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Oil sands thickened tailings – remedies from an international perspective

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ABSTRACT:

The deposition of conventional thickened tailings across the international mining industry has encountered many operational challenges over the years. These include variation in feed, solids content, beach establishment, stability and capacity constraints, drainage, consolidation, supernatant and fines. High quality design and operation of thickeners can prevent many of the problems encountered in tailings deposition. However, despite their best efforts, tailings managers still encounter significant challenges during deposition.

This paper outlines the elements of a successful thickened tailings deposition plan and describes some of the interventions available to the tailings designer or operator, which have been successfully implemented as remedies. These include control of slurry relative density, elimination of excess water, development of a conservative deposition cycle which takes account of weather, discharge control, drainage and decanting techniques, and planning for off-specification events.

It also presents potential issues with thickener implementation within the Oil Sands industry due to the nature of feed and material variability, difficulties in depositing material in the short term and long term and drying material efficiently.

Keywords: thickener, deposition, operations, beach, segregation, lessons, plan

1 INTRODUCTION

Around the world many mining operations are managing their tailings depositions using thickened tailings plans. These plans are developed to decrease the amount of water in the tailings, increase land use efficiency, and reduce energy requirements as well as many other benefits. However, despite the best effort of the tailings managers, significant challenges are being encountered during deposition.

Successful resolution of these challenges is best achieved through an integrated team effort between extraction, mining, tailings and utilities, while bearing in mind the requirements of public accountability, environmental care, reclamation and closure.

Many tailings challenges do not arise overnight. They are often the result of a combination of factors which if unaddressed may eventually spiral out of control. Similarly, the prevention and remediation of tailings operational challenges are the result of an intentional, integrated team plan which systematically addresses each aspect of the operation.

Much effort is usually expended in achieving operational success within the thickener. However there are many complications that can arise downstream of the thickener. This paper presents a brief review of some operator experience with thickened tailings, and also highlights some of the key operational challenges facing thickened tailings operations. A fundamental discussion about the key drivers contributing to tailings performance is also presented. Understanding these challenges and drivers is critical in developing successful tailings solutions. Useful experience, observation and case histories are also presented and the material is encapsulated in a conceptual tailings deposition plan.

2 LITERATURE REVIEW

State-of-the-art references regarding tailings operations are rare, and those addressing thickened tailings deposition even more so.

Catastrophic tailings failures are often described in graphic detail. There is less literature on how to avoid those failures. Sometimes the message of the paper is to identify the cause of the failure or to lay the blame, or to highlight a few key weak links in the chain of supply. What is usually missing is a comprehensive consideration of all elements in the planning, design and operation, placing each in the proper context, and with the appropriate level of attention. Sometimes failure results simply from an overemphasis on one area, and paying insufficient attention to another. Around the world many thickened tailings operations are struggling to produce satisfactory underflow, suitable for problem-free deposition. While the majority do not represent outright failure of the technology, the challenges should be examined for possible solutions and learnings that can help the industry grow.

There are numerous perceived benefits to utilising a thickened tailings scheme, including increased water recovery, reduction in water use, increased deposit density, reduced seepage and elimination of low-strength deposits (Fourie, 2012; Tacey and Ruse, 2006). The promises of thickened tailings have led to its adoption in most mining industries, including forays into the Alberta Oil Sands where the technology is relatively in its infancy, with thickeners currently being used at just two mine sites, Shell’s Muskeg River Project (Energy Resource Control Board, 2013a) and Shell’s Jackpine Project (Energy Resource Control Board, 2013b). Currently plans are being made for incorporation of thickeners into operations at Canadian Natural’s Horizon project (Canadian Natural Resources Limited, 2012) as well as at Imperial Oil’s Kearl project (Imperial Oil, 2012). There are three areas of attention in regard to thickener performance: upstream of the thickener in the plant or feed lines; within the thickener; and after the thickened material has left the thickener and is deposited.

Useful references are listed at the end of this paper. This paper will confine itself largely to the challenges and remedies experienced once material has left the thickener and is deposited within the tailings area.

3 TYPICAL OPERATIONAL CHALLENGES OF THICKENED TAILINGS DEPOSITS

The following describes typical deposition challenges of conventional thickened tailings in mining industries.

