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Dewatering options for management of fine gold tailings in Western Australian Goldfields

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Abstract

Typical tailings disposal systems in the Western Australian Goldfields consist of tailings paddock facilities, where tailings are discharged either from a single outlet or from spigots around a ring dyke. Upstream raising and central decanting of supernatant water is common practice.

Potential evaporation in this region is high, at around 2 m per year, with summer months accounting for more than half of the evaporation. This presents a challenge in maintaining a steady rate of water recovery from the facility's pond throughout the year, especially if large shallow ponds are formed. This generates a variable fresh water demand that may not be easy to satisfy if availability of a constant source is limited.

Dewatering tailings prior to disposal may prove a good alternative since, if correctly designed, a reasonably steady flow with consistent reduced water content can be expected from the thickeners or filters. Nonetheless, there is a perception that dewatering could add significant capital expenditure and complexity to the project.

The current development of both thickening and filtration technologies, along with the increased number of technology providers, has reduced the capital and operating cost significantly over the last few years. This, combined with the benefit of improving water recovery, can make thickening and filtration options viable for gold processing plants handling relatively low throughputs.

As a case study, an evaluation of alternative tailings water recovery systems for a gold mine project in the Goldfields region was undertaken. The objective was to determine the optimal tailings water management strategy for the project. The most important aspects evaluated were capital costs and water supply. This paper presents the conclusions of the evaluation and incorporates additional aspects such as landform development, closure and environmental impacts.

Keywords: *dewatering, filtration, high-density gold tailings*

1 Introduction

The Goldfields region of Western Australia presents unique conditions for the development of mining projects. Besides its natural underground richness, water scarcity and high evaporation rates mandate a thorough analysis of the specific circumstances of each project.

Although traditional disposal methods consist of tailings paddock facilities, recent technology development in thickening and filtration is becoming more affordable to new projects and subsequently assisting in the regulatory permitting and implementation of these new mines. This paper presents one particular case study where these technologies have a positive impact on the project.

Two dewatered tailings storage facility (TSF) alternatives were considered – dry stack and central thickened discharge (CTD). A cost comparison between the dewatered tailings options and the conventional base case paddock facility was undertaken and the results are presented herein.

The benefits associated with construction of dewatered TSFs have been well documented. Significant economic benefits can be achieved during TSF construction for idealised flat, unrestricted sites where reduced footprints and/or smaller embankment construction volumes can be realised (Fourie 2012). However, in cases where site restrictions, such as height limitations and topographical features, and restricted footprints are introduced, these benefits are not so evident and are more difficult to quantify.

2 Current tailings disposal method – base case

Deposition of conventional tailings, commonly defined as having a solids concentration within the range of 40 to 50% (Vick 1983), continues to be standard operating practice in the Western Australian Goldfields. Given the region's arid climate, recovery of water from the TSF is highly dependent on seasonal fluctuations in evaporation. Additional water sources and supply infrastructure are required to compensate for critical evaporative losses during summer months and ensure consistent water supply to the plant. Where access to water is a significant challenge or expense, the implementation of a dewatering circuit can be used to stabilise water recovery by removing climatic influences and reducing the required volume of make-up water.

A conventional paddock TSF design was developed as a base case option for a greenfields project site. Water balance results indicated a substantial deficit in return water from the TSF during dry months (approximately 35% of the total slurry water). This triggered an assessment of alternative dewatering options. Both thickened and filtered tailings options were investigated to assess whether tailings dewatering could be used as a cost-effective alternative to reduce the required make-up water volume.

3 Dewatering options

3.1 Slurry testwork

Benchtop testwork was performed on tailings slurry samples to identify the slurry characteristics including the thickening and filtration requirements.

Thickening testwork was performed using a 100 mm diameter dynamic thickening rig with pickets. Filtration testwork was performed using a pressure filtration test rig with a filtration area of 0.008 m^2.

As shown in Figure 1, the two samples tested presented similar density and particle size distribution (PSD). These samples are considered as having a fine PSD relative to typical gold tailings samples, with 40 to 50% passing 10 µm.

