Paste 2023 – GW Wilson, NA Beier, DC Sego, AB Fourie & D Reid (eds)

doi:10.36487/ACG_repo/2355_26

Improved slurry dewatering via process water conditioning: equipment sizing and tailings storage implications

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Abstract

The potential processing risks associated with the presence of dispersive, swelling clays in mineral orebodies are well known. Uncontrolled dispersion of such clays on contact with water results in problems including poor tailings dewatering and consolidation, increased reagent demand, dirty process water and reduced mineral recoveries and increased plant maintenance with associated economic, environmental and safety implications.

Dispersive clays are typically managed via approaches including high dosages of both polymer coagulant and flocculants in thickening, high-pressure secondary dewatering steps such as pressure filtration, belt press filtration or centrifugation, or inline flocculation and deposition of thickened tailings. Commonly, the secondary dewatering step requires re-dosing of additional coagulant and/or flocculant to regenerate a flocculated structure to develop acceptable dewatering rates.

An alternative, more proactive approach to managing tailings containing dispersive clays is to promote controlled dispersion of the clays by conditioning the process water circuit to induce a coagulative state in the clays on first contact, reducing clay breakup and ultra-fines generation during initial wetting of the ore on entry to the plant. Clay dispersion control via process water conditioning involves reagent dosing into the process water at only a single location, however, this delivers benefits at every stage of dewatering across the tailings management flow sheet.

The potential site-wide benefits of this approach are demonstrated for the ClariVie44®process water conditioner, using a combination of flocculation and settling test results, compression-permeability testwork and pressure filtration model simulations from a range of different tailings samples.

The benefits demonstrated include step changes in thickener fines capture and overflow clarity, material improvements in process plant operability and reduced down time due lower fines recirculation, elimination of coagulant dosing in the thickener and downstream secondary dewatering operations, increases in pressure filtration throughputs of up to 300%, improvements in any process technology employing secondary flocculation due to more homogenous structure development, and improved tailings storage facility (TSF) operability and lower risk due to less segregation, faster consolidation and operational dry densities and improved decant water management. Test data from the Jagersfontein kimberlite tailings are also discussed in the context of the recent TSF failure and the potential role of dispersive clays as a risk factor at this site.

Keywords: *clays, filtration, consolidation, coagulation, flocculation*

1 Introduction

The potential processing risks associated with the presence of clays, in particular smectitic swelling clays, in mineral orebodies are well known (Gräfe et al. 2017), particularly in operations where the combination of tailings mineralogy and the chemical characteristics of the process water circuit generate dispersive slurries, i.e. clays undergo uncontrolled dispersion and delaminate into individual platelets. The negative impacts of dispersed, ultrafine clays, even at low mass fractions, can include poor tailings dewatering (whether in thickeners, filters or consolidating in the tailings storage facility [TSF]), increased reagent demand, dirty process water and reduced mineral recoveries and increased plant maintenance. The high-level impacts of these factors range from economic, significantly increased capital and operating costs, to environmental and safety risks around the long-term storage of the tailings.

The common approaches to managing tailings containing dispersive swelling clays are to adopt one or all of the following: utilise high dosages of both polymer coagulant and flocculants in thickening, utilise a high-pressure secondary dewatering step such as pressure filtration, belt press filtration or centrifugation, or secondary flocculation of thickened tailings (Gräfe et al. 2017). Commonly, the secondary dewatering step requires re-dosing of additional coagulant and/or flocculant to regenerate a flocculated structure to facilitate efficient operation.

An alternative, more proactive approach to managing tailings containing dispersive clays is to condition the process water circuit to induce a coagulative state in the clays and ultra-fines. This controls and limits dispersion of the clays on entry to the process plant and the clays will remain in a coagulated state throughout the process providing enhancements and benefits across all process dewatering operations from the thickener to the TSF.

Within a metallurgical circuit, the first contact between newly mined ore and the plant process water is typically at the milling or scrubbing unit process. This step is critical in determining the colloidal state of the resulting slurry, since the clays within the ore absorb water and other polar molecules between their unit layers which initiates swelling. Once the clays have undergone swelling and delamination, the process is irreversible and therefore, it is this first contact that needs to be controlled. The degree of swelling depends largely on the nature and concentration of the cations contained in the contacting water and the ion exchange state and clay types involved (Sequet et al. 1975; Mering 1946).

Clays in a monovalent exchanged state and/or exposed to water containing monovalent cations in low concentration tend to exhibit unlimited swelling; a condition commonly referred to as uncontrolled dispersion. Monovalent cations having small hydration shells can penetrate easily into the interlayer spaces between adjacent clay platelets which are typically occupied by two or three stacked layers of water molecules which themselves are bound to the clay platelet surfaces. Once in the interlayer position, the cations can draw in more water molecules by osmotic action and therefore, initiate hydraulic swelling.

Clays in a divalent exchange state or exposed to water with a high proportion of divalent cations on the other hand tend to exhibit limited swelling since the cations have a disruptive effect on the interlayer water layer structure and they can provide links between charged sites on adjacent silicate sheets. Furthermore, once fully hydrated, a more coagulated state will exist such that dewatering is enhanced by the moderation of the number of ultrafine particles present, a coarsening of the fine end of the particle size distribution and a generally improved system permeability. This condition is commonly referred to as controlled dispersion (Figure 1).

Vietti Slurrytec (VST) has developed the ClariVie44® process water conditioner which is a blend of specific cations designed to increase the conductivity of a process water circuit and promote a more optimal cation content without introducing environmental and corrosive pollutants. ClariVie44® is dosed into the process water circuit to increase the conductivity of the circuit and thereafter, smaller top-up doses are required to compensate for the diluting effect of the raw water make-up.

