Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

This paper was first presented at the 19th International Seminar on Paste and Thickened Tailings: PASTE2016 on 6-8 July 2016.

Abstract

With the mining industry transitioning through a well-publicised downturn as a result of lower commodity prices and unstable macro-economic conditions around the world, mine owners have sharpened their focus on increasing operational productivity and minimising unnecessary capital expenditure. The management of tailings, already perceived by many as simply a cost to the mine, is one of the key areas targeted for savings. With constraints on water availability and costs associated with water, particularly in arid environments, thickened tailings disposal becomes an attractive scenario.

A central thickened discharge (CTD) tailings storage facility (TSF) was designed and commissioned at a phosphate mining operation in the Kingdom of Saudi Arabia. The design stage included comprehensive rheological and geotechnical characterisation of the tailings. The facility design was optimised for cost savings to store a specific thickened tailings product with a predicted beach slope profile and minimal supernatant pond, which influenced the perimeter embankment type and sizing.

However, subsequent operational issues with variations in thickener performance and tailings properties, combined with a disconnection from the design stage to the construction and commissioning of the TSF, led to an inconsistently segregating tailings product with a significantly increased volume of water sent to the facility and beach slopes that were flatter than designed.

This paper discusses the lessons learned from this project and the potential challenges and risks when there are large unforeseen variations in thickener performance and limited operator experience, which can lead to significantly more water to manage and reduced storage capacity compared to that designed. The paper also proposes key areas to focus on to mitigate against and lessen the impact of significant variations in the thickening process and tailings product sent to the TSF.

Introduction

Owners and designers of tailings storage facilities (TSFs) are motivated by the many benefits of thickening to assess the feasibility of selecting thickened tailings as their disposal system. The general benefits of thickened tailings include increased water recovery, reduction in the size of retaining embankments, improved facility safety, and reduced environmental impact. As a consequence of the recent well-publicized tailings dam failures, the impetus to fast track the industry to store tailings with minimal water has been increased, leading to thickening and filtering of tailings becoming the norm rather than the outlier in the near future.

However, the deposition of thickened tailings has also encountered many operational challenges over the years, with consistent variations between the system designed and that achieved in reality.

A central thickened discharge (CTD) tailings storage facility (TSF) was designed and commissioned at a phosphate operation in the northern region of the Kingdom of Saudi Arabia. The phosphate deposit was strip-mined and the ore processed in a beneficiation plant located on site, including washing, de-sliming and flotation to remove calcium and magnesium carbonates from the ore to produce phosphate concentrate.

The TSF design was optimised for cost savings to store a specific thickened tailings product with a predicted beach slope profile and minimal supernatant pond.

However, subsequent operational issues led to an inconsistently segregating tailings product with a significantly increased volume of water being sent to the facility and beach slopes flatter than designed being achieved. These issues, combined with a poor standard of initial facility construction, led to the requirement for significant change to the tailings disposal strategy and facility management.

Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

The operation required a review of the operating conditions and the design of an expansion to cater for an extended life of mine (LOM). An optimisation of the tailings disposal was also undertaken, prior to the design of the TSF expansion, including a short-term solution for improving the integrity of the existing TSF.

This paper discusses the lessons learned from this project and the potential challenges and risks faced when there are large unforeseen variations in thickener performance and operator capability. It outlines key areas to focus on during the design, commissioning and operational stages to mitigate against and lessen the impact of significant variations in the thickening process and tailings product received.

CTD overview

Tailings deposition using the CTD method occurs by radial discharge from a fixed number of spigots located within the central area of the TSF. The discharge point is progressively raised as the elevation of the tailings increases. To ensure efficiency of the central discharge system, a circular paddock dam configuration is typically constructed. The height of the perimeter embankments is dependent on the tailings beach angle achieved, as well as the distance from the point of deposition. Compared to perimeter deposition, the embankment heights are minimised as the tailings landform is conical and beaches towards the perimeter.

The initial site development comprises the construction of the perimeter containment embankments and an access spine to the discharge point. The access spine extends from the embankment perimeter to the central zone of the TSF. Internal decant structures are not required as all runoff is directed towards the perimeter. Multiple designated low points can be defined for supernatant water collection and transfer to the plant for re-use.

