Water Filtration Innovation to Optimize Recovery and Lower TCO

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Abstract Point source discharge and acid mine drainage are recognized as serious environmental challenges within the mining industry. The high variability of site-related factors continues to be a challenge with regard to implementing cost-effective long-term treatment. Recent industry sector transition to processes utilizing sulfide ores has driven the need for innovation in high-recovery sulfate-reduction processes. Significant improvements to membrane and filtration process design have allowed for considerably higher recovery ratios and lower remediation infrastructure costs. This paper will provide a technical overview of the most recent innovation in active treatment technologies, their appropriate applications, and normalized total cost of ownership (TCO).

Keywords IMWA 2013, full paper, AMD treatment, inorganic membranes, lower TCO

Introduction

Acid mine drainage (AMD) from point sources is a significant issue in the mining industry. Pollution from metals in lakes, streams, and rivers causes significant liability and environmental issues. Increased use by the industry of more sulfide ores will result in higher levels of metals and associated water quality issues. There are numerous techniques for AMD treatment. A new consideration for AMD treatment is water reuse. As water becomes scarcer, especially in drought areas, it will be important for the mining industry to consider how and where water can be reused (ICMM 2012). This paper will discuss how several active treatment technologies compare and focus on inorganic membrane treatment to achieve lower overall total cost of ownership (TCO).

Water as a Shared Resource

In mining, water is used in a broad range of activities, including mineral processing, dust suppression, slurry transport, and employee requirements, such as potable water use. The mining industry has moved toward closed-loop systems for water use. In addition, mining activities are beginning to interact more closely with agriculture, industrial activities,

Fig. 1 *eMalahleni Water Reclamation Plant, South Africa*

and municipal/commercial players. This leads to the conclusion that there is now no simple recipe for water management at mining facilities. Examples of interaction around this shared resource are found in companies such as eMalahleni Water Reclamation Plant in South Africa (ICMM 2012). The plant treats contaminated water from its own facility in the coal mining area as well as from other mining operations and delivers treated water directly into the local municipalities' drinking water systems.

Variables to Control

When attempting to control the TCO, it is important to focus on the following parameters: (1) labor, (2) chemicals, and (3) power requirements. These three elements of the overall cost will affect how economical the system can become. In most cases, the incoming water quality for treatment and the resulting end use, such as discharge to a stream or water for reuse, will dictate the type of chemistry required for treatment. Treatment will also be dictated by the environmental permits that are required for discharge or the water quality parameters required for reuse. In addition, mining companies should consider the use of triple bottom line (TBL) accounting (Roucher 2009). TBL reviews the impacts of the overall cost of ownership as well as the bottom lines of financial, social, and environmental impacts. If the mining company controls the above issues of labor, chemicals, and power, it is very likely that the parameters within TBL will also be lowered. This is certainly the case at the Barrick Homestake Mine in Lead-Deadwood, South Dakota. Their Water Conservation Standard was able to protect the company, manage the water cycle, and provide water for the sanitation district as new water for sale (ICMM 2012).

Precipitation Chemistry

Precipitation chemistry is one of the key variables to be controlled. Fig. 2 is a representation of hydroxide solubility curves. In most cases of active treatment, the goal is to remove the metals to their lowest concentrations. This can be accomplished with sodium hydroxide or lime, and by raising the pH, the solubility of the metals of interest decrease.

Iron co-precipitation is also used in precipitation chemistry. This is where metals of interest are ingrained in the precipitant or floc. When decreased metals solubility is combined with iron co-precipitation, it allows for the operation of the treatment system to meet the environmental discharge parameters.

One issue with precipitation chemistry is the precipitation of other compounds, such as calcium carbonate. This is tied directly to the pH value. After a pH of 9.5, alkalinity will be in the carbonate form, which will allow for the precipitation of calcium carbonate and increase the amount of sludge significantly, as much as 100 % in some cases. Therefore, it is important to keep pH increases to a minimum to decrease the amount of solids disposal.

Active Treatment Systems

Three different active treatment systems are compared in this paper. The first is the high density sludge (HDS) clarifier system, as

