Technical and Economical Evaluation of Tailings Dewatering Circuits in the Largest Copper Mines

Cristian Zamorano, Sergio Ramírez, Iván Sánchez and Cristian Garrido
Fluor, Chile

ABSTRACT

Several large copper mines are evaluating improvements in the tailings dewatering circuits. Most prevalent alternatives being considered optimize their thickening technologies or the implementation of tailings filtration and stacking. This requirement to optimize water recovery is due to a variety of factors; the deficit and high cost of the water make-up, environmental restrictions, and community relationships. The recent failures in conventional tailing deposit structures and the potential change to reduce the footprint of tailings impounds may also drive the desire to consider alternate technologies.

This paper presents technical and economic review of alternate technologies, considering capital investment and operational costs. The five (5) selected alternatives include thickening technologies, pressure filters and a combination with cyclones for classification and filtration of the coarser fraction and thickening of the finer fraction. The selected alternatives are developed and evaluated at trade off study level.

INTRODUCTION

Improvements in tailings dewatering circuits are required, however the existing technology does not yet offer a clearly advantageous solution, therefore evaluation of several alternatives to determine the appropriate solution for each specific application.

The principal drivers for undertake tailings dewatering improvements initiatives typically include: high make-up water costs, restriction on water availability, environmental restrictions, permits requirements, communities demands or the need to reduce tailings deposition footprint, as well as other site specific motivations. The potential of conventional tailings deposit failure, whose recent instances have had significant repercussions to both the industry and their surrounding communities, also could be powerful driver.

For several years, technology suppliers have improved their designs for tailings dewatering. Conventional thickening changed to high capacity thickening and this is the typically selected technology. Application of high density or paste thickening technology has grown significantly, however for high processing capacity, some operational difficulties persist. While the unit capacity is limited as the thickener discharge solid content increases the yield stress rises considerably driving higher torque and bed pressure. This results in the requirement of the driving system to be more robust, often to, or beyond the limits of the mechanical design. Depending on tailings characteristic, solids content in the discharge, deposit location and other characteristics of the project, rheological modifiers or shear thinning system may be required. Often the tailings transport systems for high solids content require the incorporation of positive displacement pumps, which have a high investment cost and high energy consumption.

The tailings filtration and stacking is a technology typically considered in mining plants with low throughput capacity and high profit. For high processing capacity, this technology has not been implemented, but is looked with high interest by the industry, driving to suppliers to seriously pursue lines of high capacity equipment development. Only the vertical plate pressure filters technology has been considered on this development, in which suppliers are optimizing their equipment and increasing efficiency or increasing the frequency of cycle. So far, a few tests have been carried out at an industrial level, the expected results and benefits have not yet been achieved. However, there is an optimistic expectancy of their development. Technically, it has the complexity of requiring a large number of batch filters operating in parallel and the economic evaluation is less competitive in most of cases.

Finally, in some cases the industry has implemented tailings classification to obtain a coarse fraction with very low water content and thickened the fine fraction. This alternative allows improving the water recovery and making tailings storage requirements more flexible.

In this article, five (5) alternatives of tails processing technology are evaluated at a trade off study level:

Alternative 1: conventional thickening

Alternative 2: high rate thickening,

Alternative 3: paste thickening

Alternative 4: full thickening and pressure filtration

Alternative 5: tailings classification with filtration of the coarse fraction and fine fraction thickening.

A processing capacity of 100 ktpd was defined for the case study. Parameters for developing the mass balance and sizing the equipment were taken from typical industrial cases of high capacity copper mining. The capital investment costs (CapEx) as well as the operational costs (OpEx) were determined for each alternative.

Table 1 shows basic unit operations considered within each of the alternatives evaluated and compared

Table 1 Selected alternatives description

Description	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Classification	-	-	-	-	Cyclones
Thickening					
Tailings Dewatering	Total	Total	Total	Total	Fine Fraction
Type of Thickener	Conventional	HRT	Paste	HRT	-
Filtration					
Tailings Filtration	-	-	-	Total	Coarse Fraction
Type of Filer Press	-	-	-	Vertical Plate	Vertical Plate
Stacking System					
Tailings Stacking	-	-	-	Total	Coarse Fraction
Tailings Dam					
Tailings Disposal	Total	Total	Total	-	Fine Fraction

METHODOLOGY

For all selected alternatives, Table 2 shows the feed ore characteristics at a processing capacity of 100 ktpd.

