ALUMINA LIQUOR CLARIFICATION: FILTER MEDIA CLASSIFICATION AND DEVELOPMENT USING IN-LINE, PILOT SCALE, PORTABLE FILTER TESTING EQUIPMENT

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Abstract

Historically manufacturers of industrial filtration media select candidates of new filter media for further field testing based on physical media specification and laboratory testing. Even though these tests have developed the technical sophistication to measure physical parameters such as fluid flow dynamics and equivalent pore size, ultimate design validation of the candidate filter media has been based on large-scale trials in the customer's process circuit. This may typically incorporate a full filter vessel trial with the results directly affecting the customer's product at the time of the trial. These trials are often not easy to schedule or monitor and the time frame of design validation can often be lengthy.

Over the last year Albany International has used a custom built, portable, filter testing unit to test new filter media in the clarification circuits of several Alumina refineries in Australia. The test unit can be connected in-line into the process header and new filter media is tested using 'live' liquor without disrupting the customer's manufacturing process or product.

While full filter vessel trials are a necessary developmental step with any new filter media, the use of the in-line pilot scale test unit has refined and expedited the media selection and design parameters to a significant degree prior to such trials. The traditional multiple large-scale 'trial' development has been replaced by small scale, non-intrusive, intermediate-stage testing.

This paper presents the findings of several infield comparative tests, highlighting the operational and variable differences observed utilising the filter testing unit in Alumina refineries in Australia, and illustrates how these findings are utilised in implementing design improvements to filter media.

1. Introduction

The measurement of physical parameters of process filter media as an indicator of their performance under operating conditions has long been the differentiating tool for filter media selection. The use of physical parameters of filter media in their characterisation developed over the years to include measurable characteristics such as thickness, basis weight, and air permeability.

In the 1990's this set of measurable characteristics was expanded to include two other parameters; water permeability, and pore size analysis.

Water permeability over a range of pressure drop settings has been used as an effective tool to compare the propensity of filtration media to allow water to pass through it. This test was developed to analyse the solid/liquid and fluid flow dynamics that are neglected when using only air permeability measurements. One shortfall of this test is that there is no allowance for differences in density, temperature and viscosity between the water in the permeability tester and process liquors in wet filtration applications.

Pore size distribution signatures were developed to better comparatively classify filtration media with regard to the relative size and concentration of pores in a filter media structure. This procedure has been used as a comparative test rather than a method to specify discrete particle size capture capability. While the comparative test provides useful insight into filter media structural differences, the discrete pore size values cannot be relied upon as the method relies on a number of assumptions that are frequently inconsistent with actual filter media structure (see appendix 1a).

These methods of filter media characterisation, while effective in classifying differences between filter media structure, do not provide an effective indicator of media performance under operating conditions. This is especially so in extreme operating conditions such as the clarification of caustic liquor in the Alumina refining process.

1.1 *Pilot Filter*

This paper looks at the use of a custom-built, portable pilot filter to characterise the performance of different filter media using actual process liquor at two Alumina refineries in Australia. The pilot filter was used on-line with live process liquor. The results characterise filter media performance specifically for each refinery with reference to liquor flow rate against pressure and media resistance, and filtrate clarity. The information gathered has been utilised in implementing further design improvement to filter media and has formed the basis of refinery-specific filter media recommendations.

2. Apparatus — alumina clarification pilot filter

The pilot filter and instrumentation panel are mounted into a transportable frame. The unit is typically hard piped into the customer's filter feed header in close proximity to the production Kelly filters. Process measurements collected via data logger and laptop interface from vessel instrumentation include temperature, pressure, and liquor flow rate. Filtrate solids are assessed in the laboratory after taking several samples at set time intervals during the filtration cycle. Relative media resistance is calculated using recorded process liquor variables in the Carman-Kozeny equation for flow through a packed bed (see appendix 2).

KEY WORDS: filter media, pilot filter

Figure 1 — Pilot Filter — computer interface

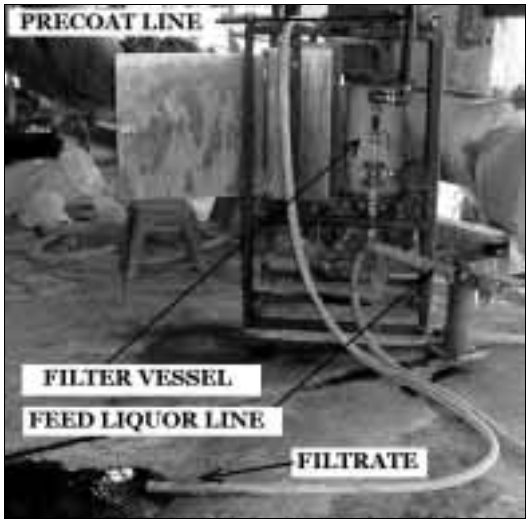

Figure 2 — Pilot Filter — process connections

The filter media is manufactured into a small filter leaf that is supported on a vertical frame installed in the filter vessel.

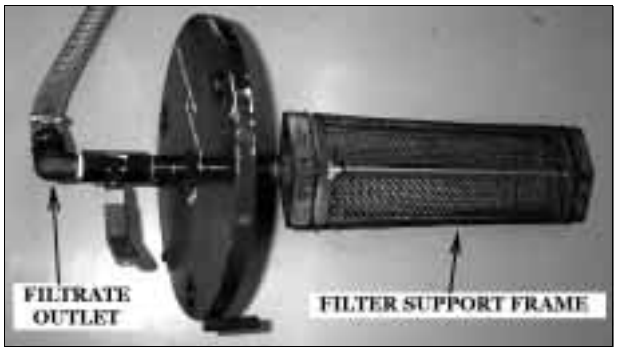

Figure 3 — Pilot Filter — filter frame

3. Repeatability of results

With the custom design of the pilot filter vessel, it was important to establish the repeatability of test results in the first refinery of application. With so many process variables that exist in the Bayer process which affect the clarification circuit, one non-variable was considered to be the filter media. With this assumption the Carman-Kozeny equation for flow through a packed bed was utilised to calculate media resistance in separate filtration tests. These tests were conducted on the same day in quick succesion, so as to minimise errors induced by any time lag and process change between the time of liquor sampling for viscosity analysis and the time of the filtration trial.

