Paste 2019 – AJC Paterson, AB Fourie and D Reid (eds)

doi:10.36487/ACG_rep/1910_06_Palmer

Operational strategies to improve paste plant performance

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Abstract

Paste thickening represents a proven and effective method for the safe disposal of tailings and maximises water recovery. The optimum density for disposal is often at the limits of that achievable in commercially available thickeners.

This paper looks at the options available to increase paste density to meet the disposal requirements and to stabilise paste properties through blending filtered tailings with thickened tailings, supported by experimental data and case studies.

Keywords: *innovations in conventional, paste and filtered tailings deposition*

1 Introduction

Paste thickening of tailings has been chasing the ideal of achieving non-segregating slurries at the limits of flow liquefaction in a single unit operation. Initially driven by water recovery objectives, the advantages of high-density deposition of tailings is growing in importance as a methodology of providing a safer deposition than conventional thickened tailings. As shown in Figure 1, paste thickening achieves the highest density achievable with thickening alone at a moderate cost; further increases in density require a significant step change in cost and complexity to filtered tailings with multiple unit operations.

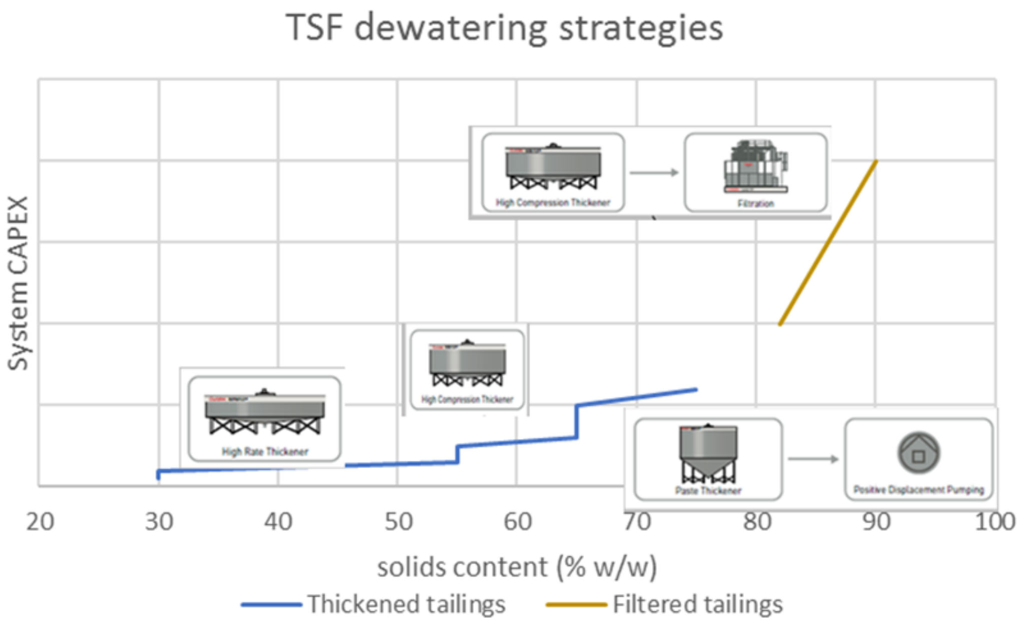

Figure 1 Tailings deposition strategies

In the past, conventional thickened tailings have increased in density as thickener design has improved, with many sites achieving thickened tailings with densities of more than 55% solids. At these densities, slurries have a low yield stress (nominally 5 Pa), and their control and transport are relatively simple.

Paste thickeners achieve high levels of separation with densities of more than 70% solids. These thickeners rely on good flocculation and mechanical raking to release water from the thickened solids. The underflow typically has a very high yield stress up to 200 Pa unsheared and it is these high yield stresses in the thickener that drive the equipment design and consequently costs.

