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Peruvian gold-cyanide tailings filtration – a detailed cost comparison

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Abstract

In recent years, conventional strategies for tailings management have been under increasing scrutiny by regulators, community leaders, environmentalists, and the shareholders of producing mine sites around the world. Engineers have been given too few viable alternatives due to costly manufacturing and limited applicability of existing technology. At last, technological advances in dewatering technology (most importantly filtration), in both productive capacity and consistency when applied to finer feed materials, have started to provide a far more attractive profile to companies who wish to pursue dry stack tailings facilities. This paper will address Dynacor Gold Mines' pursuit of a tailings management solution for their newest mill expansion at their METALEX Beneficiation Plant in Peru. With an increasing daily capacity and an absolute limit on their current tailings disposal capacity, it was determined that a new tailings pond, along with four successive 50,000m^3 expansions, would have to be built at an extensive cost. Concurrently, Prevconsult Peru EIRL, with the assistance of CEC Mining Systems, conducted filtration testing and downstream engineering on the applicability of filtered dry stack tailings as a competitive solution for Dynacor. The joint proposal was successful in the application of thermoplastic filtration technology on Dynacor's Au-Cn tailings stream. Filtration was able to provide consistent moisture contents (12%), while restraining the total project scope in order to remain cost competitive. The economic merit of this proposal has been combined with the mitigation of potential operational and downstream environmental liabilities, a simplified mine closure plan and the ability to implement progressive reclamation early on in the mine life. These results are a prime example of how technological innovation has facilitated a positive business case for the implementation of filtered tailings in combination with the measured environmental and operational benefits of a dry stack facility.

1 Changing tailings regimes

To date, a majority of the world's mining operations and concentrators have maintained conventional tailings management infrastructures. As environmental stewardship has progressed throughout the industry, conventional tailings facilities have been exposed to public scrutiny. Increasingly criticised for the amount of water that is "lost to the voids" (Davies, 2011), producers have begun to seek alternative approaches. While the implementation of dewatered tailings facilities still remains on a minority set of projects (Davies, 2002), advances in filtration technology have greatly improved the number of projects where implementation is economically viable.

Traditionally, projects in sub-arctic or arid locations, with topographic restrictions or flow sheets where economic recovery is improved by filtration, have been the best choices for dewatered tailings practices. However, the latest advances in filtration technology as well as lower cost manufacturing and remote analysis and monitoring have provided an economically viable business case to a far greater breadth of mineralization, geographical location and mine type.

Dynacor Gold Mines' current evaluation of their tailings management strategy has provided a situation to adjudicate the technical application of thermoplastic filtration, and to conduct a detailed cost analysis of the process.

2 Dynacor Gold Mines (TSX.V: DNG)

Dynacor Gold Mines (TSX.V: DNG) is a Canadian-owned and listed company and has been operating as a gold ore processor in Peru for the last 15 years. The company is one of only three publicly-owned entities to operate a gold ore processing operation in the country. Since pouring its first gold bar in 1998, it has grown its production from 3,014 ounces in 1998 to 61,274 ounces in 2012, a 1,933% increase.

Dynacor's units are located on the Pacific coastline of Peru. The company consists of five exploration properties, as well as its 240 Tonne per day (tpd) gold and silver ore processing mill, METALEX.

2.1 METALEX Mineral Beneficiation Plant

Dynacor's METALEX Beneficiation Plant (MBP) is located in Saisa District, Lucana Province, Ayacucho Region, Peru. The plant is located in the Andes highlands; at an altitude above 850 m. MBP processes ore with gold and silver content from other legal mining companies throughout the country. MBP is currently producing 240 tpd, but is projected to increase production to 300 tpd in 2014 due in part to the new incentives for gold mines put forward by the Peruvian government.

MBP has a crushing area with a space for storage of the ore, a milling and concentrating plant, which includes cyanidation and precipitation area, and a chemical/metallurgical laboratory. The MBP's processing flow sheet is seen in Figure 1. Cyanide leaching starts on mills where 68% of dissolution is obtained. Overflow of the hydrocyclone (#2), with a density of 1260 grams/litre and a size of 90% -200mm, goes into the cyanidation circuit compounded by five leach reactors. Lime is used as a reagent to adjust the pH to 11. The Carbon in Columns (CIC) absorption and desorption circuits are compounded by nine tanks with activated carbon. Gold and silver absorption is accomplished through activated carbon advancing on the backflow, which is collected in the first tank (#6). Loaded activated carbon goes to desorption. The production of the gold-cyanide (Au-Cn) tailings stream is from the last tank inside the desorption plan which is pumped through a high-density polyethylene (HDPE) pipeline into the current 85,000 m^3 capacity tailings pond. The tailings pond has been waterproofed with a 1.75mm thick geomembrane liner. Barren solution is recovered and re-circulated through a dam back into the plant.