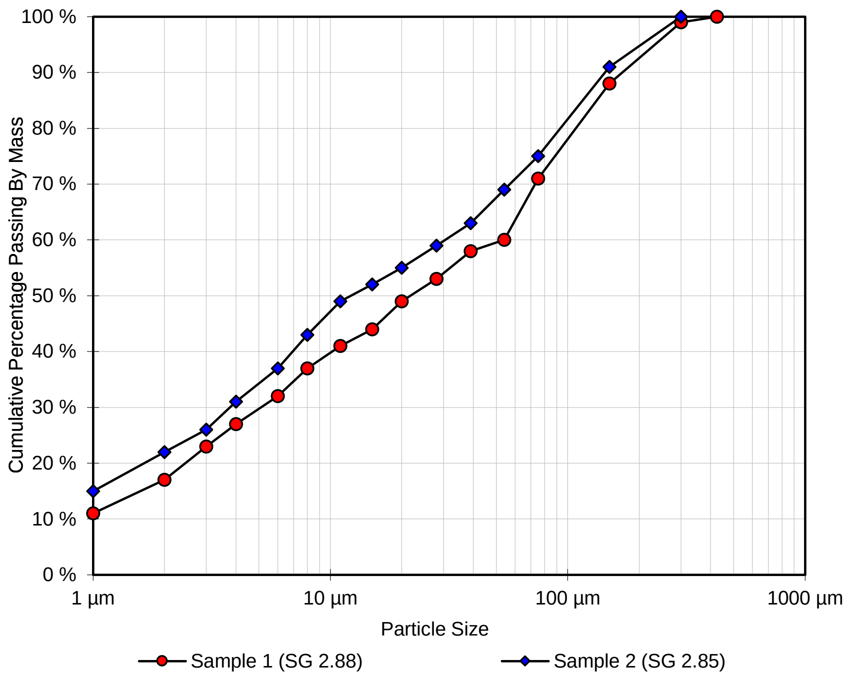

Figure 1 PSD of analysed samples (SG = specific gravity)

3.1.1 Thickening testwork

The thickening testwork included testing of the:

1. Flocculation requirements.
2. Underflow (U/F) solids concentration as a function of flux rate.
3. Underflow slurry rheology.

The key findings of the thickening testwork are shown in Table 1.

Table 1 Thickening testwork results

Sample no.	Indicative flocculant dosing	Max. U/F solids concentration*	Vane yield stress	Flux rate
1	30 g/t	65% by mass	50 Pa	0.2 t/m^2hr
2	15 g/t	63% by mass	50 Pa	0.2 t/m^2hr

*Solids concentration definition used here (process definition): mass of solids/total mass (water + solids).

3.1.2 Filtration testwork

Filtration testwork was undertaken using a single chamber benchtop pressure filtration unit. The focus was to estimate dewatering properties of the slurry associated with feeding and squeezing only. Due to the fine PSD and the presence of clays, air blowing is unlikely to achieve any additional dewatering beyond the cake surface.

The geotechnical testwork identified a target moisture of 15% (process definition).

The slurry feed concentration is 40% m (process definition) which corresponds with the last stage of the carbon-in-leach (CIL) circuit of the process plant. Pre-thickening was not considered. The cake thickness tested was 30 mm (equivalent). The key findings of the filtration testwork are shown in Table 2.

Table 2 Filtration testwork results

Parameter	Units	Value
Feed moisture	% by mass	60% (40% m)
Expected moisture through feeding only	% by mass	20%
Expected moisture through feeding and squeezing	% by mass	15%
Expected process time per cycle	Minutes	Less than 10

3.2 Process requirements and equipment sizing

The process plant is designed for an instantaneous throughput of 175 t/hr (dry solids) with the required availability in excess of 85%. The project life is six years. The make-up water requirements depend on the water recovery rates during dewatering and are summarised in Table 3 for dewatering using thickeners or filters.

Table 3 Make-up water requirements

Dewatering technology	Disposal solids concentration by mass	Slurry throughput (t/hr)	Make-up water	
			Water content in slurry (t/hr)	Water vol. rate (L/s)
Base case: unthickened tailings	40%	438	263	73
High-density thickened tailings	65%	269	94	26
Filtered tailings	85%	206	31	9

Combining these inputs with the testwork results, it is possible to estimate the key sizing parameters of the main process equipment. The thickener option is presented in Table 4, the vertical plate pressure filter option is presented in Table 5 and a screw press filter option is presented in Table 6.

