Mine Water and the Environment (2021) 40:36–41
https://doi.org/10.1007/s10230-020-00720-8

TECHNICAL ARTICLE

Managing Water to Minimize Risk in Tailings Storage Facility Design, Construction, and Operation

Donald East[1] · Ruben Fernandez[2]

Received: 18 March 2020 / Accepted: 17 September 2020 / Published online: 8 October 2020

Abstract

Reducing the amount of water in a milled tailings storage facility (TSF) is the primary way to reduce the risk of a catastrophic failure. In addition, a significant factor influencing the permitting and development of new mines, or the expansion of existing mines, is the limited availability of water in some mineral-rich countries, which has led to recent advances in water resource management and improved operational practices. Water reduction can be used to thicken the slurry to varying degrees of solids content up to a highly thickened, paste consistency using conventional or positive displacement pumps to transport the tailings, or with filters to mechanically reduce the water and convey the tailings by truck or conveyor. This paper suggests a method to optimize water use and to evaluate and reduce project risks at the conceptual development stage for both a thickened TSF and a filtered TSF.

Keywords Tailings · Water management · Mining · Tailings facility

Introduction

In line with current dam safety and risk management thinking, after the devastating impact of some recent tailings dam failures, the mining industry has a renewed focus on ways to minimize the risk associated with the design, construction, and operation of tailings storage facilities (TSF). Water is an essential component in mineral processing. One of the primary ways to reduce the risk of catastrophic failure of a TSF is to reduce the amount of water it contains, either as supernatant water liberated from the slurry and contained within the tailings basin, and/or pore water contained within the interstices of the tailings or water provided by rainfall and surface run-off.

For conventional thickened tailings with solids content up to the low 60 s percent solids, water reduction within the TSF is achieved by controlling the size of the supernatant pond to the minimum required for safe operation, subaerial tailings deposition, removing some of the pore water from the tailings by underdrainage, and encouraging evaporative drying from the exposed tailings beach. It is not common to see underdrains constructed within the basin of these type of tailings deposits, but this technique has been successfully used to recover additional water from several thickened tailings facilities in Nevada, USA for over 20 years, such as Newmont's Mill 4 and Barrick's North Block facility. In the subaerial technique, tailings are distributed at a low velocity over a portion of the tailings beach, creating layers up to 100 mm thick as the slurry flows towards the supernatant pond. As this layer is completed, the discharge points are moved to another section of the beach, leaving the water in the newly deposited layer to drain, bleed, and evaporate. As the layer becomes unsaturated, capillary suction in the fine-grained tailings causes the layer to shrink and densify. The next deposition cycle starts before the tailings dry out and become susceptible to being windblown. The under-drainage system prevents resaturation and returns the drained water to the plant. As the thickness of the deposit increases, the amount of water collected from the tailings by the underdrainage system decreases, but the drains ensure that there is minimal hydraulic pressure at the base, thereby reducing the potential for loss of water to the environment.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10230-020-00720-8) contains supplementary material, which is available to authorized users.

✉ Ruben Fernandez
ruben.fernandez@buenaventura.pe

1 Wood, Lima, Peru

2 Buenaventura, Lima, Peru

Cyclone sand tailings facility construction continues to find favor, especially at the higher throughputs and coarser tailings grinds typical of the copper industry. The cyclone underflow split is an important factor in determining the quantity of coarse sand available for sand dam construction. The sands are usually deposited onto the downstream face of the dam with spigots or deposited into paddocks prior to removal of excess water and then compacted. The method can accommodate large throughput of tailings and although it tends to require a fair amount of construction supervision, the operating costs per ton of tailings tend to be relatively low. The cyclones operate in the lower range of solids content for thickened tailings, but thickening of the cyclone overflow will recover much of the water. Thickening is usually used to recover between 45 and 50% of the tailings water in the plant and the thickened slurry is pumped to the deposition site, where water is added to reduce the solids content to about 45% solids prior to entering the cyclones. The cyclone stations are generally located close to the sand dam to minimize the distance that the sands have to be transported with positive displacement pumps, due to the high solids content of the cyclone underflow, generally about 70% solids.

The use of filtration and sedimentation to reduce the quantity of water within the tailings has seen increased use in recent years, and filtration, whether it be vacuum or pressure filters, continues to show a rapid rate of development for higher tailings throughputs. At elevations above 3000 m, as is typical of most mines in the Andes, pressure filters are more effective than vacuum filters, and units with filter plates measuring 2 by 4 m, each capable of treating up to 10,000 t/day are becoming increasingly common. Development of larger units with filter plates of 3 m by 5 m are being tested to filter up to 20,000 t/day per unit. Table 1 shows a brief list of some operations and projects that works with filtered tailings technology.