It should be noted that the Carman-Kozeny equation for flow through a packed bed assumes a constant pressure drop through the bed. During the filtration cycle in Alumina clarification, pressure builds and flow decreases as the filter cake grows. It was therefore considered that the media resistance, calculated using start up pressures and flows, was more relevant to the repeatability test than the cake and media resistance at the end of the filtration cycle.

It was found that the calculated media resistance from such tests was repeatable to within a standard deviation of 2.5% of the mean. It was concluded that these results indicated the pilot filter tests expressed a level of repeatability that would allow meaningful comparison between the averages of results for each filter media tested.

4. Case studies

This paper will present data gained at two Alumina refineries in Australia. Case Study 1 was conducted at the Alcoa Pinjarra refinery in WA, and Case Study 2 was conducted at Queensland Alumina Limited in Gladstone. It should be noted that due to the proprietary nature of the individual refinery's operating conditions, the data labels have been removed from the charts presented.

The results detailed below represent averages of several tests and are abstracts from a complex set of tests conducted on a wide variety of filter media. They are provided as an example of the nature of the information obtainable, and an indication of how this data may be utilised in the modification of filter media design.

Various types of woven filter media were examined at each site. These media were constructed using a variety of weave patterns and included yarn structures such as spun, multifilament, monofilament and combinations therein. The detail of each individual media design is not a topic for this paper, and each filter media will be referred to by numerical identification only.

4.1 *Case study 1 — Alcoa World Alumina, Pinjarra WA*

4.1.1 *Test procedure*

The level of pre-coat was determined by scaling down the volume of pre-coat used in the production Kelly filters, by the relative volume of the pilot test vessel to production Kelly vessel.

After pre-coating the sample filter bag, the trial was conducted in two stages. Stage 1 analysed the relative particulate capture ability of each cloth. Stage 2 analysed the ability of each cloth to maintain a set point flow under flow control.

Stage 1: Flow rate was determined by scaling down the set point flow in production Kelly filters in a linear relationship to filtration area. The press was then set to run at 150% of set point flow to ensure conditions were more aggressive in the pilot filter than that in the production filters and the results would be conservative. Without changing the feed valve position, filtrate samples (20) were taken starting at liquor breakthrough and continued over 1 hour of filtration. This test was aimed at observing both initial and final solids, as well as the rate of decay of solids in the filtrate.

Stage 2: Flow rate was set at equivalent set point flow, and under flow control were allowed to run for a full filtration cycle. This test was aimed at testing the ability of each cloth in maintaining a set point flow on a comparative basis.

4.1.2 *Results*

Media 1 referred to below was the filter media used in production by the refinery in the Bayer clarification circuit at the time of the trials. Media 2, 3 and 4 are all monofilament filter media, while media 5 and 6 are monofilament / multifilament combinations.

4.1.2.1 *Stage 1: filtrate solids*

Figure 4 indicates how two monofilament filter media of different weave patterns compare with the current production incumbent media in their ability to capture solids. After one hour both monofilament media provide greater particle capture than the incumbent media. However, media 3 provides lower breakthrough solids at the beginning of the filtration cycle, and a significantly faster decay rate of solids in the filtrate than the other media. It can be seen that media 3 in this case exhibits significantly greater particle retention early in the filtration cycle where the filter cake has not yet been established.

In a similar manner in figure 5, the multifilament media 6 can be seen to impart greater particle capture capabilities than media 5 or the incumbent media 1.

Media 3 is similar to media 4 in construction, and media 3 has undergone a further filter media finishing process. Figure 6 illustrates how this finishing process

