

AA04 - Enhancing Solid-Liquid Separation in Alumina Refineries: A Comparative Study of Gravity Decanters and Diastar Filters

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Abstract

This research paper explores the challenges associated with the use of gravity decanters in alumina refineries. These decanters, employed for solid-liquid separation during the Bayer process, are found to have certain limitations. As a solution to these drawbacks, the authors suggest the application of Diastar filters. These innovative pressure filters are specifically designed to deal with high-solid concentration slurries at increased temperatures and pressures. To substantiate this proposal, the efficiency of Diastar filters is compared with gravity decanters. This comparison is drawn through a bench-scale study using a blow-off slurry and SysCAD simulation modelling. The first findings reveal that Diastar filters exceed the performance of gravity decanters when it comes to solids separation, registering a specific feed capacity of nearly 0.9 m³/m²·h. In addition to superior solids separation, Diastar filters also show decreased liquor loss. This decrease leads to an increased filter cake solids concentration, thereby enhancing the overall efficiency of the solid-liquid separation process. Moreover, compared to gravity decanters, Diastar filters require less space, making them a more space-efficient choice.

The research paper also delves into the economic and environmental implications of replacing gravity decanters with Diastar filters in alumina refineries. The study suggests that Diastar filters could potentially offer significant economic benefits and positive environmental impact. However, the authors also underline the need for careful consideration of the filterability of residue specific to each bauxite and digestion conditions. They highlight that these factors can considerably affect the filtration characteristics of the residue. Conclusively, Diastar filters appear as a promising alternative for blow off solid-liquid separation in the alumina industry, given their enhanced performance, economic advantages, and environmental benefits. Nevertheless, the need for individual evaluation of residue filterability in relation to specific bauxite and digestion conditions is necessary.

Keywords: Alumina refineries, Bayer process, Diastar filters, Gravity decanters, Solid-Liquid separation.

1. Introduction

Since the development of the Bayer Process in 1888 [1] lots of process optimization have been made in refineries to adjust it for the ore characteristics and mainly to improve the process efficiency. In the earlier alumina refineries, the solid-liquid separation from digestion blow-off slurry (DBO) was performed by plate and frame filter presses [2]. The change from blow-off filtration to the current flocculant aided gravity decantation came about because of developments in thickening technologies (synthetic flocculants and thickeners design) and the necessity to reduce the high costs in labour, maintenance and depreciation associated with those filtration technologies [3]. Besides the benefits that came with these modern decanters, the process of densifying the solids in the underflow from 50 g/L (~4 % solids) to 500 g/L (~35 % solids) usually takes more than four hours, reaching in some cases up to 12 h. As a result, some part of the

dissolved alumina phase tends to auto-precipitates in the digestion blow off slurry, implying a drop of the alumina concentration (measured as A/C – alumina to caustic ratio, expressed as g/l of Al_2O_3 and Na_2CO_3 , respectively) in the decanter. A common A/C ratio drop of 0.20 points (e.g., from 0.755 to 0.735) in the settler overflow is estimated to represent an alumina loss of approximately 3 % in terms of the bauxite feeding the Bayer process. Other inconveniences of decanters are related to its footprint, and high scaling rates [3,4].

Moving towards a substantial improvement in the digestion alumina recovery, it is paramount to reduce the auto-precipitation losses (APR) and maximize the liquor productivity. This is evidenced when considering the perspective that bauxite reserves tend to degrade over time (reducing the available alumina content and increasing the related mud factor) as more efficient processes are mandatory for the industry (reducing the generation of residues and the specific consumption of inputs such as steam and caustic soda). In this context, the present work proposes replacing current decanters by Diastar filters for the blow-off solid-liquid separation.

Diastar is a fully automatic pressure vertical leaf filter, that can operate under elevated temperatures and pressures. Currently it is widely used in alumina refineries (for liquor filtration) and other applications mainly for thickening and clarification of slurries [5].

Diastar's deadtime can be brought down to around 30 seconds, making it possible to operate with filtration time as low as 3 minutes. The backwash system is designed to dislodge cakes as thin as a few millimetres. Both these features, together with the possibility to isolate each filter element in case of solids breakthrough, allow Diastar filter to handle slurries with high solids concentration and high specific cake resistance.