Increasing underflow density improves water recovery and tailings storage facility (TSF) beach angle, and the yield stress increases exponentially, rapidly increasing the cost of thickening and pumping equipment. At these higher densities, many installations fail to consistently achieve their design performance resulting in lower water recoveries and concave beach slopes (Seddon & Fitton 2011). Shear stress is relatable to slurry density; however, changing ore types can shift the relationship and control at a constant density may not provide a constant yield stress. The presence of clays can adversely affect thickener performance, reducing settled density and increasing viscosity.

Shear in transport can substantially reduce the slurry yield stress, decreasing pumping energy but also changing the behaviour at the TSF, producing lower beach angles.

High-density deposition of tailings has significant advantages for the TSF. High-density tailings can improve stability, reduce the capital required for construction and simplify the eventual dam closure. Despite these advantages, the available technologies are failing to deliver a density in tailing streams that would optimise the tailings deposition area.

One alternative technology is mixing filtered tailings with thickened tailings to produce high-density tailings streams at the optimum density for TSF design. This performance comes at the cost of more complex dewatering facilities; however, in some cases, the savings in TSF costs can offset these costs and may represent an improved solution for many cases.

2 Yield stress

Pushing thickening to the limits of separation causes a significant increase in slurry yield stress resulting in high raking torques. As the solids content approach, the liquid limits the increase in yield stress until it is almost vertical (Figure 2).

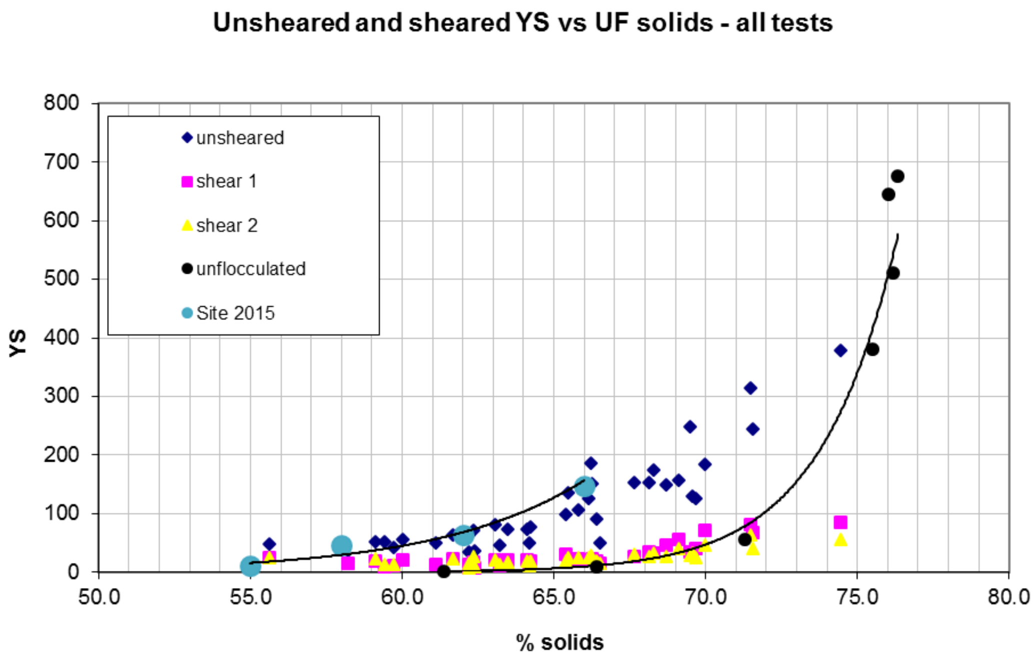

Figure 2 Yield stress versus thickened tailings slurry density

The flocculants required for separation are a major contributor to the yield stress as they link particles inducing a resistance to shear. Shear induced in pumping and transportation breaks the flocculant links, substantially reducing yield stress (Figure 3).

Yield stress and the resultant viscosity of the slurry during transport creates frictional losses and defines the pressure or force required for flow to occur; with gravity transport systems, the slurry viscosity can become the system rate limiting variable.

At the TSF, yield stress induces a resistance to flow, decreasing the energy of the slurry stream and is a major factor in determining the beach angle.