The CTD method of tailings disposal is most suitable for beach slopes steeper than conventional deposition, where a large portion of the tailings can be stored above the elevation of the perimeter embankments. In the event that the beaching profile is less steep, an increase in either the footprint area or the height of the perimeter embankments is required in order to accommodate the same volume of tailings.

Distribution piping is required along the deposition spine only, but ongoing relocation of the piping is required to accommodate the raised spine and discharge points. As with perimeter deposition, the dust generation can be managed to some degree with an appropriate deposition strategy i.e. rapid cycling of thin layers.

Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

Case Study TSF background

The TSF design was optimised for cost savings to store a specific thickened tailings product with a predicted beach slope profile and minimal supernatant pond, which influenced the perimeter embankment type and sizing. The main drivers were to minimise fresh water consumption, reduce tailings footprint by enhanced deposited density and overall failure risk control. The design considered the storage requirements, optimal facility layout, proposed embankment geometry and stability, and management of water at the site.

Saudi Arabia lies within one of the most arid regions of the world and the climate is characterized by extreme daytime heat and slight, erratic and spatially variable rainfall. The average rainfall is approximately 100 mm per year; while annual evaporation is approximately 3,700 mm.

Design aspects

Tailings characterization

The phosphate ore processing resulted in the production of two waste streams to be disposed of at the TSF; fines (fine waste) and tailings (coarse waste). The tailings and slime fractions are composed of calcitic to dolomitic crystalline minerals with minor quartz, gypsum and traces of yellow secondary uranium salts also found.

The fines would be thickened in deep cone thickeners and flotation tailings would be thickened in a high rate thickener. Thickened underflow from both thickeners would be combined and pumped to the TSF.

A geotechnical and rheological testwork programme was undertaken to support the design concept; in particular, to confirm the maximum deposited density and minimum beaching angle that can be expected.

The particle size distribution curves of the tailings streams are illustrated in Figure 1. The blended tailings product was characterized as medium plasticity silty sand; general geotechnical properties are listed in Table 1.

Settled density tests (24 hour) indicated that the slurry will achieve a relatively low short term dry density of 0.76 t/m3, which corresponds to a moisture content (w/w) of approximately 97%, well above the liquid limit and relates to a solids content of around 51%. This indicates that an average of 12,000 m3 of water may segregate from the blended tailings on a daily basis, while the potential evaporative rate of the TSF is more than twice that amount.

From the settled density tests, it was expected that earlier tailings surface would be of very low consistency, with almost no bearing capacity. It was assumed that further settlement would slowly occur by evaporation, and it was therefore necessary to maximize exposure of fresh layers by cycling the deposition around the facility. The moisture content of the blended tailings was predicted to lower closer to the plastic limit of 26%, as tailings settled and dried out; this moisture equated to a dry density of approximately 1.5 t/m3.

The rheological characteristics of the slurry were assessed by means of yield stress and viscosity measurements from tests on one sample of fines and blended tailings obtained from residues after the processing testing. It was noted that as the solids concentration was decreased, the slurry trended to a Bingham fluid for solids concentrations below 53.8%. The rheology curve of the slurry samples (yield stress vs solids concentration) is shown in Figure 2. Further indications from the plant designers confirmed that it would be possible to thicken the slurry blend to nominal solids concentration of 53%, which when compared with the rheology available, the expected yield stress would vary between 10 Pa to 70 Pa depending on the amount of fines in the slurry.

The beach slope was estimated from non-Newtonian fluid mechanics principles. The methodology adopted was based on current research on thickened tailings and formulated using laboratory test results and slurry properties such as solids concentration, rheology and number of discharge outlets or spigots. Analysis of the tailings product at 53% solids content (w/w) indicated that a beach angles varying from 2% - 3% could be expected. The steady-state beach angle adopted for the initial design of the TSF was 2%.

Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

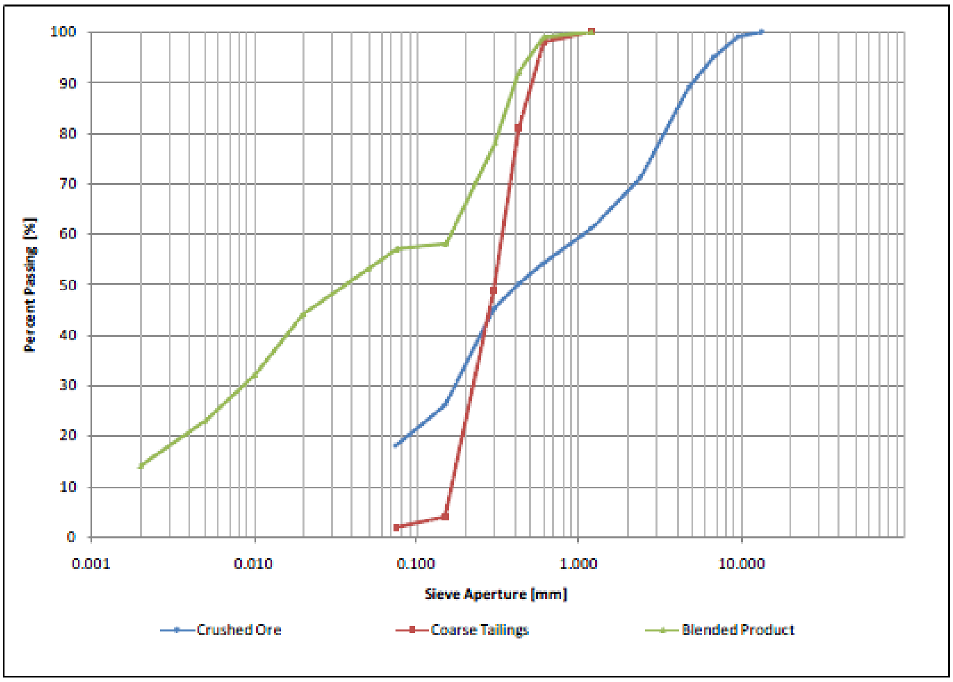

Figure 1: Particle size distribution of the tailings streams

Table 1: Geotechnical laboratory test results for the blended tailings product

Classification (USCS)	SM
Sample description	Brown, fine to medium silty sand, medium to low plasticity
Liquid limit	29
Plasticity index (PI)	3
Shrinkage limit	18
Linear shrinkage (%)	3
Settled density (g/cc)	0.76
SG	2.96

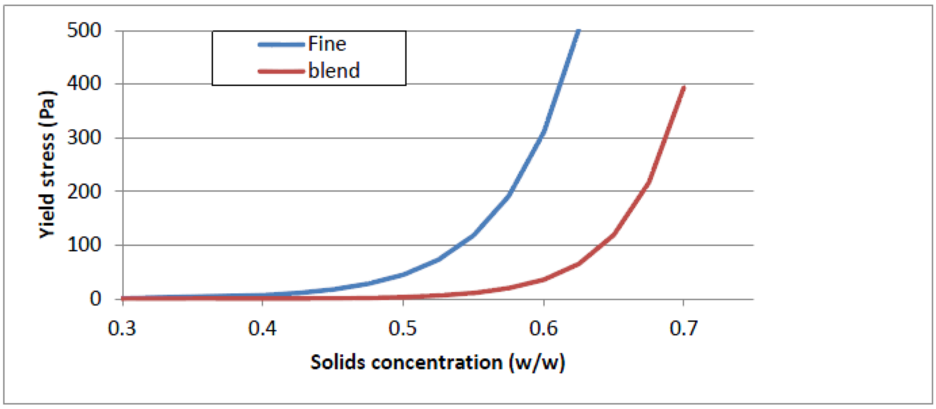

Figure 2: Rheology curve of tailings products

Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

Facility layout, water management plan and embankment design

After consideration of the confirmed tailings properties as well as the results of the geochemical evaluation and site constraints, the CTD option was selected as the optimal method of disposal. The motivation for this selection can be summarized as follows:

This method requires the lowest perimeter containment embankments; hence the least initial construction.

- Discharge would occur from a central position only, as opposed to the full or half perimeter, thereby limiting the deposition piping requirements.
- Rapid cycling of deposition and the placement of thin layers to assist in the management of fugitive dust is possible
- Expansion of the facility during operations is limited to the lifting of the access road and deposition platform.