Dislodged filtration cake settles in a cone as dense mud. Thanks to continuous mud level measurement, mud can be extracted from the filter with solids concentration as high as two thirds of the saturated cake solids concentration.

The opportunity to significantly reduce the retention time for the solid-liquid separation and, consequently, maximize digestion alumina recovery by reducing the auto-precipitation was investigated. This work represents a pre-feasibility evaluation of this application.

2. Experimental

A preliminary bench-scale laboratory study was carried out to assess the filtration performance of blow-off slurries. Subsequently, SysCAD modelling and steady-state simulation of scenarios with the replacement of the decanter by Diastar Filters were performed to demonstrate the benefits.

2.1 Filtration tests

The tests were performed in Hydro's Bauxite and Alumina (B&A) R&D laboratory, which is equipped with an autoclave apparatus for digestion of about 5 L slurry and a pressure filter designed and fabricated by Gaudfrin (Figure 1). This system allows to perform filtration tests of digestion blow-off slurry (DBO) from autoclave and from plant at temperature pressure up to 150 °C and 16 bara, respectively. More details on this system can be found in LaMacchia et al. [6].

Digestion tests were carried out using Mineração Paragominas bauxite (Miltonia 3) and plant spent liquor at temperature of 145 °C, residence time of 60 minutes, to achieve a final A/C ratio of 0.750. Filtration runs were performed at different ΔP and temperature, using blow-off slurry from autoclave and plant. Pressure was increased during some of the tests to check compressibility

of the cake (runs #1, #5, and #6). Runs #6 and #7 were performed at a temperature above boiling point to evaluate the performance of filtration pre-flashing, in this case the pressure in the filtrate receiver tank was kept at 4 bar (gauge) to prevent liquor flashing. The plant DBO samples were collected in thermal bottles, before and after dilution with the Washer's overflow. In total, eight filtration conditions were tested as summarized in Table 1.



Figure 1. Autoclave apparatus (right) and pressure filter (left) in the B&A R&D laboratory [6].

Table 1. Test conditions.

	Run #1	Run #2	Run #3	Run #4	Run #5	Run #6	Run #7	Run #8
Slurry type	<i>DBO - Autoclave</i>	<i>DBO - Plant without dilution</i>	<i>DBO - Plant without dilution</i>	<i>DBO - Plant without dilution</i>	<i>DBO - Autoclave</i>	<i>DBO - Autoclave</i>	<i>DBO - Autoclave</i>	<i>DBO - Plant with dilution</i>
Filtration ΔP (bar)	2.5, 5, 10	10	12	12	6, 11.5	4, 8	8	10
Filtrate tank pressure (bar g)	0	0	0	0	0	4	4	0
Büchner temperature (°C)	88	106	98	101	102	122	125	108

2.2 SysCAD simulation

A standalone SysCAD model of one clarification circuit line was developed based on the Hydro Alunorte process. A simplified flowsheet is depicted in Figure 2 illustrating the base case and the proposed case with Diastar filter replacing decanters for blow-off slurry solid-liquid separation. The DBO that feeds the decanters comes from the digestion area (heated slurry is cooled down in flash tanks and diluted with wash water from 1st Washer before last flash stage). Overflow is directed to the liquor security filtration and the underflow is directed to the counter-current decantation (CCD) circuit with four washers. The last washer underflow is dewatered and washed with condensate in the Filter Press, reaching final solids with 22 % moisture. For filtration case,

- C. Switching out the decanter for filtration unit operation that includes a cake pre-washing step.

In cases *A* and *B*, the 1st washer OF reports to the DBO dilution and the cake solids are removed by backflushing with green liquor (like Diastar operation for liquor security filtration) resulting in mud with ~800 g/L solids. For scenario *C* it is considered a pre-washing step being carried out inside the Diastar filter. In this case, the filter is empty after the filtration cycle and filled with wash water from the 2nd washer OF. The mud from filter is directed to the 1st washer. Impact on the filter productivity due to this pre-washing is discussed. No filter aid was considered for this application.

