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Stacked deposits of thickened and filtered fluid fine tailings using geotextile tubes – concepts/lessons learned updates

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Abstract

The Global Industry Standard on Tailings Management has the aspirational goal of "zero harm to people and the environment" from tailings facilities and provides a framework for safe tailings facility management while affording operators flexibility on how best to achieve this goal. This paper aims to consider an alternative form of fluid fine tailings management using geotextile tubes, which combines the enhanced geotechnical stability of the fluid fine tailings by dewatering and densification while effectively maximising the reclaiming of process water. To ensure that the return water is suitable for reuse in the plant and that the fluid fine tailings can be dewatered and densified faster, a physicochemical treatment (recipe) should assist solids/water separation and ensure fines agglomeration during pipeline transport before discharge in the geotextile tubes. This paper also describes the recipe/geotextile tubes concept and some lessons learned from their use as a filtration technology process designed to enhance the physical stability of fluid fine tailings deposits.

1 Introduction

With continuous improvements in the beneficiation process, ore is ground increasingly finely, resulting in large volumes of fluid fine tailings. In many mines, over 50% of the tailings are finer than 75 µm. However, the fluid fine tailings sedimentation is extremely slow due to the comprehensive effects of their physical and chemical properties, posing challenges to the safety and stability of tailings dams (Li et al. 2019). Therefore, minimising the accumulation of soft and wet tailings deposits behind dams and ensuring that they are reclaimed progressively during the life of a project will significantly contribute to the long-term reclamation performance of tailings facilities.

The failure of tailings dams is often caused by the construction method and the inability of the tailings to drain down (Williams 2021). However, external factors also contribute to failures, including increased loading of the tailings dam, earthquakes, rainfall, flooding top, heavy snow and snowmelt, foundation subsidence, erosion (external and internal), slope instability, and post-closure climatic impacts. Tailings below the phreatic surface have a slow consolidation rate, and the nearly saturated tailings reduce the dam's shear strength and effective stress. Using geotextile tubes is an innovative solution available for engineering projects that combines mechanical and hydraulic properties in a controlled manner (Krystian 2007).

The treated fluid fine tailings dewater in the geotextile tubes, and the rate of dewatering is a function of the recipe; the inline mixing process; the short drainage path of the geotextile tubes containment; internal pressure and gravity head during filling; hydraulic parameters of the geofabric material; evaporation; freeze-thaw; self-weight consolidation; and increased total stress by stacking the geotextile tubes to form stable deposits of thickened and filtered fluid tailings.

2 Lessons learned updates

2.1 Geotextile tubes/recipe concepts

Geotextile tubes are made from woven, high-strength, high-modulus, synthetic fibres with distinct pore sizes that can dewater the chemically treated fluid fine tailings. The success of fluid fine tailings disposal in geotextile tubes requires a physicochemical treatment that combines coagulation and flocculation, referred to herein as the 'recipe'. The objective of the recipe is to maximise fines capture, enhance dewatering, accelerate consolidation, and maintain the integrity of the agglomerated fines to ensure that segregation does not occur.

The geotextile tubes act as a filter pressure system, with most water recovery occurring while the tubes are being filled. The filtration properties of the geotextile tubes and the containment's short drainage path are key contributors to the enhanced dewatering and accelerated consolidation of the treated fluid fine tailings.

The geotextile tubes/recipe approach also allows for the formation of geotechnically stable, thick, layered deposits by simply stacking the geotextile tubes. Supporting data includes the interpretation of laboratory and field testing to evaluate the fluid fine tailings' inherent geotechnical and mechanical properties; rationale of the recipe; and geotechnical instrumentation monitoring real-time data to capture the fluid fine tailings behaviour changes in time.

2.2 Key testing, findings and processing methods

Identifying and quantifying the fluid fine tailings' mineralogy are considered 'critical' for successfully manipulating clay and non-clay mineral behaviours, along with porewater chemistry and pH. Therefore, this study utilised bulk X-Ray Diffraction (XRD) analysis, elemental analysis by X-ray Energy Dispersive Spectrometry (EDS) and Scanning Electron Microscopy (SEM) to characterise the mineralogy of the fluid fine tailings. In addition, quantitative elemental analysis was performed by an Oxford INCA microanalysis system attached to a JEOL JSM-6610 scanning electron microscope.

First, the fluid fine tailings slurry density, specific gravity, water content, and bulk and dry densities were determined to characterise the tailings and evaluate polymer dosage and concentration as well as released water volumes.

