An Evaluation of Highly Dewatered Tailings Disposal Applications in Large Scale Mining Operations in Chile's Atacama Desert

J.C. Scola *Golder Associates SA, Chile*

D. Landriault *Golder Paste Technology Ltd, Canada*

ABSTRACT

Golder has recently completed studies on highly dewatered tailings disposal methods for a number of large scale mining operations/projects in northern Chile. The lessons learned have been incorporated into the two case studies presented in this paper. The case studies show that there are important potential cost savings to motivate existing operations to change from conventional slurry tailings disposal systems to alternative highly dewatered tailings disposal systems.

1 INTRODUCTION

The two case studies covered in this paper are related to large scale mining operations located in the Atacama Desert of northern Chile, where precipitation is very low at 5 mm/year and evaporation is very high at 10 mm/day. Make up water for mining operations in the area has historically been sourced from surface streams and groundwater deposits mainly located in the high Andes mountains in environmentally sensitive areas. The majority of such water sources are currently considered to be exploited to their limits, whilst some are nearing depletion or will have to be closed down to limit environmental damage. Mining companies operating in the area are now turning their attention to the Pacific Ocean as the water source for their future water needs.

This paper demonstrates that extracting water from the tailings has the potential to be a better option than sourcing make up water from the sea. The tailings dewatering methods considered in these case studies range from high compression thickening, to paste thickening, to vacuum filtration, to pressure filtration; each method producing a higher degree of tailings dewatering over the previous one.

2 CASE STUDY 1

The first case study is based on an existing large copper mine processing 225000 t per day and currently depositing conventional slurry tailings at 50 wt% solids. Water recovery from the deposited tailings is very low, mainly because of the high evaporation rate in the area. This operation has a 20 year mine life ahead. Some of its make up water sources have short lives and will have to be replaced in the near future. The capital and operating costs of the potential new water sources will be high. To be able to continue depositing conventional slurry tailings, the owners will have to invest a large capital sum in the tailings management facility (TMF).

The main economic and/or environmental drivers for a mine of this size and location to consider converting to a paste/thickened tailings/filter cake deposition system are:

- Potential depletion and/or stability of long-term source of make up water offset by a major increase in water recovery from the tailings.
- Off set or eliminate high capital/operation costs for new water sources (sea water desalinisation) to maintain and/or increase production.
- Substantial capital/operation cost reduction in the TMF as compared to conventional slurry tailings disposal.

In this case study three different scenarios are considered as the base case:

- Scenario 1 is the most favorable: for the continuing disposal of conventional slurry tailings over 20 years, a total of US$ 300 million in capital is needed at the TMF for containment construction, tailings distribution pipelines upgrades and water return system upgrades. No capital cost will be required for new make up water sources. Any additional make up water is to be sourced from 3rd parties at US$ 1.40/m^3.
- Scenario 2 is the intermediate: in addition to the US$ 300 million in capital needed for the TMF facilities, an extra US$ 270 million in capital is required for one new make up water source capable of delivering 575 L/s.
- Scenario 3 is the least favorable: in addition to the US$ 300 million in capital needed for the TMF an extra US$ 700 million in capital is required for one new make up water source capable of delivering 1500 L/s.

The table below outlines the capital and operating costs associated with the three base case scenarios described above. As shown in the table, the combined tailings placement and make up water Net Present Cost (NPC) for the different scenarios range from US$ 1.033 to US$ 1.733 billon dollars over the 20 year mine life. This equates to an NPC of US$ 0.62 to US$ 1.05 (inclusive of make up water supply) per tonne of tailings placed in the TMF.

Table 1 Base case scenarios – economical evaluation

	Base Case		
	Scenario 1 lower CAPEX	Scenario 2 intermediate CAPEX	Scenario 3 higher CAPEX
1 — Tailings disposal			
CAPEX, million US$	300	300	300
OPEX, million US$ per year	5	5	5
Return water LoM[1], million m^3	189	189	189
Tailings disposal, US$/t	0.24	0.24	0.24
2 — Make up water supply			
CAPEX, million US$	0	270	700
Make up water flowrate, l/s	2324	2324	2324
Make up water[2], m^3/t	0.89	0.89	0.89
Make up water costs[3], US$/t	1.24	1.24	1.24
Total (1+2)			
Unit cost (tailings + make up water), US$/t	1.48	1.64	1.90
Net present cost[4], million US$	1033	1303	1733
Net present cost[4], US$/t	0.62	0.79	1.05

[1] LoM: Life of Mine

[2] cubic meters of make up water per t of tailings placed in the TMF

[3] at US$ 1.40/m^3

[4] at a discount rate of 10%

The alternative tailings deposition system options evaluated in this case study are listed in Table 2. The options are listed in increasing tailings dewatering capability from high compression thickening up to pressure filtration. With the increasing water removal from the tailings the volume of water recovered obviously increases which results in an increasing deposition placement angle.