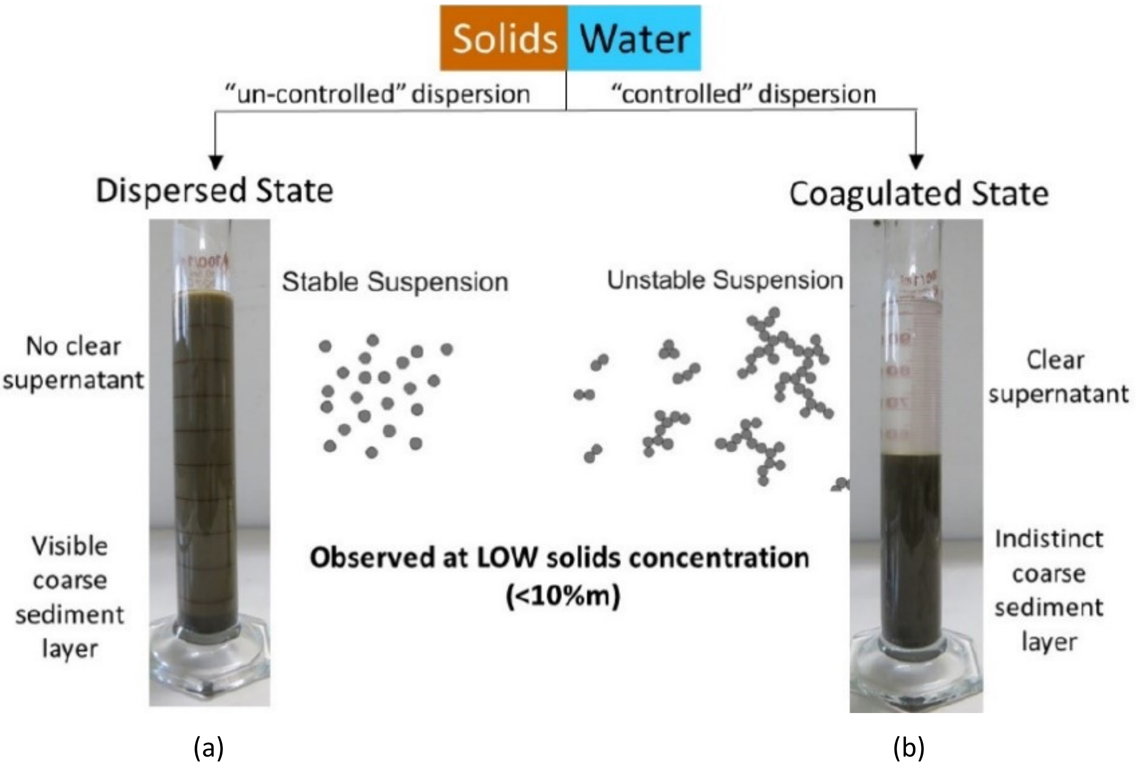

Figure 1 Illustration of (a) uncontrolled and (b) controlled dispersed slurries and key characteristics (from Vietti et al. 2019)

Since the process water conditioner is not polymer based, it is recycled in the process water circuit without the need for continuous dosing. Being recycled within the process water, it does not necessarily need to be dosed into the water at a specific location relative to dewatering unit operations, yet from this single dosing point, it will deliver benefits across every dewatering operation within the flow sheet.

In this paper, previous work (Vietti et al. 2019) is expanded upon to highlight the site-wide benefits of a process water conditioning approach using ClariVie44® for sites dealing with dispersive, swelling clays. Using test data and model simulations for a range of different tailings (coal, mineral and construction sand and kimberlite) this paper will illustrate the significant positive impacts for plant operation, pressure and belt press filter performance and sizing, as well as TSF consolidation rates. Test data from the Jagersfontein kimberlite tailings reprocessing operation is also discussed in the context of the recent TSF failure at this site.

2 Materials and methods

2.1 Material details

Material property data from a varied range of sites in Australia and South Africa were used for the purposes of this investigation:

- A thermal coal tailings from Queensland, Australia, Northern coalfields (Thermal Coal Tailings 1).
- Two thermal coal tailings from different seams in the New South Wales Hunter Valley, Australia (Thermal Coal Tailings 2 and 3).
- A construction sand tailings from a Victoria, Australia, sand quarry (Sand washing tailings).
- A kimberlite tailings from the Jagersfontein site in South Africa (Kimberlite).

Ideally, tests to assess the benefits of process water conditioning should be conducted with dry run-of-mine (ROM) samples such that controlled dispersion benefits on initial wetting can be captured. In practice, it can be difficult to source a suitable dry sample, however, testwork has shown that significant improvements can be seen even with dosing of a conditioner into pre-dispersed slurries. Importantly, if responsiveness has been demonstrated on pre-dispersed slurries, this can be treated as a baseline for the expected level of improvement with conditioning, however, once the positive benefits of control of initial clay dispersion are seen, the level of improvement in slurry behaviour observed will be significantly higher. An example of the improvements in dewatering offered by clay dispersion control over coagulation of a pre-dispersed slurry alone are illustrated in Figure 2 from historical testing on kimberlite sample (Fox kimberlite). Of the samples listed above, only the kimberlite tailings from Jagersfontein was tested from a dry sample. All samples subject to compression-permeability testing were tested after ClariVie44® dosing into pre-dispersed slurries.