Further, routine chemical analyses were undertaken to characterise ion concentrations and pH of the fluid fine tailings porewater, plant process water, and released water from the treated fluid fine tailings with the recipe (treated fluid fine tailings) to determine the amounts that can be used as reclaimed water.

Particle size distribution (PSD) was obtained by sieve and hydrometer method (SH), as per ASTM D422-63.

Then, dilution was applied to control variations of the feed densities if the initial slurry density was higher than 20 wt.% solids. The fluid fine tailings at an initial slurry density of 20 wt.% solids provided enhanced mixing and maximised flocculant adsorption at relatively low dosages.

Coagulation was applied prior to flocculation to neutralise the electrostatic charges of particles and reduce repulsion between them. A coagulant solution was prepared using Alum (aluminium sulphate) and process water. A flocculant solution was prepared using anionic polyacrylamide (PAM) polymer and process water.

The fluid fine tailings were coagulated with Alum at concentration 0.1% and dosage 0.65% (by mass) prior to flocculation with a high molecular weight (HMW) anionic PAM polymer at concentration 0.1% and dosage 0.1% (by mass).

Finally, settling tests were performed to evaluate the initial dewatering performance of the treated fluid fine tailings. The time for solids water separation and fines agglomeration using the recipe was 20 seconds.

Field trials indicated that inline mixing of the coagulated fluid fine tailings with flocculant solution does not require static or dynamic mixing. The inline mixing residence time in the pipeline was 20 seconds to provide efficient flocculation, solid/water separation, and fines agglomeration (large floc formation).

2.3 Inherent properties and soil characterisation

Mineralogy is the primary factor controlling soil particle size, shape, and properties. These same factors determine the possible ranges of physical and chemical properties of any given soil. Prior knowledge of a soil's minerals provides intuitive insight into its behaviour (Mitchell 2005).

The mineralogy of the fluid fine tailings is predominantly non-clay minerals (52.3% quartz < 75 µm) followed by clay minerals (40.1% kaolinite and 4.6% illite < 2 µm particles). The predominance of quartz can revert to kaolinite; therefore, the ratio of clay to massive minerals in the fluid fine tailings can vary from 0.8 to 1.1. Other mineral amounts such as microcline (highest), clinochlore, siderite, pyrite (lowest), anatase, rutile, albite, dolomite, and calcite add up to about 3.0% in total.

Quartz is the predominant mineral within the fine particle size fraction of the fluid fine tailings in this study. At pH higher than 2, quartz particles possess a negative charge, show dispersive behaviour and are more hydrophilic (van Lierde 1980; Hunter 1981; Hussain et al. 1996; Gan & Liu 2008). The rationale for this behaviour is that the particle surface reacts with water, forming silicic acid, which, in turn, dissociates to form a silicic anion at the surface and a hydrogen (H^+) ion that diffuses off into the solution. This chain of events negatively charges the particle surface as the diffusing H^+ ion carries away a positive charge and leaves a negative charge behind.

The behaviour of kaolinite particles depends on the sodium adsorption ratio (SAR), electrolyte concentration, and pH. Kaolinite has a negative surface charge at pH > 2 (Goldberg et al. 1991). Illite is non-swelling, has a lower cation exchange capacity than kaolinite, and is also pH- and SAR-dependent.

The measured average properties of the fluid fine tailings of this paper indicated solids specific gravity of 2.50; water content is 360.0%; solids content 20 wt.% solids; total bulk density 1.15 t/m^3; dry density 0.25 t/m^3; and void ratio 9. Understanding these initial properties is fundamental for the recipe's design, including flocculant and coagulant dosages and concentrations and release water volumes.

The PSD of the treated fluid fine tailings, right after the geotextile tube is complete (i.e., full), shows that the fines content passing 75 µm sieve varies from 87% to 100% and that the clay content ranges from 31.6% to 50.5%. The sand-to-fines ratio (SFR) of the treated fluid fine tailings varies from 0.02 to 0.16. The measured average solids specific gravity of the treated fluid fine tailings is 2.48, water content is 86.9%; solids content is 53.6 wt.% solids; total bulk density 1.47 t/m^3; dry density 0.79 t/m^3; and void ratio 2.16. The USCS classification is CH; liquid limit is 76.8%; plastic limit is 29.0%; and the liquid index is 47.8%. The laboratory and field test results indicated that the treated fluid fine tailings dewatered in the geotextile tubes during filling, providing significant enhanced fines capture as indicated by its dry density and void ratio.

