Commercial Case Studies of Life Cycle Cost Reduction of ARD Treatment with Sulfide Precipitation

David Kratochvil[1], Songlin Ye[1], and Oscar Lopez[2]

1. *BioteQ Environmental Technologies, Canada*
2. *BioteQ Water Chile SpA, Chile*

ABSTRACT

Sulphide-based precipitation of divalent metals has been shown to greatly reduce life cycle costs and waste generation for the treatment of acid rock drainage (ARD) at mine sites. BioteQ's ChemSulphide® process has been applied in multiple countries and continents and has proven to be a more cost effective solution than HDS or LDS lime plants on their own. Two case studies are presented in which the ChemSulphide® process has been applied to reduce the life cycle cost of water treatment at sites facing active ARD treatment in perpetuity. The case study examines the lessons learned and causes of plant downtime at the Wellington Oro water treatment plant. The plant, which has been operating for over five years, has continually been able to meet strict discharge requirements for cadmium and zinc while entirely eliminating the production of waste sludge, however mechanical and secondary process issues had reduced plant availability. Lessons learned and mitigation methods that are currently being implemented are presented and discussed. The second case study looks at the ChemSulphide® plant installed upstream of a HDS lime neutralization plant treating ARD at the Yinshan Mine in China. The plant selectively recovers copper as a commercial grade concentrate with the net revenues largely offsetting treatment costs to achieve both economic and environmental benefits. The net present value of the savings generated by the ChemSulphide® plants at Wellington Oro and Yinshan are also analysed and discussed.

Keywords: acid rock drainage, metal recovery, life cycle costs, sulphide precipitation, environmental compliance

INTRODUCTION

Preventing acid rock drainage (ARD) has become a key component of mine development planning and operations. Unfortunately, there are many legacy sites and/or active mines where despite the adoption of best management practices, the generation of ARD cannot be avoided, leading to the need for active treatment in perpetuity. The life cycle cost of active treatment over several decades can be very high and the amount of solid waste generated in the treatment process and the composition of this waste may not only significantly contribute towards the overall life cycle costs (LCC) but also impart long-term liabilities.

This paper presents two commercial case studies of active ARD treatment using BioteQ's ChemSulphide® process at sites with prolonged time horizons of water treatment. One is at an abandoned mine where the ChemSulphide® plant has been in operation since 2009 and where BioteQ recently performed a plant review as part of the customer follow-up process. The other is at an operating mine currently undergoing expansion and where a new ARD treatment system that combines HDS lime neutralization with ChemSulphide® was commissioned in 2014. The long-term benefits of the ChemSulphide® process including the reduction in LCC, process robustness to meet stringent discharge limits, and the reduction or elimination of waste sludge are discussed.

Traditionally, ARD has been treated with lime neutralization in a typical flow sheet shown below in Figure 1. In this process, lime is added to the metal laden water to neutralize the dissolved metals.

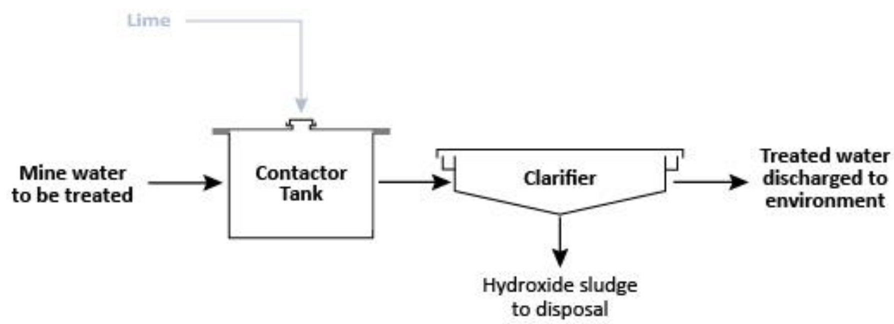

Figure 1 Traditional ARD Treatment Flow Diagram

As shown above, all metals in the ARD are precipitated in a voluminous hydroxide sludge that will bring significant disposal costs and associated liabilities. Adding to the complexity of sludge management is that storage and disposal is controlled by site-specific licenses or permits in some jurisdictions.