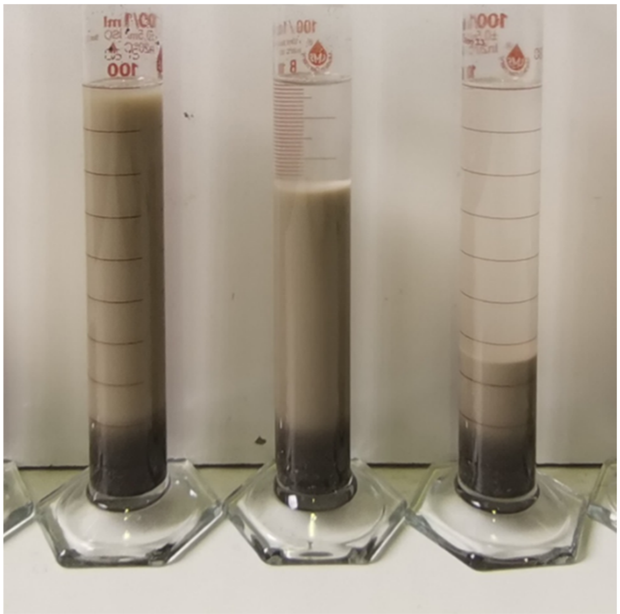

Figure 2 Example settling behaviour of a kimberlite sample under different dispersion conditions. From left: uncontrolled dispersion; ClariVie44® added to uncontrolled slurry; controlled dispersion

Material properties and details of the samples used are presented in Table 1. As these samples were from a range of different types of study, there is a somewhat inconsistent level of detail around basic material properties across the sample set; for example, no particle sizing information was available. However, they represent a range of levels of responsiveness to process water conditioning to illustrate the benefits of the approach.

Table 1 Sample properties

Tailings sample	Supernatant Conductivity (µS/cm)	Supernatant pH	Slurry description
Thermal Coal 1	1.02	8.2	Slow settling fine fraction, mixed clay content
Thermal Coal 2	2.77	8.4	Non-settling ultra fine fraction, smectitic clay content
Thermal Coal 3	2.71	8.7	Non-settling ultra fine fraction, smectitic clay content
Sand washing	3.07	8.5	Slow settling fine fraction, mixed clay content
Kimberlite	1.03	8.7	Non-settling ultra fine fraction, 30 to 50% < 30 µm

2.2 Testing methods

2.2.1 *Flocculation and water conditioning*

Primary flocculant tests reported were conducted as per standard cylinder testing methods with dosing (typically in two stages) of the required volume of a dilute (typically 0.025% w/w) flocculant solution into the slurry, followed by gentle mixing and monitoring of the settling rate, clarity and sediment density.

If polymer coagulant was used, the required volume of a diluted (0.5% w/w) solution was added and mixed into the slurry prior to the flocculant addition.

As noted above, to properly assess the full benefits of the process conditioning approach (i.e. both the dispersion control and the coagulation of fines), the required mass of ClariVie44® would be dosed into a process water sample and allowed to dissolve. Then the dry ROM tailings material would be slurried into this pre-conditioned water.

In the case of the samples subject to detailed compression-permeability testing in this work, they were thickener feed samples taken prior to any coagulant or flocculant addition. Process water conditioning was conducted via direct addition of the required mass of ClariVie44® into the slurry followed by sufficient time for dissolution.

Following water conditioning, primary cylinder flocculation tests can be conducted to assess benefits in thickening. Secondary dewatering test work (e.g. filtration or compression-permeability tests) could be conducted on a simulated thickener underflow sample, however in the current work, for simplicity, the compression-permeability behaviour of the thickener feed samples was tested with and without ClariVie44® conditioning in the absence of any polymer flocculation.

2.2.2 *Filtration/compressibility-permeability characterisation*

The tailings compressibility-permeability (C-P) information used in both the filtration modelling as well as discussions around tailings consolidation were obtained from a laboratory scale automated pressure filtration apparatus at the University of Melbourne using the approach outlined in de Kretser et al. (2001). The piston-driven pressure filtration apparatus characterises the filtration and compressive behaviour of substrate filter cakes.

The data output from the test rig allows determination of the filter cake resistance (which is inversely proportional to permeability/hydraulic conductivity) and compressibility (i.e. density versus effective stress) material properties. These output properties are mathematically related to the geotechnical parameters, the coefficient of consolidation (c_v) and hydraulic conductivity or permeability (de Kretser & Scales 2007). All the analysed output data are referenced to local solid network pressures in the absence of pore pressure, i.e. output density data is referenced to a range of effective stresses and accompanying conductivity data are for the solid network at that local density/porosity. Therefore, for relatively fine samples, the filtration apparatus can also be used in place of a Rowe cell which is commonly used to measure large strain consolidation behaviour. There are limitations relating to the smaller cell size and potential wall effects for larger particles, but with the significant advantages of rapid determination (< 1 day).

2.3 Modelling details

Model-based membrane pressure filter simulations were conducted using a modified version of an empirical pressure filter model available in the literature (de Kretser et al. 2010; de Kretser & Scales 2011). The model determines the primary filtration time and secondary filtration times associated with deposition of a user defined range of target cake thicknesses prior to final cake compression to achieve a dewatered cake. Primary filtration is defined as the process of cake formation that occurs as material is being fed into the filter under pressure during the filling or pumping stage. In many cases, pumping is stopped before cake growth spans the filter cavity, and in this case at the time when pressing commences, residual slurry exists within the filter chamber. Secondary filtration is defined as the process of filtration of this residual slurry during the initial stages of pressing.

The model only describes the filtration/cake formation behaviour and does not have functionality to predict the actual time required for cake compression. Therefore, a representative cake pressing time needs to be manually entered, however, as will be described later, the simulation results can be used to assess whether this pressing time is appropriate or is likely to be insufficient to achieve a fully compressed cake.