The precipitates resulting from Merrill Crowe and Desorption processes are taken into smelting, obtaining 99% doré. Silver is recovered from the remaining acid solution. The solution is then neutralized and sent to the tailings pond for recirculation.

2.2 Proposed tailings pond solution

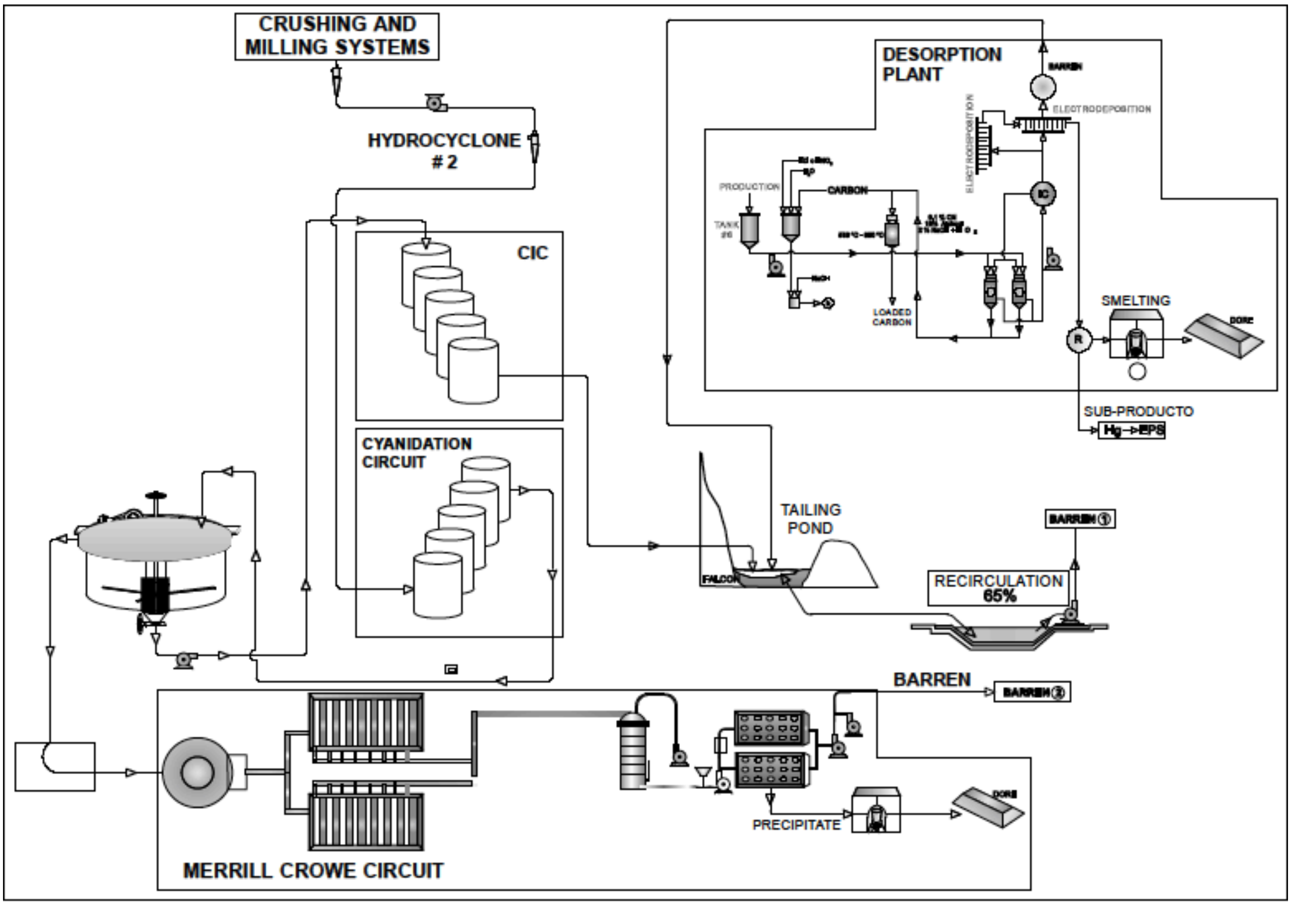
Due to Dynacor's corporate objectives to continue to increase milling capacity at MBP, the operation's tailings pond will be at full capacity – 64,478 m^3 (86,400 tonnes) – by July, 2014. In order to maintain a position for growth, Dynacor needs to find a cost-effective solution that will improve their tailings disposal capacity.

