

REDUCING WATER MANAGEMENT RISKS THROUGH PROCESSING CHANGES

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ABSTRACT

Traditionally, mineral processing plants are designed to achieve the highest recovery of valuable material with limited regard for the cost of managing waste products—both solid and water components. As an industry, we are confronting ever more stringent environmental standards and lower grade deposits requiring more intensive processing. The most profitable processing route can, in fact, lead to costly issues downstream. Issues or risks associated with waste management include water treatment and handling and storage of potentially acid generating material. The capital and operating costs of dealing with these issues are significant and should be considered as a consequence of plant design and optimisation. The authors of this paper are involved with a number of projects where process operation changes offer opportunities to mitigate risks associated with water and waste management. Examples of these changes will be discussed along with the estimated benefits to the value of the project and reduction of long-term environmental risks. Process changes include 1) the application of in-plant water treatment as opposed to dealing with the entire tailings management facility and 2) the potential to reduce metal leaching and acid rock drainage through the preferential liberation of carbonate minerals in the grinding process.

KEYWORDS

Water treatment, acid generation, mine closure, operating costs, mineral processing, recovery, waste, tailings, leaching

ACRONYMS

ABA – acid base accounting; **ARD** – acid rock drainage; **CAPEX** – capital expenditure; **HDS** – High density sludge; **OPEX** – operating expenditure; **PAG** – potentially acid generating; **QEMSCAN** – quantitative evaluation of minerals by scanning electron microscopy; **TMF** – Tailings management facility; **WTP** – water treatment plant.

INTRODUCTION

The interaction of a mineral processing plant discharge and the tailings handling or management facilities provides an interface for exploiting hidden inefficiencies, like that of the mine and mill. The mine-to-mill interface is well recognized to offer significantly higher overall benefit to an operation when improved mill feed quality (grade, fragmentation size and consistency) is delivered by the mine, even at an added cost. In other words, consideration should be made to downstream “processing” costs of waste streams when conducting metallurgical testwork and selecting the “optimal” process flowsheet.

The design and selection of metallurgical and waste management engineering solutions is another example of the mineral industry working in silos and not considering synergistic opportunities. This is particularly true considering the significant mine closure costs that can remain in perpetuity.

SRK Consulting (Canada) Inc. is assisting clients by having geochemists, water management engineers and metallurgists work together to investigate the potential for improved project economics and reduced environmental risk through combined and cooperative efforts into optimized plant tailings conditions.

OPPORTUNITIES

Recent investigations by SRK have revealed a number of opportunities to significantly reduce overall project capital expenditure (CAPEX) and operating expenditure (OPEX) costs over the life of mine by incorporating the needs of downstream waste management into process flowsheet development. A couple of examples include the application of in-plant water treatment and the preferential liberation (or exposure) of carbonate minerals to reduce or eliminate acid rock drainage (ARD) treatment costs.