The model requires the following material property data at the desired feeding and pressing pressures:

- Cake formation and equilibrium compressed cake solids concentrations.
- Filter cake resistance (typically as a specific cake resistance).

The above data are readily determined from the wide range of standard laboratory filtration test methods that can be found in the literature (e.g. Wakeman & Tarleton 1999).

In each case, the simulation results were assessed in terms of the following:

- The required fill/pumping duration to deliver sufficient solids into the filter chambers to reduce the risk of pressing diaphragm damage due to excessively thin cakes.
- The required fill/pumping and pressing durations required to reduce the risk of discharge of wet cake due to insufficient pressing.

The resultant filter throughput for filter cycle stage configurations that met the above operational constraints was then determined.

3 Characterisation results

C-P characterisation was conducted on all samples listed in Table 1 aside from the Jagersfontein kimberlite tailings sample both with and without ClariVie44® process water conditioning. The compressive and permeability (measured as a hydraulic conductivity) results are presented in Figures 3 and 4, respectively.

Key observations from the results are:

- Changes in compressibility associated with ClariVie44® conditioning are small, ranging from a slight 1–2% w/w reduction in cake solids with conditioning for the coal tailings samples, to a negligible impact for the sand washing tailings. The coal tailings behaviour is indicative of a greater content of responsive swelling clays and reflect the slightly stiffer particle network generated due to the coagulative state induced by the process water conditioning.
- By contrast, the impact of ClariVie44® conditioning on permeability is marked, with increases in permeability of order 100 to 300% for the various coal tailings samples, and around 50% for the less responsive sand washing tailings.

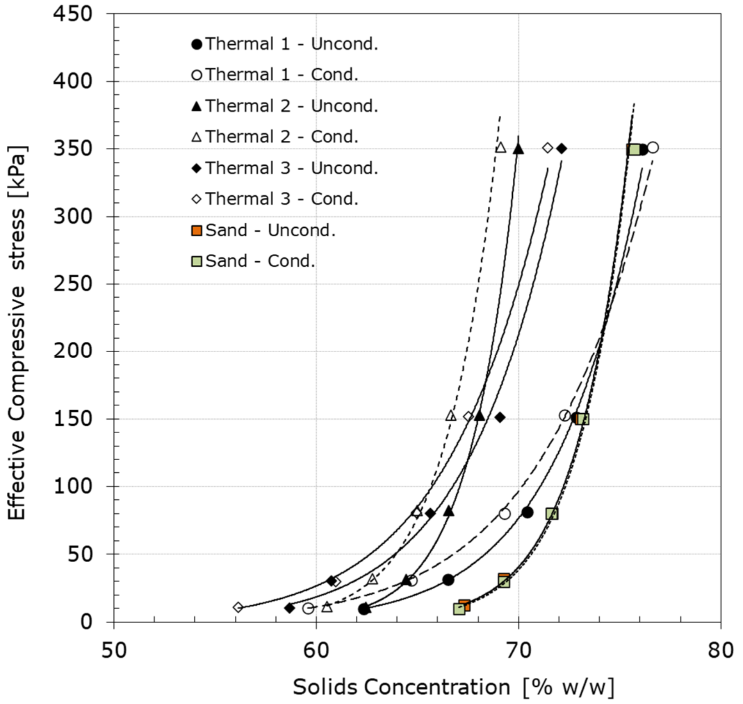

Figure 3 Effective compressive stress versus solids concentration data for various tailings samples with and without ClariVie44 conditioning

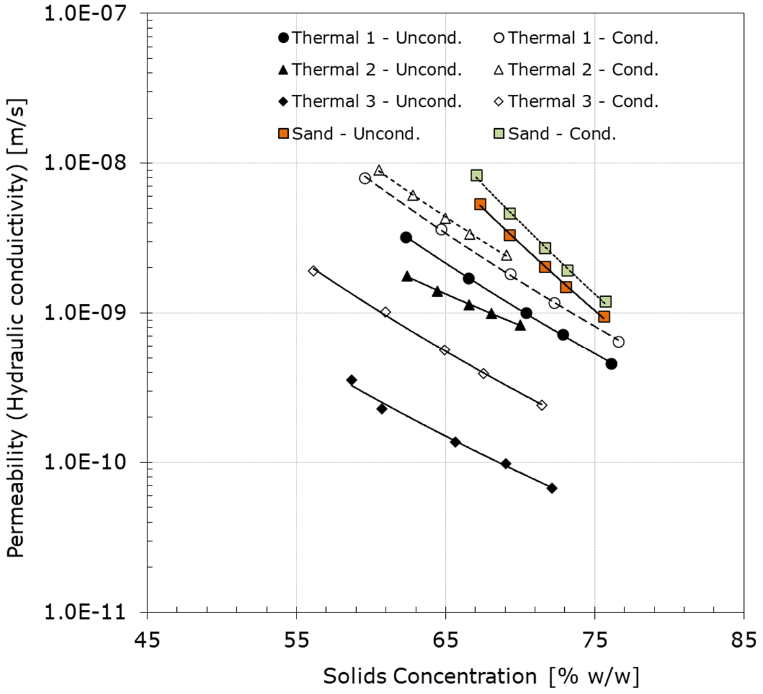

Figure 4 Effective permeability (hydraulic conductivity) versus solids concentration data for various tailings samples with and without ClariVie44 conditioning

It is important to note that the permeability improvements depicted in Figure 4 are a baseline estimate and as these tests were performed on pre-dispersed thickener feed samples and fail to capture the full impact of control of clay dispersion and breakup. Even greater improvements would be expected in a plant where the initial wetting of ROM material will be with conditioned process water due to its continual recycle from tailings dewatering operations. Under such conditions, it has been shown that a materially coarser particle size due will be generated with greatly enhanced permeability and improved sediment densities (de Kretser et al. 1997).