3.1 Solids content of thickener underflow

The solids content of thickener underflow defines the initial solids content for tailings deposition. The solids content (alternatively measured as slurry relative density) directly affects rheology, slurry yield stress and beach slope (Addis and Cunningham, 2010; Wates et al., 1987). A recent development has been the introduction of a shear thinning loop, which enables the thickener operator to generate a higher solids content for the underflow, while limiting the yield stress of the slurry (and associated rake torque), to a manageable maximum inside the thickener.

Generation of slurries of low relative density (in other words containing excess water) has historically been one of the primary problem areas encountered in tailings operations worldwide. In addition, variation in solids content (higher or lower than target) is responsible for deposition difficulties in establishing sound beaching practice, as described in the following paragraphs. Also the variation in solids content hinders the development of an ideal equilibrium beach profile (in which a relatively consistent lift thickness is established from the head to toe of the beach).

Off-specification deposition in which solids contents is too low will generate increased mine water inventory, require a more robust dewatering system, present challenges for recycle water storage, and may present difficulties in maintaining beach stability.

Off-specification deposition in which solids contents is too high, while more unusual, may lead to pumping and pipeline failure, development of unfavourable beach slopes, loss of capacity, and interruption of beach drainage, leading to ponding of supernatant.

A robust tailings scheme typically includes a narrow range of possible solids contents as one of the design parameters. Strict control of feed variation is fundamental to sound beach deposition practice.

3.2 Feed variation

Variation in feed may be more than simply a variation in solids content, or alternatively, water content. The variations may be due to a change in fines content, clay content, mineralogy or chemistry. The source of variation may be the ore itself, a process change, addition of a flocculant, or a change in dosage, or a change in plant water chemistry. Even a change in milling (in hard rock tailings) or a change in particle shape may be significant.

Jewell (2012) records that variation in mining (mined material extraction, chemical amendment, etc.) can cause significant fluctuation in tailings properties and that a single parameter may change over time. The resulting variation of the feed at discharge with regards to solids content, discharge velocity and fines content can cause several operational issues similar to those presented in Section 3.1 of this paper; in addition, the feed variation can also cause unfavourable dewatering behavior due to high clay content and subsequent slow rate of dewatering.

In extreme circumstances a lack of stability in the feed can also lead to the creation of complex, interlayered deposits, with rapidly changing strength, drainage and fines capture profiles both vertically within the deposit and laterally across the deposition area (Energy Resource Control Board {now Alberta Energy Regulator}, 2013b).

3.3 Beach establishment

The establishment of a tailings beach with optimum beach geometry (including length, slope, and lift thickness) is critical to the success of the tailings operation. The beach plays a critical role in the sizing of compartments, in drainage and pond location and tailings material distribution. Beach geometry is influenced primarily by the properties of the tailings at discharge, operational conditions, and the deposition environment (Simms et al., 2011; McPhail et al., 2012; Fitton et al., 2008). Some of the challenges with the beach establishment are as follows:

- Non-uniform beach establishment, which generates low spots and subsequent ponding of supernatant.
- Excessive beach erosion due to prolonged channel flow and deposition of low-density tailings slurries and water.
- Over-shearing of tailings during deposition resulting in excessive segregation, unfavorable tailings dewatering behavior and potential loss of pond capacity and operating freeboard.
- Deposition onto soft (insufficiently dewatered) tailings beaches, which can encourage channel flow, beach erosion and internal slope instability.
- Increased beach length or reduced beach length, requiring increased earthwork volumes for tailings deposition control.
- Variation in deposition rheology, resulting in challenges in placement, timing of and control of subsequent deposition cycles.

3.4 Slope stability

Many tailings containment facilities are designed to have a gradually sloping tailings beach with little to no ponded water. This sloped profile can be created using thickened tailings that are produced with a relatively high solids content and strength (Robinsky, 1975, 1978). An additional benefit of thickened tailings is the ability to create a stacked deposit, which reduces the overall containment facility footprint and reduces costs. Stacked deposits are dependent upon each deposited layer achieving the strength necessary to satisfy geotechnical slope stability requirements. Challenges in achieving the stacked configuration can arise from operational issues with the thickened tailings that lead to non-uniform lift thicknesses, segregation, variable water contents and non-uniform strength distributions; all of which can result in slope instabilities.

