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United Keno Hill Mines Water Treatment Improvements Study - A Critical Review

by Janice Zinck

Work performed for:
Indian and Northern Affairs Canada
Government of Yukon - Energy Mines and Resources

Project: 603343
Report MMSL 07-026 (CR)

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EXECUTIVE SUMMARY

The Yukon Government and Indian Northern Affairs Canada contacted CANMET-MMSL to complete a critical technical review of the "United Keno Hill Mines Water Treatment Improvements Study" prepared by Elsa Reclamation Development Company (ERDC) Ltd. in January 2007. The specific objectives of this review included:

1. Provide a critical review of the DRAFT - Water Treatment Improvements Study for United Keno Hill Mines issued January 2007 by Elsa Reclamation Development Company Ltd. and the seven appendices accompanying the report.

2. Suggest changes to the content of the report and supplement the existing information where possible.

3. Provide an expert, alternative assessment of the treatment technologies outlined in the report and recommend treatment options where appropriate.

This review document provides a summary of site background information, general comments on the ERDC report, supplemental information on various treatment options and their applicability to the UKHM, a ranking of these technologies based on criteria identified in the original report and finally a discussion on the treatment modifications proposed at each site.

The review and ranking of the treatment technologies concluded that all the chemical treatment processes including pond lime treatment and high density sludge treatment were expected to adequately meet discharge objectives. Several of the biological process including the Bioteq (biosulphide) process and the in-mine biological treatment process were not expected to meet discharge criteria as presented. Other processes such as anoxic limestone drains and successive alkalinity producing systems were simply deemed unsuitable for zinc treatment, particularly in cold climate conditions. In agreement with the original report, lime treatment with process modifications scored the

highest rating and appears to be the best treatment option of those reviewed. The recommended process modifications are outlined in this review report for the various UKHM treatment operations.

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BACKGROUND

United Keno Hill Mines (UKHM) currently treat drainage using lime precipitation at four sites: Galkeno 300, Galkeno 900, Silver King 100, and Bellekeno 600. Hydrated lime is mixed at a central mixing facility and delivered to the mine portals via a lime truck. The slurry lime is stored at each site in retrofitted propane tanks and continuously added to mine portal drainages. Once treated the effluent is then diverted through settling pond(s) before discharge to the environment. The processes are typically inefficient and frequent upset are encountered. Problems with the current treatment system include sludge management, ineffective treatment, poor mixing kinetics and high operational cost.

Galkeno 300

Galkeno 300 drainage contains the highest zinc concentration of the four sites (~80-160 mg/L); treatment is consistently poor and typically ineffective. The major treatment issues identified in the report at the Galkeno 300 site are process control (6.5%), feed variability (6.5%), pond mixing/settling kinetics (22.6%), desludging (48.0%) and power outages (16.1%). Based on the data presented it is clear that the zinc hydrolysis/precipitation reaction is incomplete. The pH needs to be maintained at 9.5 as a minimum and optimum pH of 10.0 for complete zinc precipitation in the field. Mixing and subsequently lime utilization are clearly inadequate at this site. While sludge removal remains the greatest challenge at this site, this is directly related to process parameters such as pH control and effective mixing.

Galkeno 900

Adit drainage at Galkeno 900 has considerably less zinc than Galkeno 300; typically 8-10 mg/L. However like Galkeno 300, treatment at Galkeno 900 frequently results in inadequate pH modification and zinc removal. According to the report, process control is the most significant factor affecting treatment at this site (54.2%). This included plugged and broken lime feed pumps and lines, plugged valves and erratic pH changes from manual adjustment of lime addition rates. The other factors influencing treatment at this site included pond mixing/settling kinetics (22.9%), desludging (11.5%), power outages (10.4%) and feed variability (1.0%).

Silver King

The Silver Mine adit drainage contains zinc concentrations typically less than 2 mg/L. For the most part treatment can effectively remove the Zn to below 0.5 mg/L. There were 92 documented process upsets from 2001 to 2006. It is not clear from the data whether the Zn in the effluent reported as dissolved or suspended material. It is expected that suspended material is responsible for a significant portion of the exceedences at this site. This is directly related to process control which was identified as the most important factor influencing effective treatment at this site; accounting for 41% of the process upsets.

Bellekeno 600

Bellekeno 600 drainage has zinc concentrations comparable to Galkeno 900; ~10 mg/L. Lime treatment has been relatively successful at this site over the past 5 years with 48 upsets. For the most part the treatment pH has been sufficient to remove the zinc. Again process control is the main factor affecting treatment at this site.

In general, all four sites need to improve pH control, enhance precipitation reactions, increase sludge densification and settling to optimize treatment performance. This can be accomplished through process modifications as discussed later in the report.

GENERAL COMMENTS

Overall the report provides a good review of the treatment issues at the various UKHM sites. The treatment challenges and events for each site are clearly documented and provide a good record of the treatment history from which process changes can be made. The report provides a good review of the literature and the criteria presented are useful for comparing the technologies. Unfortunately, there is some inconsistency in the ranking of the technologies. In addition, the ERDC report contains several typographical and format errors. These are not discussed in this review document.