Table 4 Thickening equipment requirements

Parameter	Units	Value
Thickener		
Type of thickener	–	Deep cone, picketed rake
Number of thickeners	–	1
Thickener diameter	m	34
Expected side wall height	m	7.5
Drive torque	k Nm	2,000
Drive power draw	kW	31
Drive power rating	kW	45
Flocculant consumption		
Dosing (for sizing)	g/t	30
Flocculant throughput	kg/hr	5.25
Underflow pumps		
Type	–	Centrifugal slurry pump
Flow rate	m^3/hr	155
Discharge head (per pump)	m (slurry)	38
Number of pumps in series	–	3
Total discharge head	m (slurry)	114
Total discharge pressure	kPa	1,937
Total pumping power	kW	139
Total pumping installed power	kW	225

The use of thicker chambers is open for investigation in this project. However, larger than 2 × 2 m plates were not considered as there is no practical experience of utilising larger plates in full-scale operation worldwide and, in our opinion, the use of larger plates would attract additional complexities for maintenance and supply chain (transportation logistics) that should be avoided.

Table 5 Filtration equipment requirements (pressure filters)

Parameter	Units	Value
Pressure filter		
Type of pressure filter considered	–	Fully automatic, fast acting, vertical plates (with membrane)
Number of units	–	2
Approximate plate size	m	2 × 2, 40 mm chamber
Expected filter volume	m^3	23
Expected number of chambers per filter	–	80
Expected number of filters	–	1
Estimated power draw	kW	80
Installed power	kW	90
Feed pump		
Pumping power draw	kW	72
Installed power	kW	90
Cloth washing pump		
Pumping power draw	kW	50
Installed power	kW	55
Total power draw (average – whole system)	kW	124
Total installed power (whole system)	kW	325

Screw presses are considered as an alternative filtration technology and an example is shown in Figure 2. Table 6 summarises a preliminary sizing of a screw press system for this project.

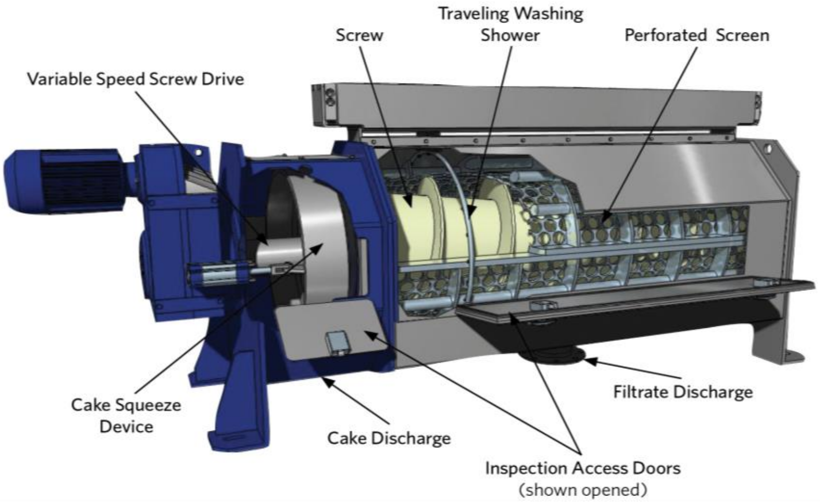

Figure 2 Ishigaki's screw press filter design (Ishigaki USA 2017)

Table 6 Filtration equipment requirements (screw press filters)

Parameter	Units	Value
Screw press filter		
Type of pressure filter considered*	–	IFS IEA or equivalent
Throughput per unit	t/hr	50–90
Number of units	–	2
Estimated power draw	kW	15 per unit
Installed power	kW	30 per unit
Flocculant consumption		
Dosing (for sizing)	g/t	100–150
Flocculant throughput	kg/hr	17.5–26.3
Ancillaries (conditioning tank, feed pump, etc.)		
Pumping power draw	kW	35 per unit
Installed power	kW	50 per unit
Total power draw (average – whole system)	kW	100
Total installed power (whole system)	kW	160

*Preliminary filter sizing and indicative pricing provided by Mr Wilfried Wimmler of Innovative Filtration Solutions (www.ifs-consultants.com.au).

Experience with similar fine tailings slurries suggests that the screw press is suitable for producing a cake moisture similar to that of the vertical plate pressure filter. The advantages include a continuous process (not a batching process as with the pressure filters), fewer moving parts and easier maintenance (generally easier maintenance is acknowledged, e.g. no filter cloths to replace), lower power usage and a smaller footprint and foundation/structural requirements. The disadvantages are that units process less throughput than pressure filters so more units are required, and they also require relatively high flocculant dosing. Notwithstanding these differences between pressure filters and screw presses, the operational costs are comparable.