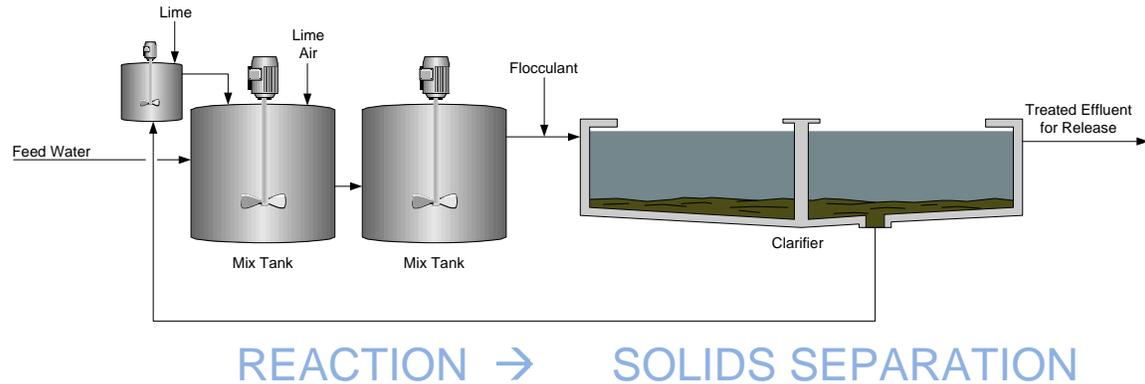
In-Plant Water Treatment

Concentration of metals and other constituents (e.g., sulfate, ammonia and nitrate in mine water) are often greater than permissible effluent concentrations. Therefore, mine operations are required to implement some form of water treatment before water can be released to the receiving environment.

The most common water treatment method implemented at mines is lime addition for the removal of dissolved metals. When lime is added to water to increase the pH value, many dissolved metals (e.g. iron, copper, lead, zinc, cadmium, and nickel) precipitate as solid metal hydroxides. Lime addition is followed by one or more solids separation steps such as clarification and filtration to remove the metal hydroxide precipitates. The by-product of the lime water treatment process is a metal hydroxide sludge that must be disposed (INAP 2010; Aube 2003).

The concept of in-plant water treatment was developed in recognition of the functional similarities between high density sludge (HDS) lime treatment and the mineral flotation process. Figure 1 illustrates the similarities. In mineral processing, ground ore is slurried with process water and sent to flotation cells where the metal-rich minerals are recovered. Lime can be added to the slurry as a depressant or to improve selectivity between the valuable and gangue sulphide minerals. Following flotation, the tailing stream is commonly thickened before being discharged to the tailing management facility (TMF) and the reclaim water (i.e. supernatant) is returned to the process plant.

High Density Sludge (HDS) Water Treatment Process



Mineral Flotation Process

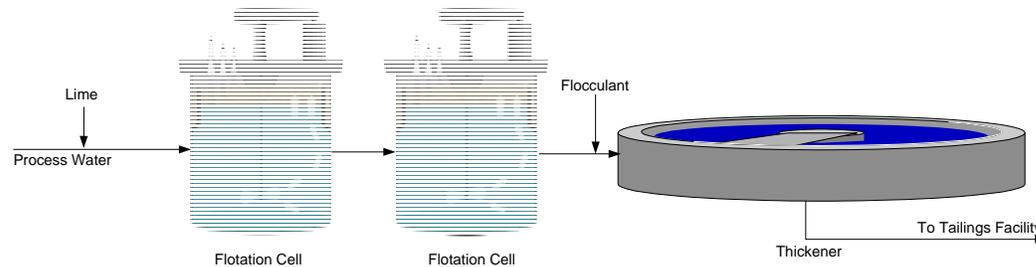


Figure 1 – Similarities between a high density sludge process and a mineral flotation process

Vigorous agitation and air sparging of the slurry at an elevated pH is similar for flotation and HDS processing. In an HDS process, feed water is mixed with lime in a reactor tank. Often the reactor is sparged with air to oxidize ferrous iron and other reduced substances that may be present in the feed solution. In addition, a portion of the metal hydroxide solids recovered in the subsequent solids separation step is returned to the reactor tank. These solids serve as nucleation sites for the metal precipitation reaction, which prevent scaling of the reactor tank. The continuous recycling of solids back to the reactor tank results in the formation of ever larger metal hydroxide particles (“snowball effect”). Larger particles settle faster in a clarifier and are able to form relatively dense sludge—hence the term, high density sludge. Simply put, the presence of solids in the reactor tank facilitates solids separation that follows the reaction process. From a water treatment perspective, the mineral solids present in a flotation cell serve the same purpose as metal hydroxide solids in an HDS reactor tank.

Following agitation and air sparging, the primary solids separation step in both processes is gravity settling, which occurs in a clarifier for water treatment and in a tailings thickener in mineral processing. In these processes, flocculants are typically added to facilitate settling.