Table 2 Feed ore characteristics

Description	Unit	Data
Moisture	% w/w	3.0
SG Solid	-	2.75
Plant Run Time	%	94.0

Table 3 shows the design parameters per alternative.

Table 3 Design parameters per alternative

Description	Unit	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Cyclone Classification						
Solid Feed	%					35.0
OF/UF	-	-	-	-	-	55/45
Solid Coarse Fraction	%	-	-	-	-	60.0
Cyclone Feed PSD (F80)	µm	-	-	-	-	200
Thickening						
Tailings Dewatering	-	Total	Total	Total	Total	Fines Fraction
Type of Thickener	-	Conventional	HRT	Paste	HRT	HRT
Solid Feed	%	35.0	35.0	35.0	35.0	26.1
Solid Discharge	%	55.0	62.0	68.0	62.0	58.0
Unit Rate	m^2/tpd	0.08	0.10	0.12	0.10	0.14
Yield Stress	Pa	20	40	100	40	80
Flocculant Dosage	g/t	15	18	20	18	20
Filtration & Stacking						
Type of Filter	-	-	-	-	Filter Press	Filter Press
Tailings to be Filtered	-	-	-	-	Total	Coarse Fraction
Solid Feed	%	-	-	-	62.0	60.0
Unit Rate	m^2/tpd	-	-	-	220	350
Moisture	%	-	-	-	18.0	15.0
General Parameters						
Final Conc. Moisture	%	9.0	9.0	9.0	9.0	9.0

Final Conc. SG Solid	-	4.20	4.20	4.20	4.20	4.20
Final Conc. Cu Grade	%	28.0	28.0	28.0	28.0	28.0
Global Cu Recovery	%	90.0	90.0	90.0	90.0	90.0
Water Rec from Dam	%	40.0	40.0	40.0	-	40.0

Main basis of capital cost (CapEx) estimate are shows below:

- Benchmark data for direct capital cost of main equipment
- Labor and installation cost factorized according industry standards
- Conveyor system and dry stacking is considered for filtered tailings
- Auxiliaries equipment are not included in comparison
- The analysis only considers processing facilities but not tailings deposit
- Allowances, contingency and deferred capital cost are not included.

Main basis of operational cost (OpEx) estimate are shows below:

- Benchmark data for unitary cost
- Labor for operation and maintenance from Benchmark data
- Water make-up and flocculant are the consumables
- Energy. Power consumption is estimate based on installed power and the typical load and utilization factor considered.
- For maintenance and spare parts, a factorization based on equipment direct CapEx cost is considered.
- General and administration (G&A) cost are not included in the comparison.

Table 4 shows the base unit cost for estimate.

Table 4 Base unit cost

Description	Data	Unit
Water	3.0	USD/m^3
Flocculant	3,000	USD/t
Energy	0.10	USD/kWh

The following data for NPC (Net Present Cost) calculation of the operational cost estimate is shown below:

- Discount rate: 8%
- Years of operation: 20

RESULTS AND DISCUSSION

The results obtained per alternative, based on methodology section to allow a good comparison between alternatives.

If an escalation based on increase or decrease processing capacity is required, the results obtained allow it easily. However, depending on the conditions of each project, such as dewatering plant located, work to be required in the tailings deposit and location, etc.; the ranking of comparison between alternatives could change.

Table 4 shows the main equipment list per alternative for the investment cost estimate.

Table 4 Main equipment list

Description	Unit	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Classification Stage						
Type of Classification	-	-	-	-	-	Cyclone Cluster
N ° of Cyclones	-	-	-	-	-	24
Thickening						
Type of Thickener	-	Conventional	High Capacity	Paste	High Capacity	High Capacity
Number of Thickener	-	2	2	6	2	2
Diameter	m	75	85	55	85	75
Type of Discharge Pump	-	Centrifugal	Centrifugal	Positive Displacement	Centrifugal	Centrifugal
N° of Discharge Pump	-	4	4	12	4	4
Filtration & Stacking						
Type of Filter Press	-	-	-	-	Vertical Plate	Vertical Plate
Area per Filter Press	m^2	-	-	-	2,000	2,000
Number of Filter Press	-	-	-	-	11	4
Stacking System	-	-	-	-	Conveyors & Stacker	Conveyors & Stacker
N° of Equipment	-	-	-	-	(*)	(*)

(*) Based on benchmark data.