3.3 Dewatering options cost estimate

This cost estimate uses pricing from leading manufacturers as well as from our database. A high level cost description of these options is presented in Table 7 where the capital cost estimate (CAPEX), operating cost estimate (OPEX, annual and over the life-of-mine (LOM)) and net present cost (NPC) are compared. The weighted average cost of capital (WACC) considered is 8%. The power cost is AUD 0.25 per kWh for equipment within the process plant and AUD 0.40 per kWh for remote equipment using small diesel generators. All values are in Australian dollars (AUD). Each option in Table 7 considers the cost of the dewatering plant as well as the cost of transporting the slurry or filter cake to the disposal area, but excludes the cost of make-up water which is considered in Section 4.

Table 7 Financial comparison dewatering options

Parameter	Unthickened tailings	High-density thickened	Filtration – pressure filters	Filtration – screw press
CAPEX (AUD, millions)	0.74	3.75	4.78	3.27
OPEX – annual (AUD, millions)	0.5	0.59	2.55	2.52
OPEX – LOM (AUD, millions)	2.3	2.74	11.8	11.64
Net present cost (AUD, millions)	3.04	6.49	16.58	14.92
Total cost per tonne of tailings (AUD)	0.36	0.77	1.97	1.78

4 Water supply options

For this particular project, make-up water is available from bore fields within a 20 km radius of the mine site. The pipeline profile is practically flat for design purposes. Utilising this information in combination with the make-up water requirements as seen in Table 3, it is possible to estimate the water supply cost for each of the options, and this is presented in Table 8.

Table 8 Water supply cost

<table>
<tr><th>Parameter</th><th>Unthickened tailings</th><th>High-density thickened</th><th>Filtration – pressure filters</th><th>Filtration – screw press</th></tr>
<tr><td>Make-up water req. (t/hr)</td><td>263</td><td>94</td><td colspan="2">31</td></tr>
<tr><td>Pumping power (kW)</td><td>234</td><td>88</td><td colspan="2">14</td></tr>
<tr><td>CAPEX (AUD, millions)</td><td>5.46</td><td>2.9</td><td colspan="2">0.62</td></tr>
<tr><td>OPEX – annual (AUD, millions)</td><td>0.75</td><td>0.29</td><td colspan="2">0.05</td></tr>
<tr><td>OPEX – LOM (AUD, millions)</td><td>3.49</td><td>1.33</td><td colspan="2">0.21</td></tr>
<tr><td>Net present cost (AUD, millions)</td><td>8.95</td><td>4.23</td><td colspan="2">0.83</td></tr>
<tr><td>Total cost per tonne of tailings (AUD)</td><td>1.07</td><td>0.50</td><td colspan="2">0.10</td></tr>
</table>

The costs above do not include permitting and related costs. They also do not include for extra boreholes in order to match the water supply demand with the aquifer recharge rate (currently being investigated).

As the conclusion of this exercise, the total cost of dewatering plus water supply can be estimated between AUD 1.4 per tonne of tailings for the unthickened and thickened options through to around AUD 2.1 per tonne of tailings for the options considering filtration, including capital repayment. Although the dry disposal options double the cost of the slurry-pumped options, the real difference is seen when the TSF costs are factored in. This is presented in the following section.

5 Tailings storage facility options

Key characteristics of the three TSF options considered for the case study are outlined in Table 9.

Table 9 TSF options comparison

Facility type	Conventional paddock-style TSF	CTD TSF	Dry stack TSF
Dewatering (% solids)	40%	62%	80% (15–25% moisture)
Dewatering Infrastructure	Conventional thickener	High-density thickener	Screw press
Tailings delivery infrastructure	Centrifugal pumps and relatively large diameter pipeline	Centrifugal pumps and smaller diameter pipeline than required for paddock-style	Haul trucks assisted by bulldozer to spread and traffic compact tailings
Tailing footprint area (ha)	68	64	56
Underdrainage	Around perimeter of facility	Localised within areas of embankment at strategic decant points	Not considered
Major earthworks	Starter embankment and ongoing upstream earth fill embankment raises around entire tailings footprint (two cells) Decant causeway for both cells, requiring ongoing centreline raises	Starter embankment located upstream of the final embankment. Construction across the full footprint after four years Causeway and deposition spine requiring ongoing centreline raises	Water diversion bund around full perimeter of footprint. No ongoing earthworks required
Lining system	Prepared clay subgrade across entire tailings footprint	Prepared clay subgrade across entire tailings footprint, plus compacted clay fill	No preparation required

Advantages and disadvantages of the three alternative TSF options are summarised in Table 10.