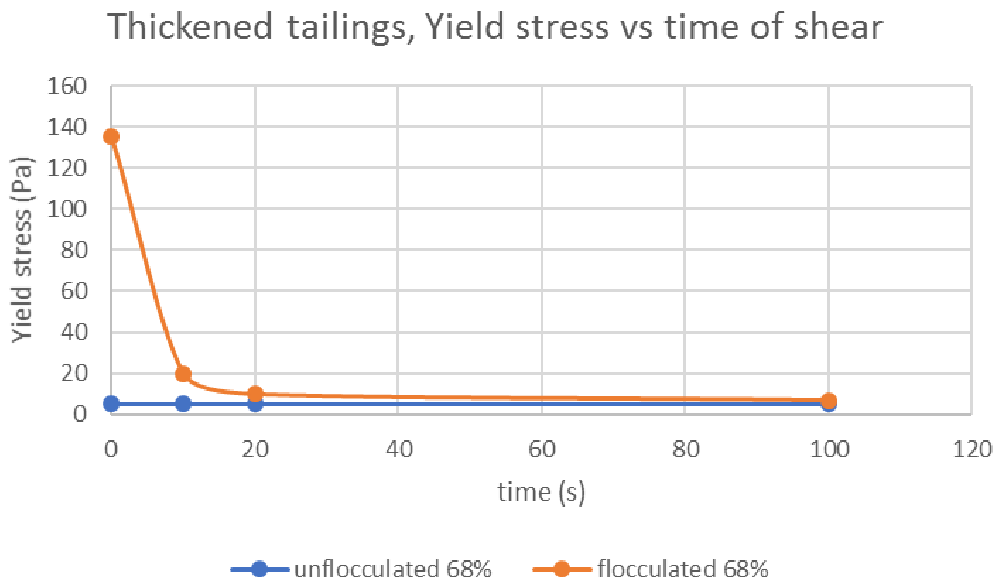

Figure 3 Shear thinning of thickened tailings

3 Deposition strategies

Tailings storage schemes can be categorised into many different strategies, ranging from unthickened tailings (where the tailings are transported to a dam for disposal and water recovery occurs as solids further separate at the dam creating a pool) to paste disposal (where a highly thickened paste is transported for either underground disposal or surface deposition, with limited water recovery after the paste is deposited).

In addition to recovering more water during thickening, increasing the density before deposition may increase the settled density in the TSF, further increasing water recovery, reducing the volume of tailings stored and extending the lifetime of the TSF (Figure 4).

Reid and Fourie (2015) undertook literature reviews and laboratory consolidation testing that supports this phenomenon – that for many tailings, increasing the deposition density results in an increase of the in situ settled density.

There are numerous variables that affect the settled density in tailings dams that makes in situ comparison difficult. Excluding the macro issues of segregation and surface drying, it is likely that the higher the volume of water drained from the tailings, the more the packing arrangement of particles can be changed during settling. This can result in a lower packing density in tailings deposited from dilute slurries. Tailings thickened as dense slurries are exposed to shear in thickening and transport that promotes a dense packing is less likely to be rearranged during settling.