To overcome this growth bottleneck, Dynacor authorised Prevconsult Peru EIRL to evaluate the options available to the company and make a comprehensive recommendation on the method of tailings disposal that should be undertaken.

Initially, a report had been prepared with the project scope and budget for a traditional tailings impoundment, using non-thickened tailings and a retention dam. Early on, expanding the existing tailings pond was deemed cost-prohibitive, leaving the construction of a new pond as the only viable solution.

At a rate of 300 tpd, 109,500 metric tonnes per annum (mtpa), the proposed tailings pond is designed to hold just 14 months of production—a planned volume of 94,030 m^3 (126,000 tonnes)—and have a footprint of 20,000 m^2. The project plan also includes four 50,000 m^3 expansions occurring at intervals of 18 months after commissioning. Since contracts with ore suppliers are short-term, the pond is to be built in intervals, which can be made flexible to the company's business requirements and monthly income of ore.

Figure 1 METALEX Process Diagram



2.2.1 CAPEX

As a precursor to the construction of MBP's proposed tailings management solution, a detailed study was undertaken of the potential CAPEX costs that Dynacor would incur. All CAPEX components include Peruvian value-added tax (IGV) (18%) and general expenses (10%).

Project CAPEX totals US$3,524,192.85 and can be broken into three main categories: design, construction and expansion. The total proposed CAPEX for the project is seen in Table 1.

Table 1 Tailings pond CAPEX budget

Item	Description	Cost (US$)
1	Pond design	65,367.00
2	Pond construction	1,108,855.85
3	Environmental Impact Assessment (EIA)	38,940.00
4	Mine closure plan	45,430.00
5	Pond expansions	2,265,600.00
	CAPEX	**3,524,192.85**

2.2.1.1 Pond design

The design and detailed engineering constitutes approximately 1.86% of the total budget, or US$65,367.

2.2.1.2 Pond construction

As seen in Table 1, the initial pond construction costs constitutes approximately 31.5% of the total CAPEX budget, or US$1,108,855.85.

Table 2 Detailed construction costs

Item	Description	Subtotal (US$)
1	Interim-preliminary works	148,701.24
2	Dam	217,807.73
3	Tailings Basin	353,367.33
4	Drainage system	79,194.43
5	Geomembrane liner	55,209.59
	Direct cost	**854,280.31**
	General expenses 10%	85,428.03
	Subtotal	**939,708.35**
	IGV (tax)	169,147.50
	Total budget	**1,108,855.85**

2.2.1.3 Pond expansions

Dynacor aims at a low risk business model, which leads to a staggered project implementation spanning six years. In this fashion, Dynacor can therefore more accurately target pond expansions on their yearly procurement agreements. Over the next six years, Dynacor would be forced to spend an additional US$2,265,600 on pond construction/expansions. Each year, this equals a final cost of US$566,400. In total, this represents 64.3% of the total project CAPEX.

The pond expansion cost breakdown can be seen in Table 3.

Table 3 Pond expansion plan

Date	Volume	Cost (US$)
+ 18 months	50,000 m^3	436,363.64
+ 36 months	50,000 m^3	436,363.64
+ 54 months	50,000 m^3	436,363.64
+ 72 months	50,000 m^3	436,363.64
	Direct cost	**1,745,454.55**
	General expenses 10%	174,545.45
	Subtotal	**1,920,000.00**
	IGV (tax)	345,600.00
	Total budget	**2,265,600.00**

2.2.2 OPEX

Operating expenditure for the tailings impoundment has been determined as US$5,000/month or US$60,000/year. This value is based on a full-time Supervisor working three 8-hour shifts per day who is responsible for checking if the tailings are being deposited homogenously, and insurances.