Although kaolinite particle sizes could exist in the range of 2 µm to 11 µm and quartz particles could exist in the range of 0.2 µm to 2 µm (Mitchell & Soga 2005), we are assuming that the amount of non-clay minerals in the treated fluid fine tailings is between 49.5% and 55.4%. Therefore, the treated fluid fine tailings are predominantly non-clay minerals, consistent with the results from the mineralogy analysis of this paper.

2.4 Properties of the commercial geotextile tubes GT500 referred to in this paper

Table 1 Mechanical properties

Mechanical properties	Test method	Unit	Minimum average roll value	
			MD*	CD*
Width tensile strength/ultimate	ASTM D4595	kN/m	78.8	109.4
Width tensile elongation	ASTM D4595	%	20 max.	20 max.
Factory seam strength	ASTM D4884	kN/m	70	
CBR puncture strength	ASTM D6241	N	8,900	
Apparent opening size (AOS)	ASTM D4751	mm (U.S. Sieve)	0.43 (40)	
UV resistance (retained after 5000 hrs)	ASTM D4355	%	80	

* MD = Machine direction (material off the roll); CD = Cross machine direction (material across the roll)

Table 2 Filtration properties of the engineered woven polypropylene yarn

Filtration properties	Test method	Unit	Typical average

Pore size distribution (O_{50})	ASTM D6767	Micron	80
Pore size distribution (O_{95})	ASTM D6767	Micron	195

Table 3 Physical properties

Physical properties	Test method	Unit	Typical average
Mass/unit area	ASTM D5261	g/m^2	585
Thickness	ASTM D5199	mm	1.8

2.5 Commercial geotextile tubes GT500 parameters

The stacked tensile strength is 220 kN/m (Figure 1). This parameter is based on lab analysis cross-machine direction (CMD) provided by the manufacturer. The ultimate strength of the geotextile tube is represented by T (ult.) = T (work) x (FS id x FS ss x FS cd x FS bd x FS creep) where: T (work) = 220 kN; FS id (installation damage) = 1.3; FS ss (seam strength) = 2; FS cd (chemical degradation) = 1.0; FS bd (biological degradation) = 1.0; and FS creep = 1.0.

In the context of geotextile tubes, the maximum tensile force in the geofabric will be mobilised during the filling (pumping the tailings into the geotextile tube). After pumping, as the slurry solidifies, this force relaxes. Therefore, a slight FS creep can be assigned for the geotextile tube, such as FS = 1.06. Verification of the FS for circumferential direction can be expressed by: FS = T (work tensile strength) ÷ (T ult.) and therefore, Factor of Safety (FS) = 220 ÷ [24.93 (1.3 x 2.0 x 1.0 x 1.0 x 1.06)] = 3.2.

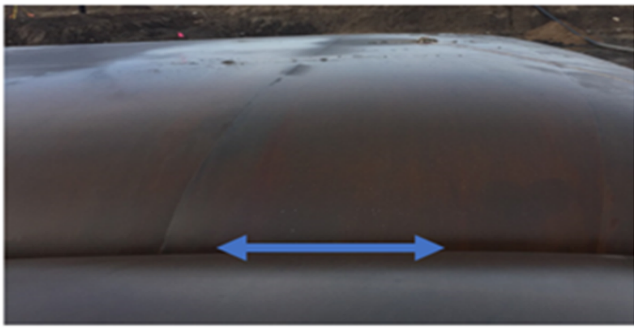

Figure 1 Commercial geotextile tubes GT500 parameters.

Table 4 Geotextile tubes GT500 parameters

Input		Output
Geotextile tube length	100 m	Max. length = 100 m
Geotextile tube height	2.9 m	Max. circumferential tensile force = 24.93 (kN/m)
Geotextile tube circumference	44.0 m	Max. average axial tensile force = 23.00 (kN/m)
Density of the fill material	1.2 t/m^3	Geotextile tube base contact width = 20.66 m
Seam type	Circumferential	Cross section area = 55.21 m^2
Fill port type	Rigid mech.	Volume/length = 55.21 m^3/m
Fabric type	GT 500	(%) max. fill capacity = 36%
		Pressure at the base = 34.256 kPa
		Circumferential direction FS = 3.2
		Axial direction FS = 3.0
		Fill port rupture FS = 3.2

2.6 Physicochemical treatment of the fluid fine tailings

The objective of the recipe is to maximise fines capture, enhance dewatering, accelerate consolidation, and maintain the integrity of the aggregate to ensure that fines segregation does not occur.

