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Is the implementation of dry stacking for tailings storage increasing? A Southern African perspective

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Abstract

It is good practice in the early phases of a new mine design, or when a new tailings storage facility (TSF) is required at an existing mine, to consider alternatives and carry out trade-off studies for tailings storage. These studies should include multiple sites and at least two disposal methods or technologies with the aim of identifying the best tailings management system for the project, generally the most cost-effective, socially and environmentally acceptable system. Dry stacking is gaining credibility and is seen as a preferred technology to manage project specific risks for various reasons: lower risk of failure, increased water conservation and water cost saving, project stakeholders and environmental considerations, better geochemical mitigation, and possible improvement in metal recovery during filtration through additional mineral dissolution. In some cases, the drivers for considering dry stacking are obvious, such as a mine located in a dry climate or new regulations, but in other places this is less obvious.

This paper evaluates the outcomes of a number of such trade-off studies mostly in Southern Africa or arid regions of Africa, which include:

- *Whether dry stacking was recommended for consideration in the next phase of the project or not, and why.*
- *If dry stacking was recommended, whether it was taken forward to implementation or not.*

The paper also looks at two mines where filtered tailings has been implemented, their overall TSF operating and stability performance, as well as opportunities and challenges of the technology. No names of the mines are included, as the focus is on whether there is an increased move towards dry stacking, and what obstacles are being experienced.

Keywords: *dry stacking, filtered tailings, trade-off studies, tailings dewatering, arid climate, risk mitigation, geochemistry*

1 Introduction

Considering alternative tailings disposal strategies to conventional slurry mining dams in order to lower the risk and consequence of failure is becoming a more important consideration during early stage development of a mining project. This is reflected through conceptual and feasibility trade-off studies during the design of a tailings storage facility (TSF), and during the development of optimisation strategies during operations. While filtered or 'dry' stack tailings disposal is profiled as a serious consideration during trade-off studies, it is rarely being implemented in Southern Africa, except in the most arid areas. This paper provides seven examples and reasons for and against the selection of a filtered tailings disposal solution over less capital intensive methods. Two of the seven case studies are stacked filtered tailings facilities where operational learnings helped to improve the design and adjust the disposal strategy.

2 Criteria in the selection of filtered tailings over other technology in the design phase

The following five cases consider trade-off studies that included filtered tailings technology to manage site specific risks and highlight the reasons for being rejected or accepted for implementation.

2.1 Case 1: expanding an unlined TSF footprint while minimising hydrogeological impacts

In this case study, an existing mine in a very arid area completed a conceptual design trade-off study to assess the different alternatives to expand the life of mine by 10–15 years. Considering that their existing TSF already covered a significant surface area and had largely filled two available valleys to its final height, additional space or storage was required. New potential areas for expansion would however require significant upgrades of the slurry delivery system and important investments and operating costs.

The trade-off study considered different locations for the expansion project, as well as disposal method, geotechnical aspects, groundwater impacts (in addition to existing impacts), biodiversity and rare species, heritage sites, and assessed operational and economic aspects of each site. The increase in surface area of the tailings over new geologic units risked to adversely increase metal leaching impacts which had to be considered in the overall solution.

The existing TSF operations included a conveying system to transport coarse tailings, and a slurry pipeline for a stream of fine tailings. Both tailings products were recombined in a mixing tank and disposed at the TSF as a conventional open end discharge slurry around large cells or paddock areas in the TSF. This system had been used for years and offered the advantage of being flexible, and relatively low cost to pump the tailings. The TSF groundwater seepage mainly reported to one main collection system, controlled by natural hydrogeologic features. However, seepage from TSFs located outside of this area would impact new geologic and hydrogeologic units requiring extensive new interception/collection systems. Also, for the extended mine life, the fine tailings fraction would decrease and possibly not be sufficient for slurry pipeline pumping without the addition of water to pump the coarse fraction.