Table 2 Tailings dewatering process system options

Option	**Dewatering Method**	**Transportation**	**wt % Solids**	**Deposition Placement Angle (%)**
1	High compression thickening	Centrifugal slurry pumps	60.0	4.5
2	Paste thickening	Positive displacement pumps	65.0	9.0
3	Vacuum filtration	Belt conveyors	76.0	12.5
4	Pressure filtration	Belt conveyors	85.0	17.5

2.1 Description of Alternatives

Option 1: Tailings dewatering will be achieved using high compression thickeners. Twelve thickening units are considered (55 m diameter, 11 operating/1 standby). Thickener underflow will be transported by centrifugal slurry pumps to the deposition locations in the TMF.

Option 2: Tailings dewatering will be achieved using paste thickeners. Eighteen thickening units are considered (45 m diameter, 17 operating/1 standby). Thickener underflow will be transported by piston diaphragm positive displacement pumps to the deposition locations in the TMF.

Option 3: Tailings dewatering will be achieved using horizontal belt vacuum filters. Ninety-six filtration units are considered (162 m^2, 69 operating/27 standby). Filter cake will be conveyed to the TMF and stacked using a belt conveyor system. Filtrate will be clarified prior to being returned to the mill.

Option 4: Tailings dewatering will be achieved using vertical plate membrane pressure filters. Two hundred and forty filtration units are considered (576 m^2, 174 operating/66 standby). Filter cake will be conveyed to the TMF and stacked using a belt conveyor system. Filtrate will be clarified prior to being returned to the mill.

Unfortunately, the increased water recovery levels associated with each option come with increased capital and operating costs as presented in Tables 3 and 4. To fully evaluate the economic viability of each of the dewatering systems, the potential cost savings in make up water supply must be taken into account in the calculation of the NPC per tonne of tailings placed over the life of the mine. This evaluation is presented in Table 5. These results must then be compared to the base case operation scenarios over the same time period. This comparison is presented in the discussion section.

Table 3 Capital cost estimate (±35%) for the different dewatering options

	Capital Cost (million US$)			
	Option 1 High compression thickening	**Option 2** Paste thickening	**Option 3** Vacuum filtration	**Option 4** Pressure filtration
Process equipment	36.1	76.2	298.0	487.1
Main "overland" pipelines	38.3	38.7	32.7	34.5
Installation costs	58.3	90.3	131.3	160.2
Total direct costs	132.7	205.1	462.0	681.9
Indirect costs	25.7	41.2	96.6	143.5
Owner costs	4.8	7.4	16.8	24.8
Contingency	32.6	50.7	115.1	170.0
Total CAPEX	195.9	304.4	690.4	1020.1

Table 4 Operating cost estimate (± 35%) for the different dewatering options

	Operating Cost (million US$ per year)			
	Option 1 High compression thickening	**Option 2** Paste thickening	**Option 3** Vacuum filtration	**Option 4** Pressure filtration
Power	9.8	16.2	32.8	24.4
Flocculant	4.9	4.9	4.9	0.0
Labor	0.6	0.6	0.9	1.0
Maintenance	1.5	3.0	11.9	19.5
Other	0.5	0.5	1.0	1.0
Earthmoving equipment	1.2	1.2	1.2	1.2
Total OPEX	18.5	26.5	52.8	47.0

Table 5 Economic evaluation of the different dewatering options

	Proposed Cases			
	Option 1 High compression thickening	**Option 2** Paste thickening	**Option 3** Vacuum filtration	**Option 4** Pressure filtration
1 — Tailings dewatering and disposal				
CAPEX, million US$	196	304	690	1020
OPEX, million US$ per year	19	27	53	47
Return water LoM, million m^3	552	764	1,132	1363
Tailings dewatering and disposal, US$/t	0.34	0.50	1.06	1.18
2 — Make up water supply				
Make up water flow rate, l/s	1749	1413	829	463
Make up water, m^3/t	0.67	0.54	0.32	0.18
Make up water costs @ US$ 1.40/m^3, US$/t	0.93	0.75	0.44	0.25
Total (1+2)				
Unit Cost (tailings + make up water) US$/t	1.28	1.26	1.50	1.43
Net Present Cost*, million US$	880	955	1389	1560
Net Present Cost*, US$/t	0.53	0.58	0.84	0.94

*discount rate 10%

2.2 Discussion

The change in technology, associated with any of the proposed options, would allow the placement of the life of mine tailings without the need to invest the US$ 300 million for the upgrade of the TMF as required by the base case. The lower make up water requirements, associated with the proposed options, would account for significant cost savings over the life of the operation.