PREVIOUS TREATABILITY STUDIES

The previous treatability study that is presented in Appendix D of the report does not represent site treatment conditions and as such the results of which cannot be easily extrapolated to on site performance. For example, the tests were performed in reactors equipped with baffles, aeration and efficient mechanical agitation. The treatment sites at UKHM do not employ high agitation mixers, reaction baffles, air spargers, or sophisticated pH controls. The effluent analyzed post treatment was filtered through a 0.45 micron membrane filter. This would not represent the effluent produced on site. At a minimum an unfiltered sample should have also been analyzed because it is clear from the data presented in the report and in Section 3.4 in Appendix D that a portion of the exceedences result from zinc in suspended material. Contrary to the treatability recommendation, treating to 8.5 will not be sufficient to remove the zinc to below discharge objectives.

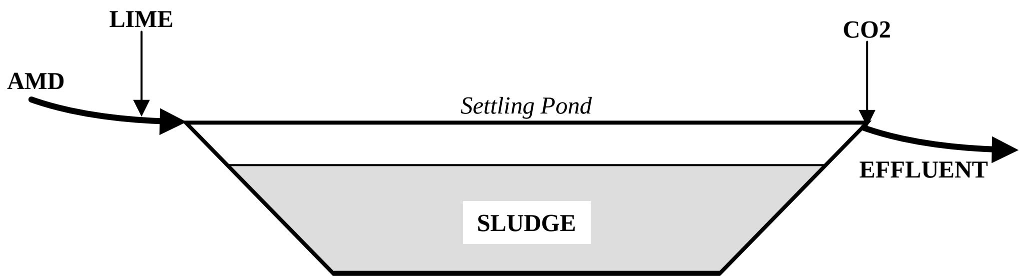
LITERATURE REVIEW

Lime Precipitation in Ponds (current system)

Although many different biological and chemical technologies exist for treatment of acidic drainage, lime neutralization remains by far the most widely applied method. This is largely due to the high efficiency in removing dissolved metals through neutralization, combined with the fact that lime costs are low in comparison to alternatives. Lime treatment essentially consists of raising the pH of the acidic drainage to a point where the metals of concern are insoluble.

The principle of lime neutralization lies in the insolubility of heavy metals in alkaline conditions. By adjusting the pH to a typical set point of about 9.5, metals such as iron (Fe), zinc (Zn), and copper (Cu) are precipitated. The final pH set point can be higher or lower than 9.5 depending on the metal contaminants and concentrations in the water.

Figure 1: Pond Treatment



Pond treatment systems are often chosen for their simplicity and low capital costs when land is available. They can be used to treat very high flow rates and even significant concentrations of metals but require a very large surface area when doing so. Treating drainage in a pond does not allow for much control of the system and thus can be more problematic than other types of treatment systems.

The pond lime treatment system entails adding lime to a stream or mixing system and allowing the precipitates to settle in a pond. The pond is often divided into a primary and secondary section. The primary pond serves to accumulate the precipitated sludge and can quickly be filled. These often require yearly dredging of sludge which then requires a storage area. The secondary pond is larger and requires a long retention time with laminar conditions to allow for "polishing" of the effluent. The lime is added to attain a pH suitable for precipitation of the heavy metals from the waste stream. A higher pH setpoint is often necessary to ensure complete precipitation of metals throughout the pond. For example, some pond systems for treating dissolved Zn often control the pH to more than 10.5, when HDS systems can efficiently remove Zn from solution at a pH of 9.3.

The lack of control typical of such systems reduces treatment efficiency during high flow rates unless other measures are taken to improve the treatment capacity. Without a feed flow rate control system, the drainage continues to enter the pond even if the lime system is down. This can upset the entire pond and result in a non-compliant discharge. It may also be impossible to shut the system down in times of high wind. Wind effects can cause turbulence in the polishing section of the pond which in turn causes resuspension of sludges and/or prevents settling of fresh precipitates. Probably the greatest disadvantage of pond treatment systems is the low liming efficiency. A system that uses in-stream addition without any mechanical mixing may have less than 50% efficiency in lime dissolution. By using an agitator and pH control system, the lime usage efficiency increases significantly. Nevertheless, these systems cannot compare with high-density systems where sludge recycling ensures that unreacted lime be used due to repetitive contact with AMD.

A low density sludge (LDS) is generated with 1-5% percent solids). This type of process has been used successfully to treat high Zn waters e.g. Kidd Mine, Timmins Ontario.

Applicability to UKHM

For pond lime treatment to be effective some degree of process control much occur. The final treatment pH needs to be maintained near 10.0 for effective Zn removal. Fluctuations in excess of one pH unit above or below this value will lead to Zn mobilization. To effectively achieve and maintain the final treatment pH near 10.0, efficient mixing and pH control must be applied. Without proper mixing, the lime will not dissolve at a steady controlled rate. This will cause extreme pH ranges during treatment leading to incomplete Zn removal and poor precipitation conditions (due to regions of super-saturation). Mixing is closely related to retention time requirements. At the UKHM site, it appears the retention time is currently not sufficient for complete zinc removal.

Aeration is not required as in most cases the influent pH is circum-neutral and ferrous will oxidize very rapidly in air near neutral pH. Manganese has similar properties to iron in that as an oxyhydroxide it has a tremendous adsorption capacity. However, compared to iron, the oxidation of Mn(II) is at least 10 times slower at circum-neutral pH. Mn oxidation is however possible where the pH exceeds 8.5. Mn oxidation is very effective for Zn adsorption as it produces a very stable precipitate.

In pond lime treatment at UKHM can be improved by installing better pH control instrumentation. Lime consumption and retention times can be reduced by improving mixing. This can be done by installing in-line mixing, improving mixing in the reactors and increasing the retention time in the settling pond with the installation of berms.