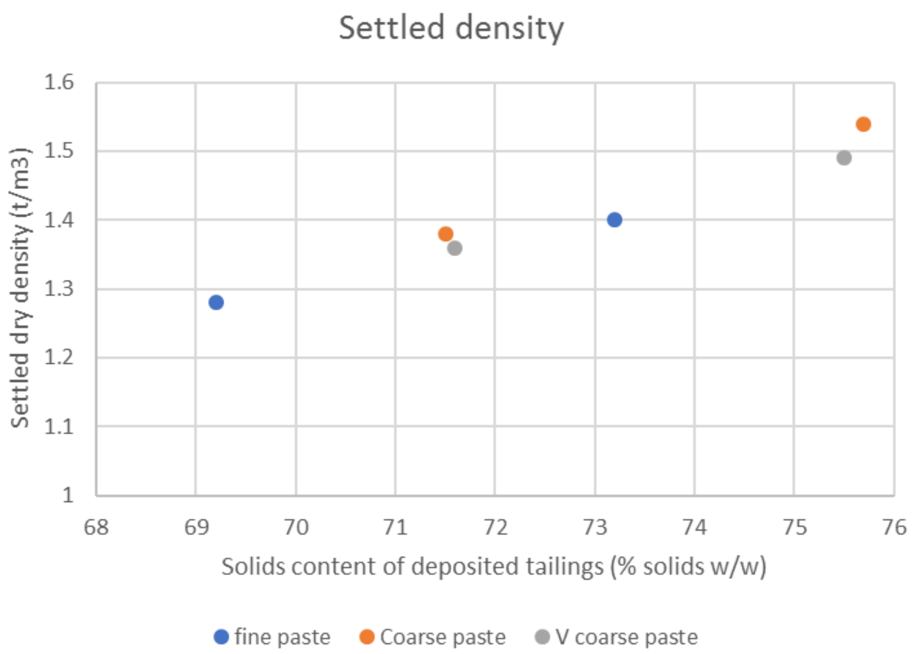

Figure 4 Settled density of thickened tailings

When considering paste deposition, the TSF is designed to take advantage of the paste properties with the deposition points arranged to distribute slurry within the tailings dam. The location and the discharge volume of these deposition points can reduce energy in each stream and help to produce a beach with the highest slope practical (as greater slopes increase the available storage volume). While an optimised design looks at many factors including rheology, terrain, earthquake loadings, slurry transport and embankment design, it is here at the dam that the priority shifts from water recovery to tailings distribution and slope stability. Increasing the yield stress improves the deposition. Density has been the traditional measure of thickener performance, but it is yield stress that limits transportation and defines the behaviour in the TSF.

The challenge is to deliver tailings to the dam with the highest yield stress consistently, yet this is seldom a control parameter at the thickening plant.

4 Solid–liquid separations

The separation of tailings from water is limited in a tailings thickener by the time taken for the separation to occur, the depth of the bed (driving force) and the yield stress of the thickened slurry (transport). Optimising the thickening process induces higher yield stress to the thickened tailing slurry than necessary due to the flocculants used in settling. While shear post thickening substantially reduces the yield stress, this overshoot in yield stress limits the ability to achieve very high separations in thickeners. Once fully sheared, slurries with higher densities can be transported and deposited.

To avoid these high stresses, thickening can be supplemented with filtration or high gravity screening of a part of the tailings stream. By recombining the two streams, a slurry with the optimum properties for deposition can be consistently produced, maximising water recovery within the limits of transport.

While the technologies to filter or screen tailings to produce a dry cake are well known, they are generally seen as an alternative to paste thickening rather than as a supplement. Vacuum filtration produces cakes with a moisture of 20–25%, which can be readily mixed with slurry to form the high-density pastes required for underground backfill. While generally used for quite small tonnages (100 t/hr), the technology is well proven and is shown to be able to achieve accurate control of the paste properties. To achieve a high-density paste suitable for paste deposition in a surface tailings facility with high rate thickening and vacuum filtration, about 75% of the slurry would need to be filtered.

When considering large mining applications (> 1,000 t/hr), the scale of the vacuum equipment becomes too small and many filters are required. Pressure filtration begins to be a more attractive solution for the filtration of large tonnages; with a smaller footprint and more manageable number of units, the total installed cost may be reduced. In addition, pressure filters can achieve a lower moisture than vacuum filters. In a cake repulping plant, if the filtered cake has a moisture of 15–20%, only 30–50% of the stream may require filtration to achieve a high-density paste.