One important difference between the two processes is that the solids concentration that leaves an HDS reactor tank is 1 to 2% solids, while mineral slurries are between 20 and 30% solids. The greater solids concentration in a flotation cell further enhances the subsequent solids separation step. Functionally, settling of the mineral slurry is similar to a ballasted clarification process. In ballasted clarification, the process solution is mixed with micro-sand, magnetite or some other dense, inert media to enhance the rate of settling and removal of fine solids. This allows ballasted clarifiers to operate at much higher rise rates, often 20 to 40 times higher, which reduces the required size of the clarifier unit proportionally.

Example 1: Kitsault Mine Water Treatment

The Kitsault Molybdenum project is owned by Avanti Mining Inc. and is located 140 km

northeast of Prince Rupert, British Columbia. The project has obtained an environmental assessment certificate and is currently in the permitting process. In-plant treatment was recently developed as a design concept for the Kitsault project.

The environmental assessment process concluded that effluent from the Kitsault mine must meet very high water quality standards, in particular for concentrations of dissolved metals such as cadmium. This prompted Avanti to examine options for removing and controlling concentrations of dissolved metals in effluent from the proposed tailings management facility.

A bench-scale water treatment study was commissioned to establish whether the water treatment functionality of the milling process would be effective for removing dissolved metals. Specifically, the goal was to remove cadmium at a concentration less than 0.05 µg/L. The bench-scale study evaluated the following:

- Removal of dissolved metals from *tailings slurry* by raising the slurry pH.
- Removal of dissolved metals from *tailings supernatant* by raising the slurry pH with lime (conventional treatment).

Tailings slurry and supernatant were obtained from metallurgical pilot plant tests completed for the project. The bench-scale tests consisted of four steps:

Step 1: spiking a tailings slurry or supernatant sample with dissolved cadmium to approximately 2.5 µg/L

Step 2: lime addition and settling

Step 3: filtration of sample water through a 0.45µm filter, which is the cut-off size for dissolved metals

Step 4: filtration of sample water through a 0.1µm filter, which would capture some colloidal-sized solids

Figure 2 shows a summary of the bench-scale test cadmium levels, with 50% of the distributed results within the boxed areas and the error bars showing the maximum/minimum values.

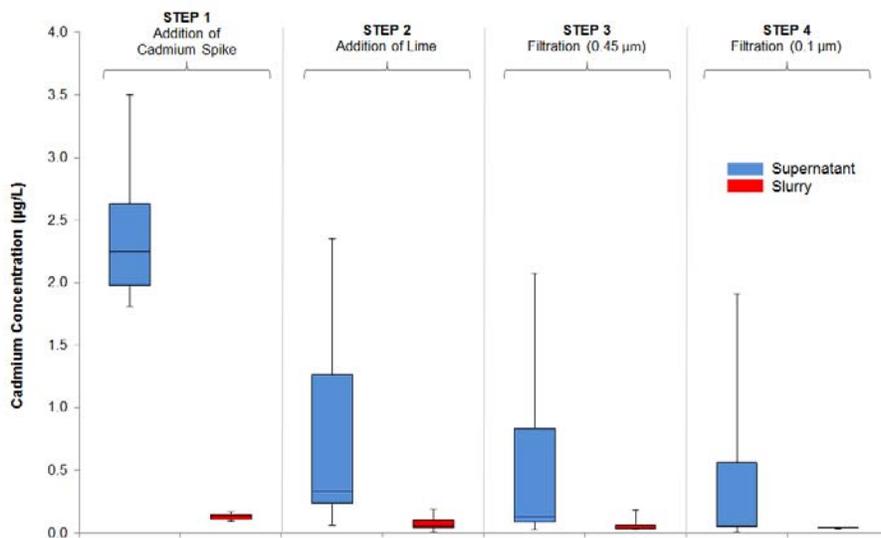


Figure 2 – Bench-scale test results for cadmium removal from tailing slurry and tailings supernatant