3.5 Supernatant water

Ponded water can be generated several different ways; from released water from the deposit, storm water collection within low lying areas of the deposit caused by differential consolidation settlement, from a poorly formed beach, poor deposition area coverage, or simply from a surficial disturbance (such as mud farming). Ponded water introduces the following operational challenges:

- It prevents a uniform beach slope from being established due to subaqueous beaching.
- It retards evaporation and strength gain of the deposit resulting in increased cycle times and delayed deposition schedule.
- It reduces surface trafficability and limits reclamation options.

3.6 Consolidation

The consolidation phenomenon is a process by which soils decrease in volume due to applied stresses. During this process soils gain effective stress through dissipation of excess pore water pressure. For tailings materials, the rate and amount of consolidation are highly impacted by compressibility and hydraulic conductivity (Carrier et al., 1983). During operation, the challenges involving consolidation include unfavourable compressibility and deteriorating hydraulic conductivity; soft tailings surfaces preventing surcharge application; and unknown long-term consolidation behavior (Krizek 2004).

3.7 Subsurface drainage

Sub-surface drainage techniques such as bottom drainage blankets, sand layering and wick drains are widely used in many thickened tailings storage facility to reduce the drainage path and to increase the rate of consolidation (Krizek, 2004). Operational challenges of subsurface drainage systems include:

- Pre-installation and non-maintainable components.
- Blinding of drainage due to consolidation and fines migration at the drainage boundary.
- Start-up challenges – tailings with unfavourable properties often get deposited onto the bottom drainage boundary, reducing its overall functionality and success.
- Access and installation challenges on soft tailings deposits for wick drains.
- Complex operation limiting the chances of success (in a case of sand layering).

3.8 Fines

Tailings and soil engineering behavior is highly influenced by particle size distribution. Fines or particles finer than 0.075 mm (geotechnical silt and clay size particles) are used in geotechnical engineering as an index parameter to classify and categorize the behavior of soils. For some thickened tailings, fines can be related in the same way to key deposit behavior including consolidation, segregation, turbidity, and strength.

Increasing the fines content in a tailings deposition stream can lead to several issues such as:

- Reduced hydraulic conductivity, leading to slower rates of dewatering.
- Excessive suspended particles in supernatant water for recycle.
- Lower deposit strengths.
- Increased segregation and possible fouling of drainage and water collection systems.
- Fines migration and possible clogging of drainage and water collection system.
- Flatter beach slopes and reduced containment capacity.

4 TECHNICAL RATIONALE BEHIND THE KEY CHALLENGES

The following provide non-exhaustive technical rationales behind a few key challenges within the mining industry.

4.1 Consolidation

Rate of consolidation can typically be expressed by a coefficient of consolidation, which is proportional to the hydraulic conductivity, and inversed proportional to the coefficient of volume change. In general, the higher the hydraulic conductivity, the faster the consolidation process will be. The hydraulic conductivity for typical oil sands TT is shown in Figure 1.

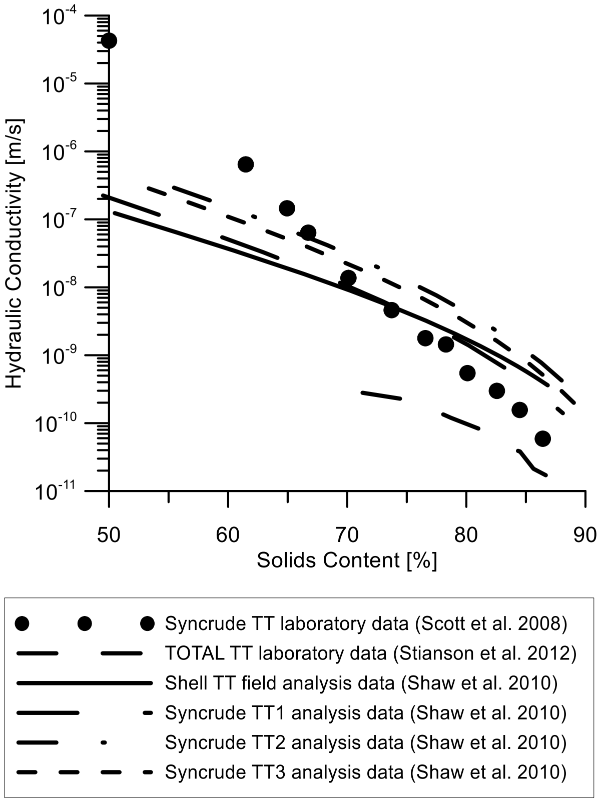

Figure 1. Hydraulic conductivity for oil sands TT SFR~1.