3 Dry stack tailings disposal solution

While studying MBP's tailings management strategy, Prevconsult Peru EIRL coordinated with CEC Mining Systems (CECMS) as a partner in evaluating the viability of filtering the Au-Cn tailings stream for dry stack disposal. The testing and resulting configuration, project scope and budget were constructed over the course of the fourth quarter of 2013 using bench-scale proprietary technology.

3.1 Filtration testing

In order to determine the project scope, detailed filtration test-work was undertaken. Historically, dry stack projects have been limited by the vendor filtration technology available to the mine. In many cases, filtration vendors have made the required capital equipment cost-prohibitive. In other cases, there have been blatant inconsistencies in the specification of the output material, forcing companies to accommodate off-specification tails into their disposal plan.

To circumvent these issues, the construction of a reliable filtration profile for the Au-Cn tailings stream, to which downstream engineering could be applied, was determined a priority.

3.1.1 Testing methodology

Preliminary filtration testing was conducted in a laboratory facility in Lima, Peru, and subsequently in larger volumes at the bench-scale laboratory in Vancouver, British Columbia in order to validate the results. While the same procedural criteria is followed for all filtration test-work, the variables and their interaction often vary greatly between products. The testing objectives for the Au-Cn tailings stream for MBP were determined as follows:

- To determine project scope (equipment requirements) for Au-Cn tailings at 300 tpd.
- To demonstrate productivity rates within acceptable dry stacking moisture contents range of 11 – 16% w.t.
- To determine an optimum filtration profile for the Au-Cn tailings slurry.
- To narrow the potential machine settings within an acceptable on-site test range.
- To provide a product specification to be used for downstream dry stack engineering.

The test-work is built around the manipulation and recorded interaction of the variables of the slurry and equipment. These changes affect the two most important target values: machine productivity (measured in tonnes per hour (tph) per machine) and filter-cake moisture contents (measured in % weight). The testing controls generally include: slurry solids content, slurry temperature, filter-plate media, pH level, and filtration timing (cycle time, pick-up time, drying time).

The number and frequency of the manipulations determine the extent of the test plan. The test plan includes all permutations of the targeted variables. However, reporting is generally constrained to a more specific section of the test plan. The ultimate goal is to progress from a wide spectrum of tests toward a continually narrower scope. The result is an optimum filtration profile that will target a specific value for each variable.

Prior to any test-work commencing, Inspectorate Labs (Bureau Veritas Commodities) was contracted to undertake preliminary physical testing to assist in profiling the ore sample. In Table 4, you can see the physical product characteristics and in Table 5, the particle size distribution for the Au-Cn tailings stream.

Table 4 Product characteristics

Au-Cn tailings characteristics			
Product type:	Gold-cyanide tailings	Target flow through rate:	300 tpd / 12.5 tph
Source:	Desorption plant and cyanidation circuit	Target moisture content:	12% w.t
Destination:	Dry stack disposal	Current slurry solids content:	40%
Additive:	None	Slurry temperature:	17°C

Table 5 Particle size distribution

Sieve size		Individual	Cumulative
Tyler mesh	Micrometres	% retained	% passing
100	149	3.9	96.1
150	105	13	83
200	74	17.5	65.5
270	53	19.2	46.3
325	44	9.2	37.1
400	37	7	30.1
500	25	6.4	23.8
Undersize	−25	23.8	
Total		**100**	

3.1.2 Qualitative findings and optimal filtration profile

Overall, 18 production tests were conducted. There was a high degree of consistency found in the measured moisture contents of the filtered tailings. This was a result of the relative thinness of the filter-cake that formed on the filter media. There was a positive response when increasing the solids content of the slurry to 55%, as the tests mean productivity increased by almost 11%.

The tailings stream was initially tested to be filtered directly from the output of the CIC tank. With the results gathered from additional testing, the recommendation of the addition of a high-density thickener tank to improve slurry solids content to 55% before filtration was made in order to improve productivity.

From the conclusions reached during the test phase, the optimum filtration profile that has been determined for the Au-Cn tailings slurry and recommended filtration equipment have been summarized in Table 6. A conservative machine net productivity figure of 7.824 tonnes per hour (tph) will be used to design the machine configuration. At this rate of productivity, the filter media was able to reach a mean value of 12.61% moisture by weight.