Simple Sludge Recycle

This is a modified process that can be effectively applied to simplified pond, basic type systems. All that is entailed in this process is to recycle sludge from the bottom of the pond to the point of neutralization. This process has a number of advantages over simple treatment processes, including: 1) reduced scaling in reactors, 2) improved solid/liquid separation, 3) reduced lime consumption, and 4) increased sludge density. The final point, the sludge density, will definitely be higher than the expected sludge density from a pond treatment or conventional treatment system, but it is not expected to attain as high a sludge density as with the HDS process. While pond or conventional treatment processes will form sludge with less than 1% solids to 3% solids, the Simple Recycle process can form sludges of up to 15% solids.

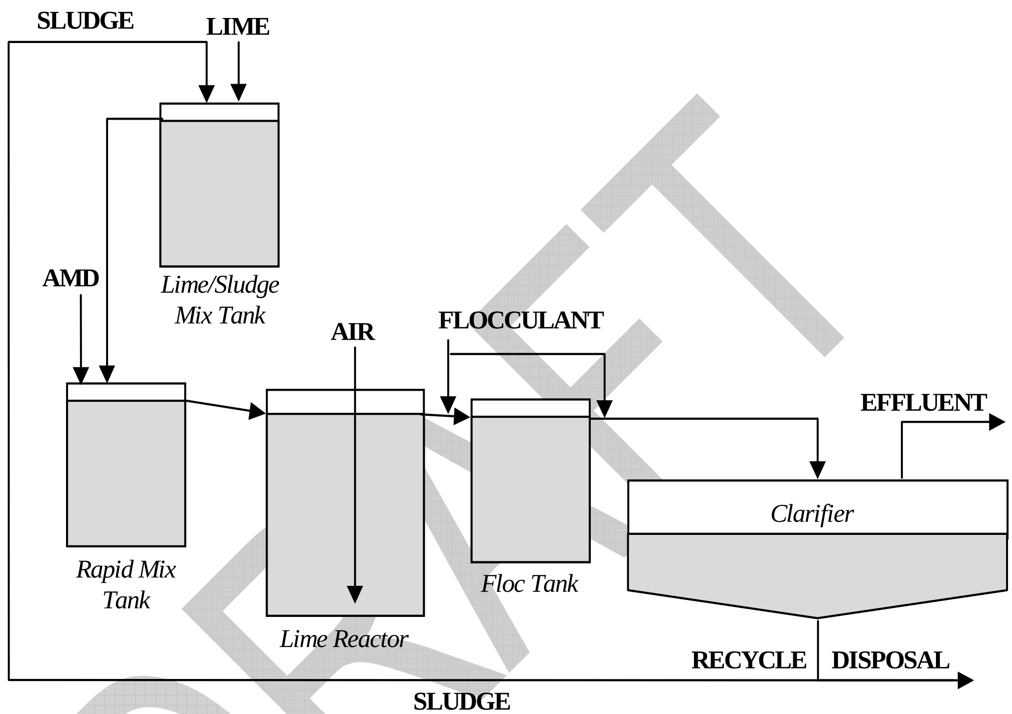
Applicability to UKHM

Simple recycle can easily be applied to the Galkeno treatment system. Sludge taken from the Sime pond can be added directly to the treatment reactor. This will help to increase the sludge density and decrease lime consumption.

High Density Sludge (HDS) Process

The high density sludge (HDS) process is the standard in the mine water treatment industry today. HDS processes recycle the clarifier underflow in specific ratios and in a specified reactor (sludge/lime reactor) for sludge densification. Aeration is often employed. Efficient solid/liquid separation is achieved using flocculant addition and mechanical clarification. Sludge is disposed of either by on-site storage or it is filtered and transported off-site. Sludge produced from HDS treatments often contains 15-30% solids.

Figure 2: Conventional High Density Sludge Process



Applicability to UKHM

HDS treatment processes are becoming the standard for mine drainage treatment. They offer excellent treatability and sludge densification while minimizing reagent consumption. HDS processes are capable of handling high flow rates and can easily adjust to extreme flow fluctuations. Currently UKHM treats several moderate to low flow drainages. It is not reasonable to replace any of these small treatment installations with an HDS plant. However, if a water management strategy was put in place to collect all the drainage and feed it to a single treatment operation, HDS treatment would be an effective option in this case. The initial capital investment could be offset by the reduced lime consumption and sludge disposal costs.

Reverse Osmosis

Reverse Osmosis (RO) is one of the most widely used pressure driven membrane processes and is the tightest possible membrane process in liquid/liquid separation. RO is aimed at the separation of ionic solutes metals and macromolecules from aqueous streams such as industrial wastewaters, mine water and mill effluents. Water is, in principle, the only material passing through the membrane; essentially all dissolved and suspended materials, organic and inorganic, are rejected by RO membranes. This allows for treatment of multi-contaminant waste streams such as those encountered in mining and mill operations. The operating pressure of RO depends on the osmotic pressure of the solution and is in the range of 3-10 MPa. The mechanisms of separation of species are based on the shape and size of permeating species, their ionic charge, the membrane material properties and composition and its interaction with the permeating species.

The application of the RO for the removal of metals from wastewater is limited by the pH range within which the membrane is stable and designed for. For instance cellulose acetate membranes are not suitable for use in pH range of above pH 7, while amide and polysulfone membranes are suitable for use in the pH range of 1-12 In addition, the performance of RO or nanofiltration (NF) can be impaired by the presence of colloidal matter, dissolved organics, and insoluble constituents, TSS.