The opportunity to dewater the fine tailings by filtration and add it to the existing coarse tailings conveying system became feasible and a preferred solution to mitigate risks related to operating costs, groundwater contamination and water consumption. Disposing of ‘dry’ tailings also offered the potential to expand in areas which weren’t suitable for a slurry system where larger embankments and beach surface areas were required for slope stability.

Unless the capex costs proved to be high for the remaining life of mine, a dry disposal solution seemed attractive on many fronts and brought forward for further design optimisation.

2.2 Case 2: control of acid generation potential

Acid mine drainage is generated by the oxidation (exposure to air and water) of sulphide minerals. This is a challenging detrimental environmental impact and generally poses significant risk to groundwater resources and surrounding communities. The risk of groundwater contamination of potentially acid generating tailings can be mitigated by containing all tailings and contact water over a lined facility, but also by limiting exposition to air and oxidation through subaqueous deposition. In certain cases, it is also possible to mix acid neutralisation additive to the tailings.

For this case study, the potential for acid generation was high. Discharging tailings slurries under water wasn’t a viable or sustainable solution. Moreover, containment of tailings and water would have required a large dam across an ephemeral river, upstream of the local community, with high consequences of failure. As soon as the geochemical analyses were completed for the project, it became evident that the tailings were highly acid generating and could not be disposed of in a conventional manner. Filtered tailings technology was considered in a trade-off study to manage the risk of groundwater contamination, the potential for acid generation and the risk to the downstream population and environment. It offered an opportunity to dispose of the tailings over a lined area, where they would be compacted to increase stability and reduce potential oxidation/air voids.

The level of acid generation and metal leaching also favoured progressive encapsulation of the tailings facility with an upstream liner and barrier system to limit oxidation and runoff contamination.

While filtered tailings can be perceived as a dry tailings product, the level of residual moisture after filtration exceeded by far the optimum moisture content of the material for compaction, with an additional risk to generate excess pore pressure in the tailings mass. This required additional drying methodology before placement and integration of an extensive underdrainage system.

In this case, the filtered tailings compaction and encapsulation system was the most viable and sustainable option for the mine to reduce risks, liabilities and post-closure requirements. This technology was recommended for future studies, integrated in the overall mine development plan and economic model. The project has not proceeded to implementation yet.

2.3 Case 3: co-disposal of filtered tailings and dust control

In this third case study, filtered tailings was selected as a preferred tailings technology at the start of the project for water conservation and recycling purposes as the project was located in an arid region with limited water supply sources. Since the process has a low water consumption, and the production rate was low, this made the investment in filtration technology a viable and sustainable solution. With no potential for acid generation and little if any metal leaching, this came as an ideal solution.

The small mine footprint area, wind and potential for dust generation, however, posed important challenges. In this trade-off study, a co-disposal option was considered for the design of the waste management facility to offer an opportunity to cover fine tailings with layers of waste rock material. The option was interesting as the haulage distances were small, and the waste was relatively broken and easy to place. Co-disposal, however, required optimisation of the mining plan and waste disposal area through material balance to ensure enough waste material in the early life of mine to provide containment, and early layering of tailings and waste for dust mitigation. To optimise the mining schedule and waste availability, borrowed material from the in situ foundation was selected to construct a starter embankment, situated in the centre of the facility to encapsulate weaker oxidised tailings material, while waste rock interlayering and embankment expansion would be placed later in the life of mine.

This project is moving to detailed design and implementation on this basis.

2.4 Case 4: optimising capex expenditures and real estate acquisition

At a platinum mine still under development, a large conventional upstream raised, spigotted deposition TSF was designed to provide life of mine storage to the tailings being produced over 25 years. The facility was located some 4 km from the plant and the mine receives summer rainfall averaging about 600 mm/yr. The tailings deposition and return water pipelines have to cross several private properties, a national road and a river.