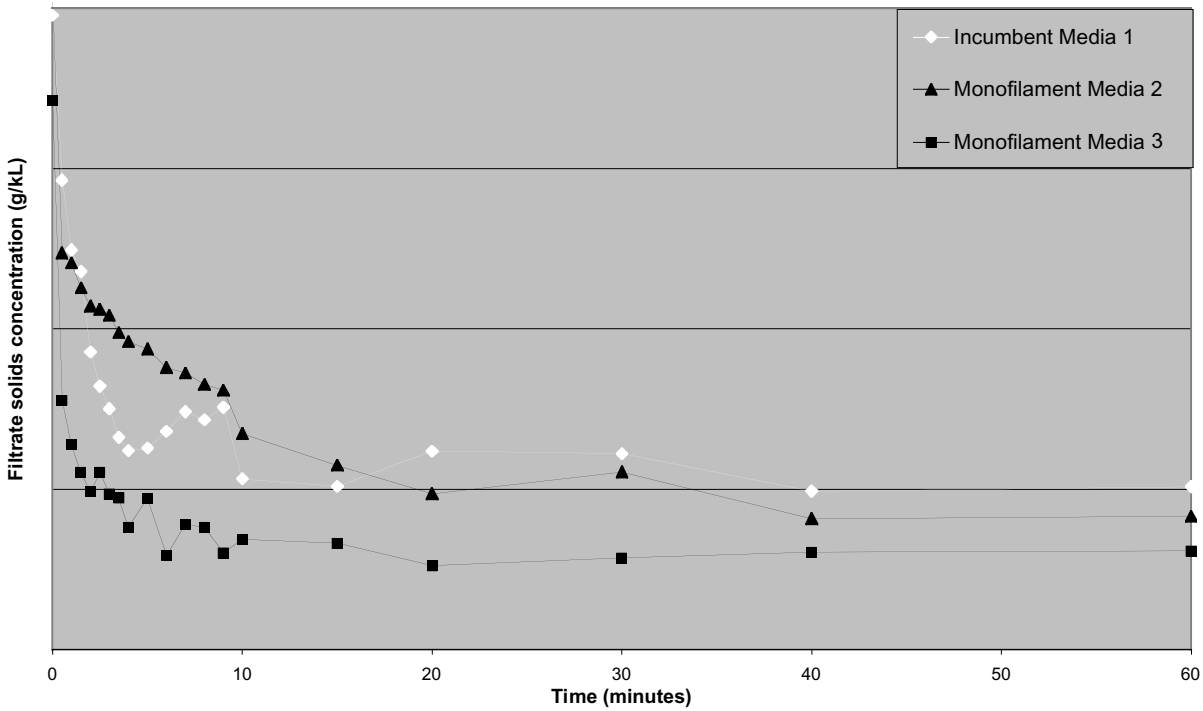

Figure 4 — Average Filtrate Solids Decay — Monofilaments

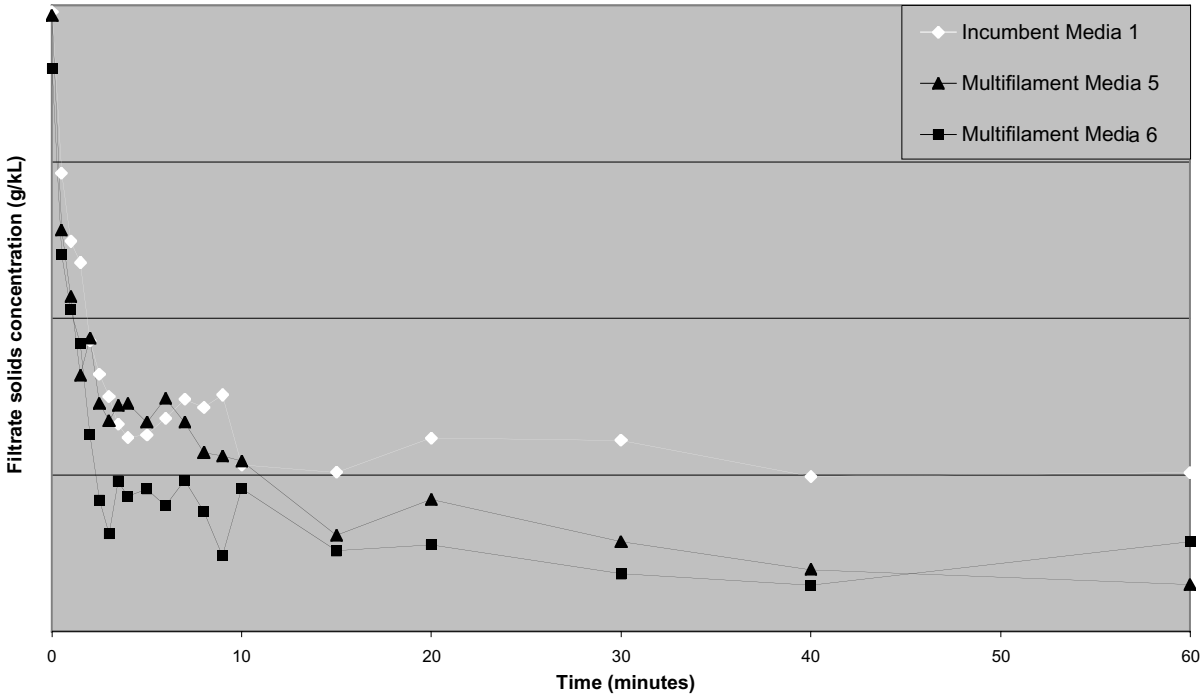

Figure 5 — Average Filtrate Solids Decay — Multifilaments

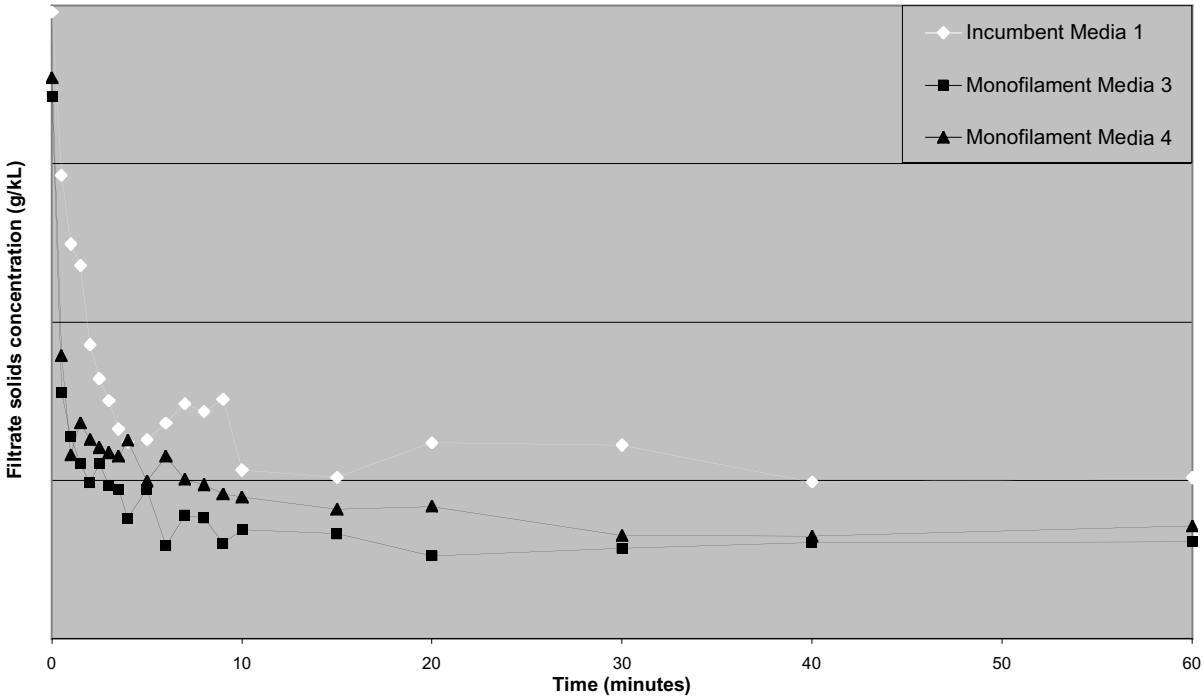

Figure 6 — Average Filtrate Solids Decay — Calandering Effects

improves the particle capture capabilities of the filter media. In this manner, the use of the portable pilot filter enables the filter media manufacturer to quantify the benefits of particular steps in the filter manufacturing process to each individual Alumina refinery.

4.1.2.2 *Stage 2: liquor flow*

Conventional filter media design is often a balance between particle capture and liquor flow rate. Typically increased particle retention is at the expense of liquor flow. However, this case study has shown that by varying the filter media structure and design, it is possible to increase both particle retention capability as well as liquor flow rate.

Figure 7 is an example of the filtration cycle obtained using the incumbent filter media. The set point flow could be maintained for 6.3 hours. After 5.7 hours the feed valve was fully open, and after 7 hours the flow rate had dropped to 50% of the set point flow.

Figure 8 illustrates media 3, which was able to maintain the set point flow for 7.5 hours, with the flow dropping to 80% of the set point flow rate after 9 hours of filtration.

In this example, it is important to note that the start up pressure (and indeed filter media resistance) of the media 3 is significantly greater than the incumbent media 1, yet media 3 is able to maintain the set point flow for significantly longer than the incumbent media 1. This, coupled with the fact that the particle retention characteristics of media 3 are better than the incumbent media 1 (see figure 5), indicates that media 3 may be more suited to this particular refinery's clarification process than the incumbent filter media 1.