Table 10 Disposal method comparison

Item	Advantages	Disadvantages
Conventional paddock-TSF	Proven and preferred disposal method in the Western Australian Goldfields Operational requirements are well documented Provides highest level of operational flexibility No thickening costs required	Lowest water recovery (water efficiency) Most complex water management Delayed access for closure Highest risk of seepage to environment Poor operational management can impact stability Highest containment costs High water management costs
CTD	Proven at this scale Allows immediate access for rehabilitation Minimal landform re-shaping for rehabilitation When compared to conventional: higher water recovery, lower seepage risk, lower ongoing containment costs	Reliant upon process equipment performance Capacity and raising is contingent on achieving the design beach slope When compared to conventional: higher tailings dewatering costs. The viability of upstream raising is contingent on achieving adequate tailings foundation strength
Filtered dry stack	Proven at this scale Highest water recovery (water efficiency) Least complex water management Allows progressive rehabilitation Lowest risk of seepage to environment Self-supporting landform Lowest water management costs	Highest dusting risk Highly reliant upon process equipment performance Emergency storage required to store poorly thickened tailings Access difficulties in wet season Highest process maintenance/downtime Highest dewatering costs Highest tailings delivery costs

6 Proposed tailings disposal method

Each TSF option was designed to accommodate the full LOM tailings production plus a contingency of 10%. The following costs focus on the major construction expenses associated with each TSF option. The objective is to provide an indication of whether costs associated with dewatering could be offset through the tailings impoundment design.

Key assumptions made as part of the cost estimate include:

- Each facility has been staged to reduce capital requirements. Starter facilities provide a minimum of two years storage.
- Closure costs have not been included.
- The maximum facility height has been limited to approximately 15 m, similar to the height of nearby topographical features, so the facility does not become a dominant feature in an otherwise flat landscape.
- Pricing has been based on a tender database developed for key construction tasks.
- OPEX cost estimated for the filtered tailings are based on Western Australian contractor rates outlined in the Standardized Reclamation Cost Estimator (Nevada Mining Association 2017) and include equipment hire and fuel/lube/wear costs.

A summary of the TSF construction costs are presented in Table 11.

Table 11 Disposal cost comparison

Parameter	Unthickened tailings	High-density thickened	Dry stacking
Earthworks (m^3)	602,000	490,500	27,800
Surface (m^2)	680,400	639,110	560,000
Initial CAPEX (AUD, millions)	6.8 M	4.1 M	0.9 M
Sustaining CAPEX (AUD, millions)	3.9 M	4.4 M	1.7 M
Total CAPEX (AUD, millions)	10.7 M	8.5 M	2.6 M
OPEX – annual (AUD, millions)	–	–	.4 M
OPEX – LOM (AUD, millions)	–	–	1.9 M
Total cost per t of tailings (AUD)	1.27	1.01	0.54

Based on these findings, it is possible to collate the total costs for tailings processing/transportation, water supply and disposal. These values are shown in Table 12.

Table 12 Overall cost per tonne of tailings

Parameter	Unthickened tailings	High-density thickened	Dry stacking
Processing and transport to TSF cost (AUD/t)	0.36	0.77	1.97
Make-up water supply cost (AUD/t)	1.07	0.50	0.10
Disposal cost (AUD/t)	1.27	1.01	0.54
Overall cost per tonne of tailings (AUD/t)	2.70	2.29	2.61

7 Conclusion

For dewatering technologies to be a viable tailings management solution in the Western Australian Goldfields, the advantages associated with its implementation must align with the specific operational challenges (i.e. water shortage) and specific site constraints. For the case study presented, the utilisation of unthickened tailings does not provide clear technical or economic benefits. On the other hand, high-density tailings and dry stacking provide cost benefits to the operator as well as a number of technical advantages and therefore are the recommended options for this study.

There are also a number of less tangible benefits which can be considered when assessing dewatered tailings options. These include, but are not limited to, more favourable permitting support, reduced pollution risk and reduced risk of facility failure. Although these benefits have not been quantified as part of this case study, they are nonetheless important factors to be considered when assessing potential TSF options.

It should be noted that the implementation of dewatering technology does come with inherent risk as the operation would be highly sensitive to the dewatering infrastructure maintaining performance throughout the operation. If the dewatering process does not perform as anticipated, this would create significant operational challenges. Notwithstanding this, unthickened tailings operations also provide unique challenges, especially on the water supply reliability and cost throughout the life of the project.

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