The client’s cash flow projections for the project were not favourable to meet the reasonably high upfront capex required for the first stage development of the TSF. The client therefore desired to investigate disposal options closer to the plant, which would have a lower CAPEX to allow them to become cash-positive within a few years of commissioning. At that point in time, they would commence development of the main TSF as per the original plan.

For the start-up condition, consideration was given to development of a ‘dry stack’ TSF. The study commenced with a conceptual design and site trade-off study to determine the preferred site and potential layout to be taken to the next level of study.

The preferred option was located immediately adjacent to the process and dewatering plant. The maximum area that could be developed was 22 ha for a seven year life at 1 Mtpa.

The waste classified as a Type 3 waste in terms of South African legislation, requiring a Class C barrier system. This typically entails, from the bottom up, base preparation to 150 mm including under-liner drainage, 300 mm of compacted clay, 1.5 mm high-density polyethylene (HDPE) liner, finger drain system and a liner protection/ballast layer. The configuration is depicted in Figure 1.

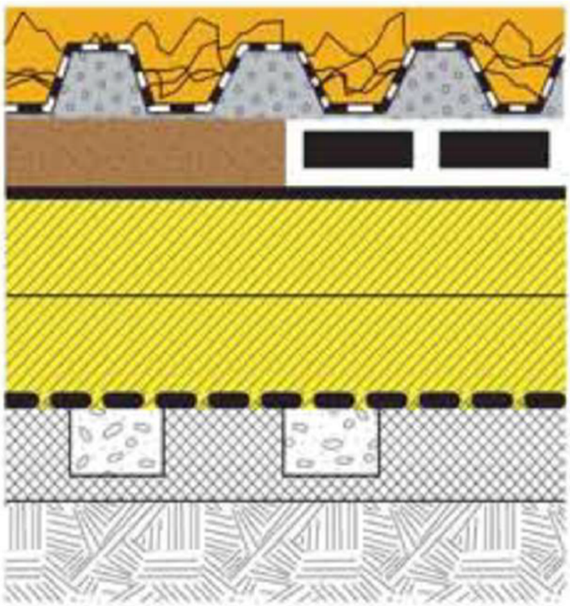

Figure 1 Class C barrier system (South African Department of Environmental Affairs 2013)

A key advantage of the dry stack versus a conventional TSF is that there is no pool to be managed on top of the facility and only surface water runoff is to be managed. To this end, a series of catchment dams were designed. At the client's request, any collected water is captured, used for dust suppression and allowed to evaporate, rather than being returned to the circuit.

Special attention was also given to the protection layer over the liner to minimise the risk of damage to the liner due to construction and operation of the waste conveyance and placement equipment.

The design was approved by the regulator and construction was underway at the time of drafting this paper.

2.5 Case 5: converting from wet to dry disposal and reducing risks over liner systems

In this case study, the expansion of the life of mine and production rate required additional tailings storage capacity. Because of time constrains related to the permitting of a new TSF area, the mine was interested to assess the possibility to convert the tailings disposal from slurry disposal to filtered tailings and increate the existing TSF life. The existing TSF had been designed and constructed in its Phase 1 as a centre-line later upstream raised cyclone facility, fully HDPE lined. This TSF was commissioned four years prior to the mine considering to double its tailings throughput. The increase in throughput had been initiated prior to the conversion in technology, and lead to an alarming increase of the supernatant pond size. This was, among other, caused by the scaling of the decant outlet pipeline and the return water pipelines due to high sulphide and neutralising lime content.

The mine hence decided to investigate the feasibility of converting the existing wet TSF to a 'dry stack', or rather a filtered TSF (FTSF). The mine targeted to achieve a 'de-watered tailings' that has 70 to 85% saturation to minimise the risk of liquefaction. The mine's aim was to reduce water losses from the process, optimal use of airspace and create a more stable waste facility with reduced risk to the surrounding community and environment.