It should also be noted that the pore size analysis of these filter media (see appendix 1b) indicates that while media 3 is likely to exhibit the greatest particle retention, it also suggests the greatest media resistance which may limit liquor flow. This is apparent where the pore size signature of media 3 is in the lower pore size range, with a lower area under the curve. While the particle retention characteristics of media 3 where confirmed in the pilot filter, the ability of media to maintain flows for longer than the incumbent media seen in the pilot filter is not apparent in the pore size analysis.

With filtrate capture characteristics and liquor flow dynamics quantified for many types and finishes of filter media, Albany International was able to identify operating advantages to be realised by full scale production trials on the basis of performances in the pilot filter with the process liquor at Alcoa's Pinjarra refinery.

4.2 *Case study 2 — Queensland Alumina Limited, Gladstone QLD*

4.2.1 *Test procedure*

The live feed liquor to the pilot filter was introduced in the same manner as in the QAL production Kelly filters with respect to flow and pressure control.

The trials, which compared each developmental fabric against the standard filter media, were conducted in two stages. Stage 1 was to analyse the relative particle capture ability of each cloth. Stage 2 was to analyse the comparative ability of each cloth to maintain liquor flow.

Stage 1: Filtrate samples (20) were taken starting at liquor breakthrough and continued over 1 hour of filtration. This test was aimed at observing both initial and final solids in the filtrate, as well as the rate of decay of solids in the filtrate.

Stage 2: The liquor flow rate was monitored over a ten-hour filtration cycle.

4.2.2 *Results*

Media 1 referred to below was the filter media used in production by the refinery in the Bayer clarification circuit at the time of the trials. Media 2 and 3 are monofilament filter media, while media 4 and 5 are monofilament / multifilament combinations.

4.2.2.1 *Stage 1: Filtrate solids*

Figure 9 shows that the monofilament media 3 was able to achieve a faster decay rate of filtrate solids in the very early stage of the filtration cycle than the incumbent