Quartz particles at pH > 2 present a negative surface charge. This negative charge increases as the pH increases (Van Lierde 1980). Quartz particles at pH 8 present a highly negative surface charge that leads to a dispersive state through electrostatic repulsive forces. These forces are affected by the ionic strength of the soil-water-ionised system, which depends on the pore solution electrolyte concentration and ion types (Verwey & Overbeek 1948). In the presence of high valence cations, such as aluminium, the repulsive forces of quartz particles are reduced, resulting in the coagulation of the particles.

Kaolinite exhibits a significant positive value of zeta potential in the presence of aluminium (Al^{3+}) cations. The zeta potential decreases from +30 mV to –7 mV as the pH increases from 3 to 10 with a point-of-zero charge at pH 9 (Peng and Di 1994). In this study's analysis, kaolinite is the predominant clay mineral within the fine particle size fraction of the fluid fine tailings. The primary source of negative charge in kaolinite clay minerals is the unsatisfied chemical bonds at the broken particle edges. The negative charge may increase by adsorbing high-valence negative ions to positive ions exposed at the broken edges. Since the anion exchange capacity of kaolinite particles is equivalent to the cation exchange capacity, it is logical that cations could influence the dispersed kaolinite in the soil-water-ionised system. The exterior surfaces of illite and kaolinite particles absorb all exchangeable cations (van Olphen 1977). Existing data shows that illite does not play a dominant role in determining the flocculation and dispersion behaviours of kaolinite/illite mixtures (Goldberg et al. 1991). Therefore, the physicochemical treatment focuses on quartz particles since they are predominant and significantly affect the flocculation and dispersion behaviours of the fluid fine tailings.

The initial slurry density of the fluid fine tailings significantly influences the physicochemical treatment performance. Therefore, diluting the fluid fine tailings to a lower solids content is an integral part of the treatment to provide enhanced mixing and energy dissipation. This process maximises flocculant adsorption, reduces fine particle segregation, and ensures efficient particle agglomeration when the flocculant is added.

The mechanism of coagulation effectively lowers the electrostatic repulsive forces between particles causing charge neutralisation and the formation of stable micro-flocs (slow-settling flocs). Charge neutralisation is equivalent to compressing the diffuse double ionic layer energy barrier (i.e., reducing the double ionic layer charge to near zero). The key to obtaining effective coagulation of the fluid fine tailings is understanding how the individual tailings mineral particles interact within the soil-water-ionised system. Charge neutralisation from the existing Ca^{2+} concentration in the fluid fine tailings pore water is usually insufficient to coagulate quartz and kaolinite particles. In addition, the levels of bicarbonate present in the pore water precipitate Ca^{2+} at nearly pH 8, affecting the ionic strength of the soil-water-ionised system. Therefore, it is necessary to add a coagulant aid to lower the surface charge and reduce the repulsive energy barrier of the quartz and kaolinite mineral particles. Coagulation is the basis of the treatment because it increases the density and shear resistance of the micro-flocs, so they are more robust during mixing and settling.

The cations added by the coagulant will also affect the total negative charge of the clay particles in the soil-water-ionised system because the remaining anions are attracted to the incompletely neutralised positive ions exposed at the broken edges of the clay particles. Furthermore, negative particles can be successfully flocculated with bridging long-chain anionic polymers because regions of the particle with a positive charge serve as points of attachment for the negatively charged polymer. A relatively small amount of anionic flocculant of medium charge density and very HMW is used to bridge the micro-flocs and form large and fast-settling flocs.

Hydrolysed metal ions, such as calcium and aluminium, play an important role in the fluid fine tailings dispersion and flocculation behaviours because they adsorb on the particle surfaces and reduce the double layer charge to near zero. In addition, it is fundamental to understand the effects of the hydrolysed metal ions on the interaction behaviour of the anionic PAM polymer and their impact on the flocculation of the fluid fine tailings. Adsorption of anionic PAM polymer on quartz and kaolinite surfaces strongly depends on pH and salinity. Salinity refers to a body of water's dissolved salt content (calcium, aluminium, magnesium, potassium, sodium, bi-carbonates, chlorides, and sulphates).

Increased calcium cations and pH cause adverse effects on the adsorption of anionic PAM polymer on quartz and kaolinite particles. Poor flocculation of quartz and kaolinite observed between pH 8 and 8.45 was potentially due to the adsorption of Ca^{2+} ions on anionic PAM polymer, causing steric stabilisation at the particle surfaces, and inhibiting the formation of hydrogen bonds. The negative impact on quartz and kaolinite particles' flocculation can be reversed by adding metal salts of higher valence than calcium, such as aluminium ions. Quartz slurry at nearly pH 8 with increased calcium concentrations (> 72 ppm) showed efficient flocculation when coagulated with aluminium ions.