The hydraulic conductivity of the oil sands TT exponentially decreases with solids content; and as the solids content approaches the liquid limit (60 to 65% solids content), the hydraulic conductivity of the tailings approaches 10-8 m/s, which is a typical value for a landfill clay liner (Alberta Environment, 2010). The low hydraulic conductivity of the tailings is one of the key challenges in attempting to consolidate the tailings beyond the liquid limit as required by Alberta Energy Regulator.

Since the consolidation behaviour of typical TT is problematic and slow, various attempts have been made to improve the hydraulic conductivity of TT (Yuan and Shaw, 2007; Demoz et al., 2010; Mohler et al., 2012; Stewart et al., 2012). Although some success has been achieved in a laboratory-scale experiment, the enhancement is typically limited during the sedimentation phase; and there is little to no improvement during the consolidation phase (Scott et al., 1985; Jeeravipoolvarn et al., 2009). Moreover the enhanced hydraulic conductivity tailings can be more sensitive to shearing during deposition. Thickened tailings products therefore require robust characteristics that can be demonstrated both in laboratory and field conditions. Several research programs are currently underway to develop the use of chemicals in enhancing consolidation (Moffett, 2010; Soane et al., 2010; Sobkowicz et al., 2013). In addition, strategic tailings deposition and drainage schemes have been implemented in an attempt to accelerate the process of consolidation (Costello et al., 2010; Shaw et al. 2010; Mikula et al., 2010; Jeeravipoolvarn et al., 2010).

4.2 Segregation

Segregation or particle sorting impacts various aspects of tailings design and management (e.g. beach slope, consolidation, fines capture, etc.). An approximated static segregation boundary for oil sands thickened tailings from data obtained in literature (Donahue et al., 2008; Sorta et al., 2010; Jeeravipoolvarn et al., 2010) is shown in Figure 2.

Currently oil sands operators produce TT product at a fines content of about 50% and a solids content of about 50%. At these values, the TT is located marginally below the static segregation boundary of TT shown in Figure 2. However, the dynamic segregation boundary for the tailings is known to be significantly below the static one, and is a function of the shear energy applied to the sample. This implies that tailings deposition must be conducted under a controlled level of shear stress to prevent segregation. Several technologies are currently under investigation, including using a tremie diffuser (Costello et al., 2010), or the application of chemical solutions to prevent segregation (Moffett, 2010).

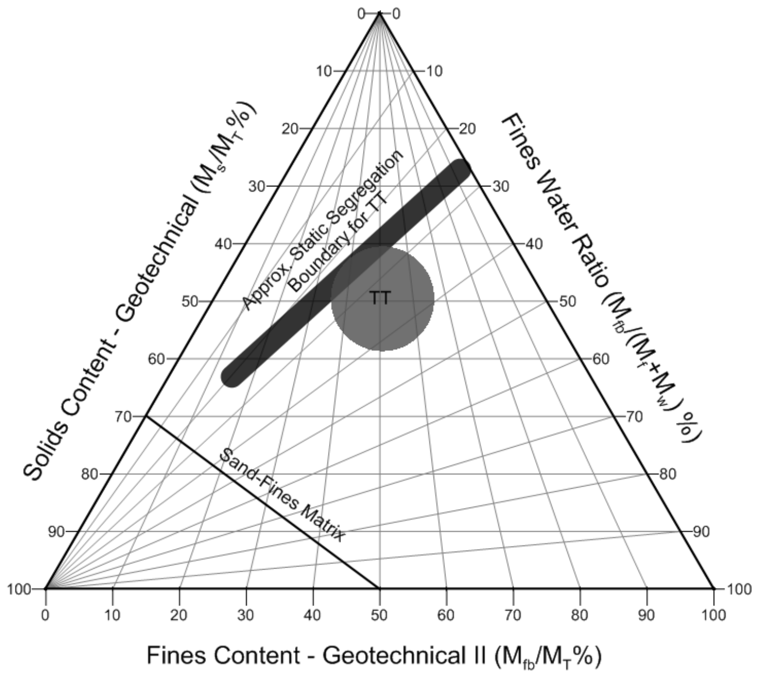

Figure 2. Approximated static segregation boundary for oil sands TT.