The most notable result was the majority of dissolved cadmium added to the tailings slurry samples was removed in step 1 *prior to* lime addition. After lime addition and filtration (steps 2, 3, and 4), cadmium removal from the slurry solution was more effective than from tailings supernatant samples treated in a similar fashion. The cadmium concentrations in most of the tailings samples were below the

target of 0.05 µg/L in steps 3 and 4. Although additional work is required to develop a more complete understanding of the metals removal processes in tailings slurry, the bench-scale results corroborate the fact that in-plant water treatment using slurry can be an effective process for metal removal.

There are a number of options that may be considered for implementing in-plant water treatment. Figure 3 shows a schematic of a typical mine water management scenario:

- Water collected from developed mine areas is pumped to a TMF.
- Reclaim water (i.e. supernatant) for mill operations is sourced from the TMF.
- Excess water from the TMF is treated using a dedicated water treatment plant (WTP if required) and released to the environment.

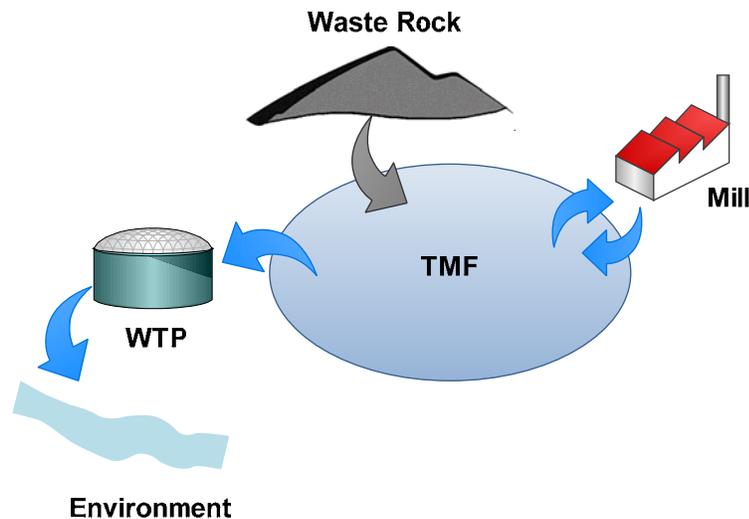


Figure 3 – Typical mine water management scenario

Figure 4 shows a schematic of a modified water management scenario that was proposed for the in-plant water treatment for Kitsault:

- Contact mine water is conveyed directly to the mill and blended with reclaim water from the TMF.
- Dissolved metals in the mine water are removed in the high pH flotation process. Precipitated metals are entrained with the tailings solids.
- All water entering the TMF (except for tailings beach runoff) is treated by the mill before it enters the TMF. Therefore, metal concentrations should remain relatively low, and it should be possible to release water from the TMF directly to the environment without the need for a dedicated WTP outside the mill.

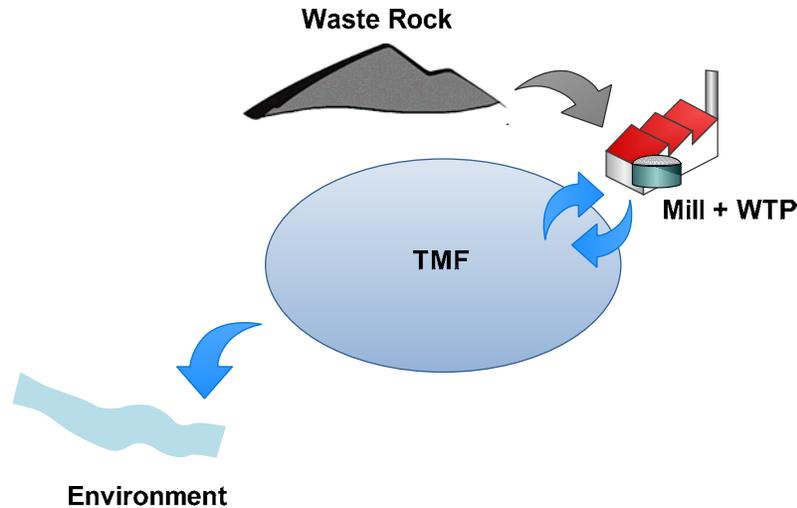


Figure 4 – Alternative water management scenario

Potential advantages of the proposed in-plant water treatment configuration include:

- Potential for the TMF to be operated as a clean water pond
- Lower risk of groundwater contamination from TMF seepage
- Reduced operating costs by eliminating a redundant, stand-alone treatment facility
- No sludge handling and disposal issues
- Reduced reagent/lime demand
- Improved ability to pace discharge according to flow in the receiving environment
- Reagent recirculation and higher winter temperatures (site specific) may enhance metal recovery and selectivity.

Potential drawbacks associated with the water management configuration illustrated in Figure 4 include:

- Potential to affect reclaim water quality
- Possibility for deterioration of water quality in TMF, with apparent lack of ability to control TMF effluent quality
- Apparent lack of control over water quality performance

The potential for adversely affecting reclaim water quality, and by extension metal recovery, is a consideration of paramount importance as it affects the profitability or even viability of the entire operation (Liu 2013). In many cases, the proportion of mine water that would be mixed with reclaim water would be small. However, in other cases or at certain times of the year such as spring freshet, the proportion of mine water to reclaim water could be more substantial. In either case, it is important that decisions to reject blending of reclaim water with mine water is made on the basis of testwork and recovery data rather than suppositions that recovery will suffer.

If the mine water quality is exceptionally poor (i.e. ARD) and recovery loss as a result of water quality changes can be demonstrated then alternative configurations could be considered. Figure 5 shows a simple flow schematic of how in-plant ARD treatment could be implemented after the flotation process. In this process, ARD is mixed with lime and a portion of the tailings slurry. The neutralized solution is then returned to the tailings stream. A single mix tank can replace a stand-alone HDS treatment plant and this scheme offers most of the same potential advantages as feeding mine water to the front of the milling process.

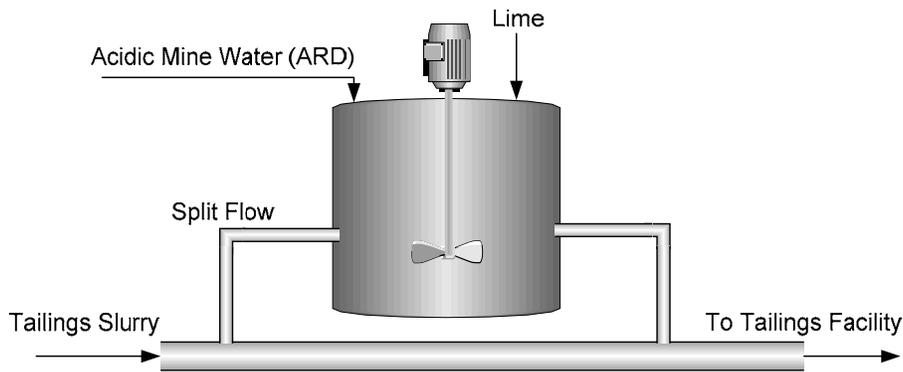


Figure 5 – Schematic of potential implementation of in-plant ARD treatment

The apparent ability to control water quality in the TMF using in-plant treatment is largely a question of proper design of engineering controls. The mechanisms for monitoring and controlling the quality of effluent from a mill water treatment process are ultimately the same as in a conventional water treatment plant. However, as with any engineering design, bench, pilot, and field-scale trials are required to optimize these processes. In fact, any metallurgical testwork completed for a particular project offers unique and very cost effective opportunities for evaluating the potential of in-plant treatment.