Table 5 Unitary water recovery and Unitary water make-up

Alternative	Unitary Water Recovery m^3/t_{ore}	Unitary Water Make-up m^3/t_{ore}
1	1.33	0.45
2	1.45	0.33
3	1.53	0.25
4	1.60	0.19
5	1.50	0.28

Table 6 shows the operating cost estimate with their corresponding structure.

Table 6 Operational cost estimate

Description	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Labor	1,240	1,240	1,760	2,320	1,920
Energy	663	818	11,549	8,386	3,536
Consumables	50,864	38,044	29,148	22,231	32,031
Maintenance	1,150	1,236	4,931	20,138	10,604
Total Cost, kUSD/y	**52,677**	**40,099**	**45,628**	**53,074**	**48,092**
Unitary Cost, USD/t_{ore}	**1.44**	**1.10**	**1.25**	**1.45**	**1.32**

Table 7 shows the economic evaluation estimate per alternative based on methodology section data.

Table 7 CapEx and OpEx estimate

Description	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
CAPEX, kUSD	21,352	22,951	91,583	373,993	196,937
NPC OPEX, kUSD	517,188	393,694	447,985	521,093	472,170
Total NPC, kUSD	**538,540**	**416,645**	**539,568**	**895,086**	**669,107**

Table 6 shows that consumable costs have the greatest influence on the total operational costs, where the main cost is based on water make-up. The flocculant consumption is another consumable considered, but it is not relevant.

As the water make-up cost has a high influence in the total operational cost estimate, Figure 1 shows a sensitivity analysis between operational unitary cost estimate and water make-up cost.