The term "dry stack" is commonly used to describe filtered tailings, which are shaped and compacted to form a stack or pile. Water can decide the success or failure of a filtered tailings stack. It should be noted that the tailings are not "dry" when leaving the filters. Filter plants are fed thickened tailings at about 65% solids and produce tailings with a moisture content of 18–22%, which corresponds to a solids content of 83–85% solids. Compaction of the filtered tailings is required for stability, water shedding, and trafficability and, to achieve this, compaction should be on the dry side of optimum, which typically may be 5–7% less than the moisture content produced by the filters. This, therefore, requires a suitable climate in which to operate. In wet climates, care must be exercised to ensure that the "dry stack" does not resaturate upon exposure to the elements (atmospheric precipitation). It is common practice to design dry stack facilities to contain filtered tailings that are less dense or have a high moisture content in a separate, non-structural area.

Illustration

To illustrate the water optimization concept during the initial planning stage of a project, the two project options considered are conventional thickened tails and filtered tails. The project has the following information:

Design Basis

Location:	High Andes of South America
Containment:	Single valley with cross-valley containment
Site elevation:	4000 m
Tailings production:	40,000 t/day
Storage required:	200 Mt
Project life:	12 years
Tailings solids SG:	2.87
Solids content for placement of thickened tails:	60%
Solids content for placement of filtered tails:	85%
Tailings P80:	75 µm
Tailings P20:	20 µm
Annual average site precipitation:	1100 mm with 5 months per year relatively dry
Annual average site evaporation:	950 mm
Annual average runoff for storage of process water:	

Water Requirements

The tailings production water requirements are dependent on the solids content at delivery to the TSF. The variation of water content vs. solids content over the normal range of thickening through to paste and filtered tailings is shown in Fig. 1.

Table 1 Summary of significant operating filtered tailings operations. Source: Ulrich and Coffin (2013) Considerations for tailings facility design and operation using filtered tailings

Mine	Country	Status	Metal	Tailings (tpd)	Filter
Metales	Mexico	Project	Gold and Silver	120,000	Pressure
El Morro	Chile	Project	Gold and Silver	112,000	Pressure
Rosemont	USA	Project	Copper	75,000	Pressure
Chingola	Zambia	Operation	Copper	24,000	Belt
Karara	Australia	Operation	Iron	22,000	Pressure
La Coipa	Chile	Operation	Gold and Silver	18,000	Belt
Cerro Lindo	Peru	Operation	Lead and Zinc	15,000	Belt
Media Luna	Mexico	Operation	Gold and Silver	14,000	Pressure
Manto Verde	Chile	Operation	Copper	12,000	Belt
El Sauzal	Mexico	Operation	Gold and Silver	5300	Belt
Mantos Blancos	Chile	Operation	Copper	4000	Belt
Alamo Dorado	Mexico	Operation	Gold and Silver	3500	Belt
Pogo	USA	Operation	Gold	2500	Pressure

Jose (2013) Deposit operation experiences of thickened and filtered tailings

Thickened Tailings

A flow sheet for production of 40,000 t/day and a tailings solids content of 60% from the tailings thickener underflow is presented in Fig. 2 and Table 2. In this case, the plant's total water requirement is 26,600 t/day (9.5 Mt/year). The amount of water locked up in the tailings is ≈ 10,640 t/day, with the remainder recoverable from the supernatant pond at a rate of 14,660 t/d plus the underdrainage of 1300 t/day. The net makeup water for the plant is therefore 3.8 Mt/year, which is the difference between the water locked in the tailings and the total recovered water of 15,960 t/day (5.7 Mt/year).

For the conceptual example illustrated in this paper, the available water for make-up is obtained from rainfall within the same catchment as the tailings storage facility (TSF) plus water released in other areas of the operation, and is limited to only 3.0 Mm^3 per year. Therefore, for the example using thickened tailings, it will be necessary to reduce the make-up water to at least 3.0 Mm^3 per year, which can be achieved by increasing the solids content of the tailings thickener underflow to 66% solids. This will have the effect of reducing the total plant water demand to 7.4 Mm^3/year. With ≈ 4.5 Mm^3/year recovered from supernatant and underdrainage, the total make-up water is 2.9 Mm^3/year, which is within the available supply limits.