4.3 Shear strength and beach slope stability

One of the key components of the design of tailings impoundment is beach slope stability. Many TT deposits form a gentle beach slope whether by design, or otherwise. However, the presence of a slope may introduce a risk of beach slope instability and other more serious repercussions such as perimeter dyke overtopping with either the supernatant fluid or the tailings itself. It is of primary importance as tailings deposition schemes are looking to reduce land use by stacking deposits higher.

The introduction of paste disposal schemes and steeper beach slopes has placed a greater premium on stable tailings beach deposition. Beach slope slumps and failures and material movements that suddenly mobilise a large portion of the tailings deposit are to be avoided. Figure 3 provides an example of an infinite slope stability calculation for a range of beaching angles. Based on a number of reasonable and representative parameters for an oil sands TT, it shows that the minimum shear strength required for a notional weaker layer within a stable deposit increases with deposit thickness or depth from surface to the weak layer. Unsurprisingly, it also illustrates that the minimum strength requirement increases with increasing deposit slope.

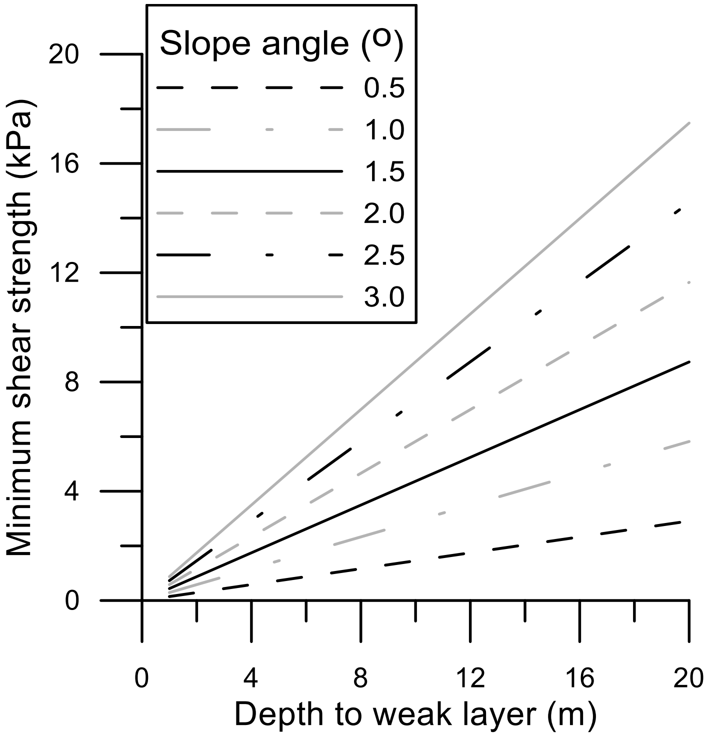

Figure 3. Maximum shear strength for a factor of safety of 1.0 versus depth to weak layer for several slope angles.

The infinite slope stability analysis demonstrates the importance of strength development in a tailings deposit and shows that the development of strength in a tailings deposit dictates how thick and how steep a deposit can be established. This highlights the fact that each layer in a TT deposit needs to be designed to allow material to gain adequate strength before stacking, and to limit the total stacked deposit height to prevent flowing or sliding. The actual design of the deposit, however, must also be based on consideration of other important design considerations. The following are some key considerations to be evaluated for deposit stability:

- Tailings type and properties (strength, density, consolidation, hydraulic conductivity, etc.).
- Deposit geometry and composition (slope, thickness, layers, etc.).
- Loading condition (drained, undrained, dynamic, static).
- Failure mode (rotational, translational, flow, creep, rupture, etc.).
- Foundation condition (strength, geometry, weak plane and layer).
- Ground water condition and management (inside and outside of a deposit).
- Level of risk associated with slope failure.

To promote deposit stability, design and management of a tailings storage facility may follow the observational method by promoting dewatering mechanics; monitoring strength development using geotechnical instrumentation; evaluating the design and the exercise of professional judgement; and if necessary, updating the design.

In addition to the above discussion, tailings shear strength is also of great importance where tailings are used for embankment construction (upstream tailings construction) and for trafficability on the tailings surface (Robertson, 1987). Reviews of tailings impoundment failures and ways to prevent slope instability have been presented by several authors (Davies et al., 2000; Blight and Fourie, 2005; Blight, 2010; Caldwell and Charlebois, 2010).