The CTD tailings facility layout, comprising a full perimeter embankment and a centrally located deposition spine, is shown schematically in Figure 3. The TSF was designed to store approximately 36 million tonnes of tailings over seven years life, while maintaining adequate freeboard to accommodate the design storm event (1:100 year, 24 hour event) without overtopping.

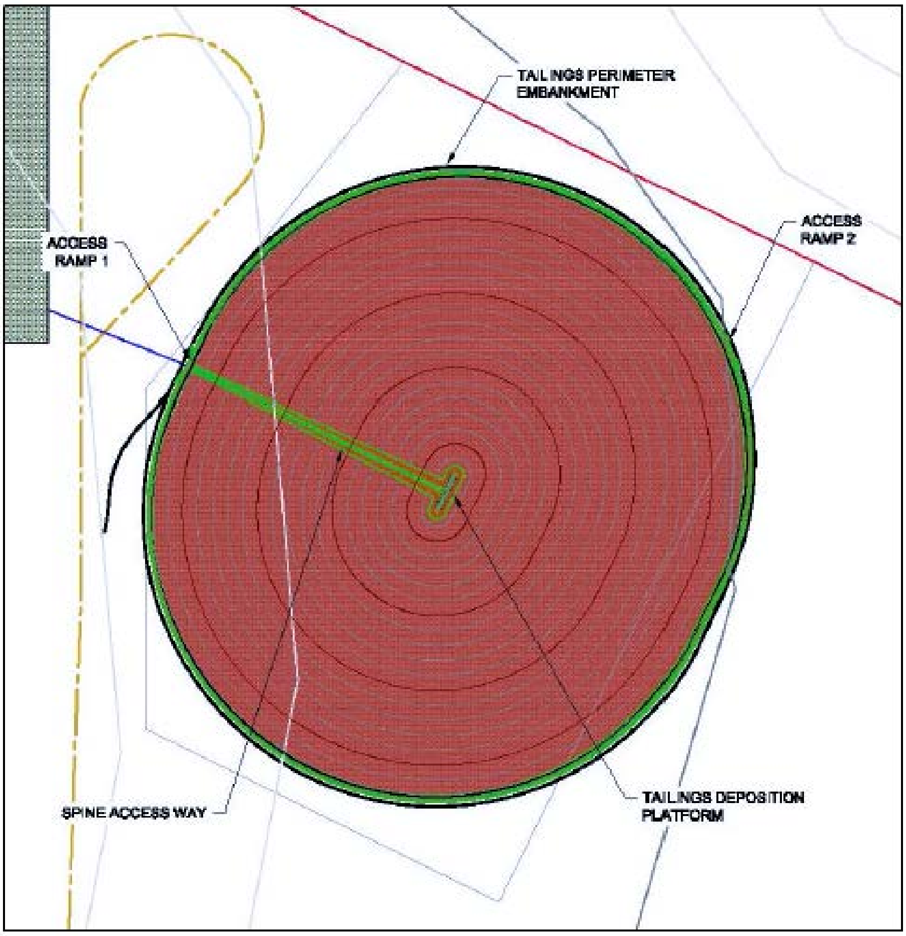

Figure 3: CTD TSF schematic layout

The water balance model indicated that the site was water deficient throughout the LOM, with minimal water available for reclaim on any given day under normal operating conditions. The TSF was designed as a passive system with regards to the management of water; thus no decant or water management facilities were included. Any free-flowing water was expected to spread out through the exposed beaches or report to the perimeter of the TSF, against the embankment, from where it would quickly evaporate.

The height of the perimeter embankments was a maximum of 4 m. The external embankment height is directly related to the distance from the point of deposition; any additional increase in the footprint would result in even lower embankments. The access spine and deposition platform was initially constructed to a maximum height of 12 m. All embankments were classified as rockfill (therefore not watertight or impermeable) and formed as homogeneous structures constructed from material made available during the pre-stripping operation. The grading of the construction material would play a decisive role in determining the ultimate permeability of the placed material and well graded material with a maximum particle size of 400 mm was recommended. This was considered appropriate, since the tailings product was designed to be sufficiently thickened so that minimal water would be available; the facility would only store transient, scattered ponded areas.