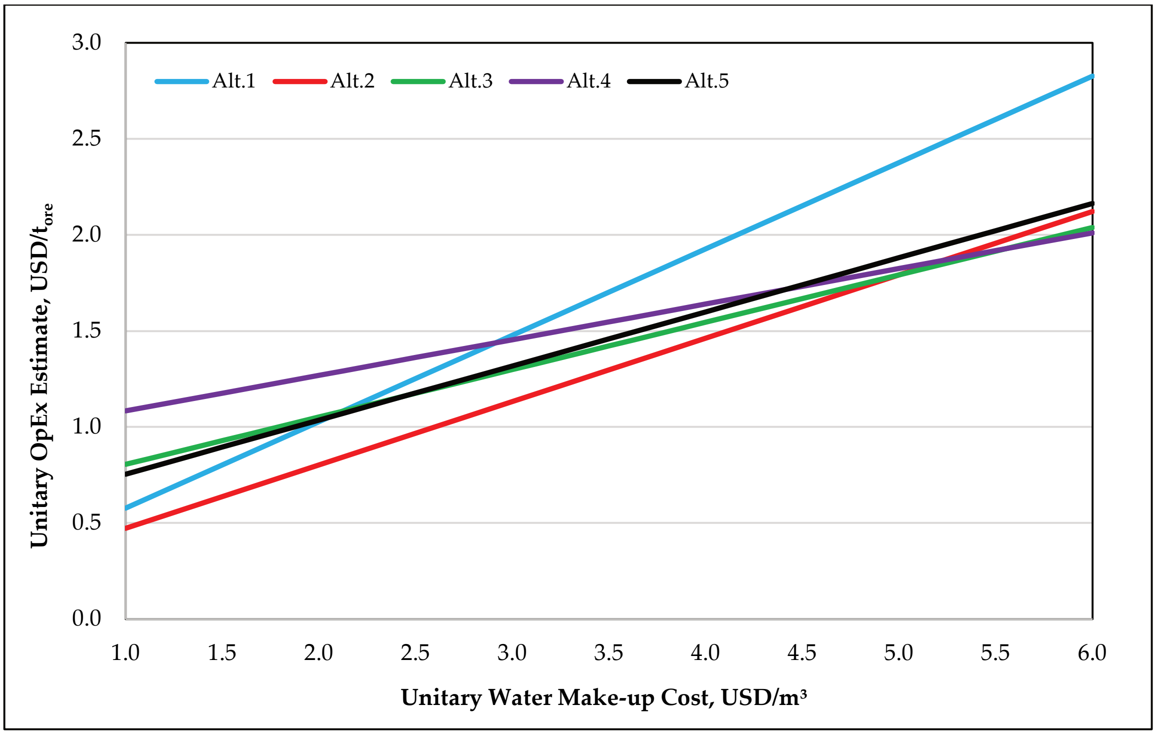

Figure 1 Unitary operational cost estimate vs Unitary water make-up cost

Figure 1 shows the high influence of the unitary water make-up cost in the unitary OpEx cost estimate based on water make-up consumption per alternative, see Table 5. It is a relevant factor to consider if necessary select or deselect any dewatering circuit.

For unitary water make-up cost of 5.0 USD/m^3, there is no considerable difference between alternatives 2 to 5, therefore other factors to select or deselect an alternative should be considered. The capital cost estimate of alternatives 4 and 5 is considerably larger, see Table 7, and this is independent of the unitary water make-up cost.

Considering values under 2.0 USD/m^3, it was expected that conventional thickening technology (alternative 1) could still be considered, however in this case a circuit with a high rate thickeners (alternative 2) has a more appropriate economical evaluation results.

Figure 2 shows the operating costs taken to NPC according to the years of operation, where it can be seen that the curve increases exponentially up to 20 years of operation and then NPC OpEx cost estimate is more stable.