A study was commissioned to consider the de-watering plant system and location, trade-offs between transport and placement options, stability and capacity aspects, and lastly, opex and capex estimates. Locations were assessed both at the existing floatation plant and near the TSF, some 3 km away. Test work included thickening followed by pressure and vacuum filtration. For transport of the material, trucking, pumping and conveying was considered.

The stability of the existing TSF was assessed up to the final height, based on assumptions of the geotechnical properties of the already deposited tailings material. No testing had been done since commissioning of the TSF and safe access onto the TSF was not possible due to the excessively large pool and wet, poorly consolidated tailings. The results indicated unsatisfactory stability at final elevation.

Settlement analyses were carried out to determine the effect on the existing TSF liner system due to the loading induced by construction of the dry stack. This indicated a high probability of damage to the liner system, but with high uncertainty in the severity of the damage, due to the lack of good quality geotechnical data.

Despite water savings in the plant, the dry stack was estimated to have a cost per tonne of approximately nine times that of the previous slurry tailings operation.

2.5.1 Conclusions and recommendations

The optimum solution was to place the dewatering plant near the TSF, and convey and place the dewatered material by conveyor. This would ideally require a 20 m lift construction, which could compromise the existing TSF's liner system. The proposed option, therefore, is to use a mobile fleet for placement and convey overland only.

Improvements required to the existing facility to support the conversion to a dry stack included improvement in stability by reducing the pool down to its design limits, constructing a beach drainage system and carrying out a detailed geotechnical investigation to obtain quality data and parameters for use in analyses.

It is also being considered to develop a Phase 2 TSF as a dry stack from the start as part of the expansion project. This will allow time for the Phase 1 TSF problems to be addressed and possibly converted later. Feasibility level designs are in progress but no final decisions or permits have been secured yet.

3 Lessons learned from operating filtered tailings facilities

The previous section considered trade-off studies that looked into the selection of dry stacking for tailings management, whereas this section includes two cases where dry stacking was implemented and have operated for several years. This has provided opportunities for learning about the benefits and the challenges of operating such facilities.

3.1 Case 6: transportation of filtered tailings

In a very arid region of Namibia, a TSF was designed and operated for about 15 years using filtered tailings disposal. This technology had been motivated partly for water conservation, but also by important earnings from the dewatering process during which additional rinsing of the tailings through the filtration pressure belt allowed to recover soluble metals. The feasibility and implementation was therefore easily justified compared to other mines where the cost or scarcity of water alone is not always a clear-cut reason. Figure 2 shows the filtration process.

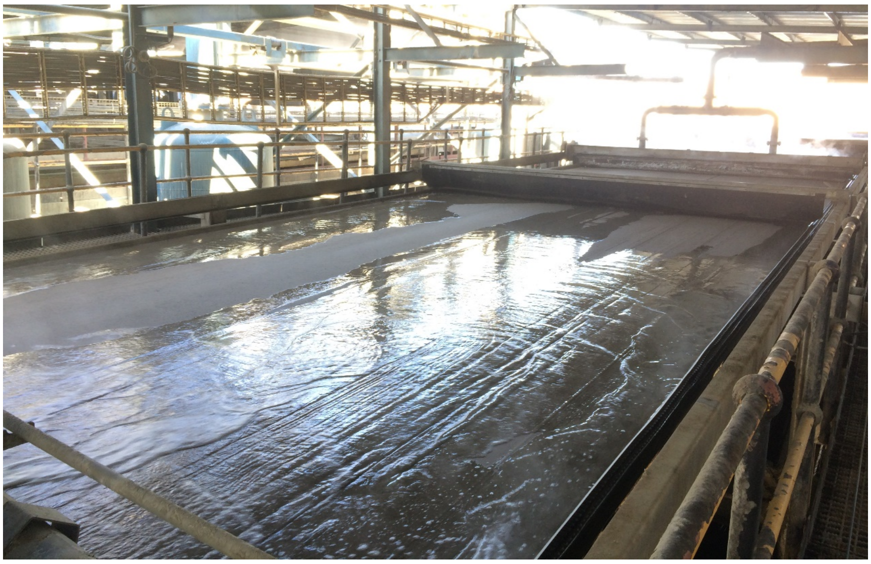

Figure 2 Mineral recoveries from an additional rinse cycle during filtration motivated the filtration process

Very early on in the operating phase, it was found that an additional 33% vacuum filtration capacity was required. This was partly due to the need for redundancy for maintenance and filter cloth replacement.