The possibility of seepage through or beneath the outer perimeter embankments was also examined. Modelling of the cross section indicated that seepage may be unlikely under normal operating conditions, but could occur to a limited degree in the event of sustained water storage. Further analyses to explore feasible recovery of water from the TSF indicated that sustained water storage would not be possible, due to the highly evaporative environment.

Tailings disposal considerations

Deposition of tailings was designed to occur from the centrally located spine or platform. The tailings delivery pipeline was located on the access road from the perimeter embankment to the deposition spine, and would be raised periodically along with the access and deposition spine. The deposition platform would need to be raised to ensure sufficient vertical deposition head. The most significant issues associated with this TSF were seepage and dust generation; it was planned that both could be managed to a large degree through manipulation of the deposition strategy to suit the onsite conditions. Disposal of the tailings was designed to be uniformly distributed among the array of spigots located at either side of the causeway. A cyclic/ rotational method of disposal, in conjunction with the placement of thin layers, was recommended in order to maximise evaporation. By maintaining a wet beach, this cycling would also control fugitive dust generation from the tailings.

Operational performance

Generation of low slurry relative densities, or containing more water than planned, has historically been one of the primary problem areas encountered in tailings operations worldwide (Boswell & Vietti, 2014). This operation is no exception, as observed during a technical visit to the site.

Although technical details of the thickener performance were not made available, it was reported that after commissioning the operation, the average solids content of the slurry was around 35% (w/w), well below the design target of 53% (w/w), and efforts to improve this density were hindered by the creation of excess torque in the thickeners.

Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

As the tailings product was intended to be a thickened product, limited bleed water from the tailings and therefore only a small pond was expected. However, as the actual solids content was well below the design target, typically averaging 35%, the amount of bleed water and therefore pond size was substantially larger than envisaged. This disposal method created a very large pond (or very wet area), which spanned approximately two thirds of the TSF perimeter. The pond extended approximately 300 m from the edge of the perimeter embankments into the centre of the facility, with a maximum pond depth of approximately 2 m. The supernatant pond is shown in Figure 4.

Figure 4: Supernatant pond looking towards the central deposition spine

The perimeter embankments were constructed from randomly sorted overburden material with limited compaction. The particle size of the overburden material was variable, with diameter sizes greater than 1 m common. A typical embankment downstream face; a significant departure from the design; is shown in Figure 5. Although the embankments were not designed to be watertight or impermeable, the design offered safe partial containment of eventual ponded water, minimizing excess seepage and risk of piping. The lack of compaction and high material variability significantly contributed to significant seepage and the potential for piping.

Figure 5: Typical grading of overburden material used for embankment construction

Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

Extensive seepage occurred around the perimeter of the TSF, typically correlating to the location of the large supernatant pond; preferential seepage through the embankment, seepage through the foundation interface layer beneath the embankment, and a wetting front or raised phreatic surface on the embankment downstream face. Typical seepage at the embankment downstream toe is shown in Figure 6.

The large supernatant pond, lack of material screening and limited compaction were considered the main causes for the existing seepage issues at the TSF.

Figure 6: Seepage at the embankment downstream toe.

The designed tailings disposal method was not followed, and it was evident that most of the tailings was discharged from the eastern side of the causeway, with minimal tailings on the western side. Internal bunds were built to prevent tailings and excess water ingress into the western side of the causeway. The latter increased the rate of rise of the tailings beach, preventing further gains in density of the disposed tailings and excess water pond standing higher against the perimeter embankment. Disposal of thicker tailings layers also hinders progressive desiccation of the exposed surface; this leads to a slower rate of self-weight consolidation as a higher rate of rise impacts pore pressure dissipation. The latter results in a lower density profile being achieved and subsequent shortening of the facility’s life.

The survey data provided indicated an achieved beach slope of approximately 1%, less than half as steep as the predicted slope, based on the rheological laboratory testing and analysis.

The tailings operational manual provides recommended procedures to operate, monitor performance of and maintain the TSF to ensure that it functions in accordance with the design, and meets regulatory and corporate policy obligations. It includes details on the operating procedures relating to construction, expansion of the facility, deposition and water management, as well as monitoring and inspection requirements. It was clear that the operators would not follow the recommended practice outlined in the manual. Aspects that differed from design recommendations should have been flagged at the initial stages before they could develop into serious issues.

Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

Lessons learned (Design assumptions and operational challenges)

Thickener plant operation

The design of a thickened tailings system is complex and involves several disciplines. The essence of this design is a philosophy of integrating the process on a common rheological basis (Slotee, 2014). The thickener should be operated to achieve the target slurry solids concentration with a rheology that must be suitable for transportation of the slurry and that meet design criteria set out for the TSF, including beach slope, settling characteristics and segregating water, amongst others.

In some cases, implementation of thickening systems can be more challenging than expected. There are numerous practical challenges in relation to consistently producing solids concentrations and underflow densities at their design targets, particularly during the thickener commissioning stage. In this particular case, the thickener was designed in disconnect with other components, which led to a dysfunctional thickening process.

A plant that is not able to consistently produce a slurry at the design solids concentration creates a knock-on effect that affects all the design elements downstream of the plant. It is therefore important that the sampling, testing and interpretation of the results is shared and discussed among the teams early in the design process; as a minimum, across thickener designers, transportation designers and TSF designers. Following a comprehensive design strategy, and carefully planned commissioning and operation of thickeners can avoid numerous problems faced in tailings disposal.

Thickener feed variation

Several factors may affect the performance of a thickened tailings operation. The key element of the system is the thickener, which should be designed to cope with the range of tailings species coming from the mill. The mineralogy and hence rheology of the tailings after extraction of the valuable minerals has a major influence on the thickening process (Jewell, 2008).

Tailings samples are often available (greenfields projects) on a very limited basis, as residue from metallurgy testing are commonly selected to cover metallurgy variability only; the latter does not necessarily come hand in hand with variability in mineralogy of the residue. Therefore, it is important to understand the degree to which the sample represents the orebody, and what other types of minerals will be present in the ore throughout the life of mine. If a steep variation is suspected, additional samples should be selected for processing. If the only available samples are not considered truly representative, the limitations of the testing and associated design parameters must be understood.

Depending on the expected variability of the tailings minerals, it might be onerous to design a thickening system that can cater for the whole range of tailings produced by the plant. It is therefore important to identify problematic minerals in the design stage, in order to incorporate flexibility in the system to manage off-specification slurry when necessary.

Excess supernatant water

Unforeseen variations in thickener performance and tailings properties can lead to significantly more water to manage and reduced storage capacity compared to that designed. Incorporating a water management plan early in the design process can help in devising a disposal strategy and downstream elements that can cater for periodic surging of supernatant water. The TSF water balance should incorporate sensitivity analyses to understand the slurry thickening rate influence (Moreno, Martin & Luppnow, 2012); this can assist in sizing and determining a suitable water management plan.

Tailings disposal

The correct operation of a CTD involves active planning of the discharge of the slurry, with high reliance on data obtained from the facility. During commissioning and the initial months, the operator should be trailing strategies to meet the objectives set in the design, guided by the operational manual. It is very important that the designer or a trained tailings engineer is involved at this stage in order to assist with any deviations of the slurry behavior and to suggest alternative disposal strategies to overcome any potential issues. Pressing points typically include the following:

- Monitoring the progression of the deposition and the achieved tailings beach in order to promote a consistent beach grading towards the dedicated water collection area(s), in accordance with the designed water management strategy
- Controlling the thickness of the deposited layers, in order to maximize density and achieve a uniform beach around the CTD, limiting the chance of water ponding at isolated locations
- Developing a conservative deposition cycle which takes account of the weather, that is sufficient to balance adequate drying out (and settling) of the exposed tailings layers and prevent fugitive dust by maintaining a wet beach
- Planning for off-specification events.

Tailings beach and capacity constraints

For CTD operations, the tailings beach slope has a significant effect on the required height of the perimeter containment embankments, and therefore cost of the facility. As the beach slope achieved is a function of the solids content, rheology and operating practices such as the number and management of discharge points selected, there are many variables that can differ between that assumed during the design and actual reality. If the achieved beach slope is flatter than that predicted in the design, there is potential that the perimeter embankment elevations and therefore fill material volumes would need to be increased in order to maintain the required storage capacity. The embankment construction schedule may also need to be adjusted, with planned raises brought forward.