4 Implications to tailings processing

4.1 Thickening and clarification

The positive benefits of ClariVie44® process water conditioning on the flocculation and thickening behaviour of responsive tailings samples has been illustrated previously (Vietti et al. 2019) for a kimberlitic diamond tailings. Whilst the main focus of this paper is the downstream benefits of process water conditioning in secondary and tertiary dewatering processes, the marked improvements delivered from ClariVie44® conditioning in the primary flocculation and thickening of problematic coal tailings samples needs to be highlighted.

Figure 5 depicts results for Coal Tailings 3, the poorest of all tested, comparing cylinder flocculation tests with a combination of polymer coagulant and flocculant, against ClariVie44® conditioned process water and flocculant alone. These trials illustrated a step change in fines capture and clarity with process water conditioning and a complete elimination of the need for polymeric coagulant. By contrast, the best behaviour obtained with unconditioned process water was still poor, with high levels of residual solids in the supernatant, even with extremely high coagulant dosages (of order 1,000 g/t).

The level of turbidity depicted in the samples in Figure 5a are typical of many Hunter Valley coal operations when dealing with problem coal seams and can result in significant upstream washery issues. The benefits of higher polymer coagulant dosing from a plant productivity perspective have recently been highlighted (Walker 2021) including:

- Generally improved plant performance and product recovery due to more stable process performance, less solids recirculation and reagent overdosing.
- Reduced blockages, maintenance and full washery downtime and facilitation of non-capex related bottleneck removal.

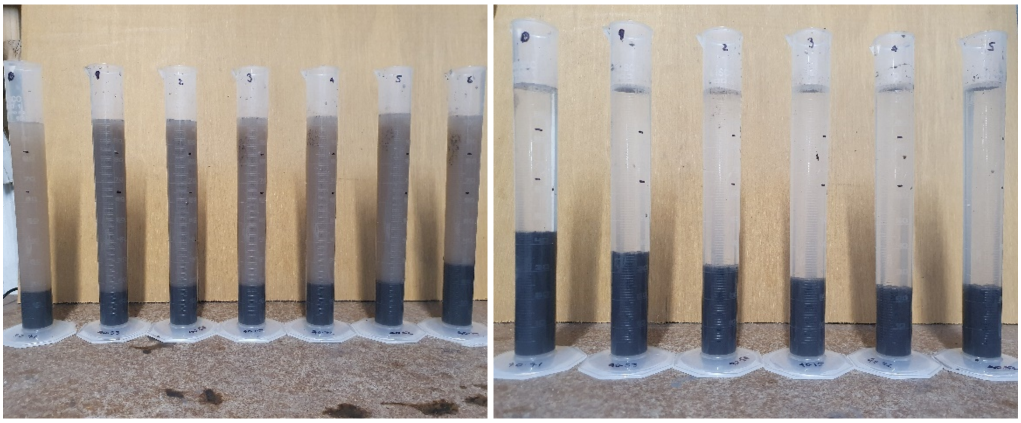
(a) (b)

Figure 5 Comparison of unconditioned and ClariVie44® conditioned flocculation test results for Thermal Coal Tailings sample 3. (a) Unconditioned process water, 1,500 g/t coagulant, variable flocculant; (b) ClariVie44® conditioned water, no coagulant, variable flocculant

4.2 Filtration and secondary dewatering

To illustrate the magnitude of the potential process improvements deliverable in downstream secondary dewatering operations in addition to those discussed relating to thickening and process water quality, a set of pressure filter modelling simulations were conducted using the compression-permeability material property information in Figures 3 and 4.

Pressure filter modelling was performed for a conceptual filter with the basic fixed design parameters listed in Table 2. Modelling was conducted with variable filling and pressing durations and variable chamber size. The 'optimum' design was selected based on the observed kinetic data and cavity utilisation constraints, as would be the case in normal filter sizing testwork. Note that for simplicity, impacts of filter cloth resistance have been neglected. Note also that some liberties have been taken with the use of the C-P data for the modelling exercise given that the highest pressures tested were 3.5 bar, whereas the filter simulation is up to 12 bar. The dangers of extrapolation are acknowledged; however, these are not relevant in the context of this being conceptual comparison exercise.

Table 2 Details of fixed parameters used for conceptual filter press model simulations

Parameter	Value
Cavity design	Double sided, membrane plate
Press loading time	60 s
Fill/pumping pressure	6 bar
Pressing pressure	12 bar
Technical time	300 s

4.2.1 Sand washing tailings

Results comparing the simulated pressure filtration performance of unconditioned and ClariVie44® conditioned sand washing tailings are presented in Table 3. The compression-permeability data indicated that the sand washing tailings, whilst containing a high quantity of clays and silts, had the highest unconditioned permeability of all the samples investigated and was the least responsive to conditioning. However, the data in Table 3 indicate that conditioning with ClariVie44® could still deliver around a 30% improvement in pressure filter productivity.

Table 3 Filtration results – sand washing tailings (Technical time 300 s, Press filling 60 s)

Feed condition	Feed solids (% w/w)	Cavity size (mm)	Fill (s)	Press (s)	Cycle (s)	Cake solids (% w/w)	Cake thickness (mm)	Throughput (kg/hm2)
Unconditioned	30.0	30.0	1,033	150	1,543	78.8	24.4	43.3
ClariVie44®	30.0	30.0	712	120	1,192	78.7	24.4	56.0

The site from which this sample was obtained actually utilises a pressure filter for the secondary dewatering of their washing tails. This filter represents a plant bottleneck which operations manage via the dosage of polymer coagulant into the filter feed. Indications from plant are that with coagulant dosing, cycle times are reduced from around 30 to 20 minutes. These times are comparable to those modelled in Table 3, supporting the general applicability of the modelling approach undertaken and suggesting that ClariVie44® would deliver comparable performance improvements to the polymer coagulant.