Quartz is the predominant mineral of the fluid fine tailings in this paper, followed by kaolinite and illite. The fluid fine tailings pore water contains about 18 ppm calcium ions; process reclaim water contains about 19 ppm calcium ions. Efficient fines agglomeration and dewatering of quartz and kaolinite particles are achieved with coagulation by aluminium ions before anionic polymer PAM addition. The fluid fine tailings zeta potential was -47 mV at pore water pH 8. The treated fluid fine tailings (with aluminium and anionic PAM polymer) zeta potential measured -14 mV at pore water pH 7.

2.7 Evaporation testing

This study conducted evaporation tests on untreated fluid fine tailings, treated fluid fine tailings and centrifuge cake to investigate and compare their evaporation rates. Test results shown in Figure 2 indicate that, at the early portions of the plots, the actual rate of evaporation of the treated fluid fine tailings is close to the potential rate of evaporation of water and is higher than the actual evaporations of the untreated fluid fine tailings and centrifuge cake samples.

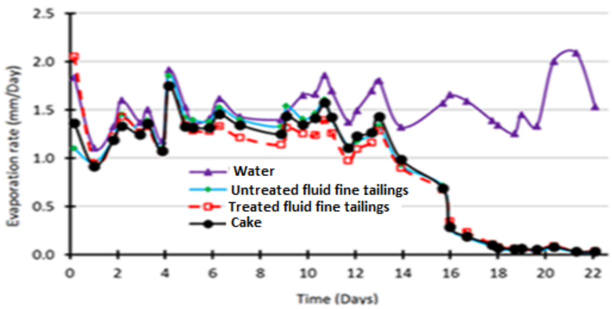

Figure 2 Rate of potential evaporation of water, untreated and treated fluid fine tailings, and centrifuge cake vs time.

It should be noted in Figure 3, through the ratio of the actual evaporation (AE) and potential evaporation (PE), that the untreated fluid fine tailings and centrifuge cake samples dewater much slower (i.e., AE/PE ≤ 1) than the treated fluid fine tailings in the early stage of the drying process while the surfaces are wet.

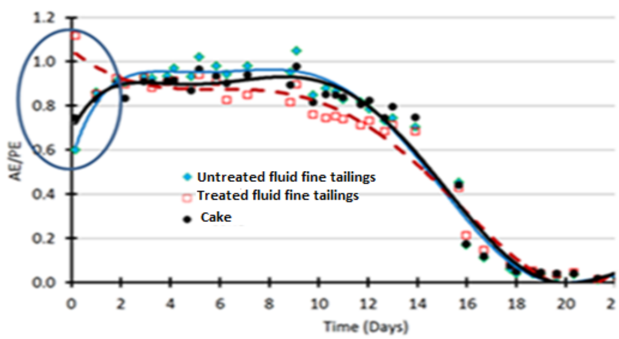

Figure 3 AE/PE ratios for treated and untreated ultrafine tailings and centrifuge cake.

The treated fluid fine tailings, however, evaporate at a potential rate ≥ 1 (i.e., AE/PE ≥ 1) when the sample is saturated in the early stage of the drying process, which is possibly attributed to the fact that the treated fluid fine tailings have an open soil structure.

As drying continues, the AE/PE ratios of the untreated fluid fine tailings and cake gradually increase to a value of 0.96 and remain constant until Day 10. Eventually, the AE/PE ratios decrease to 0.8 on Day 12. During this time, the AE/PE ratio of the treated fluid fine tailings continues to decline gradually and reaches a value of 0.8 on Day 10.

The AE/PE ratio of 0.8 is the boundary between the saturated and unsaturated states of the samples. As drying proceeded in the unsaturated region (i.e., AE/PE < 0.8), all the AE/PE ratios started to decline rapidly to their lowest values (i.e., residual) of close to zero (all the surfaces of the samples became desiccated).

In summary, the treated fluid fine tailings lose water much faster and reach the boundary region (i.e., AE/PE = 0.8) earlier than the untreated fluid fine tailings and the centrifuge cake

2.8 Undrained shear strength behaviour

Field trials under a loading condition, such as stacking two layers of commercial sizes geotextile tubes, as shown in Figure 1, were performed to evaluate and monitor the undrained shear strength and porewater pressures behaviours during one completed seasonal cycle (spring, summer, fall, and winter). Table 5 summarises the trial results.