Sulphide precipitation technology, depending on the ARD composition, can recover all the metals as salable metal sulphide products and completely eliminate the sludge generation and disposal, or partially recover the valuable metals to reduce the overall sludge management cost.

CASE STUDY: WELLINGTON ORO MINE

The Wellington Oro (WO) treatment plant is located approximately five kilometres east of the Town of Breckenridge, Colorado. A former United States Environmental Protection Agency (EPA) superfund site, the WO mine was seeping ARD with zinc and cadmium from its historic underground workings to waterways and a downstream fishery (US EPA, 2014). An international call for proposals resulted in ChemSulphide® being selected as the best available technology to meet site-specific effluent discharge regulations and minimize the quantity of solid waste generated and stored on-site. Since it is impossible to prevent water ingress into the mine, ARD treatment will be required for many decades and possibly in perpetuity at the site. The flow diagram of the ChemSulphide® treatment process designed by BioteQ and installed at WO is shown in Figure 2.

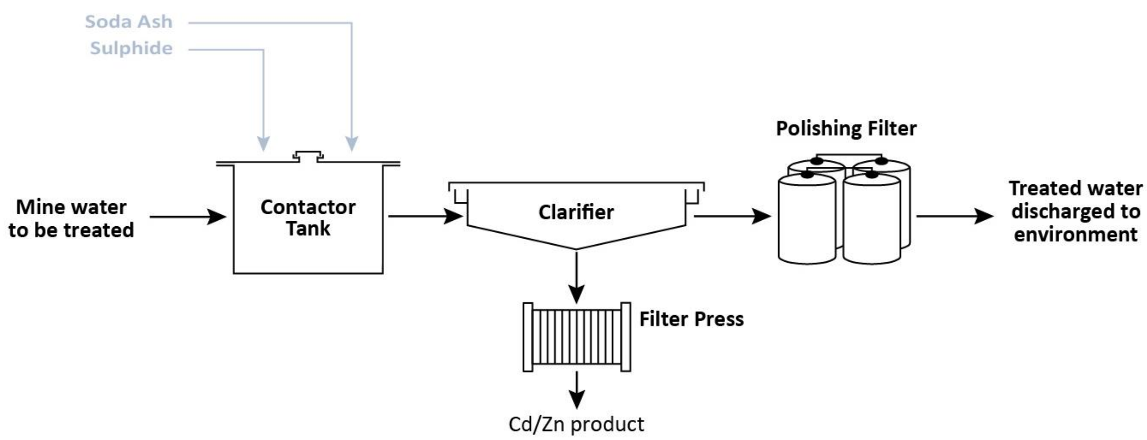

Figure 2 WO ChemSulphide® Process Flow Diagram

The ARD treatment at the site works by selectively precipitating the dissolved Cd/Zn in the mine water as metal sulphide solids using chemical sulphide as the primary reagent. The water is then separated from the Cd/Zn solid and sent to polishing filters before being discharged to the environment. The Cd/Zn solids are filtered to remove excess water, producing a high-grade metal product suitable for refining.

The plant was constructed and commissioned in 2008. Within approximately three months following the plant start-up, the treatment plant was meeting all project objectives summarized in Table 1.

Table 1 Wellington Oro Treatment Objectives and Results

Parameter	Feed	Objective	Result
Zn	132 mg/L	< 225 ppb	< 67 ppb
Cd	122 ppb	< 4 ppb	< 0.5 ppb
pH	6.15	6.5 to 9.0	7.5 to 8.5
Waste sludge generation	-	Zero waste	Zero waste
Hydraulic flow	-	9 to 27 m^3/hr	16 m^3/hr

Following the successful commissioning of the plant and training of local operators, the Town of Breckenridge took over responsibility for plant operations. In Q1 2014, the city made the decision to take advantage of the available follow-up services and invited BioteQ to perform an on-site review and optimization of the plant, five years after start-up.

BioteQ's review revealed that while the ChemSulphide® plant has continuously met regulatory discharge limits and successfully eliminated waste sludge, which were the primary benefits of the process, the overall plant availability was impacted due to several issues as summarized in Table 2.