Finally, once the clean water has been achieved the concentrate must undergo further treatment often with lime precipitation or further processing to recover the metals present.

Applicability to UKHM

While more and more mine sites are adopting membrane separation processes to produce cleaner effluents, this type of treatment is not presently recommended for UKHM. Reverse osmosis may be applied as a polishing step if and when an extremely clean discharge is required. However, presently this extreme treatment is not required. Other types of membrane separations processes would be better suited for mine water treatment (e.g. NF). Membrane separation in general requires large energy input and the membranes are subject to fouling from sulphate (gypsum) and iron (ferric hydroxide).

BioteQ / Biosulphide Process

The Bioteq / Biosulphide process generates sulphide from the biological reduction of elemental sulphur to generate sulphide. Using elemental sulphur instead of sulphate as the sulphur source provides a more rapid, efficient and cost effective sulphide supply. The reduction of sulphur takes place in a bioreactor in which none of the water to be treated is introduced. This is a very significant advantage over the reduction of sulphate which is contained in the water to be treated and that process is therefore exposed to the risks associated with fluctuating flows and water chemistry.

A simple schematic illustrating the production of sulphide reagent as hydrogen sulphide through the biological reduction of elemental sulphur is shown below (Figure 3).

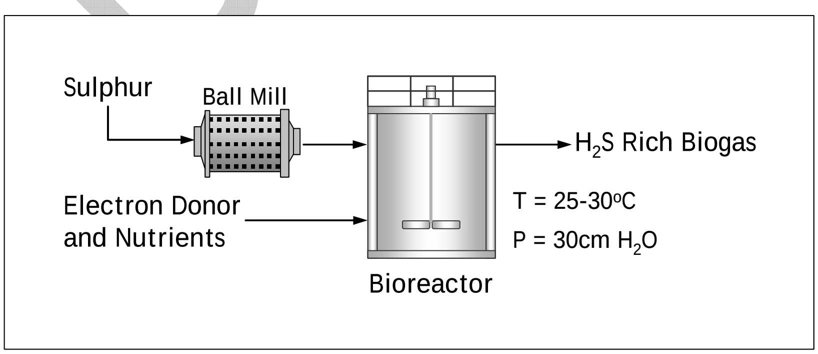


Figure 3: Biological Generation of Hydrogen Sulphide Gas

The sulphide reagent is produced by reacting elemental sulphur in a bioreactor with an electron donor, such as acetic acid, in the presence of sulphur-reducing bacteria under anaerobic conditions according to reaction.

The sulphur-reducing bacteria act as a catalyst enabling this reaction to proceed at 25° C and at a system pressure in excess of 30 cm H_2O. A continuous production of H_2S is achieved by removing the gaseous products of the reaction from the bioreactor. Since elemental sulphur is used as the sulphur source for making H_2S, instead of sulphate, no process water other than that contained in the reagents required for the reaction enters the bioreactor. Thus the bioreactor is a true stand-alone H_2S generator. The main advantages of using the biological H_2S generation include:

- Low cost of sulphide compared to the cost of Na_2S, NaHS, or H_2S;
- Minimal hazards and increased safety mainly due to the low system pressure and low inventory of H_2S; and
- Easy to scale-up and down over a wide range of H_2S production capacities.

Applicability to UKHM

The Bioteq process is bacterial based treatment process. Since the process relies on bacteria to produce hydrogen sulphide the bacteria must maintained under conditions that encourage their activity. Treatment of the UKHM drainage typically occurs at temperature less than 4°C. Ideal conditions for sulphur/ sulphate reducing bacteria are typically between 25-40°C. Sulphide generation will be challenging at temperatures consistent with the UKHM water. The Bioteq process has been applied unsuccessfully at the Raglan Mine. The site has recently changed from biosulphide to using NaHS to precipitate nickel as nickel sulphide. Without further research and proven application in cold climates the Bioteq process is not recommended for northern sites such as UHKM. In addition, iron and manganese would require additional treatment with lime for effective removal as shown below.

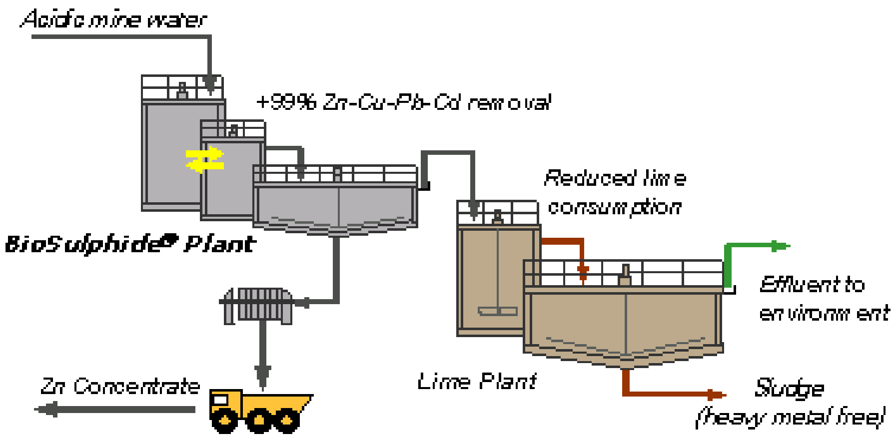


Figure 4: Hybrid Bioteq – HDS Process

Sulphide Precipitation for Zinc Recovery

Sulphide precipitation works under the same basic principle as hydroxide precipitation. The precipitation process converts soluble metal compounds into relatively insoluble sulphide compounds through the addition of precipitating agents, such as:

- Sodium sulphide (Na_2S).
- Sodium hydrosulphide (NaHS).
- Ferrous sulphide (FeS).
- Calcium sulphide (CaS).