3. Results

3.1 Filtration tests

During the filtration tests the filtrate weight is monitored to have the cumulative volume of filtrate V against time t . Figure 3 shows the curves for each run. For a constant pressure the filtration rate decreases with time due to the continuous deposition of solids forming the cake. The specific filtration rate is expressed as:

$$\frac{dt}{dV} = K_p \cdot V + B \quad (2)$$

Where:

$$K_p = \frac{\mu \cdot c \cdot \alpha}{A^2 \cdot \Delta p} \quad (3)$$

$$B = \frac{\mu \cdot R_m}{A \cdot \Delta p} \quad (4)$$

μ	liquid viscosity
c	solids concentration
α	filtration constant which accounts for the mean specific cake resistance
R_m	filtration constant which accounts for the medium resistance
Δp	filtration pressure
A	cross-section filtration area
t	the filtration time.

Thus, K_p and B are coefficients related to the cake resistance and medium resistance, respectively. By integrating the Equation (2) and dividing the two side by V we get the following equation:

$$\frac{t}{V} = \frac{K_p \cdot V}{2} + B \quad (5)$$

By this linear equation is possible to plot the experimental data of t/V against V to obtain the slope K_p and the intercept B . Interesting noting that lower values of K_p means good filterability, and it is commonly proportional to $(1/p)^n$, where n ranges between 0 and 1, often called the compressibility coefficient. For compressible cakes n varies from 0.2 to 0.8 and is 1 for incompressible cakes.

Table 2 summarizes the data of the experimental runs. It was observed that the TC (Total Caustic) of blow-off slurries from lab autoclave digestion were higher than plant samples. Due to the

significant change from one test to another in terms of viscosity, solids concentration and pressure the K_p values were normalized for a standard condition (e.g., viscosity of 1 cP, Δp of 10 bar, and solids concentration of 30 g/L).

Results indicated a better filterability of autoclave samples than plant DBO samples (comparing the K_p values). A slurry temperature drop during the handling of these samples (sampling and transportation to the laboratory) is a potential explanation, which would cause a significant gibbsite auto precipitation and change in the TC and viscosity. DBO solids cake appears to be slightly compressible with estimated n of about 0.8.

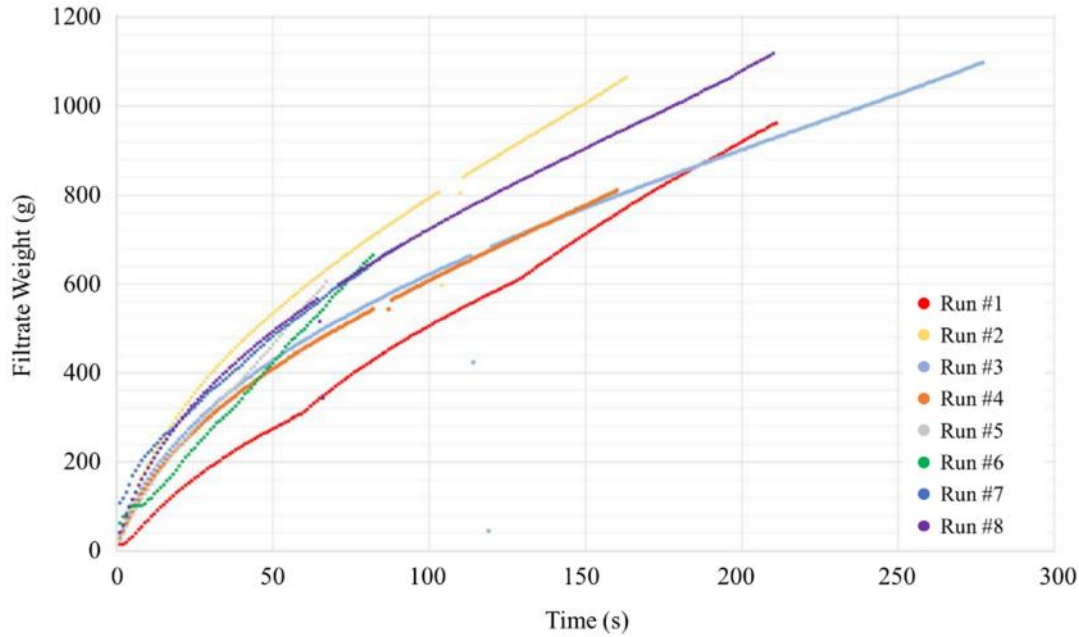


Figure 3. Filtrate Weight increase against Time for all experimental runs.