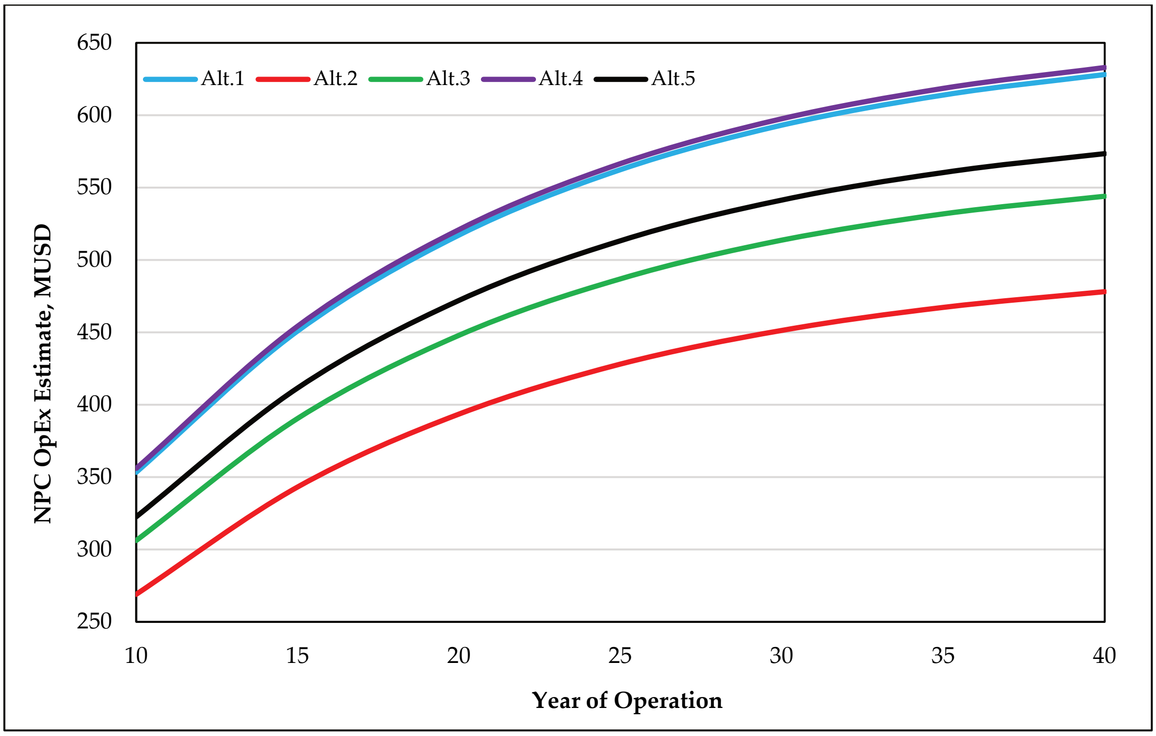

Figure 2 NPC operational cost estimate per year of operation

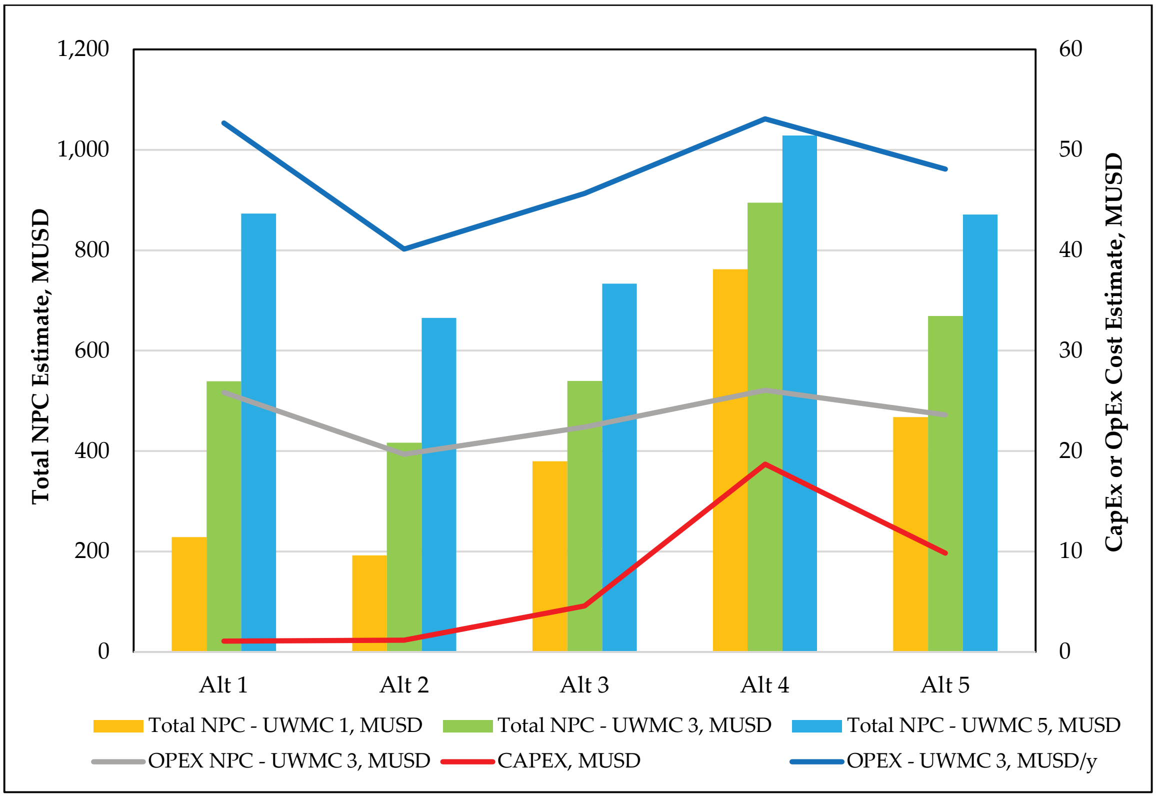

Figure 3 Economic evaluation vs unitary water cost

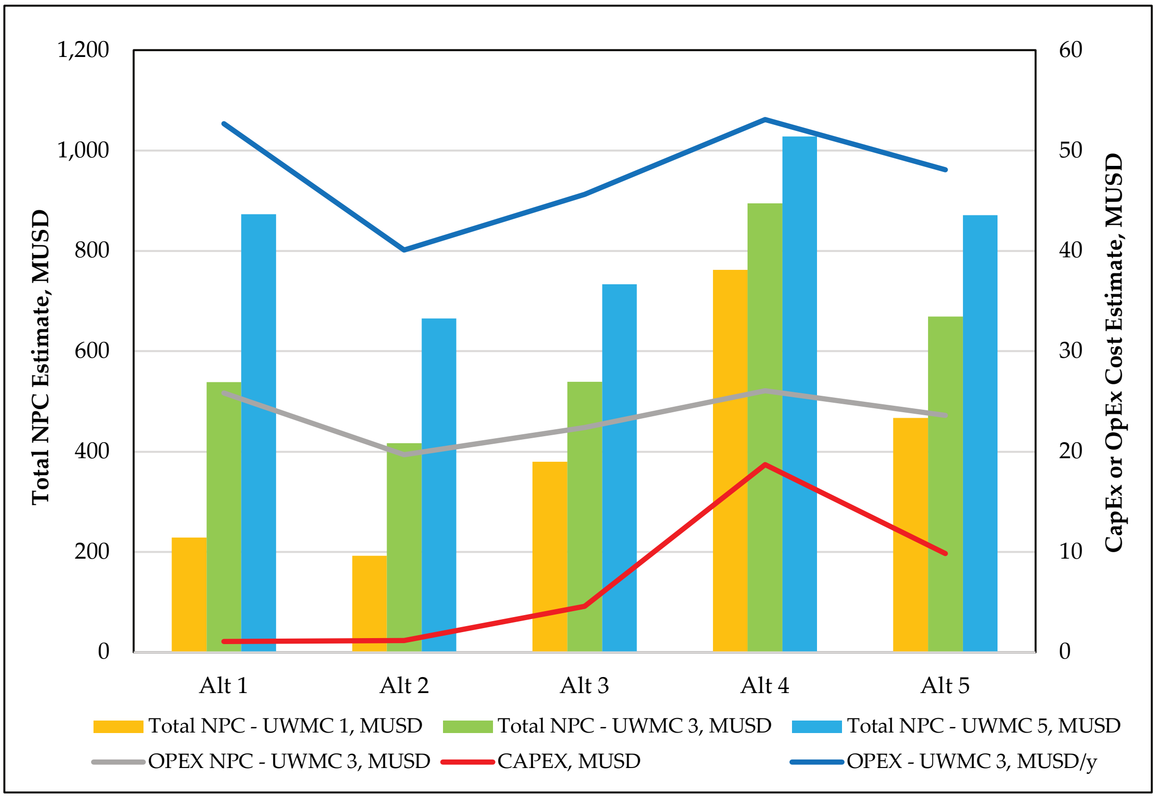

Figure 3 shows the economic evaluation for all the parameters considered (CapEx, MUSD; OpEx MUSD; NPC OpEx, MUSD & Total NPC, MUSD) based on three (3) unitary water make-up cost (UWMC) 1, 3 and 5 USD/m^3.

As explained above, the evaluation is strongly influenced by the unitary water cost, as shown in this figure an increase of this parameter reduces the difference between alternatives from the economic point of view, and other considerations should be taken at the moment of developing the evaluation.

When analyzing the results, it is generally observed that alternative 2, corresponding to high capacity thickening technology, presents a considerably better economic evaluation than the other alternatives, however it does not have associated costs corresponding to the deposit of tailings and the risk that may exist from the point of view of stability. Therefore, this could change depending on the tailings characteristics, the tailings deposit location, costs associated with containment walls, long term risks, etc.

A qualitative analysis is considering for the different thickening technologies and tailings filtration - stacking system.

Tailings Thickening Technology

Conventional thickening is being completely replaced by the high rate thickening. This technology is the preferred in the large copper mining, because in the operation it has higher solids content handling performance and flexibility in comparison with conventional thickening. In addition, the equipment diameter could be smaller or the quantity of thickeners could be less; therefore, economic evaluation is more normally favorable.

Paste thickening technology has been growing in the last years. There are many applications in small and medium mining plant operation around the world. While, for the large copper mining only a few applications are operating after long problematic periods of operational improvement, being difficult to achieve a favorable economic evaluation.