This technology is an effective alternative to hydroxide precipitation. Over a broad pH range, sulphides (S^{2-}, HS^{-}) are extremely reactive with heavy metal ions. Sulphide precipitation can be used to remove lead, copper, chromium (+6), silver, cadmium, zinc, mercury, nickel, thallium, antimony, and vanadium from wastewaters. The precipitation reaction is generally induced under near neutral conditions (pH 7.0 to 9.0). In a way that is similar to hydroxide precipitation, metal-sulphide precipitates most often must be physically removed from solution (through coagulation, flocculation, and clarification or filtration), leaving a metal-sulphide sludge. In addition, sulphide precipitation is sometimes used in water treatment following conventional lime treatment to reduce concentrations of residual metals, particularly cadmium. This is successful due to the ability of sulphide to reduce metal concentrations to much lower values than can be achieved by precipitating metals as hydroxides with lime, although the metals precipitated are not recovered as they report to the lime sludge.

Some of the advantages of sulphide treatment include effective metal removal for most metals, low retention time requirement and reduced sludge volumes. The disadvantages are significant and include potential for toxic hydrogen sulphide gas emissions and residual sulphide in treatment effluent, soluble sulphide process may result in odour problem and more complex systems frequently with high capital and operating costs than lime treatment.

<u>*Applicability to UKHM*</u>

The mine water at UKHM contains primarily zinc and no other recoverable metals in significant concentration. This coupled with the complex and potential health and safety issues, sulphide precipitation is not deemed a suitable option for UKHM. Sulphide precipitation is best used when very low discharge criteria must be met. The financial return from zinc recovery is not expected to provide significant revenue.

Moving Bed Active Filtration

Through the addition of ferrous salt solutions or zero-valent iron powder, sand beds can be used as a high surface iron delivery media that can affect high levels of contaminant removal. The ion exchange sites available on the iron-modified sand surface present an iron "reagent" delivery mechanism that is not diffusion-limited or equilibrium-limited. This is a proprietary technology that has been effectively been applied for phosphorus.

Equipment for this process includes a pre-reactor for mixing influent water with iron reagent, a moving bed sand filter, and a small clarifier basin. The majority of contaminant removal occurs in the moving bed filter, where iron oxide-coated sand (IOCS) is continually formed from the iron reagent and abraded by the motion of the sand. Contaminants are adsorbed by the IOCS surface, and then after abrasion the particulates are separated by the filter and directed toward the clarifier basin. In this manner the contaminants are continually removed from the process stream.

Applicability to UKHM

This systems is primarily design for low flow, low contaminant feed water. Little work has been done on zinc rich water at cold temperatures. In addition, the sand must be regenerated. The adsorbed iron and zinc must be removed and disposed of in some fashion. This technology seems to have very limited applications and is not the best available treatment option for UKHM.

Adsorption through Sand Beds

This process utilizes a pond system instead of reactors. While the process would have much lower capital costs than moving bed active filtration, the pond system would make treatment of higher flows more challenging due to shorter retention times and great opportunity for sand fouling.

Applicability to UKHM

The high flows and high metal concentrations in the UKHM feed water would not be effectively treated by adsorption through sand beds; may be suitable for small seeps.

Biological Treatment Cells (BTC)

Biological treatment cells remove contaminants from the mine water through various mechanisms including adsorption onto organic substrates and precipitation as sulphides. They typically utilize an active or passive organic feed supply such as manure, wood or sugar. They are typically used to treat low flows but can successfully used to treat higher flows if the cell (s) is properly sized. Three main factors are crucial to the design and sizing of an anaerobic cell. These include the volume of water to be treated, the concentration of metals present and the treatment area required to do so, and the composition of the organic biomass. Failure of biological treatment reactor cells is typically caused by a combination of plugging with metal oxides, compaction, lack of sufficient available quantities of degradable organic carbon to support sulphate reduction, or peak flow failures wherein the residence time in the pond system is insufficient to treat the peak loads encountered. In addition, in cold conditions bacterial activity is limited making treatment very challenging and prone to failure.

Applicability to UKHM

Biological treatment will be very difficult to apply at UKHM given the climatic conditions, flows and metal concentrations in the mine water. Process upsets will be inevitable. There is limited data supporting successful application of biological treatment cells for treatment of similar mine water concentrations, flows and conditions. Biological treatment cells of this nature require continual addition of a carbon source for ongoing treatment. Metals precipitate as sulphides and must be maintained in an anoxic environment otherwise the sulphides will oxidize generating acidic drainage.

Anoxic Limestone Drains (ALD)

ALDs are ditches filled with limestone gravel. As mine water flows through them, the limestone dissolves, adding alkalinity and increasing the pH. The system functions by promoting the contact of mine drainage with limestone gravel under anoxic conditions. The anoxic conditions limit the oxidation of ferrous iron, thereby minimizing the armouring of limestone with ferric hydroxide. ALDs function is to raise the pH of the water to circumneutral levels (pH 6-7) and to introduce bicarbonate alkalinity. Upon exiting the ALD, the circumneutral pH level promotes metal precipitation and the bicarbonate alkalinity neutralizes the acidity produced by metal hydrolysis. The water needs to contain very little dissolved oxygen otherwise iron hydroxides can form, clogging the drain and causing it to fail.