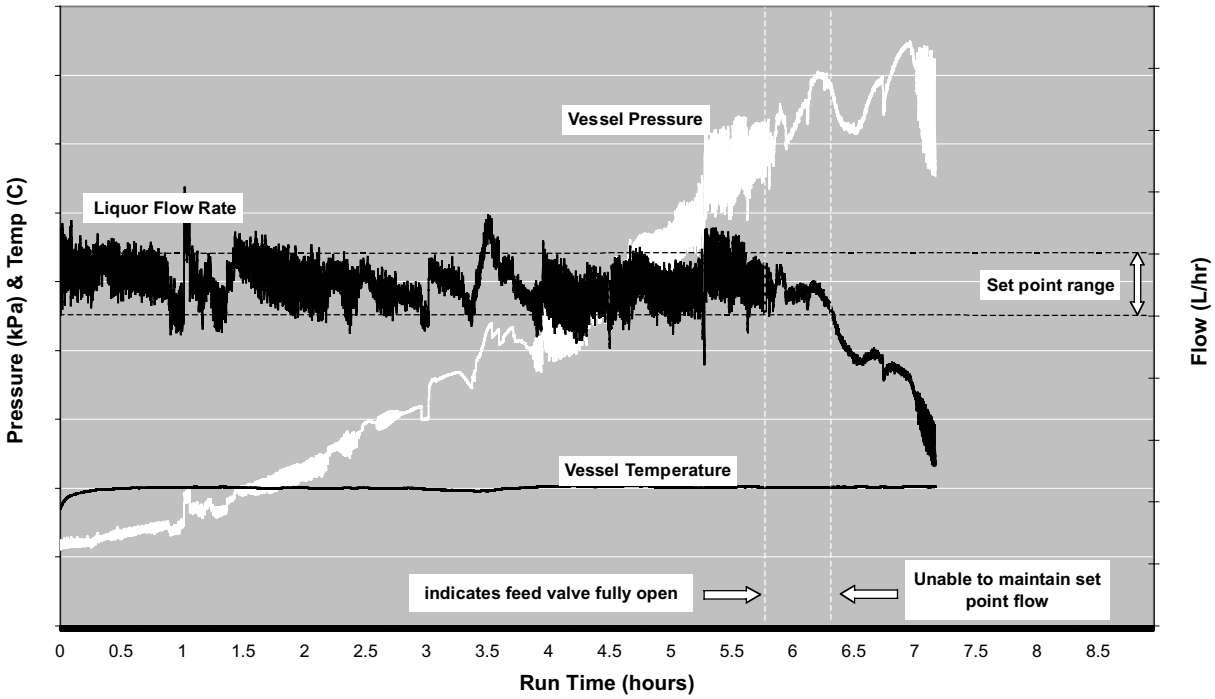

Figure 7 — Full Cycle Under Flow Control — Media 1

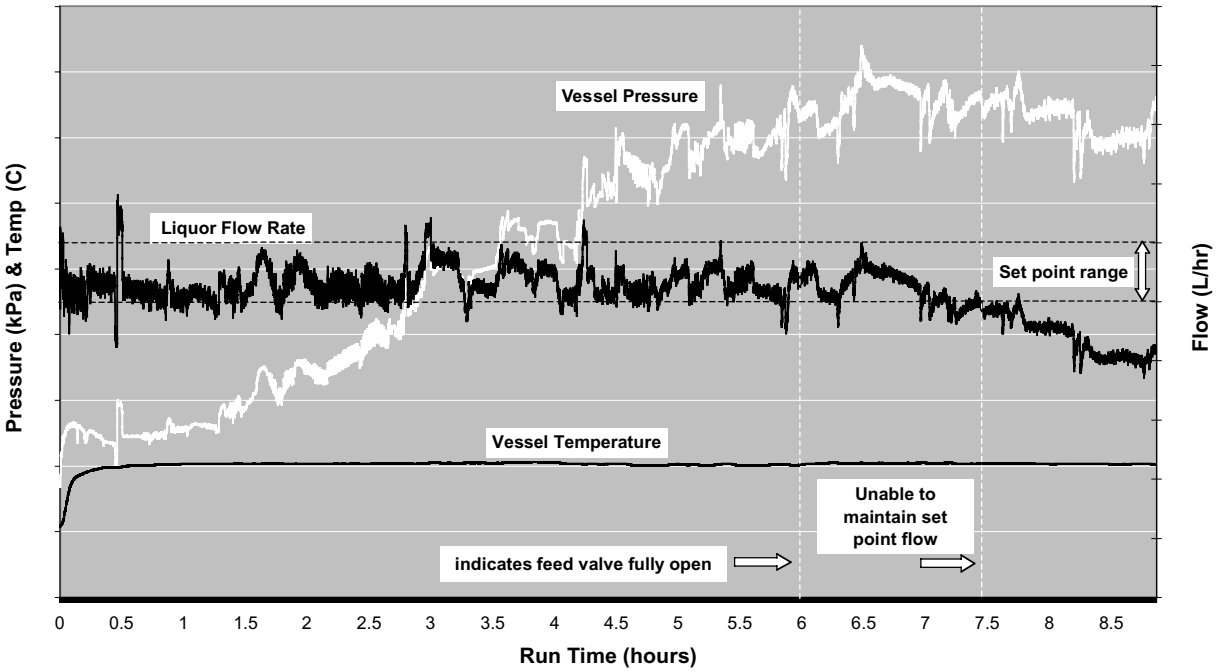

Figure 8 — Full Cycle Under Flow Control — Media 3

Media 1. However after 3 minutes there was no significant difference in the particle capture rates of media 3 compared to media 1.

Figure 10 illustrates that the mono/multifilament media 4 and 5 had a less efficient particle capture rate than both the media 1 and 2. It appears that this structure is less appropriate for the process liquor and pressures at QAL than the incumbent filter media.

4.2.2.2 *Stage 2: liquor flow*

As mentioned in case study 1, conventional filter media design is often a balance between particle capture and liquor flow rate. The results of Case Study 2 are typified by this where the tighter filter media yields increased particle retention is at the expense of liquor flow.

The incumbent filter media 1 was able to maintain both the highest initial flow as well as the highest overall full cycle flow compared to all the developmental filter media — see figure 11. The filter cake on the filter media 1 after 10 hours of filtration was noticeably larger than all the other filter media.

Of all the developmental filter media tested, the monofilament filter media 3 provided the highest overall liquor flow illustrated in figure 12. The mono/multifilament filter media 5 and 6, and the tight monofilament filter media 2 provided significantly higher resistance to flow than the incumbent filter media 1.