When repulping filtered cakes at a large scale, the mixing technology becomes a limiting factor. Paste backfill plants use concrete mixing equipment to mix relatively wet filtered cakes with slurry and cement to produce a paste that is well distributed. Vacuum filtered cake is saturated and, while considered as a solid, at the upper end of the range it tends to be liquefied with vibration. Under Atterberg testing, the cake can be classified as being close to the liquid limit. Tailings are reported to have liquid limits at 25–26% moisture and plastic limits of 18–20%, which coincides with the range of moistures produced in vacuum filtration (Amoah et al. 2018). The mixing units are at the upper end of the technology scale at 500 t/hr.

Pressure-filtered material, when dry, starts to become friable; it spreads easily on conveyor belts and can be repulped in a mixer. When the tailings contain clays, it becomes more difficult to filter. The achievable cake moisture increases and the material displays plastic behaviour. This material resists breakup in conveying and may require significant energy and residence time in mixing to achieve a homogeneous slurry. These properties match the reported Atterberg limits as it is materials close to the plastic limit that display the highest resistance to breakup and repulping. At lower moistures (below the plastic limit and at the point where proctor densities decrease), the filtered cakes are more easily broken up and repulped (Figure 5).

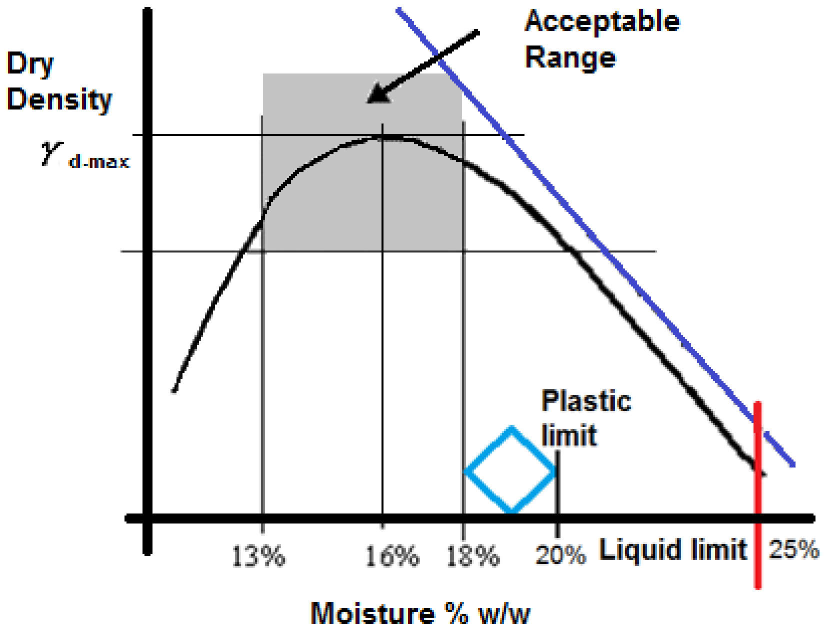

Figure 5 Proctor and Atterberg limits

5 Slurry repulping

Paste mixing systems used for backfilling operation produce a high-density paste with up to 800 Pa yield stress. The high shear is a consequence of the high solids content used to optimise cement consumption. Typical mixers required for the continuous production of paste consist of one or more rotating shafts with paddles that mix and shear the paste. Mixer volumes are available to about 15 m^3 live volume, and they have a high energy input (Figure 6).

Figure 6 Paste mixer of thickened tailings for underground paste preparation

Mixing energy is a function of the viscosity of the slurry mixture, residence time and the efficiency of the mixing device. Mixer installed power is variable; however, powers in the range of 20–50 kW/m^3 of live vessel volume are commonly used for cemented paste applications. When considering the repulping of thickened tailings for surface deposition, the power requirement is expected to be lower. Small-scale lab tests indicate that the power required to repulp filtered tailings and slurry to a density suitable for surface deposition could be as low as 1 kW/m^3. Based on these tests and pilot-scale tests, production scale units in a large mixing plant could consume less than 5 kW/m^3.

Where the filtered cake contains large pieces of cake, these are broken down by attrition or shear breakage. Mixing times of 30 seconds to two minutes were required in pilot-scale testing.