Filtered Tailings

The flow sheet for filtered tailings is presented for the same daily throughput of 40,000 t/day, and a tailings solids content of 85% in Fig. 3 and Table 3. In this case, the plant's total water requirement is only 7050 t/day (2.6 Mt/year). The water locked up in the tailings is reduced to 6900 t/day, so with no supernatant and a relatively small amount of seepage from the wetter section of the stack area, the make-up water will be ≈ 6,900 t/day or 2.5 Mm^3/year. This volume can be readily supplied by the 3.0 Mm^3 annual supply obtained from the catchment and associated supplies.

At the concept project location, the annual average precipitation is 1100 mm/year, most of which occurs over a five month wet season. For stability reasons, the filtered tailings must be compacted, and, most importantly, an unsaturated deposit must be maintained, which is not easy during the wet season. This challenge, therefore, requires a dedicated basin to store "out-of-specification" tailings, which in the example given, is located behind the structural zone of compacted unsaturated filtered tailings in Fig. 3.

For both thickened and filtered options, it is necessary to construct a fresh water dam to store the annual runoff from the designated catchments during the annual wet and dry periods. Note that the plant water balances assumed in the above examples are simplified and do not include the inputs

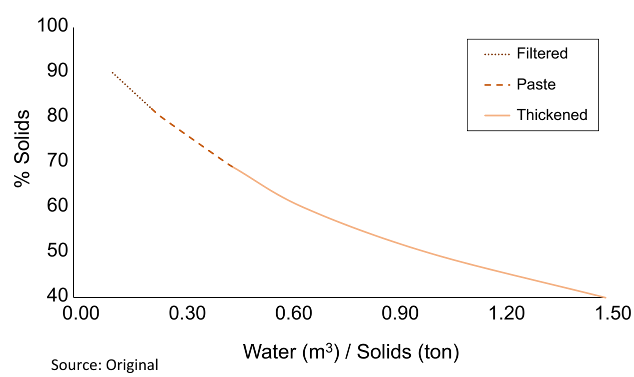


Fig. 1 Water contained vs solids content Chilean Copper Commission (2008), Berger (2017)

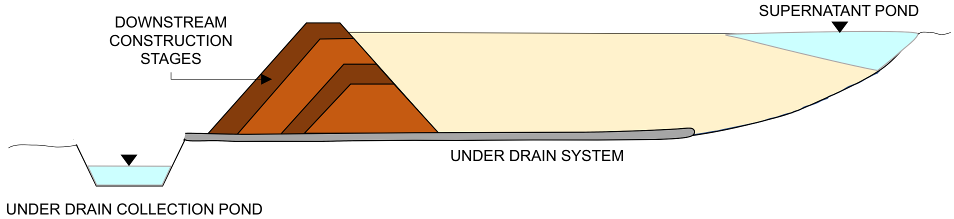


Fig. 2 Thickened tailings with underdrainage

Table 2 Thickened tailings with underdrainage flow diagram

Plant production				Under drain pond (*)				Tailings basin				Supernatant pond (*)			
Slurry m^3/day	Solids ratio (%)	Water tpd	Solid tpd	Slurry m^3/day	Solids ratio (%)	Water tpd	Solid tpd	Slurry m^3/day	Solids ratio (%)	Water tpd	Solid tpd	Slurry m^3/day	Solids ratio (%)	Water tpd	Solid tpd
40,000	60	26,600	40,000	–	–	1300	–	26,640	79	10,640	40,000	–	–	14,600	–

(*) Water from under drain pond and Supernatant pond go back to the process plant

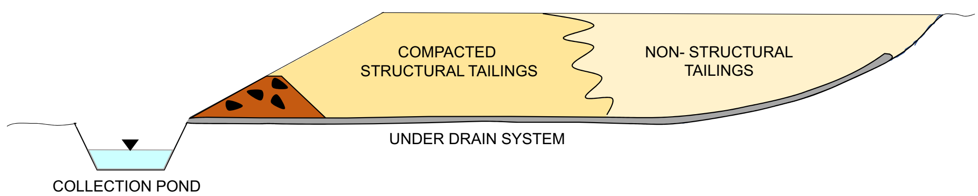


Fig. 3 Filtered tailings

Table 3 Filtered tailings flow diagram

Plant production				Under drain pond (*)				Tailings basin				Supernatant pond (*)			
Slurry m^3/day	Solids ratio (%)	Water tpd	Solid tpd	Slurry m^3/day	Solids ratio (%)	Water tpd	Solid tpd	Slurry m^3/day	Solids ratio (%)	Water tpd	Solid tpd	Slurry m^3/day	Solids ratio (%)	Water tpd	Solid tpd
21,150	85	7050	40,000	–	–	150	–	21,000	85	6,900	40,000	–	–	–	–

(*) Water from under drain pond and Supernatant pond go back to the process plant

and outputs of the site-wide water balance that would normally be carried out for pre-feasibility and feasibility design.