Table 6 Optimum filtration profile and highlights

Optimum filtration controls			
Filtration surface:	Thermoplastic	Slurry temp:	17°C
Slurry solids content:	55%	Machine timing	
pH:	10.6	Total cycle time	55 seconds
Additives:	Flomin 905VHM	Drying time	25 seconds
Details	30g/t	Pick-up time	20 seconds
Testing result highlights			
Moisture content [% w.t]		Gross productivity [tph]	
Low	9.90	High	18.96
Mean	12.61	Mean	9.60
Mode	12.50	Mode	10.08

3.1.3 Proposed equipment configuration

As a conclusion from the bench-scale testing, an equipment configuration that will meet MBP's 300 tpd mill capacity has been proposed. The mean productivity found during test-work is used to calculate machine capacity, and select the filtration equipment that can accommodate the daily mill throughput, while accounting for annualised filtration system maintenance and regularly scheduled cleaning cycles (cumulative 18.5% total operating time).

For this particular application, the installation of two CECMS-3 thermoplastic filtration systems, each with a calculated net production of 7.824 tph, has been recommended. This provides MBP's mill with an overall filtration capacity of 15.65 tph. With MBP's current production (300 tpd), the CECMS-3 filtration systems will be utilised at a rate of 80%, which will provide the mill with a buffer capacity of 3.15 tph. The detailed product configuration can be seen in Table 7.

Table 7 Filtration equipment configuration

Gross-net productivity calculation		Project plan recommendation			
Variables	**Quantity**	**Configuration option A**			
Maintenance (22/365 days)	6%	Target volume	12.5 tph	System	
Cleaning (3/24 hours)	12.50%	Capacity	15.65 tph	Size	CECMS-3
Cumulative net productivity reduction	18.5%	Production		Quantity	×2
Gross test productivity	9.6 tph	Gross	9.6 tph	Utilisation	80%
Net productivity	7.82 tph	Net	7.82 tph	Buffer capacity	20% (3.15 tph)

3.1.4 Filtration CAPEX

Resulting from the proposed configuration seen above in Section 3.1.4, a CAPEX proposal for the filtration's contribution to the project was submitted. As can be seen in Table 8, the contribution to the filtered tailings CAPEX budget is US$426,052.92. This price includes: 2 CECMS-3 filtration Systems, 96 filter plates, freight, insurance and the infrastructure required for installation. All CAPEX components include general expenses (10%) and IGV (18%).

3.2 Upstream engineering

In order to effectively filter tailings into a dry stack, some upstream engineering is required. While it is possible to filter the Au-Cn tailings stream directly from the carbon-in-pulp process, the filtration capacity (tph) of the CECMS-3 systems is significantly improved with higher density slurry feed.

3.2.1 Upstream third-party capital equipment

3.2.1.1 Thickener tank

As a result of the bench-scale testing, the introduction of a high-density thickener tank has been recommended in order to boost the slurry solids content to 55%. The CECMS-3 filtration systems will filter the thickener underflow that has formed from the addition of SNF Chemical's Flomin 905VHM Flocculant at a rate of 30g/1T solids.

A local Peruvian manufacturer has been selected to supply the required 40' × 12' high-density thickener tank at a total cost of US$154,202.40. This price includes: installation, 4' × 3' horizontal pump, cylinder tank, support frame, lifting mechanism and regulator for rakes, alarm system, engine break and vertical steel axis.

3.2.1.2 Nitric acid tank

In support of the CECMS-3 filtration systems automated continuous production, the machines undergo a nitric-acid/ultrasound cleaning cycle. The holding tank is exterior to the machine's structure (and cost). A local Peruvian vendor has been selected, contributing US$5,192.00 to CAPEX.

3.3 Downstream engineering

The design of filtered tailings facilities have some different considerations than traditional impoundments, They are generally more environmentally and topographically forgiving due to their relatively denser state (more solids per unit volume), more aggressive land use can be implemented with fewer considerations of foundation requirements.

Due to the state of filtered tailings, the stack needs to be constructed with haulage, placement, and compaction equipment in mind. These efforts generally make a fairly large incremental impact to the unit cost of the dry stack facility. The specifications provided by the completed test-work have been used to build the downstream engineering, which requires additional third-party vendor capital equipment.

3.3.1 Downstream third-party capital equipment

3.3.1.1 Conveyor belt system

Upon the discharging from the two CECMS-3 filtration systems, the filter-cake will fall into a gravity feed chute, which will feed a conveyor belt in order to transport the filtered tailings to the haulage equipment. A local Peruvian vendor has been selected to provide the 30 m conveyor belt, at a total cost of US$61,395.40. This price includes installation as well as steel infrastructure required for support.

