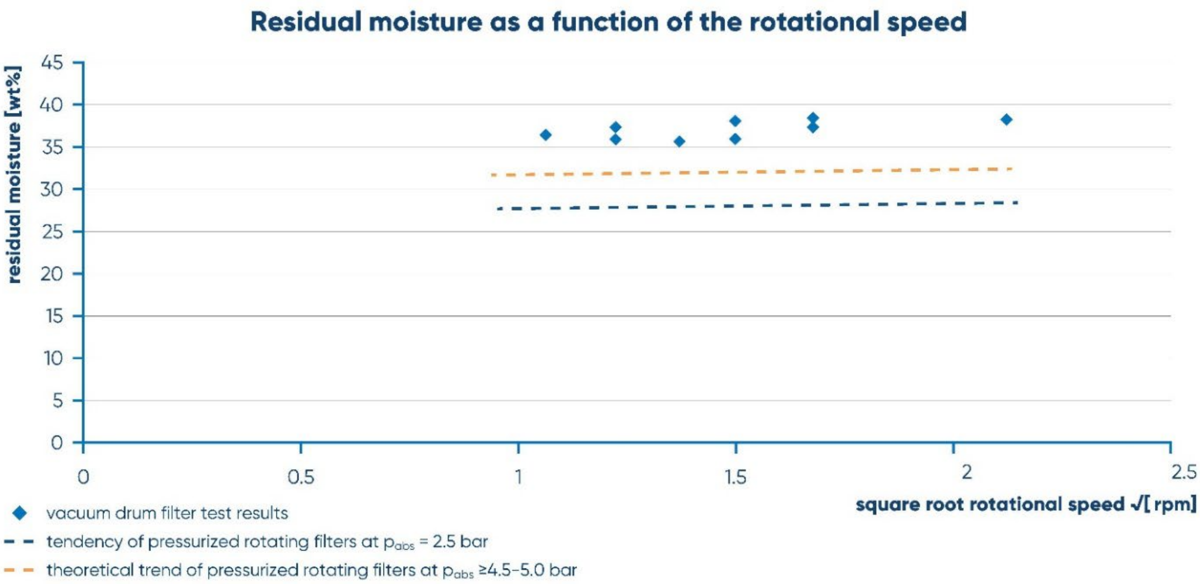

Figure 5 Residual cake moisture of rotary drum filters as a function of the rotation speed

Steinlechner et al. (1996) summarises that a differential pressure greater than 5 bar exceeds the capillary pressure of the red mud, significantly reducing the residual moisture likely to a level lower than what is influenced by the thixotropic characteristics of red mud. This non-thixotropic filter cake reaches a sufficient strength for a cake discharge by means of compressed air blow back. At high driving forces ($p_{abs} \geq$ 4.5–5.0 bar), red mud filter cakes often crack, reducing the economic efficiency of pressure filtration. This effect was observed during extended test series at Krauss-Maffei with various bauxite types, as well as during trials conducted and described by Raberger (2016) for SGS Minerals (Société Générale de Surveillance SA).

As stated in the report, residual moisture levels in the range of 22.0–28.0 wt/wt% H_2O are achievable when using filter presses. However, Rousseaux et al. (2008) describes their main shortcomings in their relatively low specific filtration rate due to long batch cycles, often requiring larger filter sizes.

Table 1 compares the achievable residual moisture levels in red mud filter cakes depending on the applied dewatering technology. The listed values are based on field experience with red mud at an average particle size of 45% < 2–10 µm. Coarser red mud fractions (e.g. sandy bauxite) can be dewatered to even lower moisture levels, for instance by approximately −5 wt%, using vacuum filtration.

Table 1 Technology comparison based on final cake moisture content

Technology	Pressure difference (bar[a])	Residual moisture (wt/wt% H_2O)
Rotating filter	−0.6	35.0–40.0
Rotating filter	2.0–2.5	31.5–33.0
Rotating filter	≥4.5–5	25.0–27.5
Filter press	16	22.0–28.0

When using vacuum filtration, the residual moisture in the red mud filter cake remains above the thixotropic threshold, meaning the compacted cake is prone to reliquefaction when subjected to mechanical energy and/or external forces. Depending on the bauxite quality, this threshold typically lies in the range of 25–28 w% residual cake moisture.

Pressure filtration operating at pressures up to 5 bar absolute also fails to reduce the moisture content below this threshold. Figure 6 shows the cake formed at both filtration technologies at the cake discharge, further illustrating typical cake appearances.

(a) (b)

Figure 6 (a) Cake discharge vacuum drum filter; (b) Filter press cake (p_{abs} = 6–7 bar)

Only high pressure filtration has the potential to achieve moisture levels below this threshold, however, for rotary filters, it has not yet been implemented on an industrial scale due to various risks such as cracking, abrasion, and other technical challenges.

Currently, filter presses are the only technology that has been successfully applied for overpressure filtration at an industrial scale. Disposing non-thixotropic red mud is less complex as standard belt conveyors or trucks can be used instead of energy-intensive, high pressure pumps and additional reactors. Steinlechner et al. (1996) describes the advantages as being reduced land requirements and fewer safety obligations.

Nevertheless, as mentioned above, the washing efficiency of such filter presses is poor, which means that the desired red mud quality must be achieved and maintained through intensive CCD.