The filter cake produced was transported by conveyor, and due to a high clay and mica content chutes at transfer points were regularly blocked and ineffective belt cleaners caused spillage close to the towers. Two modifications were made; one was to add water to increase the moisture content from 38 to 40%, which reduced hang-up in the chutes, and the second was to change the shape of the chutes from box-like to more tube-like (banana shaped). These operational improvements meant that on the dump, the tailings slumped and flowed further, some of which was advantageous. It was considered better for the tailings to flow than to hang-up on the dump with steep slopes, that might remain unstable, and inhibit safe advances of the spreader equipment over it. This change was fundamental in terms of stability, as tailings were made to 'fail' and to rest at a residual strength slope angle.

Figure 3 shows the radial stacker and some of the tailings deposition.

Figure 3 View of the radial stacking system

The negative impacts of adding more water meant that more water had to be imported, and supernatant water could be seen ponding on low spots on the dump. The excess water also infiltrated the groundwater, which had not been anticipated. With the spreader conveyor being up to 40 m above ground level, the tailings 'flowed' at all moisture contents, but flowed further as the moisture content increased. This required containment or sidewall construction by mining (using overburden) to be accelerated to keep ahead of the longer beach length.

As with any filtration process, when upset conditions occur, the wet tailings have to be stockpiled at a bypass pad close to the plant. The tailings have to be dried out and regularly removed. The design incorporated a reload hopper, back onto the conveyor. However, it was found that this overloaded the conveyor when it was already carrying cake. As a result, the tailings were trucked away at great cost. The reload system needed to be modified to allow for more of a trickle discharge onto the conveyor, which was never done.

3.2 Case 7: increasing production by adding a filtered tailing operation

At an existing mine, the only way to increase production was to reduce water consumption per tonne milled since the water allocation permit could not be increased. Dewatering of the tailings was selected such that a large percentage reported to a dry stack stockpile, while the remainder continued to be delivered to an existing TSF. The vacuum filtered tailings were loaded into trucks, hauled to a dump and end tipped onto a coarse reject platform from a front-end process of the plant. A co-disposal dump was formed with layering of the two materials.

The learnings here are that filtered tailings can be retro-fitted to an existing operation, and even if the full stream is not dewatered due to capital and operating costs, it may still prove cost-effective and achieve the desired reduction in water consumption to support a production increase. The continued use of the existing wet disposal facility on a part-time or much reduced basis might seem inefficient, but may be more flexible and cost-effective than building all the redundancy required for a full conversion to filtration only.

The co-disposal site was close to the plant, which meant that the haulage costs remained competitive when compared to conveyors and spreaders. The site also lent itself better to co-disposal than wet disposal, with the identified wet disposal site located further from the plant, and at significant elevation above the plant. The co-disposal opportunity also presented itself when the new rejects plant was built, a dry process, and a coarse rejects disposal site was needed.

The existing wet TSF was nearing the end of its life when the filtered tailings plant was constructed, and delayed the capital costs of building a new TSF.

4 Overarching trends and conclusions

There is very strong common motivation in the selection of filtered tailings over conventional slurries. Key trends and conclusions can be summarised as follows.

