BAUXITE RESIDUE FILTRATION EXPERIENCE IN GARDANNE AND ALUMINIUM OF GREECE ALUMINA PLANT

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Abstract

For many alumina refineries, bauxite residue management is a main concern and for some of them the target is to produce straight from Bayer process a re-usable material, without intermediate treatment.

This paper highlights the full development of the application of Press Filter Technology on bauxite residue filtration, in two different refineries, in order to produce cake that can be handled easily so as to be sent directly to the client, who uses these residues as raw materials for several applications.

In a first part, this paper outlines the testing methodology developed and the results obtained in order to predict the performance of a full size plate and frame press-filter.

Secondly, the operational experience gathered during start-up of the Press Filter unit in Gardanne is presented.

Impact of some process parameters are described in detail such as effect of solid concentration in feed flow-rate. Optimal settings of the parameters of the sequences of a complete filtration cycles are also outlined.

The paper also details some of the distinctive features of the installed unit.

Finally, present results obtained from operation of Gardanne and Aluminium of Greece plate and frame Press-Filter units are compared with predicted performances based on the pilot scale tests.

1. Introduction

It is well-known that the plate and frame press filter is a system able to solve filtration problems related to slurries containing mostly very fine particles and then characterized by very poor filterability. As bauxite residue are characterized by a very fine size distribution (generally more than 90 % of the particles are finer than 5 µm), the press-filter seems, on first thoughts, to be an appropriate technology.

Some papers describing filtration technologies (such as the Hi-Bar technology) have been published in the literature (Bott *et al.*, 2002) and drum filters are used industrially to filter bauxite residue in some refineries. The present paper is dealing with plate and frame press-filter technology applied to bauxite residue filtration and presenting the whole approach, from initial pilot testing to the description of the installed unit and its first industrial results with respect to operations and performances.

In Gardanne Alumina Plant and Gardanne Alumina Technical Center many efforts have been conducted to find possible uses of Bauxite residue, named Bauxaline® when used for commercial purposes (Martinent *et al.*, 2002). Strategy chosen by GAP (Gardanne Alumina Plant) was to implement a press-filter so as to be capable of producing Bauxaline in increased quantities, after different pilot tests.

The pilot press filter used to carry out the trials was composed of 4 plates (Figure 1), which can be chambered plates or membrane plates. These plates were 630 mm by 630 mm and made in polypropylene. The principal pieces of equipment of this pilot press-filter were the following:

- a hydraulic jack capable to ensure a pressure of 270 bars
- a feed pump capable to ensure a feed pressure of maximum 5 bars
- a compressor to provide the compressed air for the various necessities (blowing, core blowing, pressurization of the membranes, ...)
- PLC for control and regulation purposes.

Figure 1. Picture of the pilot unit used to carry out the pilot trial presented in this work.

The equation for filtration on a support at a constant pressure is well-know and can be written as follows:

$$t = \frac{\mu\alpha\, W}{2\,\Delta P\,\Omega^2}V^2 + \frac{\mu R_s}{\Delta P\,\Omega}V$$

With the following notations:

- t = filtration time (s)
- V = volume of filtrate recovered after a given filtration time (m^3)
- μ = viscosity of the filtrate (Pa.s)
- W = mass of dry filter cake per unit volume of filtrate (kg/m^3)
- ΔP = filtration pressure (Pa)
- Ω = filtration surface area (m^2)
- R_s = resistance of the filtration equipment to flow per unit of filtration surface area (1/m)
- α = specific cake resistance (m/kg)

This equation clearly shows the influence of following parameters on filtration time:

- temperature through the viscosity of the filtrate
- feed solids of the slurry through factor W
- filter cloth through factor Rs, which represents the resistance of the filter system (filter cloth) to flow
- specific cake resistance (factor fl), which is an intrinsic characteristic of the solid particles to be filtered.

As a consequence, the aim of this work is to study the effect of the parameters outlined above on filtration time.

Another main objective of the pilot trials was to check if it would be possible to obtain a filter cake of a solid content as high as 75%.

Finally, secondary objectives of this pilot trial were also to define:

- the type of plates which would be adequate to obtain the targeted solid content of 75 %
- the productivity of the press filter treating bauxite residue coming from the last washer of Gardanne Alumina Plant
- the time necessary for each sequence of the total filtration cycle.