2.3 Lifetime cost comparison

Table 2 presents a comparative summary of the investment, operating, and maintenance costs associated with filter presses and vacuum drum filters (own representation). A detailed discussion of these aspects is provided in the subsequent subsections.

Table 2 Capex/opex comparison of filter presses and vacuum drum filters in red mud plants

	Filter press	Rotary vacuum drum filter
Equipment acquisition costs	++	++
Operation costs		
Energy consumption	++	++
Operator costs	++	+
Consumables	+++	+
Maintenance cost	++	+
Operational availability	++	+++
Service life expectation	++	+++
Sludge pre-treatment costs	++	+
Cake post-treatment costs	+	++
Space demand (footprint)	+++	++

+ = low; ++ = moderate; +++ = high

2.3.1 Comparative assessment of investment costs

The initial investment costs for filter presses and rotary vacuum drum filters are roughly comparable. While a filter press with comparable capacity is slightly less expensive, it is common practice to install a standby unit to compensate for production interruptions during routine cloth cleaning intervals, which take several hours, or during maintenance activities. However, due to the significantly higher specific filtration rates achieved by rotary vacuum drum filters, the required filtration area is reduced by multiple times, resulting in a smaller overall footprint.

2.3.2 Energy consumption

For vacuum drum filter systems, the main energy consumer is the vacuum pump motor. The remaining drives (drum, agitator, and discharge roller) consume only a relatively small amount of energy. In contrast, filter presses require large pumps for both slurry and wash water feed, as well as additional energy for plate movement and cake compression. Consequently, the total installed power and direct energy consumption of filter presses are slightly higher. However, a major advantage of filter presses is the significantly lower residual moisture of the produced cake (Table 1). This leads to reduced cake post-treatment costs as the dewatered red mud can be transported by truck instead of being pumped in a slurry form, which is an energy-intensive process required for vacuum drum filters. When this factor is considered, the overall energy demand of both systems becomes roughly comparable.

2.3.3 Operational and maintenance aspects

Filter presses generally entail higher operating and maintenance demands. As the filter cloth cleaning is performed in filter presses only during the daily cleaning interval, the expensive filter cloths need to be replaced more frequently than for drum filters, where the cloth is cleaned continuously during operation. Since drum filters require a much smaller filtration area to achieve the same throughput, the total amount of filter cloth, and thus the primary spare part cost driver, is also substantially lower. In addition, filter plates in filter presses are considered wear parts and require replacement after some years, while drum filters, operating at low rotational speeds, are widely regarded as maintenance-friendly. The typical service life of filter presses is in the range of 25–30 years, while drum filters operate longer than 50 years.

2.3.4 Process water and pre-treatment requirements

As illustrated in Figure 5, filter presses require substantially more wash water than drum filters and typically need 2–3 additional large washers in the pre-treatment stage to achieve the desired washing efficiency via CCD. This increases both investment costs and overall water consumption.

2.3.5 Automation and operational reliability

A key advantage of rotary vacuum drum filters is their fully automatic and highly reliable operation, allowing for unattended and continuous performance. In contrast, filter presses may occasionally require manual intervention, particularly during cake discharge, if cake release is incomplete due to inefficient cloth washing.

3 Projection: research and design initiatives to enhance filter press performance

One approach to enhancing the washing efficiency of filter presses in industrial applications is process optimisation. Gerards & Panholzer (2025) describe that the ANDRITZ Group filter presses have already been integrated with the company's proprietary addIQ® control system, designed to optimise filtration performance through artificial-intelligence-enabled functionality. By ensuring homogeneous cake formation during the feeding phase through precise control of key process parameters such as flow rate and pressure and by utilising recovered wash liquor, the ratio between total washing volume and recovered caustic can be improved. A combination of gap washing and diagonal cake washing in an optimised volume ratio has demonstrated improved washing efficiency. The goal of the engineering team's current efforts is to develop guidelines for ideal sizing of the filter plates.

Featuring a double cloth washing system (Figure 7), operating at pressures of up to 80 bar effectively halves the cleaning interval. In addition to improved cleaning performance, this system enhances cloth regeneration, resulting in extended cloth service life. Furthermore, the new design offers improved maintenance accessibility, allowing filter plates to be replaced easily from above.

(a) (b)

Figure 7 (a) Double cloth washing device; (b) Maintenance-friendly filter plate replacement

4 Conclusion

The volume and caustic content of bauxite residue, also known as red mud, make this byproduct of alumina production via the Bayer process a material that must be handled with particular care. Both red mud dewatering technologies discussed in this paper – continuous vacuum drum filters and filter presses – are valid options for dewatering and washing of red mud.

Optimising the CCD circuit ensures that red mud reaches the required quality at the final washer stage, supporting the implementation of a filter press. Another advantage of this technology is its significantly lower residual moisture, which may extend the operating life of the deposit pond. However, washing efficiency and specific filtration rate of filter presses are poor in comparison to rotating drum filters.

Besides that, declining bauxite quality can also favour the use of continuous vacuum filters, which enable effective red mud cake washing. In general, vacuum drum filters are simple to operate and less sensitive to process variations. Their suitability for all bauxite types adds flexibility to the operation. To the best of the authors' knowledge, continuous high-pressure filtration has not yet progressed beyond the experimental stage.

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