5 OPERATIONAL LESSONS FROM THICKENED TAILINGS DEPOSITION PRACTICE

The following comments are intended to be somewhat provoking – offered from the perspective of the tailings operations team, which is usually saddled with the responsibility of creating a stable thickened tailings deposit from anything that comes out of the end of a pipe. These experiences highlight the consequences of the challenges described earlier.

5.1 The operation of a thickener and the deposition of thickened tailings have a very narrow intersection set

The function of a thickener is to produce a pumpable tailings slurry, in which a typical yield stress could be anywhere from a few Pa to a few hundred Pa. The purpose of a tailings deposition scheme in turn is to create a stable deposit that will not move, in which a desirable deposit yield stress is ideally a few hundred Pa to a few kPa. That yields very little common language for the thickener operator and the deposition manager to be talking to one another. As a result, they usually end up at cross-purposes, as they each have fundamentally non-commensurate objectives.

5.2 The thickener circuit and the tailings facility are not the place to dump excess water

Traditional plant operations worldwide have long considered the thickener, tailings pumping distribution box and consequently the tailings disposal facility as the quick solution for the disposal of any excess fluid. Excess fluids could include wash water, overflows, and flushing water from anywhere in the plant. Even worse, for fear of sanding a line, when volumetric flowrates drop unexpectedly, excess water is added as a quick fix to maintain line velocities.

Until the production of tailings feed is tightly controlled to within a narrow operating margin, and viewed as a performance specification for the thickener operation, the tailings deposition process is bound to suffer from ongoing variation in feed quality.

5.3 A thickener can be asked to do too much

The common belief is that the thickener operator actually knows how to operate and control a thickener and that due to process pressures he is forced to operate the thickener at less than optimal conditions. This is simply untrue. In almost all cases the thickener operators are profoundly ignorant of the sedimentation process that takes place in a thickener and on how to control it. In general they rely on a set of control philosophy rules provided by the thickener supplier on how to operate the thickener.

Thickener control is difficult due to the multi-functional and chaotically variable inputs such as (amongst others):

- Solids tonnage
- Ore mineralogy
- Process water quality
- Flocculant dose
- Mixing shear conditions

Faced with such control challenges and production pressures such as minimizing thickener downtime by avoiding a sanded thickener at any costs (i.e. maintaining low rake torque), the under-pressure operator is often left with little alternative but to operate the thickener so that it provides as little operating problems as possible. A common practice is to keep rake torque below the imposed limits by running the underflow pumps to the maximum in an intermittent on/off manner. This generally means that the thickener is not allowed to perform the task of thickening and delivers a more dilute and problematic underflow slurry to the deposition site.

Unfortunately, there are many thickener control philosophies which are specified and which have not worked because they are either based on fundamentally flawed assumptions or due to inappropriate instrumentation. The fact is that these control philosophies and rules are still propagated by the vendors as they are unaware of anything else and unfortunately they are completely inadequate to control paste thickeners.

5.4 Thickeners work better for silt and worse for clays

Thickeners have a long and successful history in the worldwide minerals extraction industry. They have been synonymous with the extraction of gold, copper, platinum, diamonds and many other minerals over the past five decades or so. These hard rock tailings (with the exception of diamond tailings or kimberlites) are usually the result of a milling or grinding process, generating tailings, which are mostly in the geotechnical silt fraction range (coarser than 2 micron and finer than 75 micron). Since milling is a very energy-intensive and expensive extractive process, the ore is not milled any finer than is absolutely necessary for the optimal recovery of mineral. At the same time, the milling process is designed to reduce particle size to one where subsequent extractive processes are efficient. If the milled ore contains too much of a sand fraction, valuable ore may remain locked up in the sand. The end result is that the best milling results in hard rock tailings usually generate a largely single-size particle distribution, or gap-graded tailings.

Over the years, anecdotal evidence tends to indicate that thickeners operated in milled hard rock mines are described as being “forgiving” with regards to changes in feed tonnage and ore type. On the other hand thickeners operating in mines with abundant clay minerals in the ore are described as being difficult to operate due to the short “reaction time” available once process variables change. These problems however, may not be related so much to the physical and mechanical design of the thickeners but rather to a lack of understanding of the sedimentation process and control thereof.