Example 2: Sisson Reclaim Water Treatment

Most mine operations now re-use water from the TMF for mill operations. One of the challenges using TMF water for some sites is the clarity or total suspended solids. Several clarification technologies are available, one of which is lime treatment, particularly where suspended silica is an issue. In addition to the use of clarification agents to lower the total suspended solids in the reclaim water, often the ionic strength is lowered along with trace metals that are subject to environmental regulatory limits. As discussed in Example 1, the steps taken to clarify reclaim water are often similar to water treatment processes and therefore opportunities to optimize mill clarification—or at a minimum understand its impact on water quality—may have significant advantages for overall water quality leaving the mine site.

The Sisson project, located in central New Brunswick, is currently in the environmental impact assessment review process. The mill requires large volumes of water to be reclaimed from the TMF, and lime treatment followed by CO₂ addition is required to lower total suspended solids in the reclaim water. The mining plan also includes surface water treatment to lower the concentrations of certain contaminants prior to entering the receiving environment. Based on the water balance on site, treatment will be required starting in Year 8 for the remainder of the mine life and in perpetuity at closure. The possibility to eliminate dedicated surface water treatment and lower overall project risk is currently being investigated as it was found that the clarifying steps for mill reclaim water are also removing contaminants from the water. If the residue from the clarification steps can be shown to sequester metals in a stable form over the long-term, then based on current testwork, water quality in the TMF may be suitable for direct discharge to the receiving environment.

Example 3: Preferential Carbonate Exposure

The potential for mine waste to produce ARD is determined from calculated acid-based accounting (ABA) results (MEND 2009; INAP 2010); that is, the ratio of acid-producing sulphides to acid-consuming carbonates. While a number of factors need to be considered when determining the ARD potential of a mine waste, typically twice as much carbonate than sulphide (on a molar basis) is required for the waste to be classified as non-potentially acid generating (non-PAG). ABA is typically determined on pulverized samples, but if liberation of carbonates at certain grind sizes is favoured over sulphides, then

the ABA of a sample might be shifted enough to re-classify tailings from potentially ARD generating (PAG) to non-PAG. It is an important distinction that carbonate minerals need to be exposed and not necessarily liberated to have an impact on the ABA.

The ability to quantify these relationships is now becoming more feasible in environmental studies using tools such as Quantitative Evaluation of Minerals by Scanning Electron Microscopy or QEMSCAN (Reid et al, 1984; Gottlieb et al, 2000). QEMSCAN results can measure the area, association, and degree of surface exposure of carbonate minerals at the same time as being used to evaluate the liberation of valuable sulphide minerals. This is yet another opportunity where analysis of the same samples using the same methods can provide valuable information to both the metallurgist and geochemist.

SRK has identified a number of mine operations that produce non-PAG TMF material despite project feasibility studies showing the tailings to be PAG. While work is ongoing, the hypothesis is that processing plants are operating at a coarser grind size than the feasibility study laboratory testwork conditions. This is because they are operating at a higher tonnage than design without making adjustments and improvements to the grinding circuit. This coarser grind is sufficient to almost fully expose the carbonates, but at least partially inhibit the sulphide mineral exposure (and of course, liberation).

An example of QEMSCAN measured sulphide and carbonate exposure from a number of relatively coarse (approximately 50% coarser than 150 μm) tailings sites are shown in Figure 6 (site names withheld). Tailings sites A, B, and E have up to three times more carbonate exposure than sulphide. These differences are significant, especially for samples that may only have similar sulphide and carbonate content and would otherwise be classified as PAG, based on pulverized testwork. In other words, due to the current plant operating conditions, tailings may be non-PAG when the studies considered it to be likely PAG material.