3.3.1.2 Haulage and compaction equipment

Placement of filtered tailings by truck necessitates the integration of haulage and compaction equipment in order to maintain structural integrity of the stack. The compaction equipment is already a capital asset of MBP.

3.3.2 Dry stack design specifications

Site preparation costs will include the clearing and compaction required before tailings are deposited, as well as the installation of the underlay geomembrane. The total cost for this site work will be US$53,737.20.

Upon completion of the contract between the parties involved, the filtered tailings dry stack detailed engineering will take place. At this stage, details will be determined regarding zonation strategy, compaction specifications and layers/depth of the filtered tailings. Currently, there are two possible location options, which are 500 m and 250 m away from the tailings pond, respectively. Detailed engineering has been included in the project CAPEX budget at a total cost of US$38,940.00. The EIA has also been included at a total cost of US$38,940.00.

3.4 Total project CAPEX

The total filtered tailings project CAPEX is US$778,459.92. A summary of the capital expenditures that were detailed in Sections 3.1.5-3.3.4 can be seen in Table 8.

Table 8 Filtered tailings CAPEX

Item	Description	Cost (US$)
1	Dry stack engineering	38,940.00
2	EIA	38,940.00
4	Dry stack site prep	53,737.20
5	Filtration systems	426,052.92
6	Thickener tank	154,202.40
7	Nitric-acid tank	5,192.00
8	Conveyor system	61,395.40
	CAPEX	**778,459.92**

3.5 Total project OPEX

The total filtered tailings project OPEX is US$21,085.74/month or US$253,028.84/year. A summary of the operating expenditures is shown in Table 9. In Year 0 (0 – 12 months), maintenance, on-site servicing, and filter plates are not calculated as part of the OPEX. These costs are covered as part of the 12-month manufacturers warranty included in CAPEX of the filtration systems.. Therefore, in Year 0 the OPEX is US$15,947.57/month or US$191,370.80/year.

Maintenance and on-site servicing costs of the CECMS-3 filtration systems have been assumed from prior installation experience to equal approximately 12% of the equipment’s CAPEX. Replacement of CECMS-3 filter plates are calculated at an US$28,800 annualised cost. These two costs combine to determine the total monthly cost of the 2, CECMS-3 filtration systems (excluding energy consumption) shown as Item 1 in Table 9. Electricity costs for capital were calculated at 15.55-kilowatt hours of consumption at a rate of US$0.10 per kilowatt-hour (kWh). Third-party vendor maintenance costs have been assumed from prior installation experience to equal approximately 10% of the equipment’s CAPEX. Haulage and compaction costs were calculated at 224 m^3 of production per day at a rate of US$1.72/$m^3$. Flocculant costs were calculated at a consumption of 270 kg/month (375 g/hour) based on the effective testing dosage of 30 grams/1 Tonne of solid feed material, and a rate of US$3.55 kg. The project will require a full-time administrator and supervisory responsibilities of 3 hours of labour/day, at a cost of have US$10,437.00/year or US$869.75/month.

Table 9 Filtered tailings OPEX

Item	Description	Cost per month (US$)
1	2, CECMS-3 maintenance	5,138.17
2	Electricity, Total	1,135.15
3	3rd party vendor maintenance	1,384.17
4	Haulage and compaction costs	11,600.00
5	Flocculant	958.50
6	Administration/Supervision	869.75
	OPEX	**21,085.74**

4 Slurried versus filtered tailings

Through careful study, required downstream engineering and a proposed project budget for filtering tailings at MBP have been established. In Table 10, the project specification differences between filtered and non-filtered tailings strategies have been broadly defined.