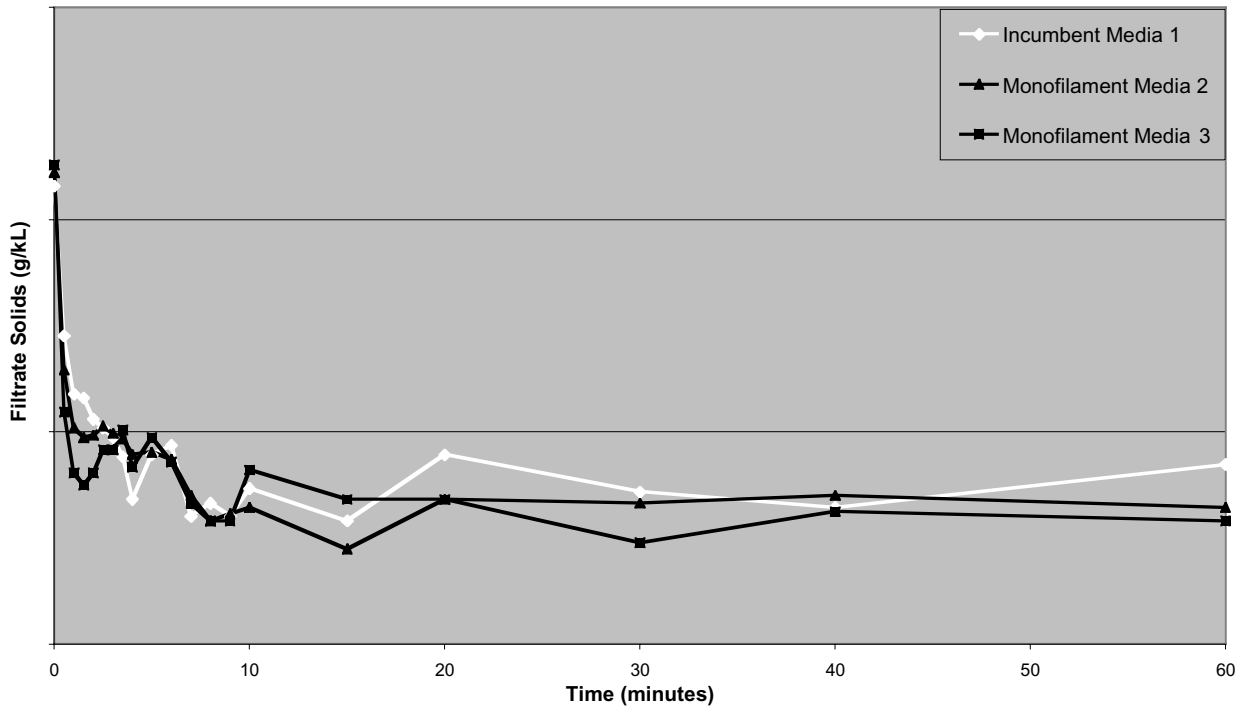

Figure 9 — Average Filtrate Solids Decay — Monofilaments

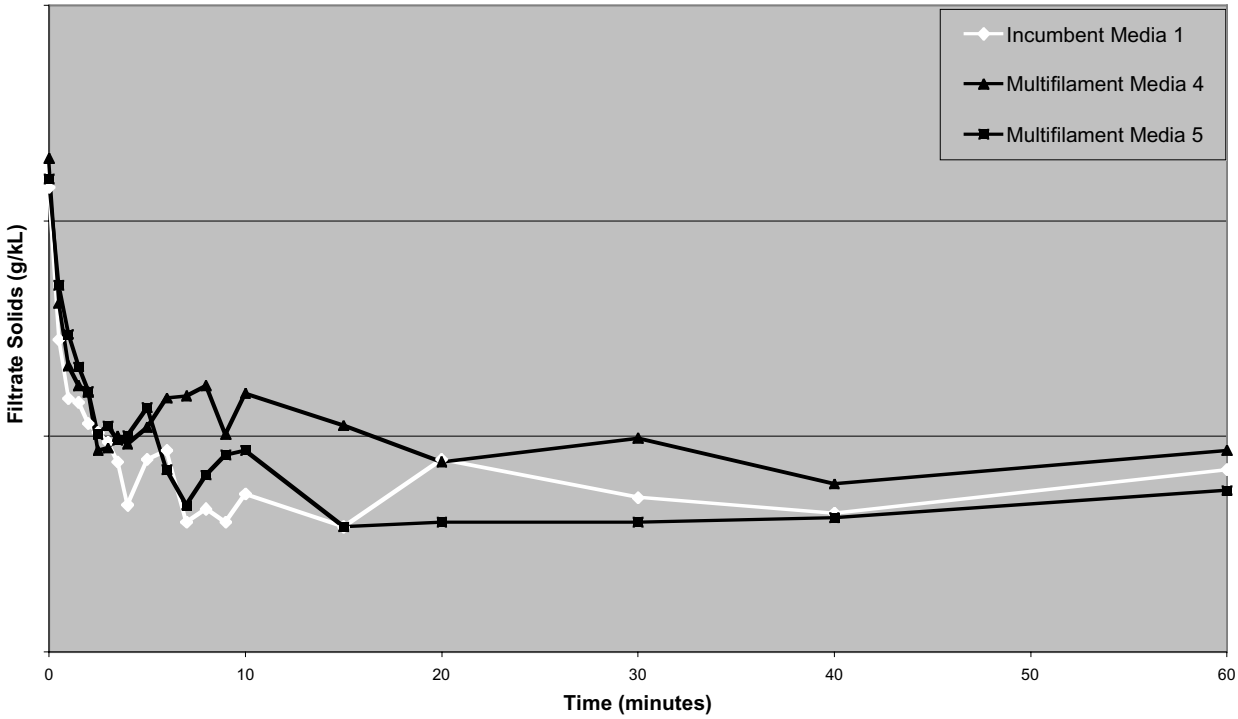

Figure 10 — Average Filtrate Solids Decay — Multifilaments

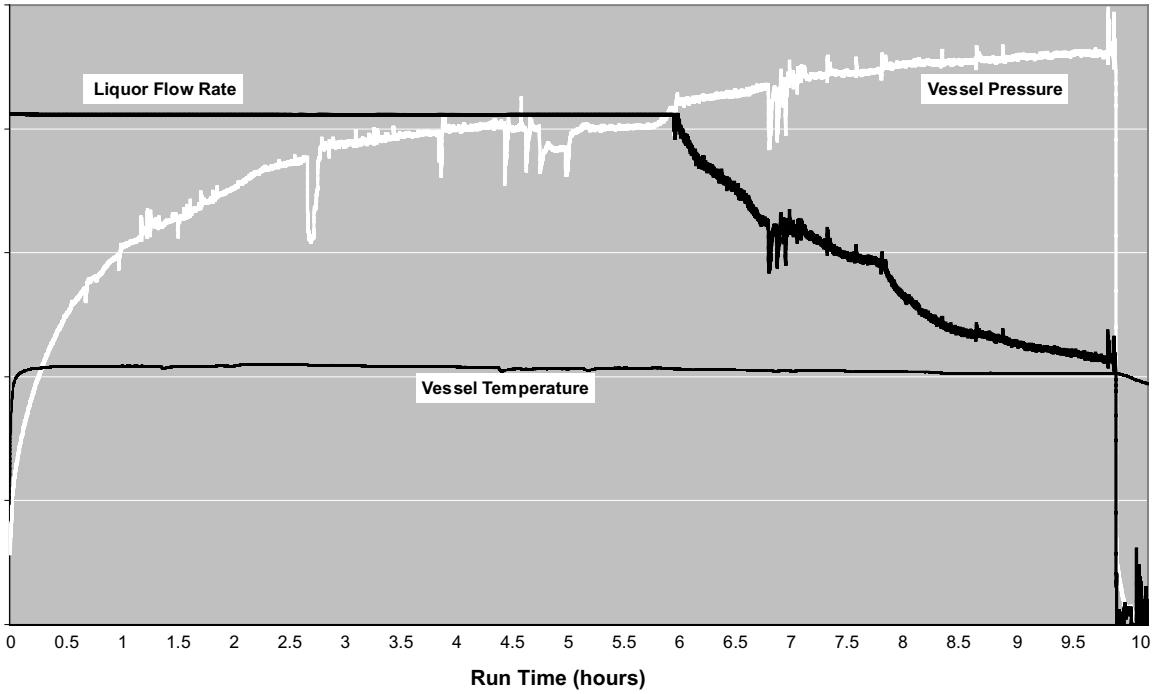

Figure 11 — Filtration Cycle (10 hours) — Incumbent Media 1

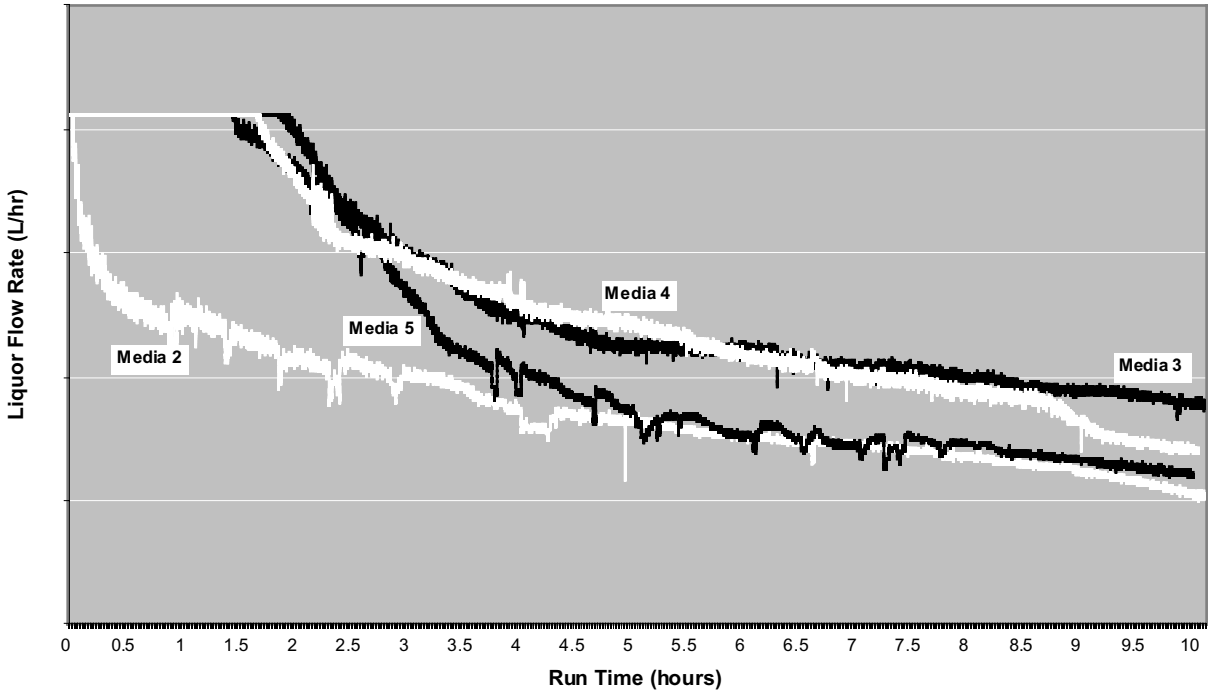

Figure 12 — Filtration Cycle (10 hours) — Developmental Media

Albany International's product development program in new generation filter media is continuing to further develop weaving concepts. The results of this study will re-direct this development program with the substitution of yarns for more suitable structures to the specific filtration pressure range of the QAL clarification process.