Relative Cost Models

To estimate the total life cycle costs of filtered and thickened TSF's, a conceptual cost comparison was made for the capital and operating cost of each option, assuming some average expected unit costs for a 12 year equipment life, based on the site described above. The details on which the estimate is based in shown in Table 4.

Note that the land requirements for both options are approximately equal. There is, however, the potential to store ≈ 15–20% more tailings within the same footprint with the filtered option due to the higher density of the compacted tailings compared to the density of the hydraulically-placed thickened tailings. This is shown in Fig. 4 by a 3 year extension in storage life. The costs for the 12 year life of mine are also graphically compared in Fig. 4.

Risks

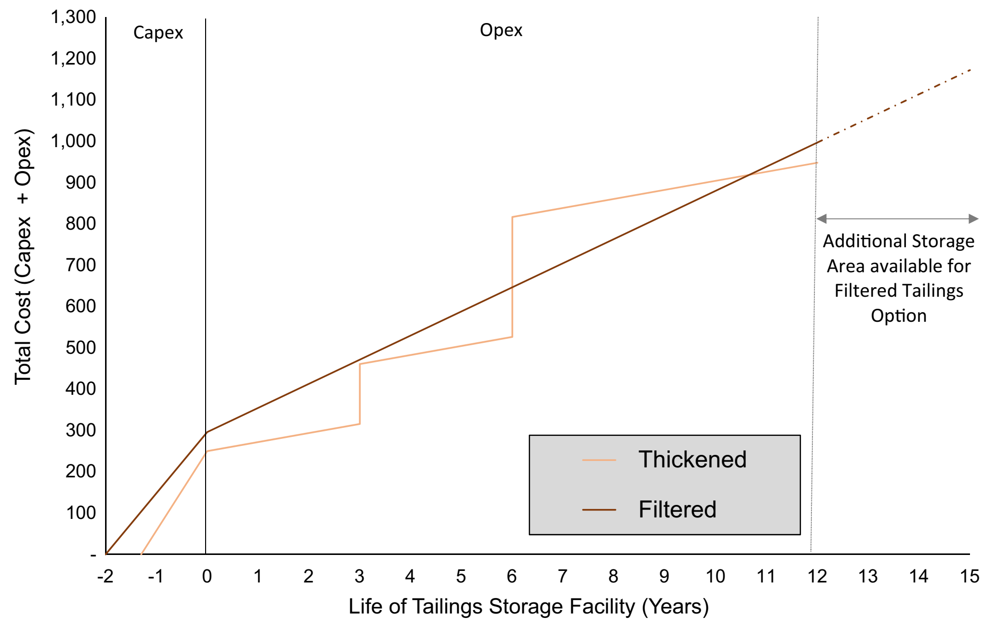
Risk management is a basic part of tailings dam safety, and managing water risks by employing best engineering and operational practices is the key to dam safety. In assessing some of the risks between thickening and filtering, water quantity is a fundamental difference. In addition, land (location and area required), operational risks (water management), and closure risks (water management) are additional factors that must be included in a TSF risk assessment.

Table 4 Relative cost for thickened and filtered tailings options. Source: Original

Method	Phase	Area (Hectares)	Year	Dike (Mm^3)	Tailings (Mm^3)	Capex ($M)	Opex ($/t)
Thickened	Starter dike	120	0	18		250	1.5
	1st raise	200	3	25		145	1.5
	2nd raise	300	6	48	180	290	1.5
	Final	300	12			685	1.5
Filtered	Starter dike and filter plant	220	0	1		296	4
	Final	250	12	1	180	0	4
	(*)	280	15		220	0	4

(*) For a similar area, the filtered option has larger storage capacity, then more lifetime of the facility

Fig. 4 Cost for 40,000 tpd Concepts



Source: Original. Assuming cross valley TSF design

Comparing a thickened vs. filtered TSF, water represents a greater risk for thickened tailings since they contain significantly more water. With respect to operational risks, filtered TSFs have more mechanical equipment, routine maintenance, placement management to be concerned about, and wet weather restrictions play a greater role in risk assessment than at conventional thickened TFSs. In the example provided, the land for the TSF is owned by the mining company and therefore it has a low probably and low risk. The relative risks are ranked in Fig. 5.