Table 5 Excess pore pressure dissipation

Parameter	Geotextile tube (initial condition)	After 1 year	Seasonal cycle completed
Static pore pressure U_0 (kPa)	19.62	10.79	
Excess pore pressure Δu (kPa)	9.86	2.35	
B-bar	0.50	0.22	Pore pressure dissipation

Table 6 shows that the undrained shear strength of the treated fluid fine tailings increases with time, responding well to the relatively rapid loading of two layers of geotextile tubes. The second layer was stacked immediately following the completion of the first layer (still at 2 kPa undrained shear strength).

Table 6 Average undrained shear strength of the stacked geotextile tubes

Parameter	Geotextile tube filling completed	After 1 year	Comments
Peak	2.0 kPa	15.0 kPa	Field, Lab, and Monitoring Data
Remoulded	0.3 kPa	2.8 kPa	

2.9 Forecasted physical stability

The results in Table 6 indicate that the tensile strength with low elongation provided by the geofabric is a key reinforcing parameter of the geotextile tubes deposits. This allows stacking at low undrained shear strength (2 kPa), usually achieved when the filling of the geotextile tube is completed at the recommended height by the manufacturer.

Let us consider using a geotextile tube of commercial size 100 m length x 44 m circumference with a total volume capacity of 5,521 m^3. Based on field trial results, during the first year of installation, the treated fluid fine tailings within the tubes will achieve 85 wt.% solids and a dry density of 1.75 t/m^3. Therefore, the total dry solids captured per tube will be about 9,662 T. Assuming the installation of a total of 400 commercial tubes to form two layers per year, as a construction rate, the total capture of dry solids per year would be about 3.86 MT. Suppose we stack 20 layers of tubes to form a ± 30 m high deposit, occupying an area of about 700 m x 700 m, at an average slope 2(H):1(V) and similar drainage conditions shown by the results of this paper. In that case, we could capture about 38.6 MT of dry solids during ten years of operation. Then, we likely could assume that the lower to mid zones of the deposit would already have sufficient time to dissipate the majority of excess pore pressure. Thereby, the effect of the slow rate of loading (construction of the deposit) from the upper layers would allow time for drainage of the layers below; therefore, there would effectively be no increase of pore pressure in those zones of the deposit. In this case, it is possible to have drained and undrained responses during shear under our loading and drainage conditions.

3 Stacked deposits of thickened and filtered fluid fine tailings using geotextile tubes

3.1 Mining industry paradigms

Minimising the accumulation of soft and wet tailings deposits and ensuring that they are reclaimed progressively during the life of a project will significantly contribute to the long-term reclamation performance of tailings facilities. The mining industry has used flocculants with the expectation that they alone will benefit fine particle agglomeration and dewatering. Unfortunately, significant amounts of trapped water remain in the flocculated tailings, resulting in a low rate of shear strength gain and long consolidation timeframes that pose substantial challenges in converting the fluid fine tailings into deposits capable of facilitating reclamation.

In light of net present value (NPV) accounting, the mining industry has taken a sustainable, low-cost approach. Starting with low front-end costs to achieve the most economical solution to an acceptable level of tailings deposit, such as transporting tailings as a slurry to a surface dam, limits alternatives under consideration and increases operating costs over time, leading to high back-end costs. Therefore, the industry should be challenged to use the best available tailings technology that works and progressively optimise costs. This approach will ensure that reclamation is possible and that the post-closure long-term performance of the tailings facility is safe.

Figure 4 Example of increased storage volumes of soft and wet tailings deposit less capable of facilitating reclamation.

3.2 Recipe referred to in this paper

The fluid fine tailings, predominantly quartz and kaolinite particles at pH 8, present a highly negative surface charge (-40mV) that leads to a dispersive state by the action of the electrostatic repulsive forces. As a result, a significant amount of trapped water remains if treated with flocculant alone, as shown in Figure 5.

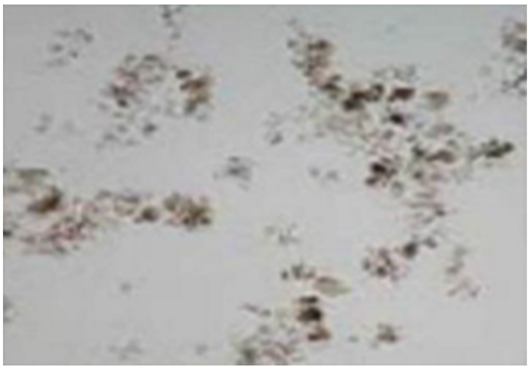

Figure 5 Example of poor flocculation showing a significant amount of trapped water.