The industrial press-filter of Gardanne is presented in a second part. Main features of the installed unit are presented. Main industrial filtration parameters and performances are detailed and compared to pilot test results. Finally, some main issues which still need to be improved and possible solutions are outlined.

2. Initial Pilot Testing and Evaluation

2.1 Determination of fundamental filtration parameters

The aim of this section is to determine the specific cake resistance fl and the resistance of the support Rs, for the

The equation

$$\frac{t}{V} = \frac{\mu \alpha W}{2 \Delta P \Omega^2} V + \frac{\mu R_s}{\Delta P \Omega}$$

enables the determination of α and R_s.

We had the following filtration conditions:

Filtration pressure ΔP = 6 bar = 6 10^5 Pa
Filtration surface area Ω = 1.76 m^2

Table 1 gives the resistance of two filter cloths tested, the R-type and B-type. As can be seen from Table 1 the resistances of the support to flow of both filter cloths are identical.

Table 1. Resistance of the support to flow of filter clothes investigated

	R-type	B-type
Rs (m^{-1})	5.09E+12	5.13E+12

The average specific cake resistance determined with these pilot trials, during which the filtration pressure was kept at a constant pressure of 6 bars, was α = 1.78 10^{12} m/kg.

Generally, filtration of a given product is qualified as following:

- a product filters quite well when :
  $\alpha < 10^{10}$ m/kg
- a product has an average filterability when :
  10^{10} m/kg < α < 10^{12} m/kg
- a product has a very poor filterability when :
  $\alpha > 10^{12}$ m/kg

Based on these considerations, it can be stated that Bauxite residue from Gardanne are characterized by a very poor filterability.

2.2 Trials with Chambered plates

The sequence of air blowing allows to gain approximately 2 % of solid content, but it should be noted at this stage that industrially blowing need the implementation of huge compressors. Besides, bauxite residue filter cakes are very compact, hence characterized by a very low permeability to air.

The solid contents obtained are around 65 %, which is far from the desired target. Consequently, it can be concluded that chambered plates without membranes are not adapted to filter bauxite residue.

2.3 Trials with plates equipped with membranes

The configuration of the pilot equipped with membrane plates is presented in Figure 2.

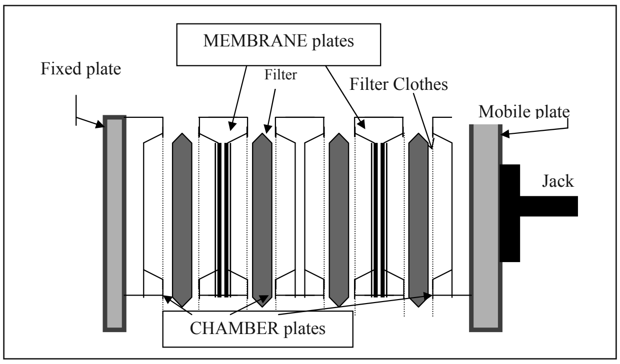

Figure 2. Configuration of the pilot equipped alternatively with chamber and membrane plates so as to have the cake being squeezed by one side

The results of the most relevant trials are presented in Table 2, given below.

Table 2. Most relevant pilot trial results with Membrane plates

	15-nov	27-nov	19-nov	14-nov	13-nov	20-nov	20-nov
	E1	Cycle 3		Test 1	4	Cycle 6	Cycle 9
Dimension of chamber (mm)	40	40	40	40	50	40	40
Number of chambers	4	4	4	4	4	4	4
Type of filter cloth	B	B	B	R	R	B	B
Filtration surface area (m2)	1.76	1.76	1.76	1.76	1.76	1.76	1.76
Feed solids concentration (g/l)	298	353	365	400	400	465	465
T of feed slurry (°C)	33	30	30	9	43	30	30
Filter feeding time (min)	19	14	16	14	18	12	12
Feeding pressure (bar)	6	6	6	6	6	6	6
Squeezing time (min)	4	3	5	4	3	3	3
Squeezing pressure (bar)	14	14	14	14	14	14	14
Weight of filter cake obtained (kg)	51.6	45	53	53.3	64	53	57
Thickness of filter cake (mm)	34	28	32	36	45	35	35
Squeezing coefficient (%)	85	70	80	90	90	87.5	87.5
% Solids of cake obtained (%)	70	71	71	69	70	71	71
Productivity not including dead time (kg/h/m2)	54	64	61	70	73	86	92
Average feed flow rate not including dead time (l/h/m2)	180	182	167	174	182	184	198