Conclusions

Sedimentation and filtration methods used to reduce the amount of water in tailings continue to evolve, and more efficient systems with larger throughputs are becoming available. Reducing the amount of water within the TSF is becoming both an environmental and social necessity. It is also an effective risk management tool.

In the conceptual model described herein, the life costs of the TSF-associated water reduction methods (thickened vs. filtered) appear to be very similar. However careful study and design evaluation of the costs of filtration are essential based on thorough testing of filter efficiency, and evaluation of cloth life, energy costs, and safe transport/placement of the unsaturated tailings. Equally, during operation, the efficient management of filtration equipment, including spare

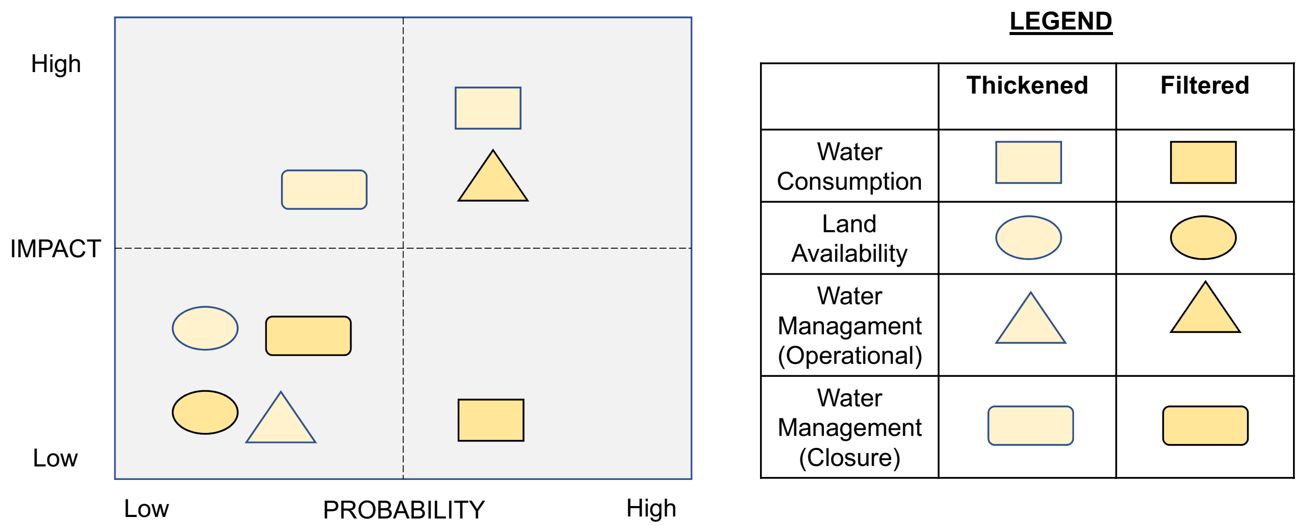


Fig. 5 Relative risk ranking for conceptual model

parts, will have an important effect on the operating cost. The comparative cost curve can then be updated as more certainty is achieved during the following design stages.

There are many risks that have to be managed in the design and operation of a tailings facility, but with a thickened TSF design, the risk is principally one of water management, both within the tailings mass and in the supernatant pond. With a filtered TSF design, the points of concern are the operating and maintenance costs and safe "dry" tailings placement in wet weather conditions.

Acknowledgements The authors would like to express their thanks to the peer reviewers, whose identity we do not know, and to the editorial team.

References

Berger KC (2017) Study of tailings management technologies. Report to Mine Environmental Neutral Drainage (MEND) Project, Ottawa, https://mend-nedem.org/wp-content/uploads/2.50.1Tailings_Management_TechnologiesL.pdf. Accessed 5 Oct 2020

Chilean Copper Commission (2008) Best practices and efficient use of water in the mining industry. Chile. https://www.cochilco.cl/Research/best_practices_and_the_efficient_use_of_water.pdf. Accessed 5 Oct 2020

Jose L (2013) Deposit operation experiences of thickened and filtered tailings [in Spanish]. https://www.iimp.org.pe/pptjm/jm20131017_relaves.pdf. Accessed 5 Oct 2020

Ulrich B, Coffin J (2013) Considerations for tailings facility design and operation using filtered tailings. In: Jewell R, Fourie AB, Caldwell J, Pimenta J (eds) Proceedings of the 16th International seminar on paste and thickened tailings, Australian Centre for Geomechanics. Perth. https://doi.org/10.36487/ACG_rep/1363_15_Ulrich