Cake properties have a significant effect on the mixer performance; the size of the cake pieces and the plasticity of the pieces affect the mixing time. The size of cake pieces is affected by the cake discharge and materials handling stages between the filter and the mixer. The drop from the filter to the conveyor reduces the cake from large slabs the size of the filtering plates (2 × 2 × 50 mm) to small pieces down to less than a few hundred mm. Each subsequent transfer point further reduces the cake piece size. Much of the cake is reduced to powder (a small fraction of pieces greater than 50 mm) when the filtered material is close to the optimum stacking moisture (Figure 7).

Where the tailings contain significant amounts of clay or when the cake is wet and close to the plastic limit, the size reduction is less effective and a higher fraction of large cake pieces are produced.

Figure 7 Pressure-filtered cake

A conceptual filtered tailings and cake repulping plant is shown in Figure 8. This would be capable of 750 m^3/hr of thickened slurry (paste) with over 70% solids. The plant shows two large pressure filters on the top floor and feeder conveyors that collect the discharge cake on the intermediate floor. These conveyors are required to buffer the batch discharge and regulate a near continuous flow of cake to the mixing station. Repulped tailings can then be transported to the TSF with pumps or a gravity discharge system.

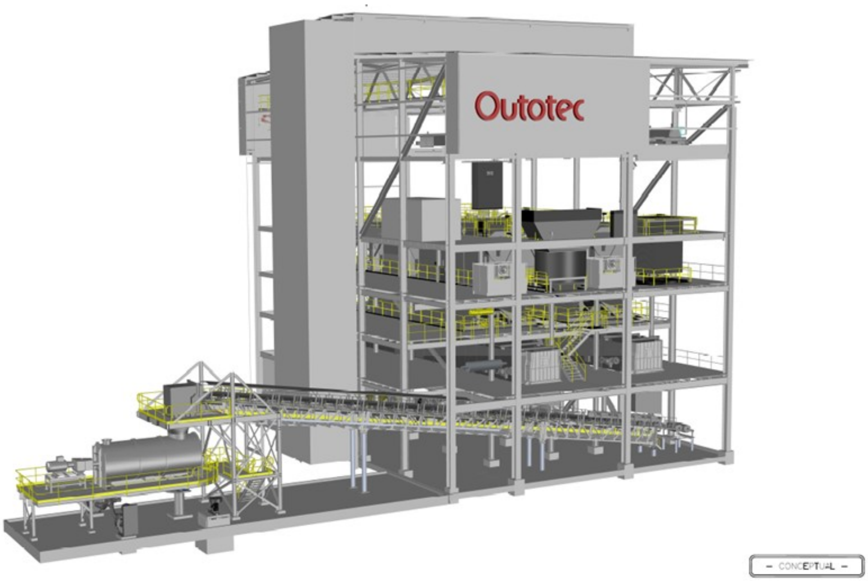

Figure 8 Conceptual cake repulping unit

Pilot plant testing with filtered cake of 83% solids mixed with a slurry at 58% solids showed that the cake could be repulped with mixing equipment to produce a paste with 65% solids (Figures 9 and 10; Table 1).

The material tested was difficult-to-filter copper tailings containing clays that settled poorly. Thickener trials from the plant showed that 58% solids could be reliably achieved from the existing thickener underflow and this density should be used to represent the slurry. Because the trials were conducted at a facility remote to the site, the slurry for use in the pilot trial was a simulated slurry generated from mixing solids with plant water rather than thickening from a dilute feed with flocculants. This slurry preparation was selected as it represented sheared slurry that would be pumped by centrifugal pumps over a moderate-length pipeline from the thickeners to the filtration and repulping plant. The initial trials were conducted with filtered tailings at 83% solids that were produced from the simulated slurry to represent high capacity filtration.

Additional tests were conducted in the pilot on filtered tailings with 86.5% solids to produce a slurry of 64.8% solids. The filtered tailings were produced at 86.5% solids to simulate dry cake at close to the optimum stacking moisture. It was observed in the pilot trials that while the filtration capacity was lower, the drier cake was more friable and easily mixed. During the trials, the filtered cakes are broken up during transportation with breakage at the transfer points and when dropped from the filter to the cake transport conveyor. During mixing trials, the mixer power intensity was 5 kW/m^3 and residence times of less than 60 seconds were required to fully mix the two streams.