The conclusions which can be drawn from these trials are as follows:

- the squeezing sequence allows to increase the solid content by 8 %, up to around 70%
- the average productivity not including dead time is in the range of 60 to 95 kg/h/m², for feed solid concentrations in the range of 300 to 465g/L
- the feed flow rate not including dead time is in the range of 140 to 200 kg/h/m², depending on the feed solid concentrations
- the average squeezing coefficient varies between 0.70 and 0.93.

In industrial automatic press filter units the dead time amounts 30 to 35 % of the time of one total cycle. It can be then concluded that the anticipated productivity of an industrial unit would be in the range of 43 to 65 kg/h/m² for Bauxite residue of Gardanne Alumina Refinery.

2.4 Definition of a typical filtration cycle found with operation of the pilot press-filter

The aim of this section is to detail the successive sequences - and their associated durations - of a complete filtration cycle which were close to optimal conditions. The test which is detailed here was conducted at a feed solids concentration of 465g/L and allowed to obtain the targeted cake characteristics and productivity.

As can be calculated from Table 3, the total cycle time amounts to 21 minutes.

The effective filtration phase is composed of the 3 successive sequences "Filling, Compaction, Squeezing" and lasts a total time of 17 minutes. The so-called dead time is composed of the sequences "Closing, Opening, Discharge" and lasts in total 4 minutes, which amounts to approximately 20 % of the duration of the total filtration cycle.

The feed flow rate at the beginning of the filtration phase is an important tuning parameter and should be in the order of magnitude of 2.0 m³/h/m².

The following consideration illustrates this. When the filter was set up so as to produce 2 filter cakes (i.e. 2 chambers and a total filtration surface area of 0.88 m²), the initial feed flow rate was 1.6 m³/h. Similarly, when the filter was set up so as to produce 4 filter cakes (ie. 4 chambers and a total filtration surface area of 1.76 m²), the initial feed flow rate was 3.5 m³/h. The filling time is clearly proportional to the total volume of all the chambers to be filled. For this reason, the initial feed flow rate should be increased proportionally to the total volume of all the chambers to be filled.

But it is also very important to tune this feed flow rate so as to ensure a homogenous filling of the whole filter volume, especially if the feed solid concentration is at the higher side, which tends to increase the viscosity of the slurry to be fed to the filter.

As can be understood from the considerations given above, the only sequence of the filtration cycle which can be optimized is the "compaction sequence". The only actuators to optimise the compaction cycle are:

- the filtration temperature, because increasing temperature will decrease the viscosity fl of the filtrate
- the feed solid concentration, which will affect the factor W
- the filter cloth, which will influence R^s, the resistance of the support (filter cloth) to flow per unit of filtration surface area.

2.5 Effect of feed solid concentration

A well-known rule of thumb in filtration is that in order to increase the productivity of the filter, it is necessary to increase the feed solid concentration.

It is interesting to trace the experimental pilot trial results presented in Figure 3 by plotting the productivity not including dead time as a function of the feed solid concentration.

According to this data, it well confirmed that the filter productivity increases when solid concentration is increased.

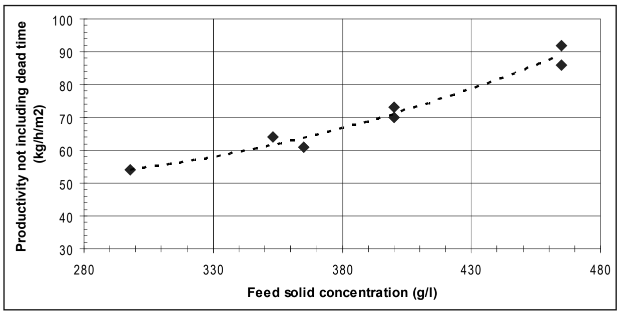

Figure 3. Productivity not including dead time as a function of the feed solid concentration