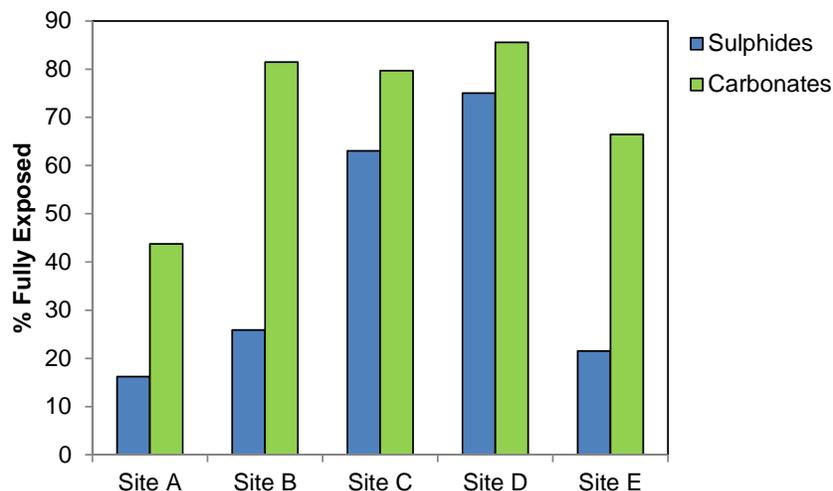


Figure 6 – Comparison of sulphide and carbonate mineral exposure for tailings site samples

ECONOMICS OF IN-PLANT WATER TREATMENT

In-Plant Water Treatment

Table 1 shows examples of order-of-magnitude cost savings that could be realized by implementing in-plant water treatment similar to that discussed for the Kitsault project. These examples are not specific to the Kitsault example but are within a similar order of magnitude. Assuming that Example 1 applies to a 30,000 tonnes/day mill, then the estimated cost saving, aside from other potential benefits, is

on the order of \$0.20/tonne.

Table 1 – Examples of project savings by implementing in-plant water treatment

		Example 1	Example 2
Mine Life	years	15	25
Design Treatment Capacity	m ³ /hr	200	900
CAPEX Savings	\$ Millions	15	25
OPEX Savings	\$ Million/year	1	1.75
Undiscounted Project Savings	\$ Millions	30	69

For the Sisson project, the estimated capital costs for surface water treatment are estimated at USD\$20M and operating expenses at USD\$1.5M (Samuel Engineering, 2013). These costs are likely conservative as other measures, such as groundwater pump back wells, may also be required to ensure TMF seepage does not impact groundwater in the area. Final testwork is near completion and if assumptions are confirmed, then it is reasonable to suggest that water treatment costs could be removed, resulting in significant savings for the project, but also much lower risk to the environment.

Potential cost savings associated with in-plant water treatment are highly site specific and must be evaluated considering other factors such as the potential for improved water treatment performance, sludge disposal, seepage management, etc.

Preferential Carbonate Mineral Exposure

Shifting the ABA of tailings to result in material being classified as non-PAG would result in cost savings during operation and at closure. In addition, significant savings may also be realized by lower financial bonding requirements for a project due to less environmental risk and potential elimination of a water treatment plant.

As an example, Figure 7 provides a summary of reasonable costs to treat water from PAG tailings during the first 20 years of operations and then the first 10 years of closure. In the example, water treatment is needed in Year 6 at \$20M in CAPEX. Operation ceases production in Year 20 and then placement of a tailings beach cover capable of inhibiting sulphide oxidation is required at \$45M in CAPEX with water treatment thereafter. For most sites, the operating expenses incurred after Year 30 would need to be funded in perpetuity. The net present value in this scenario is \$65M, using a discount rate of 3% and a tailings beach area of 2.2 Mm² for a total cost of \$111M for the life of mine.