Table 2. Test results.

	Run #1	Run #2	Run #3	Run #4	Run #5	Run #6	Run #7	Run #8
TC (g/L as Na ₂ CO ₃)	339	286	292	292	354	311	342	275
Filtrate volume (mL)	740	860	930	720	530	540	580	950
Slurry solids conc. (g/L)	44.6	30.2	36.9	36.6	44.2	31.3	31.3	36.7
Cake thickness (mm)	2.5	2.5	3	2.5	2	1.5	-	3
Cake moisture (%)	21	36.1	36.9	35.8	13.9	40.3	-	26.4
K_p (s/m ²)	7 562 @ 2.5 bar 9 732 @ 5.0 bar 8 297 @ 10 bar	25 805	37 362	36 143	6 938 @ 6.0 bar 7 005 @ 11.5 bar	7 625 @ 4.0 bar 4 923 @ 8.0 bar	14 963	24 231
B (s/m)	1 150	360	400	450	680	1 080	960	350

The cake of Run #1 was washed inside the filter with 800 mL of water maintaining the test temperature. The caustic concentration was then monitored to evaluate the washing performance. Figure 4 shows the washing curve.

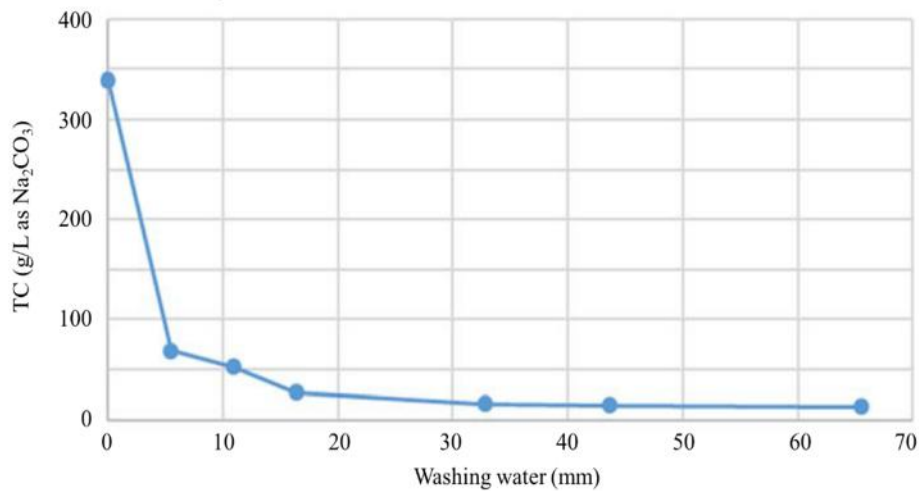


Figure 4. Cake washing efficiency – Run #1.

In general, for DBO filtration, the cake formed in 3 minutes ranged from 1.9 mm to 2.2 mm and the estimated Diastar specific filtration capacity would be around 0.4 m³/m²·h and 0.9 m³/m²·h with and without pre-washing step in the filter. Considering a Net-wash of 1.0 the results of cake washing indicated a dilution effect of TC ~85 g/L.

3.2 SysCAD simulation

In Table 3 some outputs for each scenario are summarized for comparison. The main benefit of replacing decanters by Diastar filters is the increase of digestion alumina recovery associated with the reduction of APR losses within the clarification processes. That is due to the possibility to achieve a short solid-liquid retention time and higher solids concentration. With filtration cycles of about 10 min (against of ~4 h in decanters) the extent of alumina auto-precipitation reaction can be reduced ~67 % (reducing the $\Delta A/C$ from 0.030 to 0.010; interesting nothing that a kinetic estimation [8] indicates a $\Delta A/C$ of only 0.003). In addition, a higher solids thickening is obtained during the cake filtration, which is released by backflushing and discharged from filter at about 800 g/L solids (against ~500 g/L in decanters). It represents a significant reduction of green liquor transferred to the CCD circuit, resulting both in lower Net-wash demand to recover alumina and soda in this circuit and higher dilution (reducing APR, liquor viscosity and density, and likely improving the washing efficiency in the washers). Results indicate a reduction of 45 % for scenarios *A* and *B* (without pre-washing) and 75 % for scenario *C* (with pre-washing), respectively, 1.2 and 0.5 t liquor / t solids (2.2 t/t for base case).