The only true measurement of the beach slope is that actually achieved in the field and early surveys of the beach should be undertaken once a consistent slope is observed. The operator should trial various disposal strategies, for example, varying number of operating spigots, spigot diameters, and cycling of the disposal areas.

Dealing with existing operational issues

The topics covered in the previous sections typically relate to addressing concerns at the design stage or early commissioning/ operations stage.

However, problems may also arise with the existing thickened tailings operation, such as low solids produced from the thickener, a larger than expected pond and inadequate water management infrastructure to deal with the large volume, or possibly the perimeter embankment not being designed to retain water, or beach slopes formed are flatter than expected.

While the operation is unlikely to be shut down, the “non-performing” TSF will potentially create liability in terms of cost and risk, which may become intolerable at some point. Incurring additional costs is particularly unfavourable in the current climate of low commodity prices.

Underperformance of the TSF should be noted as early as possible, as it may be necessary to raise the embankments ahead of schedule; the first step is to acknowledge that there is a problem and revert to the initial designer or another qualified tailings consultant.

Common questions to be asked include: Is there a problem with the thickener? Can it be fixed? At what cost? Is the current pumping/pipe arrangement suitable for handling the higher solids content?

In the meantime, the existing facility needs to be retro-fitted to accept the current tailings product. Water management should be treated as a priority, and could entail addressing any seepage issues. Perimeter embankments may require installation of a buttress or a drain.

In this case study, the TSF presented a number of issues that were generated by not achieving the design thickening rate. The most important aspects to address in order to improve the integrity of the facility was to limit the impact of the seepage through the embankment, to design an embankment raise and a revised water management plan that could cope with ongoing excessive supernatant water that could be blended in with the future expansion of the facility. While the plant operators contemplated fitting the thickeners with pickets to enhance development of the mud-bed, doing so would not improve the expected slurry density to fully meet the initial design criteria. The operators therefore requested that the facility be re-designed to cater for lower than initially designed solids concentrations.

Tailings central thickened discharge; challenges faced and lessons learned from design to operation

Juan Jose Moreno and Nicholas Thompson

Conclusions

The development of a successful thickened tailings system requires a multi-disciplinary approach. Close integration between the main design disciplines, namely tailings disposal, thickening and transport teams, throughout the design phase is crucial. It is also important that the full design team, including the tailings consultant, maintains involvement through to commissioning which will allow early detection and evaluation of possible issues with the thickener plant before they develop into an economic liability.

This case study presented the opportunity to deal with common challenges related to a thickened tailings operation which had been poorly implemented. The authors consider the lessons learned through this case as very valuable. The following points should be given attention throughout the development of a thickening tailings project:

- Recognise that the thickener should be designed to produce a required solids concentration with a rheology that must be suitable for transportation of the slurry and meet design criteria set for the TSF
- Understand how well tailings samples (used for testing) represent the orebody, and what other types of minerals will be present in the ore throughout the life of mine
- Ensure that the sampling, testing and interpretation of the results is shared and discussed among the various discipline teams early in the design process
- Identify the eventual problematic minerals present in the orebody during the design stage, in order to incorporate flexibility in the system to manage off-specification slurry when necessary
- Incorporate sensitivity analyses related to the variation of the slurry thickening in the TSF water balance and eventual water management plan
- Perform thickening and disposal strategy trials during commissioning and the first operative months; the aim should be to meet the objectives set out in the design and operational manual.
- Closely monitor the performance of the key elements of the system, such as thickening rate, segregating water, beach slope and achieved dry density to allow early detection of any variation of the design criteria.

References

J.E.S Boswell, A. Vietti, Thickened tailings deposition – operational challenges and remedies, Tailings and Mine Waste 2014, Keystone, Colorado, October 2014

J.S Slotee, Problems in design thickening systems. Paste 2014, Vancouver, June 2014.

J. Moreno, J. Martin, D. Luppnow, Thickened tailings water balance – dealing with excess water, Paste 2012, Sun City, April 2012

R. Jewell, Ensuring the credibility of thickening technology, Paste 2010, Perth, April 2010