4.1 Project specifications

Table 10 Project specification comparison

Item	Tailings impoundment	Dry stack tailings
Quantity of tailings	300 tonnes per day, 109,500 mtpa	300 tonnes per day, 109,500 mtpa
Footprint	20,000 m^2	5,000 m^2
Tailings underflow solids content	40%	84 – 88%
Capital equipment	Pipeline	Thickener, ceramic filtration system, conveyor, truck and compaction equipment
Dam	Dam and weir to collect and store tailings and supernatant	No dam or weir required. Dry stack material is unsaturated, dense and stable

4.2 Financial analyses

Table 11 consolidates the costs of both potential projects over the course of the first 84 months of their life. It is clear from this analysis that the filtered tailings management strategy is more cost-effective in both the near and long term. Even with the number of capital components required to complete the thickening, filtering and deposition, the dry stack strategy still has a US$480,133.00 competitive advantage in initial capital expenditure. At year zero's completion, the dry stack solutions total cost still remains US$348,762.28 under the traditional pond. While filtered tailings do have a higher year-over-year operating expenditure (422% more) due to the increased cost per tonne of transportation, over a six-year life cycle, the total life cycle cost (LCC) of the dry stack method is still US$1,456,189.83 less than the construction of the tailings pond and its expansions.

Due to the need for the implementation of the tailings pond construction as a result of contractual ore purchase contacts, benefits from potential economies of scale from the pond construction are unable to accrue. This act of construction and expansion would have to continue, especially if production were to be scaled further. With the current capital expenditure put forth in the dry stack strategy, production could be expanded up to 340 tpd without investing in additional equipment. To reach 600 tpd, an additional two CEMS-3 filtration systems would be needed, which is a lower incremental cost than the construction of a pond of sufficient capacity.

Additionally, tailings ponds have no salvage value. As mobile assets, the capital infrastructure that would be constructed in order to deposit filtered tailings at the MBP has the ability to be re-located, potentially to another processing facility or a reclamation site, given a change in company strategy or economic forces. This is a large shift from the traditionally 100% sunk cost structure seen in conventional tailings facilities.

Table 11 Life-cycle costing comparison

Life-cycle costing analysis (US$)								
Tailings pond	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Totals**
CAPEX	1,258,593	566,400	–	566,400	566,400	–	566,400	3,524,194
OPEX	60,000	60,000	60,000	60,000	60,000	60,000	60,000	420,000
TOTAL	1,318,593	626,400	60,000	626,400	626,400	60,000	626,400	3,944,194
Dry stack	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Totals**
CAPEX	778,460	–	–	–	–	–	–	778,460
OPEX	191,371	253,029	253,029	253,029	253,029	253,029	253,029	1,709,544
TOTAL	969,831	253,029	253,029	253,029	253,029	253,029	252,029	2,488,004

4.3 Environmental risk mitigation, reclamation and closure

A purely financial analysis of the tailings management options is necessary, but not sufficient, as an explanation for a final recommendation. While initial capital expenditure and on-going operating expenditures are an important up-front budgeting consideration, each strategy has its own, drastically different, downstream implications associated with environmental risk, and costs for reclamation and simplicity of mine closure.

In both of the following categories, filtered tailings disposal greatly diminishes the exposure and potential liabilities at the mine site.

4.3.1 Environmental risk mitigation

Overall, dry stack tailings represent less environmental liability for their proponents (Keesey, 2007). Their denser state removes the necessity of building the extensive water management infrastructure that is required for traditional tailings ponds. The reduction in water content of the tailings allows for a dramatic decrease in net water losses seen during processing. By recycling this water, companies are only losing the water content (10 − 15%) that the filtered tailings are deposited at. Additionally, moisture penetration of the dry stack tailings is minimal due to their dense, compacted, unsaturated, and hydrophobic nature (Keesey, 2007). In fact, tailings that are compacted to their optimum moisture have an "equivalent hydraulic conductivity in a similar range to a typical liner element with average installation and other defects" (Davies, 2011). This means that there is limited drain-down of leachate because of low seepage rates through the stack.

Typical environmental considerations for a tailings facility are mitigated by the implementation of a filtered tailings stack as well as effective closure with cover. These include:

- Potential for acid rock drainage (ARD) generation during operation.
- Potential for ARD generation after closure.
- Potential metal leaching (ML) during and after closure.
- Potential for seepage to impact groundwater during and after closure.
- Potential for geotechnical hazards.
- Permanent aquatic habitat loss.
- Footprint area, visual impact, and terrestrial wildlife habitat loss (Golder, 2007).

Over the long term, dry stacking tailings offers the best solution for mine tailings disposal of potentially acid-generating and other hazardous tailings (Journeaux, 2012).

4.3.1.1 Seismic events and static liquefaction

Filtered tailings that are placed in dry stacks at normal specifications and using proper procedures, are done so in an unsaturated state and are not susceptible to liquefaction. This makes filtered tailings in dry stacks essentially immune to catastrophic failure (Berkers, 2007). Additionally, as the dry stack grows in size, the tailings within the stack become even more solid due to added pressure (Berkers, 2007). The same corresponding increase in strength and reliability with size is not readily apparent with conventional tailings deposits.