Table 2 Wellington Oro Plant Availability Impacts

Operational Issue	Impact on Operability
Frequent soda ash pump seal failure	Increased downtime, higher maintenance costs
Hard scale deposit build-up in polishing filters	Higher operating cost to include media filter replacement every 6 months
Significant % of time spent in recycle	Reduced plant availability

Further review of the plant operating data and discussions with plant operators revealed that over the course of the past five years, plant operating conditions changed substantially from the original design. The key parameters that have changed are noted in Table 3.

Table 3 Wellington Oro Plant Changes in Operating Conditions

Parameter	Unit	Design	Actual Results
Feed flow	m^3/hr	9 to 34	< 9 m^3/hr
Feed alkalinity	mg/L as $CaCO_3$	0	120 to 150
Metal acidity	mg/L as H_2SO_4	410	150 to 175

The changes in the operating conditions needed to be taken account during the on-site review and plant optimization to determine the extent to which they contributed to the operational issues identified in Table 2 and the recommendations to address the plant availability impacts.

Elucidating Pump Seal Failure

The soda ash pumps installed at WO are centrifugal pumps with a single mechanical seal. Originally, the seal flush plan was based on using the pump discharge (6% soda ash solution) as the source of gland water. This was recognized by the operators as the main cause of seal failure due to the build-up of soda ash crystals in the seal. The new flush plan involved using local groundwater as the gland water source. By switching the flush plan to groundwater, the frequency of seal failure was reduced but not enough to have a positive impact on the overall plant availability.

BioteQ's review of the groundwater quality data revealed the water contained very high levels of calcium hardness (~ 1,200 mg/L). Although this type of water may be suitable as gland water for many pumping applications, its use as gland water for pumping concentrated soda ash solution at WO is problematic. The reaction between calcium hardness and sodium carbonate results in the precipitation of calcium carbonate inside the pump seal which is the most likely cause of pre-mature seal failures.

Therefore, BioteQ provided the city with two options to remedy the current situation including: 1) install a small house size water softener for reducing calcium hardness upstream of pump glands, and 2) replace soda ash with caustic soda as the alkali used for pH adjustment in the ChemSulphide® process.

Elucidating the Formation of Hard Scale Deposit in Polishing Filters

Samples of the scale that built up in the multimedia filters were analyzed and revealed that the solids contained calcium and iron carbonate. As part of the on-site review, BioteQ reviewed the current plant feed water quality data and completed acid titrations of the feed water to confirm the alkalinity present in the mine drainage. Water quality data showed the feed to contain approximately 400 mg/L Ca with the titration results indicating a feed pH of 6.3 and alkalinity of approximately 130 mg/L. This data points to the fact that the plant feed is saturated with respect to $CaCO_3$.

Based on the original design criteria it was expected the feed would contain zero alkalinity and high metal acidity which would result in the generation of free acid and a drop in solution pH in the metal precipitation stage via reaction (1). Therefore, the original design included the addition of soda ash into the metal sulphide precipitation contactor in order to buffer the pH in the reactor.

$$Zn^{2+} + NaHS = ZnS + Na^{+} + H^{+} \tag{1}$$

Due to the fact the feed already contains 130 mg/L alkalinity and metal acidity is only 175 mg/L, the addition of soda ash to the treatment process results in a significant increase in the alkalinity of the treated water. This was confirmed by an acid titration performed on the reactor discharge solution indicating that the alkalinity increased by 260 mg/L to 390 mg/L as $CaCO_3$.

The increase in alkalinity produces solution supersaturation and significantly increases the scaling potential of the treated water where both $FeCO_3$ and $CaCO_3$ can precipitate out of solution. Scale formation in the multimedia filters can be explained by the filter media having a high solid surface to liquid volume ratio inside the filter housing. This acts as seed for relieving at least a portion of the solution supersaturation.

It is also likely that the gradual build-up of scale inside the filters was exacerbated by a less than optimal back-flush regime where it is imperative that the best possible conditions are created to remove solids trapped inside the filters. The current back-flush conditions are far from optimal due to the following:

- The plant flow rate is below the minimum back-flush flow required (multimedia filters use filter discharge to back-flush); and
- Limited volume of water in the backwash feed tank.