It has been found that the accumulation rate of the mud bed within a thickener is linearly proportional to the thickener solids throughput (t/m2.h). For non-clay milled hard rock slurries the relationship is very flat (i.e. low rate of rise of the mud bed) and so the thickener appears to be very forgiving to process changes; for clay containing slurries, the relationship is very steep (i.e. high rates of rise) and so the thickeners appear to be very sensitive to process changes and "slime" easily and quickly (Vietti and Dunn, 2014). These differences appear to be related to the hydraulic conductivity of the mud bed – the conductivity of a mud bed consisting of milled hard rock tailings tends to be high and therefore the mud bed consolidates quickly while for clay containing tailings it tends to be low and therefore the mud bed consolidates slowly.

Thickener operational performance and control is depends on the sedimentation and consolidation properties of the solids within the feed. Since there are essentially two independent processes occurring within a thickener under dynamic operation i.e. sedimentation of the flocculated solids onto a mud bed and the accompanied accumulation thereof with time AND consolidation of the mud bed with time, appropriate thickener control needs to take both processes into account.

5.5 Two-stage thickening may be an option

Uncoupling the thickening for heat/water recovery and thickening for deposition processes may be an option. In the first stage a traditional thickener could be used primarily for heat recovery and/or water return in the plant. Since the operation is targeting heat/water recovery for the plant the tailings would not be required to be thickened to the same extent as for deposition. This helps reduce the pumping cost by minimizing the water return line as well as reducing the viscosity of the flow.

Nearer the ultimate deposition point through a second thickener or in-line methods the tailings can be thickened again for the purposes of optimizing deposition where operation is not contingent on heat/water recovery. This option may be more viable for operations where thickening infrastructure is already in-place as there would be significant capital costs for a green field project.

5.6 Shear thinning loops can help

The introduction of a shear thinning loop at the base of the thickener allows slurry underflow to be thicker (more dense), while decreasing the yield stress of the slurry. It thus enables slurries of higher relative density (and hence less water content) to be affordably pumped to disposal, while reducing water volumes in circulation.

Unfortunately, in many existing Paste thickening applications, the shear thinning loop system is turned off, either to save on the extra pumping power costs or simply because the thickeners are not generating high enough density underflows due to the thickener operating practices mentioned earlier. However, if proper control of the thickener is achieved, the benefits of a shear thinning loop for ease of discharge of the dense underflow from the thickener and the reduced power consumption of the overall tailings delivery pump system are apparent.

5.7 In-line thickening may have a supplementary role

There is a growing trend to measure in-line thickener underflow densities, and where necessary, to add flocculant downstream of the thickener to the discharge line, as a means to improve both dewatering and tailings deposition. Again this may be an industry reaction to the poor performance of thickeners due to inadequate thickener control.

5.8 Thickener pilots and trials are less expensive than thickener failures

The high cost (in dollar terms sometimes upwards of seven or eight figures) of thickener construction and operation (even at pilot scale) has hindered the comprehensive evaluation of thickener design and performance, especially for new mines.

However, the cost of failure of a thickened tailings scheme may be much higher than the cost of an expensive thickener pilot. The risks may include production losses, higher operating costs, extensive plant downtime and unplanned and emergency maintenance, and might even extend to reputational damage and loss of shareholder value for the mine in question.

Key to a successful thickener pilot trial is generating design data for sizing the thickening circuit and process equipment to match the process specifications. Equally important is gathering data for specifying the correct thickener control philosophy for the material being treated. Often thickener control philosophy is specified and tested only in the later project phases with disastrous and costly effects.

Gidley and Boswell (2013) offer a 16-step model for technology development in oil sands tailings based on interviews with leading oil sands technology development experts.

6 A SUCCESSFUL THICKENED TAILINGS DEPOSITION PLAN

A successful thickened tailings deposition plan is a systematic approach to all aspects that influence the performance of the tailings deposit. Some of the primary elements are listed below.

6.1 Dyke construction schedule

Dyke construction should be planned at least three years in advance of requirements. Any requirement for pre-build should be detailed in the design. Sufficient storage must be maintained so that deposition can continue throughout the year, independent of construction periods, while continuing to maintain the required freeboard. At least six months of contingency space should be maintained.

6.2 Embankment stability

This item is one of the critical elements. In the case of the oil sands, the rigorous implementation of the observational approach is vital in ensuring risk-appropriate and cost-optimized containment of tailings.