To further compare the performance of the polymer coagulant and ClariVie44® conditioned samples, comparative single pressure filtration tests were conducted in a dead-end compact pressure filter cell under the following conditions:

- A fixed pressure of 3.5 bar was used. Whilst lower than the pressures applied in the full-scale filter, the test data still highlights the relative filterability of the samples.
- A fixed initial slurry volume was used and tests were run until both cake formation and cake compaction was complete.

The results in Figure 6 confirm at bench scale the approximate magnitude of the improvements seen at full-scale with polymer coagulant dosing, but more importantly also highlight that ClariVie44® delivers comparable or better conditioning performance. Note that the improvements seen in filtration would be in addition to upstream benefits in flocculation and thickening, whereas the benefits of polymer coagulant dosing would be confined to the filtration unit operation alone.

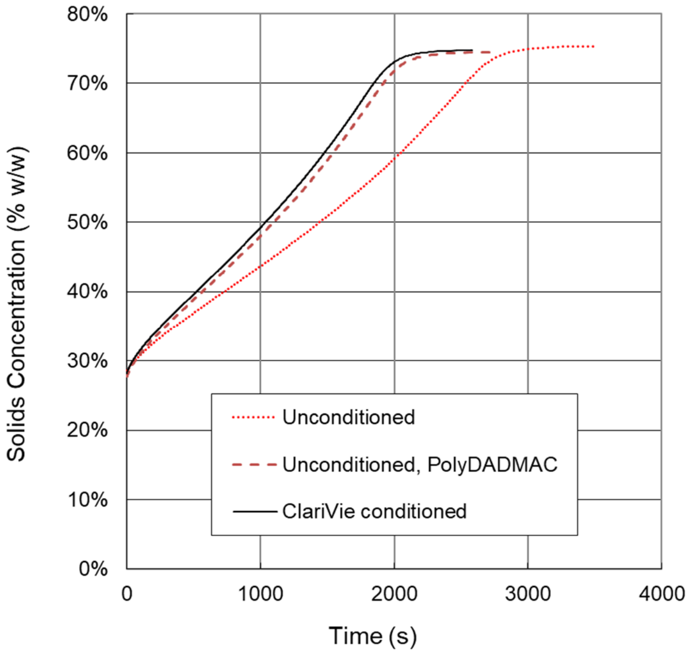

Figure 6 **Sand washing tailings. Comparison of filtration performance of unconditioned simulated thickener underflow, unconditioned with polymer coagulant and ClariVie44® conditioned samples (3.5 bar laboratory piston filtration test)**

4.2.2 Thermal Coal 2 tailings

Results comparing the simulated pressure filtration performance of unconditioned and ClariVie44® conditioned Thermal Coal 2 tailings are presented in Table 4. In addition to the filter cycle throughput information, the required filter area for processing of 120 dry tonnes/hour of tailings is also presented. Key observations from the results are:

- ClariVie44® conditioning indicates significant throughput enhancement (> 100%) and required area reduction (>50%) for a given tonnage.
- The enhancement in filtration rates is so large that operation with larger cavities is favoured. The results presented highlight the further improvements obtainable in throughput, which would deliver both capex and OpEx reductions (less area, smaller number of plates and less cloths to change, etc.).

Table 4 **Filtration results – Thermal Coal tailings 2 (120 t/h dry, technical time 300 s, Press filling 60 s)**

Feed condition	Feed solids (% w/w)	Cavity size (mm)	Fill (s)	Press (s)	Cycle (s)	Cake solids (% w/w)	Cake thickness (mm)	Throughput (kg/hm2)	Area (m^2)
Unconditioned	25.0	20.0	899	180	1,439	72.9	16.4	22.0	5,459
ClariVie44®	25.0	20.0	200	120	680	72.3	16.4	46.0	2,610
ClariVie44®	25.0	30.0	313	120	793	72.3	21.8	52.5	2,286

Ultimately, these data highlight how optimal conditioning could potentially move the economic goal posts for a pressure filtration option to a point where it may be a viable option for a given site which otherwise may not have been the case.

4.2.3 Thermal Coal 3 tailings

Results comparing the simulated pressure filtration performance of unconditioned and ClariVie44® conditioned Thermal Coal 3 tailings are presented in Table 5.

Table 5 Filtration results – Thermal Coal tailings 3 (120 t/h dry, technical time 300 s, Press filling 60 s)

Feed condition	Feed solids (% w/w)	Cavity size (mm)	Fill (s)	Press (s)	Cycle (s)	Cake solids (% w/w)	Cake thickness (mm)	Throughput (kg/hm2)	Area (m^2)
Unconditioned	25.0	20.0	11,589	2000	13,949	78.1	16.2	2.5	48,031
ClariVie44®	25.0	20.0	2,940	600	3,900	78.0	16.2	8.9	13,642
ClariVie44®	30.0	20.0	2,222	600	3,182	78.0	16.0	10.8	11,161

Key observations from the results are:

- Extremely poor filtration is exhibited in unconditioned state with an extremely high required area.
- ClariVie44® conditioning indicates significant throughput enhancement (> 300%) and required area reduction (>75%) for a given tonnage.
- Given the associated poor thickening behaviour of the unconditioned material, improved thickener dewatering may be expected with process water conditioning due to better settling rates. Data illustrate a 20% improvement in throughput associated with a moderately improved feed solids concentration.
- Ultimately, the data indicate that designing a pressure filtration plant for this material would not be feasible, even with ClariVie44® conditioning. However, the data highlight the significant synergies achievable via process water conditioning, whereby a single dosage in to the water circuit delivers compounding improvements across the tailings management flow sheet (as well as within the return water/process water circuit).