The paste thickener diameter has a restriction with a maximum approximate of 55 – 60 m, because with high solids content the yield stress is normally over 100 Pa and a high torque is required. With this condition, the tailings handling is more complicated and positive displacement discharge pumps are typically required; which increases the investment cost and energy consumption considerably. In addition, the tailings deposit slope should be changed or designed for this condition.

Tailings Filtration and Stacking System

The option of full dewatering by pressure filter and staking system has an improvement in water recovery; therefore, a make-up water consumption is lower. However, it is not enough to obtain a favorable economic evaluation. The advantages found from other points of view, such as, better environmental and social impact could become a relevant aspect to be considered in evaluation.

In addition, recently there have been some tailings deposit catastrophic failures with a large number of fatal losses, causing a negative social and political impact that could raise social pressure to incorporating significant improves on tailings managing.

The dry tailings stacked has a low moisture, but it can also generate stability problems that should be managed before being implemented.

Due to the high processing capacities required in large copper mining, attractive economic evaluations are not yet available for this technology to be implemented. In addition, although tests have been carried out at an industrial level and there are projects that could reach high processing tonnages, a level of system reliability that allows large miners to risk considering this technology has not yet been obtained.

Other Factors to be considered before Technology Definition:

- Availability of plant areas and tailings deposit
- Social impact
- Water availability for make-up
- Rheological tailings characteristics
- Reagent cycle, reduction of impurity purge

CONCLUSION

The results show that traditional thickening technologies have a strong economic advantage compared to those that consider paste thickening and filtration-stacking. However, as the unit cost of water make-up increases, filtration and paste becomes more attractive competing with the traditional technologies. Beyond of pure economic analysis, it is possible that the filtration becomes more attractive considering sustainability.

Although advances have been made from the point of view of increased capacity in pressure filtration equipment and tests have been carried out at an industrial level; the results obtained have not been as expected and there is not enough maturity from the technical point of view to be implemented in the large copper mining.

Suppliers continue to optimize their pressure filtration technologies in order to increase processing capacity and finally be implemented in the large copper mining. However, to filter the total tailings generated in a plant that processes around 100 ktpd, a large number of filters are required and as this is a batch process the sequence of filtration cycles would be complex if implemented and it also requires a conveyor and stacking system, not simple to be operated.

Currently, older plants have preferred to invest in improvements to their existing thickening equipment, changing from conventional thickening to high capacity technology with changes in the driving system, feedwell modification and improvements in flocculant dosage system. In addition, for better tailings deposition, tests are being carried out with rheological modifiers, flocculant mixtures or addition of in-line flocculants before deposition.

In addition, modifications are being made in the slope and the tailings deposit plan, in order to optimize water recovery.

NOMENCLATURE

CapEx	Capital Expenses
OpEx	Operational Expenses
UF	Underflow
OF	Overflow
PSD	Particle Size Distribution
NPC	Net Present Cost
UWMC	Unit Water Make-up Cost

REFERENCES

Rodrigo Gutiérrez. (2019) '*Operational Challenges of the Use of Thickened Tailings*', Gecamin-Tailings, Santiago, Chile.

Discussion Panel Summary. (2016) '*Challenges in implementation of highly Thickened Tailings Technology in Large Production Rates*', ACG – Gecamin-Paste.

Raul Espinace, Gabriel Villavicenncio and Andy Fourie. (2016) '*Thickened Tailings Disposal Technology Experiences in Chile*', Gecamin-Paste, Santiago, Chile.

Christian Kujawa, Jeff Winterton, Rachel Jansen and Robert Cooke. (2019) '*Innovative Process Engineering to Create Better Tailings Facilities*', Gecamin-Tailings, Santiago, Chile.

Mathew Revell and Richard Pearce. (2016) '*A revolution in Paste Plant Design*', Gecamin-Paste, Santiago, Chile.

C. Crystal, C. Hore and I. Izama. (2018) '*Filter-Pressed Dry Stacking: Design Considerations Based on Practical Experience*', Proceedings Tailings and Mine Waste, Keystone, Colorado, USA.

Fred Schoenbrunn, Todd Wisdom, Reuben Neumann and James Chaponnel. (2016) '*Tailings Filtration Demostration Plant*', Gecamin-Paste, Santiago, Chile.