Applicability to UKHM

This method is a simple chemical passive treatment method that utilizes limestone to increase the pH in order to hydrolyze and precipitate the metals of concern. Like SAPS (discussed below) this process is typically applied to treat coal mine drainages and can effectively remove iron and aluminum. Unfortunately, the limestone can only increase the pH to near neutral (~ pH_i of the UKHM mine water) and cannot remove Zn by hydrolysis as the pH needs to be at least 9.5.

Successive Alkalinity Producing System (SAPS)

Successive alkalinity producing systems (SAPS) combine the use of an anoxic limestone drains and an organic substrate into one system. Anoxic limestone drains are buried cells or trenches of limestone into which anoxic water is introduced. In a SAPS, mine water is ponded from 1 to 3m over 0.2 to 0.3m of organic compost, which is underlain by 0.5 to 1m of limestone. Below the limestone is a series of drainage pipes that convey the water into an aerobic pond where metals are precipitated. The hydraulic head drives ponded water through the anaerobic organic compost, where oxygen is consumed and ferric iron is reduced to ferrous iron. Sulphate reduction and sulphide precipitation can also occur in the compost. Water with high metal loads can be passed through additional SAPS to reduce high acidity. Iron and Al clogging of limestone and pipes can be removed by flushing the system.

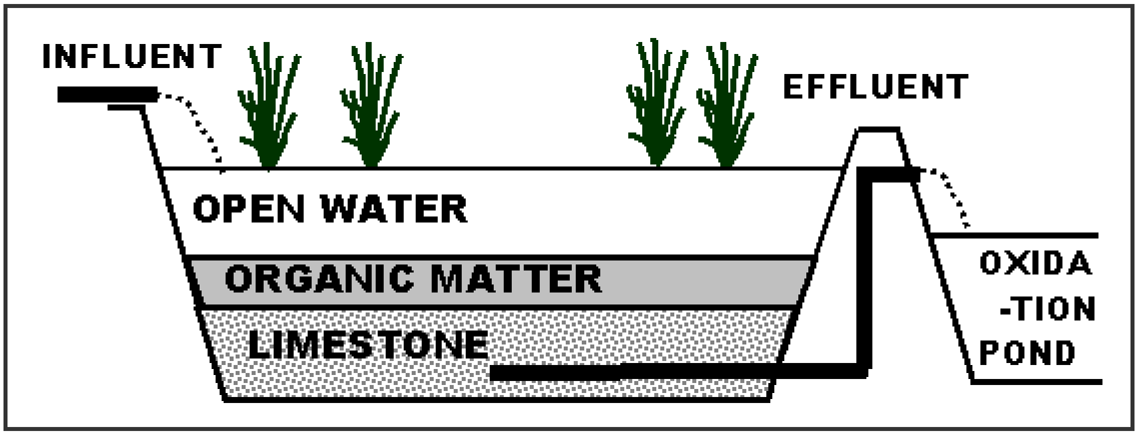


Figure 5: Successive Alkalinity Producing System (SAPS)

Applicability to UKHM

SAPS have principally been designed for and applied to coal mine drainage as it typically contains metals that precipitate in low pH regimes (Fe(III), Al). While the organic matter in the SAPS can potentially provide some degree of sulphate reduction it is not expected to be substantial. The purpose of this layer is mainly to remove oxygen, subsequently reducing ferric to ferrous, so that iron can precipitate in the oxidation pond rather than amour the limestone. SAPS are generally not recommended as stand alone systems and work best as components of an integrated system. Zinc removal will not be effective in a SAPS. Neither sulphide precipitation from sulphate reducing bacteria nor adsorption onto ferric hydroxide precipitates will achieve the necessary level of zinc removal. Furthermore, limestone cannot increase the pH to the level required for zinc hydrolysis/precipitation. As such successive alkalinity producing system would not be an effective treatment option for UKHM.

Ion Exchange (IX)

Ion exchange can be used as a stand alone process or used to strip recoverable metals such as zinc from the mine water prior to lime treatment.

Ion exchange is a reversible chemical reaction wherein an ion (an atom or molecule that has lost or gained an electron and thus acquired an electrical charge) from solution is exchanged for a similarly charged ion attached to an immobile solid particle. These solid ion exchange particles are either naturally occurring inorganic zeolites or synthetically produced organic resins. The synthetic organic resins are the predominant type used today because their characteristics can be tailored to specific applications.

An organic ion exchange resin is composed of high-molecular-weight polyelectrolytes that can exchange their mobile ions for ions of similar charge from the surrounding medium. Each resin has a distinct number of mobile ion sites that set the maximum quantity of exchanges per unit of resin.

The problem with ion exchange is that the resins are very expensive and flows are too high for this technology to treat the mine water economically. The metal recovery potential does not sufficiently compensate for the overall cost of the ion exchange treatment. On-going treatment would require a considerable investment in capital and operating requirements,

Applicability to UKHM

This sophisticated treatment is typically applied to low flows, high concentration process streams. It would not be a suitable treatment option for UKHM due to its high maintenance and operating requirements. In addition, the high UKHM flows would be difficult to treat with ion exchange. Iron would need to be treated with lime either upstream or down stream of the IX treatment.