Figure 9 Mixing after 30 seconds

Figure 10 Mixing after 60 seconds

Table 1 Pilot plant repulping tests

Material	w/w%	Density g/l	Yield stress Pa
#1 Slurry, thickened tailings	58	1,600	–
#1 Cake, filtered tailings	83.3	–	–
#1 Slurry, after mixing	65.3	1,731	110
#2 Slurry, thickened tailings	58	1,610	–
#2 Cake, filtered tailings	86.5	–	–
#2 Slurry, after mixing	64.8	1,721	105

Additional tests were conducted at lab scale on a copper concentrator tailing that are easily filtered with low clay (Table 2). The material can be thickened to 64% with paste thickening and 59% with high rate thickening. The object of the testing was to simulate tailings mixed to a paste that would maximise beach slope. The material displayed similar behaviour in the materials handling and mixing. Figure 11 shows the size reduction of the filtered material after the materials handling phase.

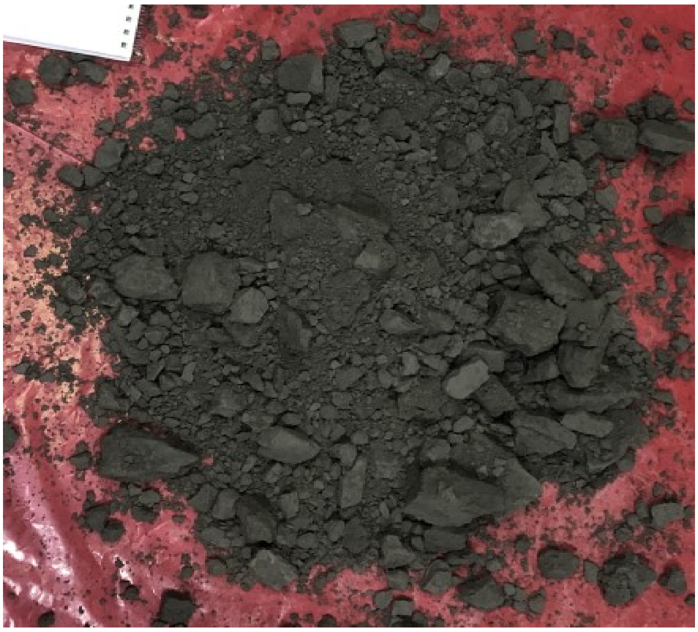

Figure 11 Cake size reduction in materials handling

Table 2 Lab scale repulping tests

Material	w/w%	Density g/l	Yield stress Pa
#3 Slurry, thickened tailings	59	1,618	–
#3 Cake, filtered tailings	86	–	–
#3 Slurry, after mixing	70	1,829	110
#4 Slurry, thickened tailings	59	1,618	–
#4 Cake, filtered tailings	86	–	–
#4 Slurry, after mixing	72	1,873	220

Repulp testing is limited in the simulation by the feed cake preparation, as most of the size reduction occurs in the materials handling phase. Small-scale paste mixing systems can only accept small cake pieces, which may understate the power or time required for repulping. Filtered cake should undergo several dropping stages to simulate the materials handling attrition that will occur in full-scale operation. Further research is required to quantify the degree of breakup this provides, and the size distribution expected site inspections are planned to determine the relationship between cake moisture and size reduction during the materials handling of filtered cakes.

The outcome of these observations is that filtration and materials handling should be designed to optimise the repulping stage in addition to filtration area.

6 Density control versus slurry rheology

Although the duty of a thickener can be defined in quite simple terms, the thickener will experience a wide range of operational conditions throughout its life. Mass flow of solids varies with milling rates; the concentration of solids in the feed varies with operational issues; and the ore treated in the mill changes with the geology of the mine.