4.2.4 Considerations for belt press filtration and other secondary flocculated methods

Whilst the discussion above has been in relation to use of pressure filtration for the secondary dewatering of coal tailings, the observed behaviours for Thermal Coal Tailings 3 are such that, even with ClariVie44® conditioning, the low filter cake permeabilities render pressure filtration unviable.

The site processing Thermal Coal tailings 2 and 3 actually utilises belt press filters for secondary dewatering. In order to combat the impact of dispersive clays, extremely high dosages of flocculant and coagulant are utilised at both the thickener and then again at the belt press filters. Whilst these high dosages are able to settle the tailings and deliver dewatering rates such that belt press filtration performance is acceptable (but only barely), the recovered water quality is still poor (Figure 5a).

In the case of belt press filters, in addition to the rate of dewatering, the high polymer dosages for these problem tailings are also required to ensure homogenous cake development and prevent solids loss from cake extrusion out the sides of the filter.

Tests with ClariVie44® illustrate that a single point addition into the process water would improve the underlying dewaterability of the clay fraction such that the need for coagulant across all dewatering steps is eliminated and filtrate clarity will be significantly improved. Furthermore, a more homogenous secondary flocculated structure is evident in belt press filter feed conditioning tests, suggesting the potential for significant throughput and operability improvements.

Furthermore, whilst not currently evaluated, all the improvements observed in the context of belt press filtration would be directly applicable in other dewatering techniques utilising secondary flocculation such as centrifuges, screw press filtration, geotextile dewatering tubes and basic in-pit inline flocculation processes.

4.3 TSF operational implications

4.3.1 Deposition and consolidation

The previous section focused on the impact of process water conditioning on filtration as a secondary dewatering step; however, even if a standard slurried or thickened tailings storage option is employed, the fundamentally altered permeability behaviour of the tailings will deliver long-term benefits over the lifetime of the storage facility.

To illustrate long-term consolidation benefits from process water conditioning, the coal C-P data presented in Section 3 were converted into coefficient of consolidation data and are presented in Figure 7. The key implications of this data are:

- Process water conditioning with ClariVie44® delivers a step change increase in consolidation rates, which would operationally translate into improved operational dry densities for a given rise rate.
- Acknowledging that many coal mines process multiple seams with highly variable dewatering characteristics, the use of process water conditioning can reduce the impact of lensing/layering of impermeable regions which could became consolidation rate limiting zones for the entire TSF.
- The poorest unconditioned C_v data (Thermal Coal tailings 3) is indicative of certain seams in the Hunter Valley where deposited tailings exhibit negligible consolidation over the lifetime of the storage. In these cases, capping and rehabilitation becomes unviable due to the unconsolidated state even after years of consolidation, representing a significant environmental and safety risk.

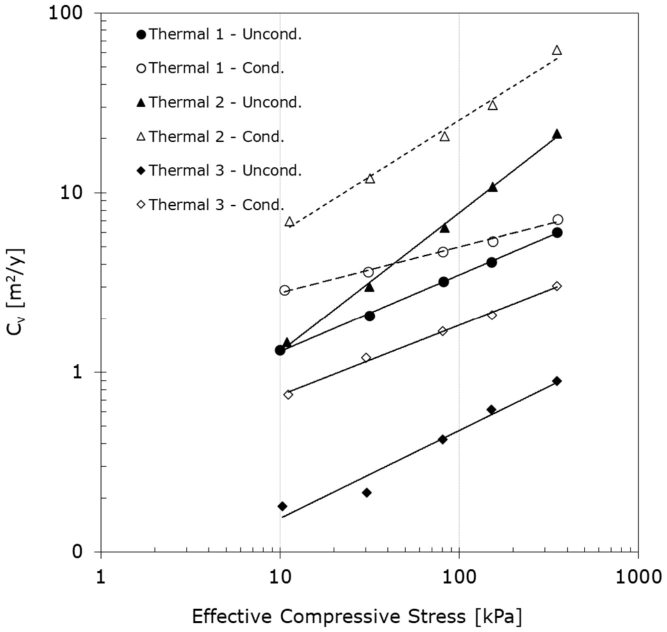

Figure 7 Coefficient of consolidation versus effective compressive stress data for various tailings samples with and without ClariVie44® conditioning

4.3.2 Risk mitigation: Jagersfontein TSF failure

In September 2022, there was a major TSF failure at the Jagersfontein kimberlite tailings reprocessing operation in South Africa. Some of the authors have previously conducted work on the tailings at this site and investigated the responsiveness of this material to a process water conditioning approach. Whilst the exact reasons for this failure will not be known until the conclusion of formal investigations, there are a number of observations that can be made from the historical test work conducted, the design of the TSF, and the implications from a TSF risk profile.

As part of historical work to inform the tailing thickener design and sizing, a critical coagulation assessment was conducted to assess the responsiveness of the tailings to process water conditioning. This work, depicted in Figure 8, highlighted the appreciable dispersive clay content and dispersive water chemistry in the Jagersfontein tailings, as well as its high potential responsiveness to process water conditioning. Cylinder flocculation work also highlighted the step change in fines capture possible above a critical coagulation conductivity (Figure 9).