In–Mine Biological Treatment

In-mine or *in situ* biological treatment involves continuous addition of an organic substrate such as molasses to turn the entire mine pool into a large bioreactor. In theory the technology inhibits further acid generation by creating a reducing environment and raising the pH of the water to near neutral. In the Lilly/Orphan Boy Mine test case zinc and manganese were not effectively removed from the mine water. The zinc removal efficiency reached a maximum of 70% and a low of 20%. This zinc removal efficiency was observed in water much warmer than that treated at UKHM. The zinc removal rate is expected to be much lower at colder temperatures as the bacterial activity is much slower and relatively inefficient. Furthermore, this type of process will require carbon addition in perpetuity as the mine must be forever maintained in an anoxic, sulphide producing state.

Applicability to UKHM

This is a relatively new and innovative technology. Currently there are no similar applications of this technology in Canada, particularly in northern Canada, treating high zinc waters. In fact, most of the examples stated in the report occur in much warmer conditions at sites in southern USA (e.g. Nevada). Until proven to work under similar conditions (temperature, [Zn]) this technology should not be considered as a stand alone treatment option at UKHM.

Combined In-Mine plus *In Situ* Secondary Biological Injection

There is no information provided on this treatment process in the ERDC report, however it is rated. It is assumed that the process will involve in-mine treatment with a carbon source following injection of the mine water (with further carbon addition) into permeable formations in the surrounding UKHM area.

Applicability to UKHM

The fact that no information is provided on this treatment process suggests that detailed treatment planning has not taken place as to how this process could be applied at UKHM. For example, location of the injection wells, size and dimension of wells, risk and impact to the surrounding permafrost and risk/long term impact to the region, etc. The lack of information provided is reflected in the ranking presented in the next section and in Appendix A.

Ranking of Technologies

Each treatment technology discussed was ranked using the criteria summarized below and are defined in detail on page 27 of the ERDC report.

- Threshold criteria (pass/fail criteria that must be met in order to continue evaluation of technology);
- Balancing criteria (used to evaluate and balance each technology against each other); and
- Modifying criteria (used to incorporate stakeholder acceptance factors).

The results of the ranking exercise are presented in Appendix A and summarized below in Figure 6. For comparison, the rankings from the ERDC report are also included. Only those technologies that were expected to meet the threshold criteria are considered acceptable and presented graphically in Figure 6.

Generally all the chemical treatment processes including pond lime treatment and high density sludge treatment were expected to adequately meet discharge objectives. Several of the biological process including the Bioteq (biosulphide) process and the in-mine biological treatment process were not expected to meet discharge criteria as presented. Other processes such as anoxic limestone drains and successive alkalinity producing systems were simply deemed unsuitable for zinc treatment, particularly in cold climate conditions. Detailed rankings and comments for all processes regardless of their ability to meet the threshold criteria are presented in Appendix A.

In agreement with the original report, lime treatment with process modifications scored the highest rating and appears to be the best treatment option of those reviewed.