3. The Press-Filter Unit installed at Gardanne

3.1 Distinctive features of the press-filter unit of Gardanne

One of the main conclusions of the pilot testing was that membrane-type plates offer an optimal performance in the

Table 3. Description and duration of the sequences of a complete filter cycle

SEQUENCE	DESCRIPTION	DURATION
Closing	Closing of the filter by a hydraulic jack Applied pressure is 270 bars Pressure sensor installed on hydraulic device	1 min
Filling	Filling of the filter (during this filling sequence, the drainage valves installed on the upper par of the plates are closed whereas the drainage valves of the bottom of the plates are open). This sequence is stopped as soon as the pressure at the discharge of the feed pump reaches 2 bars.	3 min
Compaction	Feeding of the filter (during this effective filtration sequence, all the drainage valves are open). This sequence occurs at constant feeding (filtration) pressure. In the trial carried out in this work, we had ΔP = 6 bar. This phase is the so-called classical « filtration on a support at a constant pressure »	9 min
Squeezing	During this sequence, the membranes are pressurized at a constant pressure of 14 bars.	3 min
Opening	During the opening of the filter the "drain drops" are removed by means of an intermediate cart.	1 min
Discharge	The filter cakes are discharged and recovered on the lower cart.	2 min

sense that they succeed in reducing both the residual moisture and the cycle time. For this reason, membrane-plate technology was selected for the press-filter of Gardanne.

The press-filter installed in Gardanne is a 400 m^2 filter. It has been provided with a side plate shifting device, giving the best guarantees for cake discharge, and right plate shifting. Filter closing device is provided with 4 hydraulic jacks for even pressure distribution on a moveable header, capable to deliver a closing pressure of 240 bars (Figure 4).

A plate shaking device during the discharge phase ensures release of the cake.

A PLC controls the phases and cycle time for all the press filter functions.

Figure 4. Photo of the new industrial press-filter installed in Gardanne Alumina Plant

The main features of the membrane plates of Gardanne press filter are:

- replaceable membranes
- special construction material in polypropylene
- central product feed inlet
- squeezing pressure up to 15 bars
- membrane inflating by water, the membranes are inflated individually
- special profiled surfaces of the plates for a longer life of the filter clothes.

A general flow diagram illustrating main flows and operation philosophy is presented in Figure 5.

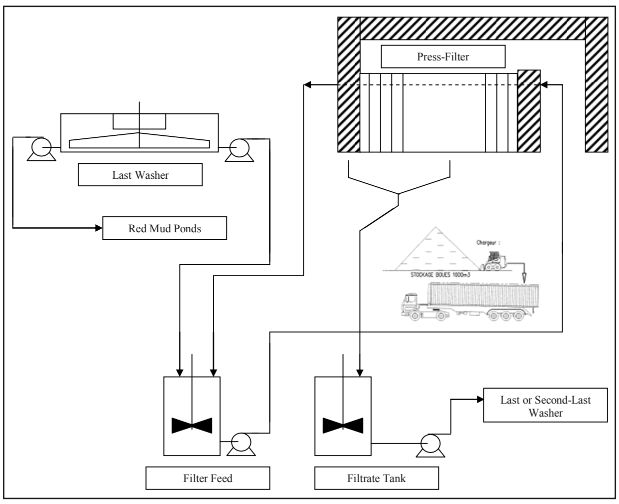

Figure 5. General flow diagram illustrating main flows and operation philosophy of press-filter of Gardanne Alumina Plant

3.2 Equipment installed and typical operation

The concentration of the mud coming from the last washer is fluctuating significantly, with values in the range 250 to 450g/l. This variability is due to technology of settlers (old conventional flat bottomed settler with lateral mud extraction). The average flow rate pumped from the last washer to the filter feed tank fluctuates in the range from 40 to 60 m^3/h.

The filter feed pumps are centrifugal pumps characterized by the capacity to feed the filter in two extreme conditions: in a first phase, corresponding to the ''filling sequence'', the pump is capable of a high flow rate at a low discharge pressure, and in a second phase, corresponding to the ''compaction sequence'', the pump is capable to a low flow rate but at a high discharge pressure. More specifically, the Gardanne press-filter feed pumps are ensuring flow rates of maximum 220 m^3/h at 1 bar during the ''filling sequence'' and of minimum 30 m^3/h at a constant discharge pressure of 7 bar during the ''compaction sequence''.