5. Conclusion

The use of the custom engineered pilot filter testing unit has provided a significantly increased understanding of how a variety of filtration media perform with individual Alumina refinery process liquors. This information has provided filter media characterisation beyond the traditional physical media specification.

This study has enabled filter media design validation with greater accuracy and relevancy to the individual customer, with a significantly shorter time frame than traditional methods. The testing program, whilst performed on-line with live process liquor, does not affect the customer process or product at the time of testing.

Albany International will continue to use the portable, pilot scale, filter-testing unit in its research and development program as a performance investigation and design validation tool in Alumina refinery clarification circuits.

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Dale Hosking	Operations Process Engineer — Clarification
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Appendix 1

Pore Size Analysis

Appendix 1a

Porometer Assumptions:

- All pores are filled and the test sample is thoroughly wetted and saturated with the prescribed liquid
- All pores in the filter media are presented by a parallel wall cylindrical model
- Liquid flow during porometer operation is laminar

The relationship between pore size and surface tension of wetting liquid and air pressure require for the expulsion of the said liquid and is represented by the equation below.

$$D = 40 \gamma / P \qquad \text{… Equation 1.0}$$

Where D = Pore Diameter in μm

γ = Surface tension of the liquid in mN/m

P = Applied air pressure in millibar

Appendix 1b

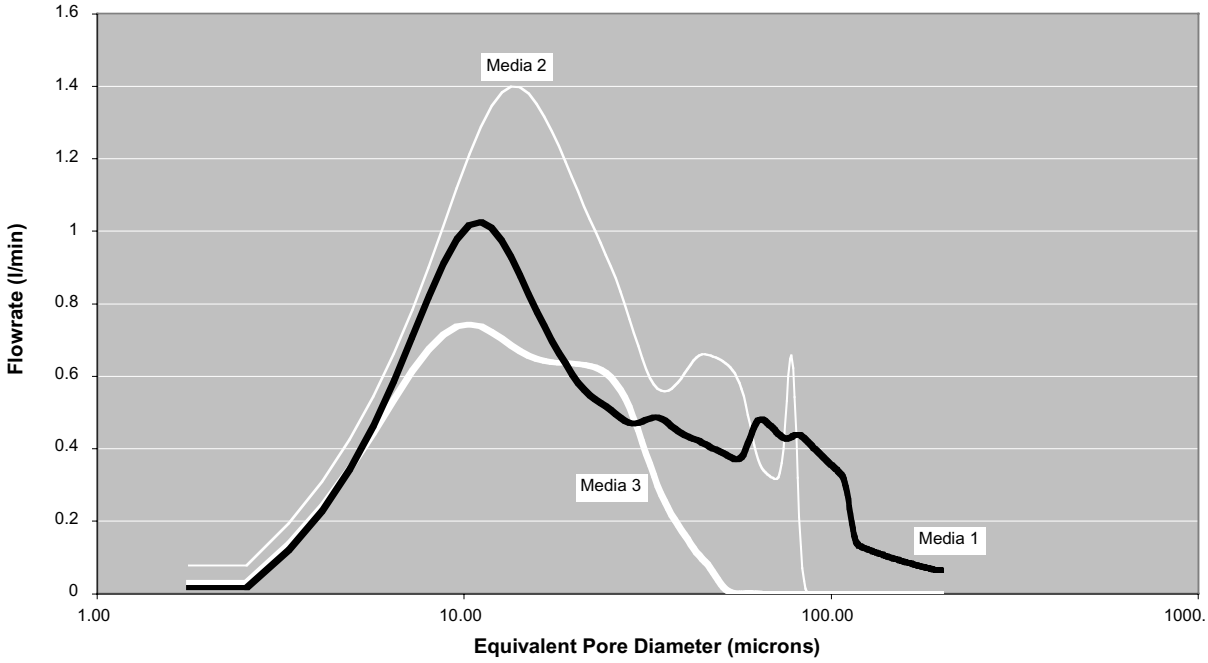

Figure 13 — Pore Size Analysis

Appendix 2

Re-arranged Carman-Kozeny equation for flow through a packed bed

$$\frac{dV}{dT} = \frac{\alpha C \mu V}{A^2 \Delta P} + \frac{\mu R_m}{A \Delta P} \quad \text{… Equation 2.0}$$

where dt/dV = 1 / feed flow at time 't'
ν_o = initial feed flow
α = Filter cake resistance
C = Feed solids concentration
μ = Liquor viscosity
V = Filtrate volume ≈ feed volume
A = Filtration area
ΔP = Pressure drop through the press
R_m = Cloth resistance

Solved for R_m gives …

at t = 0, $\frac{dt}{dV_o} = \frac{1}{\text{Initial feed flow}} = \frac{1}{v_o}$

and V = 0, $\therefore \frac{\alpha C \mu V}{A^2 \Delta P} = 0$

$$R_m = \left(\frac{dt}{dV}\right)_{t=0} \times \frac{A \Delta P}{\mu}$$

$$\therefore R_m = \frac{A \Delta P}{\mu v_o} \quad \text{… Equation 3.0}$$

Note, cake resistance can be calculated by….

$$\alpha = \left(\frac{dt}{dV} - \frac{\mu R_m}{A \Delta P}\right) \times \frac{A^2 \Delta P}{C \mu V} \quad \text{… Equation 4.0}$$

where $\frac{dt}{dV} = \frac{1}{\text{average feed flow}}$