Based on this process analysis, BioteQ recommended the following three remedies: 1) automate the filter backwash based on the level in the filter feed and backwash collation tanks to ensure adequate backwash volume and time is allocated to cleaning the filters; 2) move the soda ash addition downstream of the polishing filters; and/or 3) replace soda ash with caustic as the alkali of choice to control the pH in the process and for discharge. While moving the soda ash addition is a more versatile solution that is applicable over a wide range of feed water quality, it may still result in scaling in the effluent piping. The replacement of soda ash with caustic completely eliminates carbonate formation and scaling but is applicable only when the plant feed contains sufficient alkalinity to buffer the pH in the metal sulphide precipitation stage.

Elucidating the Cause of Poor Plant Availability Due to Recycle

The ChemSulphide® process is designed for continuous operation; as such, any time there is a plant upset that causes the process to shut down, there will be a certain amount of operating time before on spec water can be produced again. Typically, the longer the process is shut down, the longer it takes to get the process back up to steady state.

The current plant configuration does not allow for an automatic recycle of off spec water back to the mine if a minor upset occurs. If an off-spec issue occurs, the plant automatically shuts down and requires operator intervention to start back up. As the plant was designed for operation with limited supervision, there are times when the process will be idle for 10-12 hours depending on operator availability. This can turn a small process upset, which with a recycle loop would result in a minor upset, into the plant being shut down for an extended period and then taking 3-5 days for the process to restart.

In order to keep the process running following an upset, BioteQ recommends that automated valves and a recycle line should be added to the discharge line to ensure the plant can continue to circulate water when producing off-spec water. This should reduce the 3-5 day timeframe for plant restart to a matter of hours. The existing manual valves can be modified to accept a pneumatic or electric actuator and, along with a few modifications to the PLC program, the plant will be able to recycle automatically.

Plant Review Summary

The review of the ChemSulphide® plant operation five years after plant start-up revealed the following:

- The ChemSulphide® process is robust and has been successful in meeting project objectives that include compliance with stringent discharge limits and the elimination of waste sludge;
- To ensure high plant availability and low maintenance costs, it is important to use only soft water as gland water for centrifugal pumps used for conveying soda ash solutions for pH control;
- Where mine drainage may contain significant alkalinity, the plant design should allow for the use of caustic in addition to soda ash to avoid the risk of scaling in polishing filters; and
- When sizing the filter feed and backwash tanks, it is important to consider not only the maximum design flow but also the minimum design flow.

Positive Impact of Metal Recovery on Life Cycle Costs

On average, the WO ChemSulphide® plant treats and discharges over 45,000 m^3 of water annually while recovering over 99% of the zinc and cadmium in the ARD. The recovered metals equate to roughly 23,000 lbs of Zn/Cd which are formed into a filter cake concentrate and shipped to a smelter. By recovering these metals, the WO treatment plant avoids the production of HDS lime sludge which would necessitate the construction of dedicated sludge ponds and/or significant costs of ultimate sludge disposal in a final resting place such as an industrial waste landfill.

CASE STUDY: YINSHAN MINE

In Q2 2014, BioteQ along with its joint venture partner Jiangxi Copper Corporation (JCC), completed the construction and commissioning of a new water treatment plant at JCC's Yinshan mine. The treatment plant combines conventional high density sludge (HDS) lime neutralization with the ChemSulphide® process to treat ARD and recover copper. The plant is the second such plant built by the partners. The first was constructed at the nearby Dexing Mine in 2007 and has been operating continuously and successfully since start-up.

At Yinshan, there are two main sources of ARD including surface run-off collected from the open pit and toes of the waste rock dumps, and water collected and pumped from underground mine workings. The initial objective for the site was ARD treatment to meet regulatory requirements with a properly designed HDS plant. However, during the project definition stage, it became evident that the copper and zinc concentrations in the ARD have sufficient economic value to warrant potential metal recovery. A subsequent engineering feasibility study confirmed this and the decision was made to expand treatment to include the ChemSulphide® process to recover copper with a further allowance made for a possible future expansion to include zinc recovery. The flow sheet of the ARD treatment system installed at Yinshan is schematically depicted in Figure 3.