The end of the filtration phase is automated by a flow meter which is located on the filtrate discharge pipe. The flow meter indicates the minimum feed-flow rate of bauxite residue suspension (35 m^3/h) which is strictly related to the end of a cycle, the opening of the press-filter and the discharging phase.

The filtrate produced during the filtration phase is transferred by gravity to a filtrate tank. So as to minimize process fluctuations, a constant flow of filtrate is transferred from filtrate tank to the bauxite residue wash train.

The storage area which has been provided below the filter was designed so as to ensure a storage capacity of three full days of operation.

3.3 Present results obtained and comparison with predicted performances (based on the pilot tests results)

Main filtration parameters and performances are:

- operating temperature is around 30 °C
- up to 12 bars operating pressure
- 72 +/- 1% dry solids in the cake, with a density of around 2000 kg/m^3
- 28 to 30 minutes of total cycle time, which is decomposed as indicated in Table 4.

Table 4. Duration of each sequence of the industrial press-filter cycle

* Closing sequence time	= 2 min
* Filling sequence time	= 3 min
* Compaction sequence time	= 8 to 10 min
* Core blow time	= 4 sec
* Depressurization of membranes time	= 1 min
* Drain drops evacuation time	= 1 min
* Squeezing sequence time	= 8 min
* Opening sequence time	= 1 min
* Discharge sequence time	= 4 min

It appears that the total cycle time is around 28 to 30 minutes. The compaction sequence time is directly related to the mud concentration fed to the press-filter.

When the mud concentration in the last washer is equal to 400g/L, the total cycle time is 28 min. For a mud concentration of 400g/L, the filter can produce 16.9 t/h of filter cakes (in terms of dry solids), which means a productivity of 42.8 kg/h/m^2. As compared to the predicted productivities based on pilot trial results, this value appears to be rather on the lower side of the predicted range (see paragraph 2.3).

Also interesting is to analyze the ''productivity not including dead time'' value. In case of the total filtration cycle time of 28 minutes, the dead time amounts to 9 minutes, which represent 32 % of the total filtration cycle time. Hence, the ''productivity not including dead time'' equals 63.1 kg/h/m^2, which is also within the range but on the lower side of the predicted range based on the results of the pilot trials (see paragraph 2.3.). In paragraph 3.4. we will discuss some considerations which should improve this productivity.

Concerning dryness of the industrial filter cakes obtained, it is interesting to observe that industrial values are slightly higher than values obtained during the pilot trials. Indeed, dryness of pilot filter cakes was in the range 69-71 % whereas the industrial cakes are systematically found in the 71 to 73 % range, which is a fairly good result.

With respect to filter cloth incrustation problems, it can be said that the cloths remain quite clean from any mud cake deposit during a full week of operation.

A weekly cleaning with pressurized water is then sufficient to sustain filtration performances.

3.4 Path forward: ways of improvement

In a near future, Gardanne Alumina Refinery may have to increase the output of its press filter, and following ways are at least contemplated:

- Increase the feed solids concentration to the filter
- Increase the filter feed pump flow rate.

For feed solids increase, Figure 3 clearly demonstrates that by improving solid concentrations of the mud feeding the filter from a reference value of 380g/L to respectively 430g/L and 470g/L would increase the productivity not including dead time from 67 kg/h/m^2 to respectively 78 kg/h/m^2 (plus 17%) and 90 kg/h/m^2 (plus 34 %).

Installation of an Rio Tinto Alcan Deep Cone Washer will allow this step change easily.

Feed pump flow rate increase up to 500 m^3/h is contemplated, in order to reduce filling time by half. Total cycle time should drop at 25 minutes, against an actual duration of 28 minutes. By this way, filter productivity will increase to 48 kg/h/m^2, well in line with predicted results from pilot unit.

4. The press-filter unit installed at AoG

The same methodology was adopted to develop the plate and frame press-filter project of AoG (Aluminium of Greece). As a matter of fact, the same pilot unit was used to carry out the pilot trials. When the very first trials were carried out with the chambered plates, it immediately appeared that the filterability of the AoG red mud was strikingly better than the filterability of the mud of GAP.