Based on these considerations, the scenarios were simulated considering an increase of the green liquor A/C target from base case of 0.740 to 0.750, which may represent a plant alumina yield increase of ~2.8 g/L. The estimated digestion recovery increase was 1.5 %, which implies a proportional reduction in the bauxite factor. Associated with that, the digestion A/C target was set 10 points lower for the proposed scenarios, enabled by the APR reduction. Thus, the specific bauxite consumption, and consequently, the solids in clarification circuit is significantly reduced, which also reduces the fixed caustic soda losses in ~1.5 kg NaOH/t alumina (associated with the lower reactive silica amount in the process).

Another benefit demonstrated in the simulation is the soluble soda recovery. By strictly replacing decanters (scenario *A*), a TC reduction of ~15 % in the bauxite residue is attained. In scenarios *B*

and C in which decanter tank is considered for additional washing stage, the TC reduction may reach ~43 % and 55 %, respectively. The soda recovered in scenario C is higher due to the additional pre-washing in the filter (cake released backflushing with washing water).

Table 3. SysCAD simulation outputs.

Scenarios	Output	Digestion slurry	Decanter OF / Filtered Liquor	Decanter UF / Filter UF	Last Washer UF	Bauxite Residue
Base Case	Slurry Mass Flow (t/h)	1,550	1,581	254	199	108
	Solids Conc. (g/L)	60.0	0.1	500.0	613.8	1,575.3
	TC (g/L as Na ₂ CO ₃)	280.0	260.5	260.5	51.4	13.1
	A/C	0.770	0.740	0.740	0.672	0.672
A	Slurry Mass Flow (t/h)	1,550	1,583	152	172	94
	Solids Conc. (g/L)	58.5	0.1	800.0	613.8	1,593.9
	TC (g/L as Na ₂ CO ₃)	280.0	260.9	260.9	43.4	11.2
	A/C	0.760	0.750	0.750	0.668	0.668
B	Slurry Mass Flow (t/h)	1,550	1,583	153	170	94
	Solids Conc. (g/L)	58.5	0.1	800.0	613.4	1,593.5
	TC (g/L as Na ₂ CO ₃)	280.0	261.0	261.0	28.5	7.5
	A/C	0.760	0.750	0.750	0.632	0.632
C	Slurry Mass Flow (t/h)	1,550	1,583	178	169	94
	Solids Conc. (g/L)	58.5	0.1	593.6	613.0	1,593.3
	TC (g/L as Na ₂ CO ₃)	280.0	261.0	121.5	22.5	5.9
	A/C	0.760	0.750	0.713	0.610	0.610

4. Discussion

Preliminary tests allowed to estimate the specific filtration capacity for typical digestion blow off slurry. For a Diastar filter operating at 10 bara for a DBO flow of 1,500 m³/h with solids concentration of 60 g/L and liquid viscosity about 1.4 cP, the capacity estimated is about 0.9 m³/m²·h and the filtration area required is, therefore, approximately 1650 m². Thus, considering a Diastar unit with 550 m², a total of 4 filters (3 operating and 1 spare) is required with a rough CAPEX estimation for such implementation of about 10 MUSD. Considering the following benefits of this implementation the estimated payback is about 3 years.