For upstream tailings construction, susceptibility to static (and dynamic) liquefaction should be closely monitored and avoided. Control of internal erosion (piping) is currently a renewed focus within ICOLD and member associations. Filter and drainage integrity and limitation of settlement require high quality design and regular monitoring and inspection.

6.3 Tailings planning

Sound tailings planning is required early on in the design phase. Upon commissioning the long-range plan is mapped out, after which detailed planning is developed for both mid-range (annual and seasonal) and for short-term planning (monthly, weekly and daily).

6.4 Off-specification intervention plan

Items include tailings line sanding-out or failure; design and operator interventions; interventions arising from implementation of the observational method in the event of dyke movement; control of thickener underflow solids content; rapid elimination of excess water and precipitation events through sound drainage and decanting techniques; development of a conservative deposition cycle; discharge control; and allocation of storage space for off-specification discharge, recovery and remediation.

6.5 Role of chemicals and additives

Further investigation into fit-for-purpose chemicals and additives may help widen the operating window for deposition and reduce the amount of off-specification material. Some areas where additives can help performance are: hydraulic conductivity (and secondarily consolidation), surface crack depth and density and deposit shear strength.

6.6 Beach deposition

The paragraphs above have shown the critical role of beaching in facilitating tailings deposition, in allowing dewatering and consolidation, in controlling segregation and in maintaining stability. Effective beaching deposition practice is usually a strong indicator of a successful tailings scheme.

6.7 Maximizing drying efficiency

In cold weather or short summer season climates (such as northern Alberta) every effort must be made to maximize the drying season by being ready to deposit as early as the season permits. It is critical that the last layer of the previous season be of high quality and within operational controls because the behavior of this layer will dictate how soon operations can begin in the spring. It is also critical to adjust the deposition schedule based on deposit performance. In general lifts require more drying time during the shoulder seasons than in the summer. However, this is not a justification for depositing thicker lifts in the summer months for reasons described herein.

6.8 Pond location

Pond location management is essential to many aspects of tailings management, including:

- Control of beach slope and run-out distance.
- Establishment of stable equilibrium beaching.
- Protection of freeboard, pond volume and tailings deposition capacity.
- Facilitation of the timely recycling of supernatant free of suspended solids.
- Rapid removal of excess precipitation and flood events.

6.9 Fines capture

There is a fine balance between maximizing the capture of fines in sand beaches (which is one of the most cost-effective technologies for the purpose), and avoiding the risks of embankment instability and static liquefaction. This is not to say that it should not be attempted: the rewards are clear, but the attendant risks should be carefully managed.

6.10 Accumulation of fluid fine tailings

In Alberta, Canada, the publication and application of Tailings Directive 074 and subsequent industry and regulatory initiatives now prescribe limits for this practice in detail.

6.11 Dewatering

In 2012, the development of a Tailings Roadmap for the Alberta oil sands drew attention to the existence of over 600 potential technologies that were considered at the time for the treatment of fluid fine tailings in the oil sands. The study also selected over 20 technologies for further development.

It was acknowledged in the study that no single technology existed which would universally solve the problem. Many operators are now considering dewatering technologies in parallel or in combination.

A comprehensive tailings plan is required to detail plans for the dewatering of tailings, in particular fluid fine tailings.

6.12 General

In addition to the important items above, the following elements should also be included in a tailings plan, and are not elaborated upon further in this text:

- Development of trafficable surfaces;
- Compliance with local and international laws;
- Tailings reclamation;
- Water inventory;
- Debris management;
- Recycle water; and
- Land use.

7 CONCLUSION

The technology of tailings thickening has developed over the past decades to become synonymous with the successful international practice of mining and extracting many minerals, including gold, copper, platinum, diamonds, coal, and other precious and base metals. The industry has a proven track record in dealing with typical thickened tailings management challenges of variation in feed, solids content, beach establishment, stability and capacity constraints, drainage, consolidation, supernatant and fines.

The Alberta Oil Sands are venturing into utilising conventional tailings thickening schemes. As in other mining areas, early operation has been met with challenges. It would be a pity if the true benefit of conventional tailings thickening is overlooked simply because remedies to these challenges are not readily or immediately apparent.

This paper draws from a review of literature, a consideration of the fundamental science and international operating practice, placing the issues in context, and offering insights and interventions for local thickened tailings deposition challenges.

8 ACKNOWLEDGEMENTS

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