Table 5 summarizes the specific cake resistance at a pressure of 6 bars determined on the press-filter pilot unit for GAP and AoG red mud.

Table 5. Specific cake resistance of GAP and AoG bauxite residue as determined during pilot trials

	Specific cake resistance at a pressure of fl P = 6 bar
Bauxite Residue GAP	1.8 10^{12} m/kg
Bauxite Residue AoG	2.1 10^{11} m/kg

As previously stated, it can be concluded that the bauxite residue from AoG have an "average filterability", whereas the bauxite residue from GAP have a "poor filterability".

The trials conducted on the membrane plates confirmed these findings and were recommended for the industrial unit for the same reasons as those detailed in paragraph 2.1.

The filter installed in AoG is equipped with a total filtration surface of 545 m^2.

The average filtration cycle time is 32 minutes and it produces 33.7 t/h of red mud (dry solids basis).

The filtration cycle is decomposed as indicated in Table 6 given below.

Table 6. Duration of each sequence of the industrial press-filter cycle

* Closing sequence time	= 2.5 min
* Filling sequence time	= 1 min
* Compaction sequence time	= 6 to 8 min
* Core blow time	= 30 sec
* Depressurization of membranes time	= 2 min
* Drain drops evacuation time	= 1min
* Squeezing sequence time	= 5 min
* Opening sequence time	= 2 min
* Discharge sequence time	= 10 min

Using the methodology described in section 3.3, it can be calculated that the total filtration time is 14 minutes on a total filtration cycle time of 32 min. Hence dead time represents 56 % of the total filtration cycle, as compared to 32 % for the GAP press-filter.

This is mainly due to the size of the AoG press-filter, which is bigger than the GAP one and required more discharge time but some technological differences with respect to filter-cake discharge also partly explain this difference.

The productivity not including dead time of the AoG press-filter is 142 kg/h/m^2, which appears to be lower than the value which was anticipated from the pilot tests.

This is mainly due to the change in bauxites processed in AoG between the moment of the pilot trials and the moment of the start-up of the filter.

Table 7 gives the typical chemical composition and granulometry of bauxite residue of GAP and of AoG during pilot testing and actual.

Table 7. Chemical composition and granulometry of bauxite residue of GAP and AoG

		Bauxite Residue GAP	Bauxite Residue AoG – Pilot test	Bauxite Residue AoG – Actual
Loss on Ignition	%	8.0		
Al2O3	%	13.3	19.0	15.0
TiO2	%	11.3		
Fe2O3	%	51.1	43.6	47.1
SiO2	%	6.5	7.8	6.7
CaO	%	4.5	12.2	11.1
Na2O	%	3.9	3.5	3.0
D10	µm	0.5	0.6	-
D50	µm	3.3	6.4	26.7
D90	µm	50.0	75.8	106.6

Finally, it is interesting to note that the productivity not including dead time of the AoG press-filter at 142 kg/h/m^2 amounts to more than the double of the value of the productivity of the Gardanne filter at 63 kg/h/m^2, which highlights the fact that the bauxite residue from AoG have a much better filterability than those of GAP.

5. Conclusions

The press-filter installed at Gardanne successfully ensures the industrial production of a dry bauxite residue with a sandy-like, non-sticky appearance and low soda content. The achieved percent solids of the filter cakes are very stable from one cycle to another and equal 72 +/- 1 %.

These product characteristics enable simple product handling and transport and are the prerequisite for transforming bauxite residue from disposal product into a valuable product. The filter cakes are being transported to the storage area without any problems, which is an achievement insofar as this occurs in a crowded area between plant and storage site. Moreover, some projects using Bauxaline in landfills have been carried out and other such projects are being considered.

Hence, it can be stated that the initial target set for the implementation of a press filter in Gardanne is fulfilled.

It also important to mention that the pilot work predicted well the press-filter performance and allowed for the proper selection and sizing of the equipment to reach the target bauxite residue quantities to be treated.

With respect to the press-filter of AoG, it has been a success-story since its start-up. The filter cakes of AoG's bauxite residue are used by some of the major Greek cement plants for some of their cements.

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