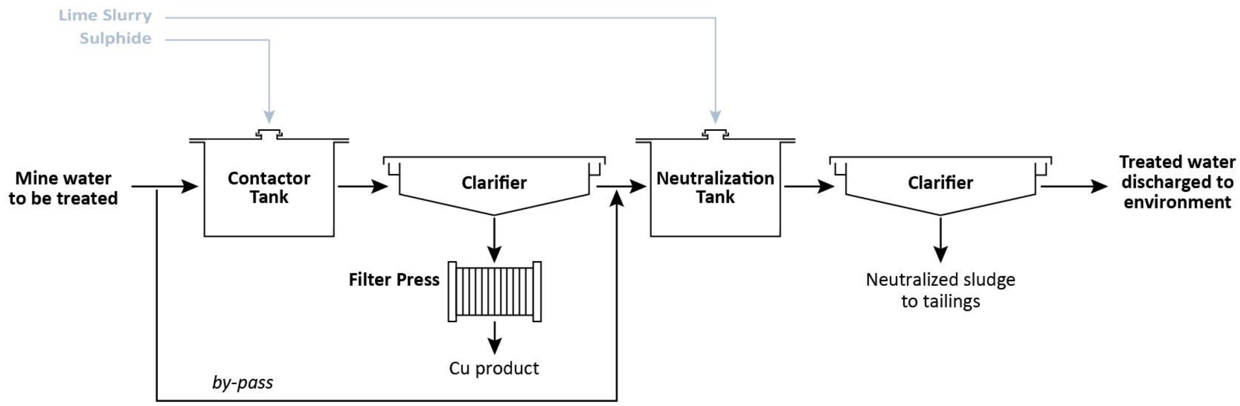

Figure 3 Yinshan ChemSulphide® Process Flow Diagram

As can be seen from Figure 3, a portion of the mine water is designed to by-pass the copper recovery stage. This is due to the fact that not all sources of mine impacted water at Yinshan contain sufficient amounts of copper to warrant recovery and the need to reduce the capital cost of the overall treatment. A chemical sulphide reagent is used to precipitate the dissolved copper in the ARD into a copper sulphide slurry. The slurry is dewatered to produce a high-grade copper concentrate that is sold to a local smelter.

Although the ChemSulphide® circuit of the overall treatment currently recovers only copper, the operating conditions of the plant also removes arsenic and cadmium from the ARD to ultra-low levels which is deported to the copper concentrate hence preventing them from being discharged to the environment. A downstream HDS lime plant is currently used to remove zinc (before the Zn recovery is put into place) along with aluminum and iron, prior to final discharge. The plant effluent is discharged into a local river that is part of the watershed of the largest fresh water lake in China – the Poyang Lake. The HDS lime sludge with reduced metal content is disposed of in the tailings pond.

Due to permitting and construction delays of the ARD collection and storage facilities, the plant has yet to reach and operate at the maximum design capacity for an extended period of time. Average copper concentrations in the plant feed are also lower than designed for the same reasons. The plant has been fully tested during the May to July 2014 storm season peak flow days and has met all design expectations. Table 4 summarizes the key design objectives against the actual averages since the start of operation.

Table 4 Yinshan Treatment Objectives and Results

Parameter	Feed	Objective	Result
Cu	80 mg/L	1 mg/L	< 1 mg/L
Cu concentrate grade	-	35%	31-33%
Cu recovery	-	90%	90%
pH	2.6	2.2	2.2
Hydraulic flow – Cu recovery	-	700 m^3/hr	400 m^3/hr
Hydraulic flow – HDS	-	1,000 m^3/hr	600 m^3/hr

BioteQ continues to provide technical support for ongoing plant operations.

Positive Impact of Metal Recovery on Life Cycle Costs

Using the actual capital cost of the fully installed plant and the operating cost figures from the first three months of operation, the projected LCC of ARD treatment with a 20 year net present cost (NPC) was estimated for three treatment scenarios: HDS alone, HDS with the current copper recovery, and the future possible scenario of HDS with copper and zinc recovery.