Coagulation of the fluid fine tailings with high valence cations of aluminium (Al^{3+}) lowers the electrostatic repulsive forces between particles causing charge neutralisation and formation of stable micro-flocs (slow-settling flocs), as shown in Figure 6.

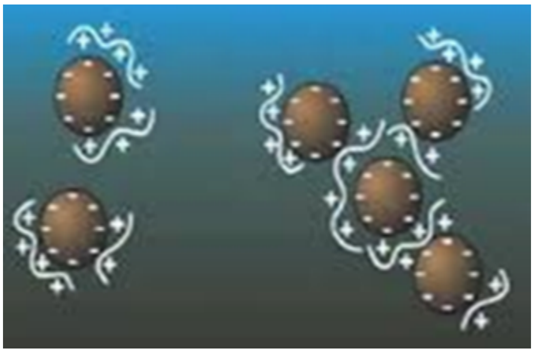

Figure 6 Quartz and kaolinite particles' repulsion forces are reduced with high valence cations addition.

Figure 7 shows efficient flocculation, whereby fine particles agglomeration and water separation when coagulated fluid fine tailings are flocculated with an anionic PAM polymer addition at a small concentration and dosage.

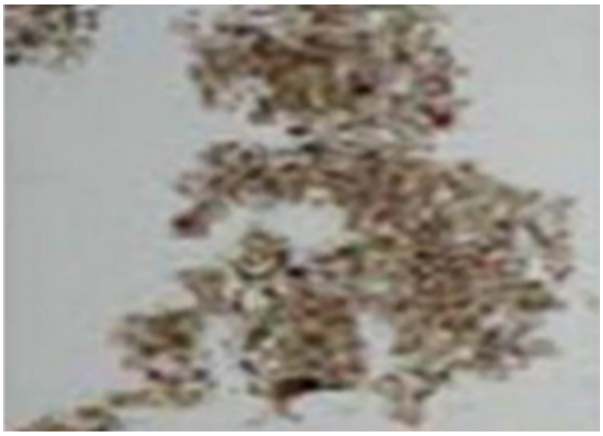

Figure 7 Example of efficient flocculation of quartz and kaolinite particles.

The fluid fine tailings were coagulated with Alum (aluminium sulphate) at a concentration of 0.1% and dosage of 0.65% (by mass) prior to flocculation, with a high molecular weight (HMW) anionic PAM polymer at a concentration of 0.1% and dosage of 0.1% (by mass).

3.3 Summary of the key lessons learned: updates, concepts, and new approaches in tailings management

1. Geotextile tubes are soil-filled, high-strength, high-modulus, woven geotextiles made from synthetic fibres with distinct pore sizes used as dewatering containment. They resist ultraviolet deterioration and biological degradation and are inert to most naturally encountered chemicals, alkalis, and acids.
2. The inherent properties of the fluid fine tailings constituents and extraction process, including water chemistry and pH, collectively dictate the mechanical and physical properties of the fluid fine tailings.
3. Efficient fines agglomeration and dewatering of the fluid fine tailings of this paper (quartz and kaolinite particles) were achieved with coagulation of the particles by aluminium ions before an anionic PAM polymer addition.
4. The fluid fine tailings solids/water separation is achieved by inline coagulation/flocculation (recipe) addition before the discharge into the geotextile tubes. Key factors for an efficient inline solids/water separation are the residence time of the mixing process and the minimisation of shearing (no static or dynamic mixing is required).
5. Filling the geotextile tubes is controlled by the specific strength and hydraulic parameters of the geofabric (seams and intake ports) that limit the intake pressure and the filling height of the geotextile tubes.
6. Field data indicated that, during filling, dewatering is due to internal pressure and gravity head initially and self-weight consolidation and stacking (loading) subsequently.
7. Once the treated fluid fine tailings are discharged in the geotextile tubes, the filtration properties of the geofabric and the short drainage path of the containment are the key contributors to the enhanced dewatering and accelerated consolidation. Evaporation and freeze-thaw are also identified as contributors to dewatering with time.
8. The geotextile tube deposits with treated fluid fine tailings act more as a filter pressure system, with most water recovery happening while the bags are filled. Fines capture ranges between 97 and 99% (51% silts and 47% clays). The material inside the geotextile tubes shows a considerable gain in strength over ten days, reaching over 5 kPa at the bottom of the deposit.
9. Tensile strength with low elongation provided by the geofabric is a key reinforcing parameter of the geotextile tubes deposit, allowing for stacking at low undrained shear strength (2 kPa), usually achieved when the filling of the geotextile tube is completed at the recommended height by the manufacturer.