Tables 6 and 7 show that options 1 and 2 are business cases for base case scenarios 1 and 2. Options 1 and 2 are not viable technical solutions for base case scenario 3, given the associated deficit in the make up water supply.

Table 8 shows that options 3 and 4 are business cases only for base case scenario 3. The "challenge" associated with the filter cake option is to organise the unprecedented manufacturing effort associated with the procurement of such amount of filters.

Table 6 Base case scenario 1

	Base Case Scenario 1	**Option 1** High compression thickening	**Option 2** Paste thickening	**Option 3** Vacuum filtration	**Option 4** Pressure filtration
Net present cost* million US$	1033	880	955	1389	1560
Net savings* million US$		153	78	-356	-527
Net present cost* US$/t	0.62	0.53	0.58	0.84	0.94

*discount rate 10%

Table 7 Base case scenario 2

	Base Case Scenario 2	**Option 1** High compression thickening	**Option 2** Paste thickening	**Option 3** Vacuum filtration	**Option 4** Pressure filtration
Net present cost* million US$	1,303	880	955	1389	1560
Net savings* million US$		423	348	-86	-257
Net present cost* US$/t	0.79	0.53	0.58	0.84	0.94

*discount rate 10%

Table 8 Base case scenario 3

	Base Case Scenario 3	**Option 1** High compression thickening	**Option 2** Paste thickening	**Option 3** Vacuum filtration	**Option 4** Pressure filtration
Balanced make up water supply	Yes	No	No	Yes	Yes
Net present cost* million US$	1733	880	955	1389	1560
Net savings* million US$		853	778	344	173
Net present cost* US$/t	1.05	0.53	0.58	0.84	0.94

*discount rate 10%

The economic evaluation demonstrates that the implementation of the highly dewatered tailings disposal options assessed have great potential for cost savings for different scenarios of the base case.

3 CASE STUDY 2

The second case study is based on another existing large copper mine also processing 225000 t per day and currently depositing conventional slurry tailings at 57 wt% solids. Water recovery from the deposited tailings is reasonably good, in spite of the high evaporation rate in the area, mainly because of the cell deposition strategy implemented in the TMF at a high operating cost. The current TMF has a very short life and will have to be replaced in the near future. This mining operation has a 20 year life ahead. The operation make up water supply is assured from large surface and groundwater sources at a relatively low operating cost of US$ 0.60/m^3.

The main economic and/or environmental drivers for a mine of this size and location to consider converting to a thickened tailings deposition system are:

- The operation requires a new TMF for future conventional tailings disposal.
- The topography of the existing TMF is suitable for non-conventional tailings disposal on top of the conventional tailings and for that it will not require the construction of additional containment structures.
- It is a Brownfield project with potential to change to a “new” tailings management technology.

3.1 Description of Alternatives

Base case: A large rock dam is required at the new TMF site for conventional tailings disposal. The associated CAPEX is US$350 million. Conventional TMF operating costs are high at US$ 25.2 million per year (includes high rate thickening to 57 wt% solids, impoundment compartmentalisation and water return).

The option screening criterion is to obtain a “non-segregating slurry” with a placement property to allow a 2% deposition slope to be obtained.

Option 1: Mill tailings dewatering will be achieved using high compression thickeners. Three 75 m diameter thickening units will be strategically located on higher ground around the perimeter of the TMF. Thickener underflow will be transported by centrifugal slurry pumps to the deposition locations in the TMF.

Option 2: Mill tailings dewatering will be achieved using high compression thickeners. Four 62 m diameter thickening units will be strategically located on higher ground around the perimeter of the TMF. Thickener underflow will be transported by centrifugal slurry pumps to the deposition locations in the TMF.

Option 3: Mill tailings dewatering will be achieved using high compression thickeners. Six 50 m diameter thickening units will be strategically located on higher ground around the perimeter of the TMF. Thickener underflow will be transported by centrifugal slurry pumps to the deposition locations in the TMF.