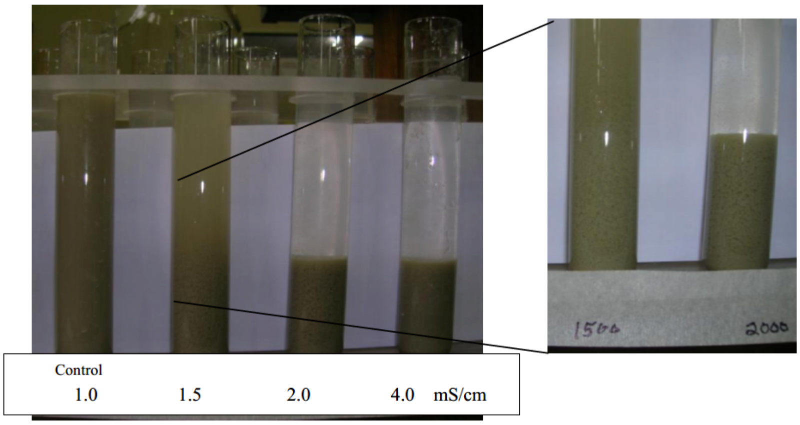

Figure 8 Critical coagulation concentration assessment on Jagersfontein tailings indicating responsiveness to process water conditioning

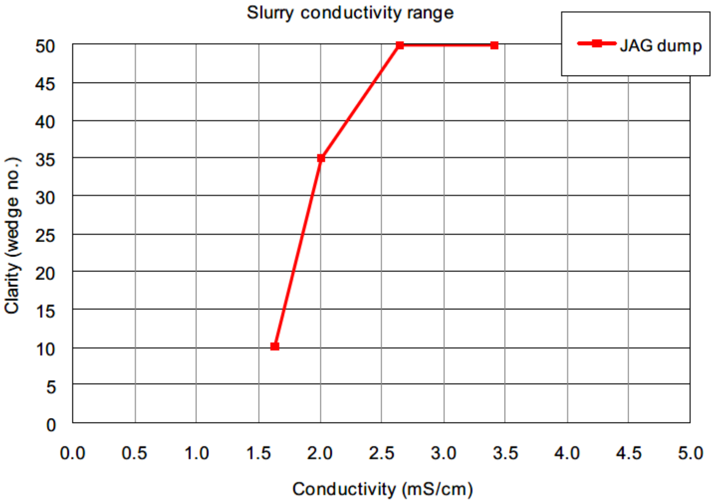

Figure 9 Impact of process water conditioning on cylinder flocculation test supernatant clarity for Jagersfontein tailings

In the context of these results and the behaviours discussed elsewhere in this paper, there are a number of observations that can be made around the risk profile of the facility at Jagersfontein:

- The TSF design utilised embankment construction using compacted coarse tailings. Note that the upstream method was not employed. Discharge was into the upstream end of the facility via a single point discharge. The facility originally was divided into two; however, satellite images suggest that over time, the dividing bund either failed or was overtopped such that the decant pond was located adjacent to the downstream embankment.

- During early reprocessing operations, based on the testwork presented, the site employed NaCl as a rudimentary process water conditioner. Whilst able to deliver some of the benefits discussed in this paper, NaCl has the drawback that if conditioning is not maintained, the dispersive issues will worsen and that it is more corrosive to plant equipment. Based on historical imagery of the TSF and decant water colour, it was clear that there was an appreciable colloidal clay content in the decant water, indicating either an absence of, or an insufficient level of, dispersion control.
- In the context of the behaviours illustrated in this paper, these observations indicate high segregation of tailings at Jagersfontein would have been occurring on deposition with subsequent migration of ultra-fines with decant water towards downstream embankment. The resultant limited settling and very poor compaction reduces the ability to manage decant pond size/TSF water inventories due to the poor dewatering rates. Whilst the actual failure mechanism is as yet unknown, this operational condition represents a high-risk state.
- By contrast, had process water conditioning been properly executed and maintained, the behaviours illustrated here indicate there would have been enhanced capture of ultra-fines within the existing primary dewatering thickener unit, resulting in a more homogenous, higher density tailings being deposited at the TSF. This in turn would have eliminated or reduced fines migration towards the high-risk downstream embankment zone. The combination of higher density deposition, the absence of uncompacted slimes and a clear decant water pond facilitates better management of decant pond size and TSF water inventories, leading to a fundamentally lower risk state.

It should be emphasised again that the reasons for the Jagersfontein failure are as yet unknown. The discussion presented here is not an implication that process water conditioning could have avoided this failure; however, it illustrates how this approach could have materially reduced the risk profile, or ultimate consequence of the failure.

5 Conclusion

Through a combination of observations from settling and C-P testwork and pressure filtration model simulations across a range of different tailings samples, the potential step change benefits in management of dispersive, swelling clay tailings afforded through a process water conditioning approach have been illustrated. Clay dispersion control via process water conditioning involves reagent dosing into the process water at a single location; however, this will deliver benefits at every stage of dewatering across the tailings management flow sheet.

The potential benefits highlighted in this work include step changes in thickener fines capture and overflow clarity, material improvements in process plant operability and reduced down time due lower fines recirculation, elimination of coagulant dosing in the thickener and downstream secondary dewatering operations, increases in pressure filtration throughputs of up to 300%, improvements in any process technology employing secondary flocculation due to more homogenous structure development, and improved TSF operability and lower risk due to less segregation, faster consolidation and operational dry densities and improved decant water management.

Acknowledgements

The authors acknowledge the support of SciDev Pty Ltd, for the supply of some of the samples characterised in this paper.

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