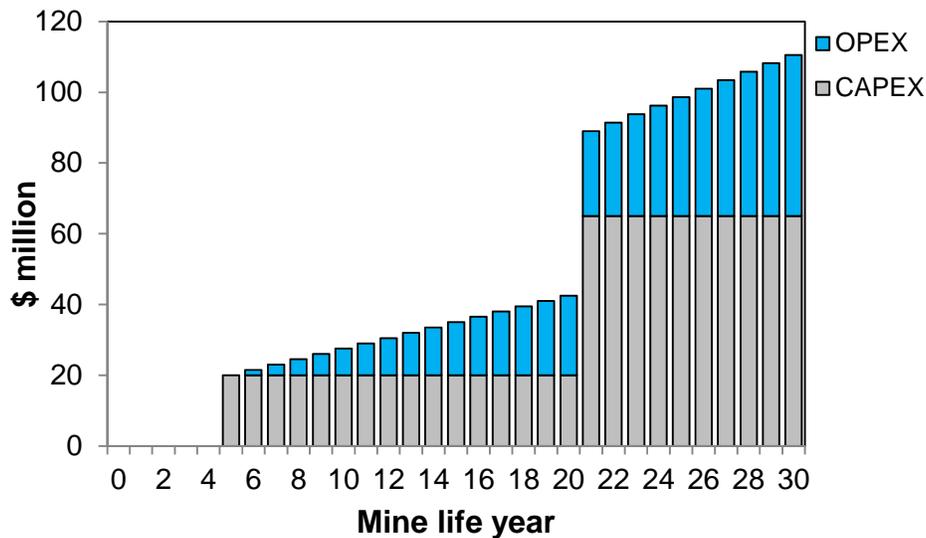


Figure 7 – Potential cash flow requirements for PAG tailings

By modifying the plant grind size, it is possible to reduce or even eliminate the generation of PAG material and therefore avoid these treatment costs entirely. In most flotation plants, regrinding of the rougher flotation concentrate is required so the primary grind size has the greatest impact on the bulk of the rougher tailings reporting to the TMF. A coarsening of the primary grind may provide sufficient exposure of the carbonates to shift the ABA balance to non-PAG material. Such options should be considered as part of the metallurgical testwork program in evaluating the “optimal” grind size for overall project economics.

Changing grind size may have other effects, the most obvious being lower metal recovery and therefore lower anticipated revenue. However, many metallurgical plants that are processing low grade ore at high tonnage tend to grind coarser than design specifications and are already sending coarser feed to their separation circuits but are unaware of potential downstream benefits for ARD management and cost reductions. In addition to lowering water management requirements for a project, the decrease in potential long-term risk would likely also lead to better acceptance from regulators and stakeholders involved in project permitting.

FUTURE CONSIDERATIONS

Most projects typically have metallurgical and environmental consultants working in isolated silos, with little interaction or collaboration. Tailings characterization for metal leaching and ARD potential and tailings supernatant water treatment usually happens after flowsheets are optimized and the process is locked in by the metallurgical team.

However, if studies to better understand water management risks are incorporated with metallurgical studies, the potential benefits outlined in the sections above may be identified early and be able to increase project economics and lower project risk. In the case of Sisson, it is fortunate that a potential benefit from water clarification was identified, but if it had been investigated earlier, it is possible that less water management contingencies would have been required along with the subsequent savings to the project. In the case of Kitsault, the potential synergies between mill operation and water treatment were identified early on and it was possible to coincide water treatment testwork with metallurgical testing at relatively low additional cost.

Potential areas of collaboration between metallurgical and environmental teams include:

- Flowsheet development—identify potential metal recovery processes that could lead to a water quality benefit
- Comminution studies—geochemical and mineralogical characterization of tailings of different grind sizes to understand sulphide and carbonate exposure;
- Tailings and waste assessments—optimization of in-plant water treatment by examining tailings or waste streams internal to the milling process.

SRK is currently working with a number of clients to avoid high closure costs, deal with environmental issues (e.g. PAG handling and design process plant flowsheets) that consider the “bigger picture”. The process plant and waste handling interface provides yet another example of where collaboration and cooperation can lead to significant project savings.

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