Some details related to the base case and options are presented in Table 9. The capital cost estimates are presented in Table 10. The operating cost estimates are presented in Table 10.

Table 9 Tailings dewatering process system options

Option	Dewatering Method	Transportation	wt % Solids	Deposition Slope %
Base case	High rate thickening	Open launder	57	0.5
1	High compression thickening (3 x 75 m dia.)	Centrifugal slurry pumps	67*	2.0
2	High compression thickening (4 x 62 m dia.)	Centrifugal slurry pumps	68*	2.0
3	High compression thickening (6 x 50 m dia.)	Centrifugal slurry pumps	69*	2.0

*In this case study smaller diameter thickeners have the capacity to discharge higher wt % solids underflow because they have a higher Nm/m^2 factor (higher available torque to thickener surface area ratio) which allows them to move thicker muds to the discharge outlet.

Table 10 Capital cost estimate (±35%) for the different dewatering options

	Capital Cost (million US $)			
	Base Case High rate thickening	**Option 1** High compression thickening 3 x 75 m	**Option 2** High compression thickening 4 x 62 m	**Option 3** High compression thickening 6 x 50 m
Process equipment		22.8	27.2	23.0
Main “overland” pipelines		64.1	63.8	64.3
TMF – start up facilities	350	-	-	-
Installation costs		22.5	25.2	26.0
Total direct costs		109.4	116.2	113.3
Indirect costs		18.9	20.4	19.7
Owner costs		3.8	4.1	4.0
Contingency		26.4	28.1	27.4
Total CAPEX	350	158.6	168.9	164.5

Table 11 Operating cost estimate (±35%) for the different dewatering options

	Operating Cost (million US$ per year)			
	Base Case High rate thickening	**Option 1** High compression thickening 3 x 75 m	**Option 2** High compression thickening 4 x 62 m	**Option 3** High compression thickening 6 x 50 m
Power	5.9	3.7	3.8	4.0
Flocculant		4.5	4.5	4.5
Labor		0.7	0.7	0.7
Maintenance		0.9	1.1	1.1
TMF	19.3	0.5	0.5	0.5
Earthmoving equipment		1.2	1.2	1.2
Total OPEX	25.2	11.5	11.8	11.9

An economic evaluation is presented in Table 12.

Table 12 Economical evaluation of the different dewatering options

	Base Case High rate thickening	Option 1 High compression thickening 3 x 75 m	Option 2 High compression thickening 4 x 62 m	Option 3 High compression thickening 6 x 50 m
1 — Tailings Dewatering and Disposal				
CAPEX, million US$	350	159	169	164
OPEX, million US$ per year	25.2	11.5	11.8	11.9
Tailings dewatering and Disposal, US$/t	0.51	0.23	0.24	0.24
2 — Make up Water Supply				
Make up water flowrate, L/s	1391	1311	1253	1196
Make up water, m^3/t	0.52	0.49	0.47	0.45
Make up water costs @ US$ 0.60/m^3, US$/t	0.31	0.30	0.28	0.27
Total (1+2)				
Unit cost (tailings + make up water), US$/t	0.82	0.53	0.52	0.51
Net present cost*, million US$	676	313	320	311
Net present cost*, US$/t	0.40	0.19	0.19	0.19
Net savings, million US$		363	356	365

*discount rate 10%

3.2 Discussion

All three options are business cases and show very similar bottom lines. The change of technology to thickened tailings would allow extending the life of the current TMF eliminating the need to build a new one. The change to thickened tailings would increase the life of the existing TMF site up to 80 years through the stacking of the tailings at 2% placement angle. The implementation of any of the three highly dewatered tailings disposal options proposed has the potential to save an estimated US$ 350 million.

This assessment is based on the “thicken twice” concept. Also assessed was the option of discontinuing the “thickening at the mill” unit operation and doing “thickening only once” at the TMF area. Results showed it to be more expensive. The savings from the discontinued thickening step are more than offset by larger CAPEX and OPEX needed to handle the larger flowrates.

4 CONCLUSIONS

These two case studies demonstrate that highly dewatered tailings disposal methods have great potential for overall life of mine cost reductions when compared to "Conventional Slurry Tailings Disposal Methods" as applied in large scale mining operations in northern Chile. A good part of the net savings is related to reduced costs for make up water supply.

However, each case must be evaluated considering its own drivers and site specific conditions and is very much dependent on the material properties (dewatering, transportation and placement properties) which are all related to the mineral and chemical composition of the tailings.