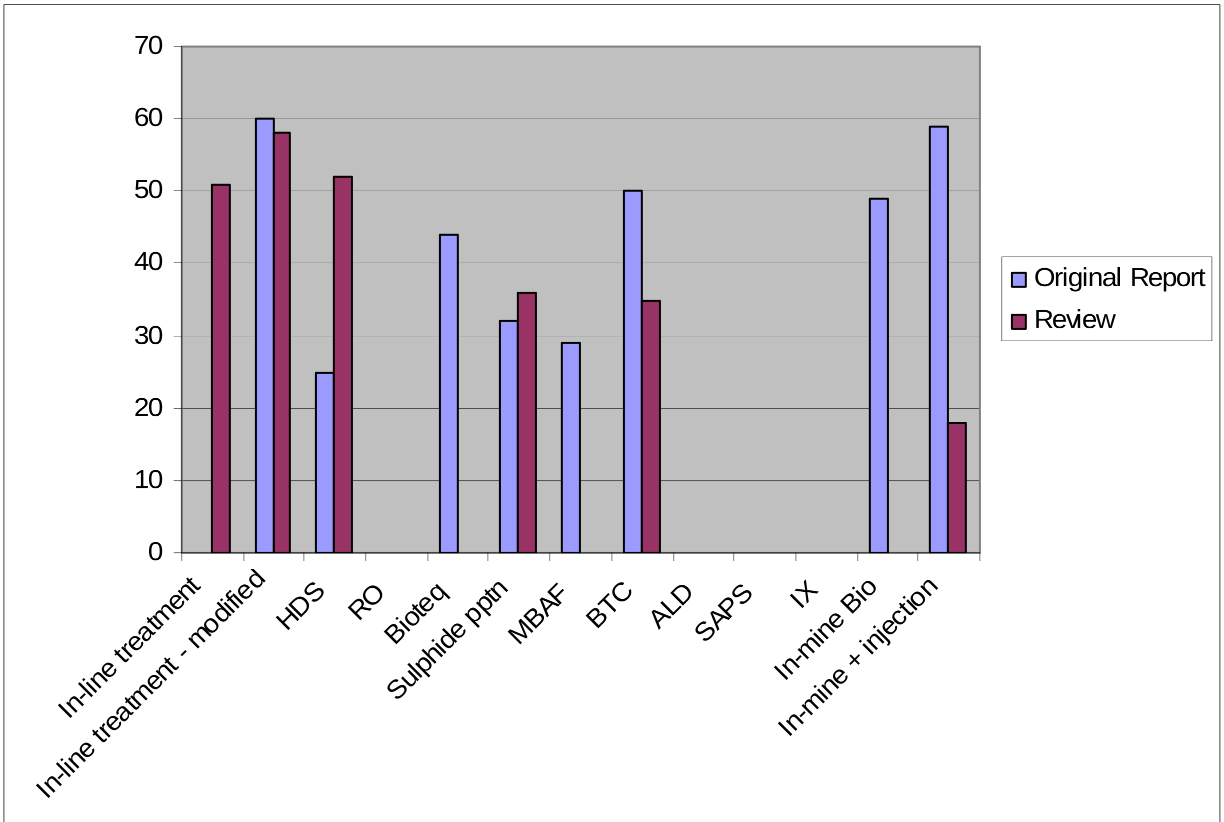


Figure 6: Ranking of Potential Treatment Technologies

PROPOSED TREATMENT MODIFICATIONS

Several potential treatment modifications were presented for the various UKHM treatment sites. All proposed modification options should undergo some level of cost benefit analysis (relative to the investment/risk) before any process change or procurement of new equipment is made. Where necessary, this cost benefit analysis would be supplemented with bench/pilot testing. Additional testing should ideally be completed on site or at a minimum simulate on-site conditions as best as possible. Potential treatment options and modifications for the various sites are discussed below.

Reroute G300 to G900 and construct a new lime treatment plant or retrofit existing system

Combining the two flows should reduce operating (monitoring, maintenance, reagent, costs) however this will require considerable capital investment. This option should be investigated further by completing treatability tests to evaluate lime consumption, effluent quality and sludge properties resulting from treating the combined drainage. If the results of the treatability testing are favourable, a cost benefit analysis should be completed.

Process modifications - Galkeno 300 treatment system

Process modifications are necessary to improve the treatment performance at Galkeno 300. If it decided that a new system will be built to accommodate flows from both Galkeno 300 and 900 then the process modifications required at Galkeno 300 will not be as extensive. The decision whether or not to combine the drainage should be made before any process modifications are made at either site.

The first priority at Galkeno 300 (and all other sites) is to install pH control and automation. Without proper control of the pH during precipitation, not only will sludge volumes be excessive but effluent concentrations will likely exceed discharge objectives.

If Galkeno 300 will continue to be a water treatment site then the following process modifications are supported.

- Install transformer and connect to grid power
- Construct new sludge settling pond; test and if effective install sludge removal pipes in bottom of pond.

- Install sludge recycle pump

While sludge recycling should improve sludge densities to some degree the greatest enhancement in sludge densification will result from control of the precipitation reaction. Sludge densification by way of mechanical clarification will not be effective if the particles are formed under super-saturation conditions such as encountered with poor liming and poor mixing practices. Under these conditions, very small particles nucleate and coagulate into a gel-like structure which is very difficult to dewater by mechanical means.

Bench scale testing to identify the optimum flocculant and dosage is recommended as is sludge characterization before and after process modification.

It has been recommended that in-pond mixers be installed to improve circulation, precipitation and settling in the pond. Pond mixers may increase suspended solids concentrations in the pond decant and discharge. Instead it is recommended that berms be constructed in the ponds to increase retention and avoid short circuiting.

Until the mine water treatment is under control and discharge is regularly in compliance any test work not related to the pond treatment should be postponed. This includes:

- Pilot test in-situ injection and distribution of treated decant; field-engineered; and with directional controls on discharge to reduce highway glaciation impacts; and
- Construct pilot test diversion dam underground to redirect flow in a controlled and manageable system with a possible added benefit of increasing the iron to zinc ratios at Galkeno 300.

Process modifications - Galkeno 900 treatment system

If flows from Galkeno 300 and 900 are not to be combined, process modification should be made first at Galkeno 300 followed by Galkeno 900. Like Galkeno 300 pH control and automation are the priority for Galkeno 900. This will improve both effluent and sludge quality. Mixing should also be enhanced at this site to improve lime utilization and precipitation reactions. A rapid mix tank or another such reactor would be beneficial for this purpose. In-line mixers might also have some application here as they require minimal power demand. However, the performance of such systems in winter conditions must first be pilot tested before installation. Flocculant testing should also be considered for this site. In low strength dissolved metal water, suspended solids frequently account for a significant portion of exceedences. Sludge removal pipes require testing before they should be considered. The thixiotropic properties of the sludge make sludge removal challenging and this can vary for site to site. The recommendation to install a larger lime holding tank in a new insulated building near the treatment operation is supported. It will decrease overall haulage time and vehicular emissions.

Process modifications – Silver King treatment system

At Silver King pH control and automation should be installed. A mixing tank or rapid mix reactor could be installed to improve mixing. In addition, flocculant testing should also be considered for this site to improve sludge setting and the presence of particulate matter in the treated effluent. As with Galkeno 900, the recommendation to install a larger lime holding tank in a new insulated building near the treatment operation is supported. All process modifications such as sludge removal pipes should be tested before changes are implemented.

Process modifications - Bellekeno 600 treatment system

Similarly, at Bellekeno pH control and automation should also be installed. A mixing tank or rapid mix reactor could be installed to improve mixing. In addition, flocculant testing should also be considered for this site to improve sludge setting and the presence of particulate matter in the treated effluent. The recommendation to install a larger lime holding tank in a new insulated building near the treatment operation is supported. All process modifications such as sludge removal pipes should be tested before changes are made. A pond liner would be warranted if seepage is causing either chemical or physical impact to the surrounding area.

Final comments

Injection pilot testing should not proceed without a detailed geotechnical review and impact study for the area and after the water treatment on site is under control. In addition, all sites should have in place regular plant operation, monitoring, maintenance and contingency plans. Finally, in-mine sludge disposal should be evaluated for application at this site.

APPENDIX A -

Revised Treatment Technology Matrix

See attached Excel Spreadsheet.