Slurry density is the most commonly used method of measuring thickener underflow characteristics. It is used to control the thickener discharge rate and can be used as a feedback to flocculant addition control. Results reported from multiple sources (Seddon & Fitton 2011, and later Pirouz et al. 2017), all show that thickener underflow density is not constant and that behaviour of the thickened tailings at the point of deposition can vary considerably.

Yield stress may be a better measurement of slurry properties than underflow density. However, underflow density is easily measured and proven, reliable and cost-effective. In addition, density measuring instruments are readily available. For these reasons, density measurement instruments are widely used to control underflow density. Density remains relatively constant from the thickener discharge through the tailings transport to the TSF.

Slurry rheology by contrast is shear sensitive and undergoes significant change from the thickener discharge to the point of deposition and online measuring devices are not readily available. Slurry rheology can be calculated at discrete points by measuring the pressure loss across a section of pipe at a known volumetric flow rate; however, this method is not widely used as an online control and is limited in the range of shear rates that can be measured by the slurry transport conditions.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has published the results of an instrument that can measure the rheology of a slurry in real time across a range of shear rates (CSIRO 2018). They have designed new monitoring software known as the Online Rheometer, which measures the rheology of a fluid of interest by taking a side stream and measures the pressure drop generated over a pipe of known dimensions for a series of known volumetric flow rates.

FlowScan have developed a non-contact measuring device that looks at slurry velocity profiles to provide a relationship between shear rate and shear stress for any fluid online.

While there are no reports of commercial operation of either of these instruments, it seems possible that the rheological properties of thickened tailings can be measured and that these measurements could be incorporated in a thickener control system. Sampling and providing shear mixing to the samples could address the shear time influence. If the challenges of online rheology measurement are solved, there remains the challenge of controlling the slurry rheology. As with density control, the long lag between flocculation and thickener discharge may not make significant changes in thickener underflow stability.

In contrast for a system with a repulping stage, both solids density and slurry rheology can be readily controlled by altering the amount of dry material mixed with the slurry. This control step has a fast response which enables adjustment because of rate or material property changes. With a repulping system, the dry material is mixed with thickened slurry. The mixture will be partially sheared and more closely represent the properties at the final discharge point. This will enable a more reliable assessment of the slurry rheology. Under these conditions, accurate slurry properties could be maintained.

7 Pumping and slurry transport

Underground paste mixing systems operate at high-density and typically transport paste vertically down without pumping and frictional losses in piping are less of a concern. In surface tailings applications, the thickened tailings are transported from the thickener to the TSF over longer distances with minimal elevation changes, and frictional losses in piping can be a significant factor. While high concentration slurries can be thickened, often the high friction losses in the transport step between thickening and deposition limit the concentration of solids in the slurry that can be deposited or the distance to which it can be transported.

As the slurry rheology is the defining property that sets piping friction losses and pump suction performance, controlling the slurry properties at the highest density practical within the yield stress and viscosity limits of the slurry transport system will optimise water recovery in solid-liquid separation and provide the best tailings deposition behaviour.

Positive displacement pumping systems can transport high-density slurries with higher densities than centrifugal pumps operating under the same conditions. One of the biggest challenges in tails pumping is the rheology variability and this can be improved with better rheology control or repulping systems. Due to high piping losses, paste preparation should be located as close to the point of deposition as practical. Variable production rates still provide a challenge for pumping systems and these can be improved with modular pumping systems and multiple pipelines.

Conclusion

This paper has looked at an alternative process to address the variability of slurry rheology as produced from paste thickener systems. The study investigated alternative measures in the form of control or repulping that could be used to stabilise thickened tailings rheology. Pilot-scale tests and field data from operating underground backfill plants have demonstrated that filtered cakes can be repulped with slurry to produce a homogeneous paste with densities higher than those achievable through thickening alone. The results also indicate that high-density slurry density and rheology can be controlled and stabilised through these measures.

Stabilised slurry rheology may give substantial benefits in slurry transport and tailing deposition.

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