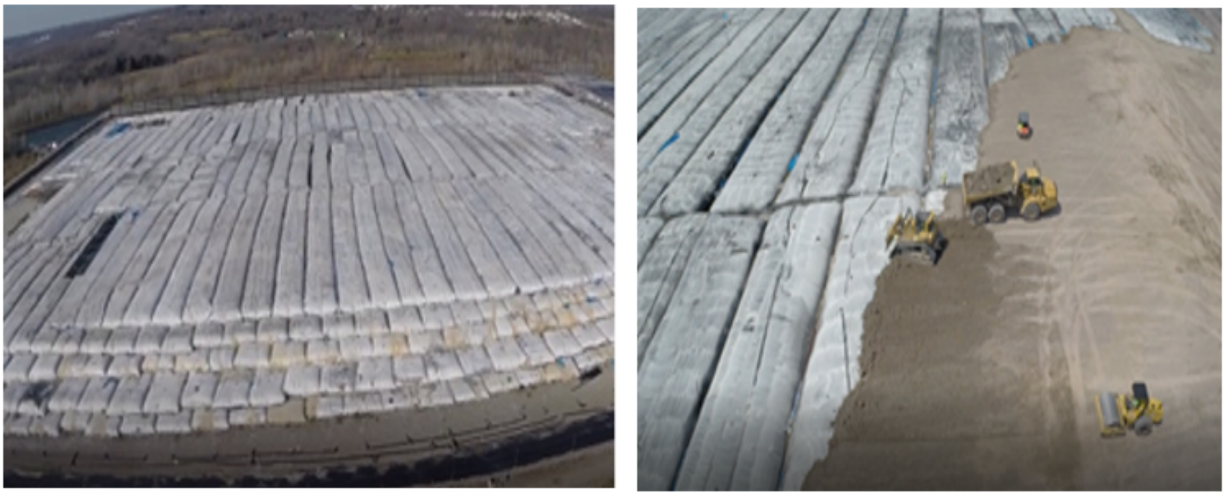

Figure 8 Example of stacked geotextile tube deposits, including capping (adapted from TenCate Geosynthetic Americas).

Figure 8 Example of reclamation of geotextile tube deposits after capping (adapted from TenCate Geosynthetic Americas).

10. Some benefits provided by the implementation of the geotextile tubes as filtration media for the thickened fluid fine tailings with the recipe include:
    a. New approach in tailings management to minimise/or eliminate risks posed by some conventional tailing facilities.
    b. Improvements in existing poor tailings management:
        i. Effectively managing water at operations.
        ii. Minimum material handling (inline mixing and discharge in the geotextile tubes).
        iii. No spreading or compaction is required.
        iv. Simplified infrastructure.
        v. Reduced footprint.
        vi. Assured geotechnical stability of tailings deposits (drained and undrained responses during shear and reinforced shear strength by the geosynthetic fabric).
    c. Optimising in-plant and in-facility dewatering of tailings by combining thickening and filtration to accelerate consolidation.
    d. Optimising co-disposal of ultrafine tailings and coarse-grained wastes, and waste rock.
    e. Tailing's rehabilitation post-closure:
        i. Buttressing support.

ii. Reprocessing of tailings (fine-grained and fines) and depositing in-pit.

4 Key discussions and conclusions

The Global Industry Standard on Tailings Management has the aspirational goal of zero harm to people and the environment from tailings facilities and provides a framework for safe tailings facility management while affording operators flexibility on how best to achieve this goal. In light of net present value (NPV) accounting, the mining industry has taken a sustainable, low-cost approach. Starting with low front-end costs to achieve the most economical solution to an acceptable level of tailings deposit, such as transporting tailings as a slurry to a surface dam, limits alternatives under consideration and increases operating costs over time, leading to high back-end costs. Therefore, the industry should be challenged to use the best available tailings technology that works and progressively optimise costs.

The implementation of stacked deposits of thickened and filtered fluid fine tailings using geotextile tubes has the potential to change the way that mine waste is managed, greatly reducing geotechnical risk and the complexity of closure compared to traditional methods. We envisaged that by sharing the successful lessons learned from the geotextile tubes/recipe approach as a feasible alternative solution for tailings management, we can play a crucial role in demonstrating that reclamation is possible and post-closure, long-term performance of tailings facility is safe.

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