The LCC were calculated using a 5% discount rate with no adjustment for future cost escalation for inflation, and assumes a fixed copper price of $3.30/lb and zinc price of $1.13/lb over the life of the project. It should be noted that base metals in China trade at a price premium of approximately 10 to 15% over the London Metal Exchange prices.

The calculated LCC are also based on zero sludge disposal costs. This is true for the Yinshan mine operation where HDS lime sludge is pumped to an existing tailings facility nearby. However, in many cases of active ARD treatment, this option for sludge disposal is not available and the sludge handling and disposal costs can be quite significant.

From this perspective, the LCC presented in Table 5 represent the worst case scenario for the positive impact of metal recovery by the ChemSulphide® process on the overall economics of ARD treatment. For illustration of the additional potential benefit of the ChemSulphide® process for other sites, the sludge reduction associated with metal recovery are also provided.

Table 5 Yinshan Plant Life Cycle Cost Comparison (US$)

	HDS	HDS + Cu	HDS + Cu/Zn
CAPEX			
ChemSulphide®	-	$ 3,400,000	$ 3,900,000
HDS Lime	$ 5,300,000*	$ 4,300,000	$ 4,300,000
OPEX			
ChemSulphide®	-	$ 1,100,000	$ 2,117,000
HDS Lime	$ 875,000	$ 827,000	$ 807,000
Value of Metal Recovery			
Cu	-	$ 1,768,000	$ 1,768,000
Zn	-	-	$ 1,224,000
Net OPEX (incl Metal Value)	($ 875,000)	($ 159,000)	$ 68,000
LCC (20 yr NPC @ 5%)	$ 16,200,000	$ 9,681,000	$ 7,353,000
Cost per m^3 ARD treated	$ 1.17	$ 0.70	$ 0.53
Sludge Reduction (tons/year)	0	1,440	5,160
Sludge Reduction (m^3/year)	0	1,030	3,690

*** Construction of a HDS plant alone would cost $1 M more due to cost efficiencies from shared infrastructure and mechanical/electrical installation when a HDS plant is built in conjunction with a ChemSulphide plant.**

As indicated by the LCC comparisons, copper recovery can offset the HDS treatment cost and reduce the long-term liability associated with treating ARD by more than $ 6 M. On an initial capital cost of $7.7 M for the HDS + Cu recovery option, the LCC is $9.7 M to treat ARD for 20 years.

When zinc is also recovered in combination with copper recovery, the liability of treating ARD can be turned into a profit centre. The capital cost for HDS + Cu/Zn is $ 8.2 M. The LCC is $ 7.4 M. Over a 20 year treatment period, the project will have generated a profit of $ 800,000.

CONCLUSION

ChemSulphide® is a robust and efficient process technology for the treatment of mine impacted waters to meet regulatory compliance while contributing positively to the LCC of the project. The technology has been applied at multiple sites with different site conditions and requirements.

At Wellington Oro, the ChemSulphide® plant has operated for five years, successfully meeting stringent discharge requirements and generating no waste for disposal. By eliminating waste and its associated liabilities, operational costs are reduced. And as operating conditions change over time from the initial design, the process can be modified to maximize plant operability.

The newly installed Yinshan plant illustrates how a metal recovery component when treating ARD can reduce project LCC. Depending on the value of metals in the ARD, the flow rate and metal prices, the revenues generated can range from offsetting treatment costs to becoming a profit centre.

The two cases presented in this paper can be applicable to many mine sites that have similar ARD issues. Sulphide precipitation, due to its high process efficiency and metal selectivity, can also be combined with other mine water treatment applications such as ion exchange and membranes to address complex ARD issues, or meet ultra-low effluent discharge limits.

Mine water treatment is a necessity but can be costly. The two cases in this paper demonstrates that options now exist to treat ARD to comply with environmental regulations and reduce LCC, thereby improving overall project economics.

REFERENCES

USEPA (2014) *French Gulch*, September 16, 2014, http://www2.epa.gov/region8/french-gulch