These facts are crucial in areas of high seismic activity, like Peru. At the interface of the Nazca and South American tectonic plates, the Peruvian coast commonly experiences earthquakes. The same force behind the creation of the Andes mountain range and the Peru-Chile Trench has plagued the country with eight earthquakes greater than 6.0 on the Richter scale in the past 20 years.

4.3.2 Progressive reclamation and mine closure planning

Filtered tailings deposits have little post-placement deformation versus conventional tailings (Davies, 2011). This is due to the minimal particle segregation of the tailings, which allows for increases in deposited density and reduced volume (Journeaux, 2012). Unlike conventional tailings ponds, which undergo considerable consolidation settlement over time, dry stack facilities can be constructed "very close to their approximate closure configuration" (AMEC, 2008).

All these factors lead to a high degree of structural integrity, if surface water run-off is managed effectively. Although re-saturation of properly placed and compacted filtered tailings is extremely difficult, a closure cover material is still required to prevent air-borne dust and to produce an appropriate growth media for project reclamation (Davies, 2011).

Even more progressive reclamation measures can be taken into consideration during the development of the dry stack. Armouring the exposed tailings slope at progressive elevations with waste rock (Berkers, 2007), and re-vegetation as part of the annual operating cycle (Davies 2011) is a successful method to pre-empt risks of erosion on tailings slopes. By encouraging reclamation early on in the project life cycle, filtered tailings stacks provide significantly simplified mine closure and allow for a more physically and chemically stable project in the long term (Keesey, 2007).

4.4 Intangible future benefits

There are many quantifiable downstream benefits from the implementation of a filtered tailings dry stack. However, there are also some that remain intangible, yet will be even more valuable to organisations in the long-term.

4.4.1 Regulatory approval

More recent implementations of filtered dry stack tailings facilities have been done with the prospect of achieving a more appealing regulatory position. In Brazil, for example, a number of iron ore projects that have implemented filtered dry stacked tailings have reduced their environmental assessment period by up to two years. Currently, Peru does not have defined legislation surrounding filtered tailings. However, as equipment vendors and environmental consultants continue to work diligently with the Peruvian government, there are hopes that a set of reliable institutional practices will be codified in the near future.

4.4.2 Investor sentiment and shareholder value

Equally important, the implementation of filtered tailings can have a positive impact on the proponent's share price. By impacting the company's balance sheet in a positive manner through the continued integration of long-term environmental benefits, the use of progressive reclamation and limitation of mine closure costs, filtered tailings have the ability to positively affect investor sentiment. When coupled with a strong corporate vision, leading management and well-positioned assets, filtered tailings can be a turnkey technical solution to limit potential financial liabilities and improve an organisation's public profile within the international capital markets community. To this end, filtered tailings have strong economic merit when compared with alternative—and potentially costlier—forms of tailings management.

5 Conclusions

In this paper, a detailed cost comparison of two tailings management strategies has been presented: a higher environmental-risk tailings pond with multiple capacity expansions and no salvage value; and an easily scalable, mobile, and overall more affordable filtered dry stack tailings facility. In both initial capital expenditure and the six-year LCC of this project, filtered tailings have a distinct economic advantage. In this case, the company's business model of contract driven ore processing has forced the short-term implementation/construction of a smaller tailings pond to limit their fixed costs over the project's life cycle. This pressure has limited the accrual of potentially cost saving economies of scale from the tailings pond's construction. The success in applicability of this filtered tailings solution has been driven from innovation in filter plate design. In this case, the newer thermoplastic filter media has allowed for consistent moisture contents, even when applied to a relatively fine particle size distribution feed material. Given the test work that was completed, an economical project plan was completed that provides more than sufficient daily capacity for the intended growth in MBP's processing throughput. These operational and financial benefits of filtered tailings have finally been married to the long known and research-supported environmental benefits of a dry stack facility. The technical community is in consensus that filtered tailings have a fraction of the liability regarding environmental contamination, reclamation and mine closure. All these factors have combined to produce an extremely positive business-case for the implementation of a filtered tailings dry stack facility at Dynacor Gold Mine's METALEX Beneficiation Plant in 2014.

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