- Production increase of approximately 30 000 tonnes of alumina per year, by raising the liquor to precipitation A/C in 10 points (+2.8 g/L yield, due to the reduction of APR losses). At a margin of 100 USD/t the revenue is 3.0 MUSD/year;
- Recovery increase with associated reduction of bauxite factor of ~1.5 %. Estimated savings of 1.7 MUSD/year at a bauxite price of 50 USD/t;
- Caustic soda savings by increasing soluble soda recovery and decreasing fixed caustic soda consumption. For a typical gibbsitic bauxite with 47 % Available Al₂O₃ and 5 % Reactive SiO₂, at a caustic soda price of 400 USD/t, the fixed soda savings is 0.62 MUSD/year. The savings with soluble soda vary depending on the scenarios: 0.11 MUSD/year (scenario A), 0.34 MUSD/year (scenario B), and 0.43 MUSD/year (scenario C). Total soda savings may range from 0.73 MUSD/year to 1.05 MUSD/year.

Among the scenarios, *C* seems to be less interesting, as the number of necessary filters doubles due to a lower filtration rate ($\sim 0.4\text{m}^3/\text{m}^2/\text{h}$, less filter availability due to the need to empty and fill it with water for pre-wash), with an increment in savings of only 0.09 MUSD/year. Compared to gravity decanters, Diastar filters require less space, making them a more space-efficient choice. For a brownfield project, however, scenarios *A* and *B* must be better evaluated concerning the associated cost of retrofitting, demolishing, and available footprint. Environmental aspects related to the significant reduction of caustic in residue may also be considered, mainly in the context of its disposal and the ambition to implement/increase its utilization.

Despite the benefits demonstrated, it is worth noting that the filterability of blow-off may significantly change from different bauxite slurries and digestion conditions, so this opportunity must be evaluated for each individual case.

5. Conclusion

This work presents a preliminary evaluation of digestion blow-off solid-liquid separation by filtration with the main benefit of reducing the auto-precipitation losses in clarification circuit. The opportunity of using the Diastar filters for this purpose is highlighted, considering its potential to perform higher thickening of solids in short filtration cycles (about 10 min). A total gain of 0.020 in *A/C* ratio is estimated in comparison with decanters. Savings due to reduction of bauxite and soda consumptions were also calculated, together representing a benefit of about 5.7 MUSD/year for a typical plant of 1.0 Mtpa. The cost for this implementation was estimated to be approximately 11 MUSD, with a payback time of 3 years.

Worth noting that other potential benefits may be further evaluated and accounted, such as the reduction of flocculant and TCA consumption, reduction of bauxite residue alkalinity and with potential to lever its utilization, reduction of plant net-dilution (when necessary for evaporation control – obviously it competes with the soda recovery benefit, but may enable more flexibility for plant volume control), and even the by-passing of the security filtration if demonstrated a reduction of solids concentration in green liquor below 5 mg/L. A pilot plant test is recommended to confirm these benefits as well as the challenges for the DBO filtration in Diastar filters. This test is planned for the next phase of the project in Hydro Alunorte.

6. References

1. F. Habashi, A hundred years of Bayer process for alumina production, in *Light Metals*, ed. By L.G. Boxall (Phoenix, AZ, 1988), 3–12.
2. R. Bott, T. Langeloh, J. Hahn, Filtration of pregnant hot slurries with Hibar Filtration - A key for innovating the digestion process. *Proceedings of the 10th International Alumina Quality Workshop*, 2015.
3. B.E. Raahauge, F.S. Williams, *Smelter Grade Alumina from Bauxite: History, Best Practices, and Future Challenges*, Springer, Cham, 2022, pp. 255.
4. B.J. Hogan, A. Furlong, Going FAR (Floating Alumina Refinery), *Proceedings of the 10th International Alumina Quality Workshop*, 2015.
5. Gaudfrin, “Diastar Filter”, [Online]. Available: <http://www.gaudfrin.com/the-diastar-filter/>. [Accessed 13 June 2023].
6. Robert LaMacchia et al., A Novel Experimental Apparatus for Red Side Studies. *Proceedings of the 36th International ICSOBA Conference*, Belem, Brazil, 29 October - 1 November 2018, *TRAVAUX* 47, 181–190.
7. S.P. Rosenberg, S. Healy, A thermodynamic model for gibbsite solubility in Bayer liquors, *Proceedings of the 4th International Alumina Quality Workshop*, Darwin, Northern Territory, 2–7 June 1996, 301–310.

8. M. Kiriazis, Settler and Washer alumina reversion, *Proceedings of the 7th International Alumina Quality Workshop*, 2005, 123–126.