4.1 Integrated tailings and water management

In all cases described above, there is a reduction in water consumption per tonne processed when dry stacking is compared to wet stacking, including the case where production is increased to maximise use of available water (Case 7). In some cases, the production rate was pre-determined and the TSF was essentially designed to fit this rate. However, projects should be considering a more optimal approach that matches production to more cost-effective mining, process and tailings solution due to the costs of dry stacking. Only Case 4 selected dry stacking in a moderate rainfall area, compared to all other cases being in semi-arid to arid areas. In Southern Africa, and most likely elsewhere, a dry climate and scarcity or cost of water is likely to drive decisions towards dry stacking, but not where water is readily available or low cost. However, if the tailings have the potential to be acid generating, dry stacking does offer a solution even where water is available at low cost. There are some jurisdictions where hydraulic disposal of tailings is either outlawed or difficult to permit, even where water is freely available, in which case, dry stacking has to be considered.

4.2 The consequence of failure and permitting requirements can take precedence over capital and operational costs

All TSFs need to be evaluated in terms of their consequences, especially slope failure, as this impacts on life, property and the environment. Consequences also include surface and groundwater impacts due to seepage, especially when the tailings is potentially acid generating or metal leaching. In most cases, dry stacking is considered to have a lower risk of slope failure, and hence a lower consequence classification. Where a barrier system is included in the design for groundwater protection, this can adversely affect stability both for new dry stack designs or for converting a wet TSF to a dry stack (Case 5).

Historically, closure considerations were not a strong driver in decision making, but are now factored in at the design stage. Dry stacking options offer some benefit either because no re-shaping is necessary, or they have been compacted and wind erosion is controlled. Access is also not inhibited by fines and water. However, final closure still requires substantial commitment and until more mature facilities have been built, the real benefits may not be fully appreciated.

Costs remain a key factor in selecting a tailings management system. In most cases, the dry stacking option has higher capital and operating costs. However, more and more projects are assessing risks and other benefits in terms of reputation, sustainability and responsible mining. It was interesting that for Case 4, a smaller dry stack close to the plant was more cost-effective short-term than a wet and larger TSF 3 km from the plant for life of mine. Different conditions and drivers make each case unique. For Case 1, the short life extension of the existing mine did not make the decision to convert to dry disposal obvious.

4.3 Summary of case studies technical comparison

Table 1 summarises the comparative benefits of the cases evaluated. Lower risk of slope failure and reduction in water consumption are two benefits which were common to all or nearly all cases (at least six out of seven).

Table 1 Assessing benefits of dry disposal for case studies evaluated

Mine site/benefits	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Lower consequence classification	Likely	Yes	Yes	Yes	TBD	Marginal	Yes
Lower risk of slope failure	**Yes**	**Yes**	**Yes**	**Yes**	**TBD**	**Yes**	**Yes**
Reduced water consumption	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Same**
Production increase	Possible	No	No	N/A	N/A	No	Yes
Higher capital costs justified	Yes	No	Yes	Yes	Not obvious	Yes	Yes
Higher opex costs justified	N/A	No	Yes	Yes	Not obvious	Yes	Yes
Reduced groundwater impact	Yes	Yes	Yes	N/A	No	No	Yes
Closure advantages	No	Yes	Yes	Yes	Not obvious	Not obvious	Yes

TBD – to be determined. N/A – not applicable.

5 Conclusion

In four of the cases evaluated, the tailings were potentially acid generating and would impact the environment without remedial action. In Cases 1 and 6, filtration was considered adequate by the client, environmental impacts and/or regulations, while in Cases 2 and 5 a barrier system was included in the design, which adds to the costs.

Only Case 7 considered co-disposal, and therefore no trends have developed that indicate this is a favoured option. However, it should be evaluated as an option as a minimum in trade-off studies for open pit mines.

Finally, even where dry stacking scores well in the trade-off study, this does not mean it has been selected and/or implemented. There are practical and operating aspects that are still taking time to become 'accepted' as proven technology in terms of maintenance and cost.

References

South African Department of Environmental Affairs 2013, *National Environmental Management: Waste Act: Regulations*, Notice 634 of 2013.