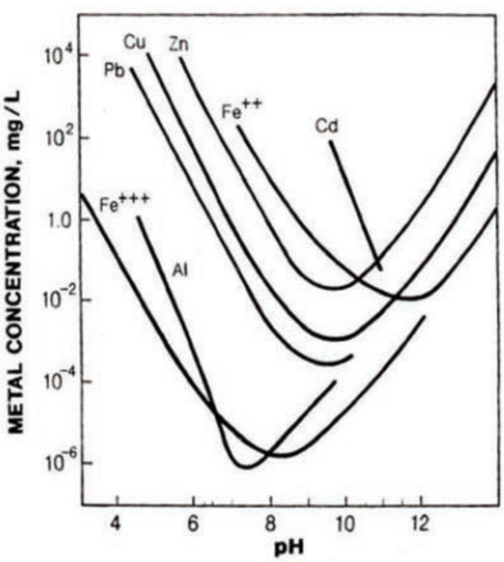

Fig. 2 *Solubility Curves*

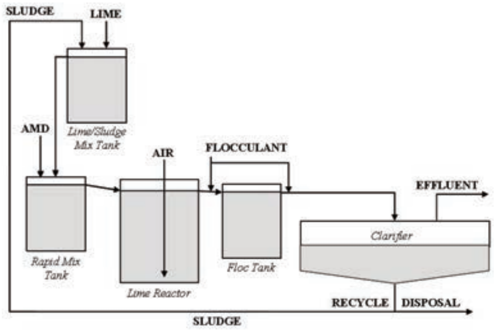

***Fig. 3** High Density Clarifier*

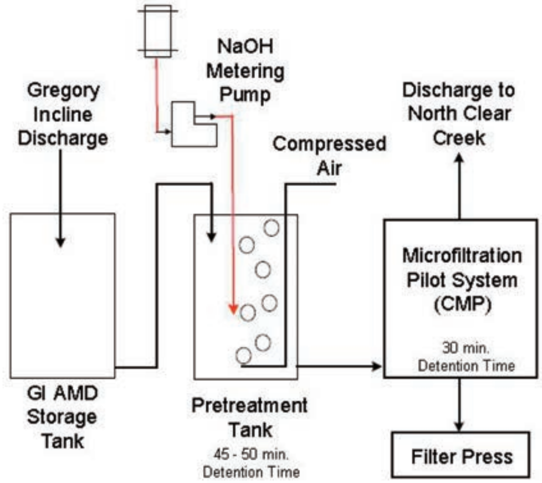

***Fig. 4** Simplified Membrane Treatment System*

shown in Fig. 3. The concept of the HDS system is to recycle the solids formed in the system to allow for better chemical utilization and higher sludge densities. Higher sludge densities allow for smaller treatment systems and thus decrease the footprint of the overall treatment system. In addition, an HDS system will add air in a reaction tank to allow for better oxidation of the metals, such as iron to allow for better efficiency of the precipitation step.

The second and third treatment systems are membrane systems: a polymeric membrane system and an inorganic (ceramic) membrane. Both membrane systems are microfilters and utilize a process similar to that of the HDS system. The difference is that the membrane provides a physical barrier between the AMD and the effluent of the facility. Fig. 4 depicts a membrane treatment system for the ceramic pilot study at the Gregory Incline, Clear Creek County, Colorado. This was an EPA demonstration project, which produced excellent results for water quality and metals removal.

The only difference between this system and a polymeric system is the actual membrane. Both systems will operate at a pressure of 241 kPa and both systems have a backpluse system to decrease flux decline.

The main difference between the two types of membrane is the lifespan of the membranes themselves. At the Blackhawk Colorado AMD treatment facility, the original membranes were tubular polymeric membranes. The lifespan of these membranes was approximately 6 to 9 months. Due to the replacement cost of these membranes, an alternative was investigated. We installed ceramic membranes in 1995, and these membranes are still in service.

Ceramic Crossflow Membranes

Since installation of the ceramic crossflow membranes at the Blackhawk facility in 1995, over 35 systems ranging from 38 L/min up to 1325 L/min have been installed throughout the world. As shown in Fig. 5, the crossflow membrane is an "inside out" flow pattern. The transmembrane flow is attempting to keep the

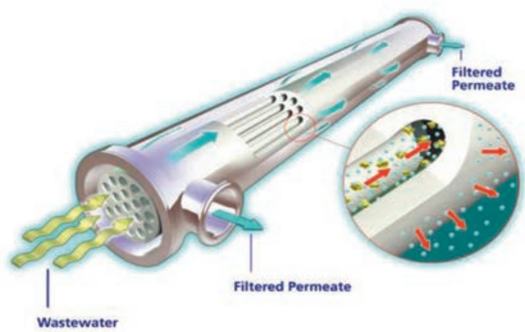

***Fig. 5** Ceramic Microfilter*

Reynolds number very high, which requires a high flow rate. Typical flow rates are 3 m/s. The operating pressure for this type of membrane is 241 kPa. The transmembrane pressure or pressure over the membrane surface is typically 35 kPa. Thus, the power requirements for this type of system are very low.

The advantage over the HDS clarifier is that the high solids in both systems will allow for higher utilization of the chemicals that are added for precipitation. The difference between the HDS and the membrane systems is with the absolute barrier of the membrane between the solids and effluent, there is little chance of a violation of the permit.

Results of Membrane Treatment

A ceramic microfiltration system was installed at the Upper Blackfoot Mining Complex treatment system near Lincoln, Montana (Fig. 6). This was a joint effort between CDM Smith and the State of Montana. At this facility, it was found that the ceramic microfilters were able to operate at a lower pH value when compared to an HDS clarifier. The system has been able to meet the discharge requirements on a consistent basis.

From a cost standpoint, the cost savings resulted from the reduction of labor, lower chemical costs, a smaller footprint for the building, and lower power costs. The labor at the site is typically 8 hours per day, except in runoff season, when the labor is increased to 24 hours per day. The increased labor is typically to handle the additional sludge being generated by the system. The flow increases at the facility approximately 300 % during spring runoff. The lower chemical costs are a result of being able to meet the discharge values at a pH of 8.5. During spring runoff, the pH has to be increased to 9.5 or higher. This has resulted in a significant amount of sludge increase due to the precipitation of calcium carbonate, which then increases both the chemical costs as well as the labor costs.

Fig. 6 *CMF System at the Upper Blackfoot Mining Complex*

The smaller footprint is due to the size of the membrane system, which is typically 20 % of the footprint of the HDS clarifier system and significantly shorter in height. The power costs are lower for the membrane system due to the low pressure required for operations at 241 kPa.

Table 1 provides effluent removal values at the Upper Blackfoot Mining Complex treatment system for comparison purposes.

Fig. 7 provides capital and operating costs for the comparison of the HDS, polymeric, and ceramic membrane systems. This figure is based on the comparison of a 1136 L/min system that was identified in the EPA report on the Gregory Incline (MWTP 2002).

Options to Further Reduce Costs

The potential to further reduce costs is found in new precipitation technologies. Specifically, we have found electrocoagulation (EC) and high shear reactors to be beneficial. EC is an expensive and capital intensive process, but allows for precipitation at a lower pH value. The EC process separates the water molecule into hydrogen gas and a free radical of oxygen. It also corrodes the plates and provides iron or aluminum as free metals in solution. This combination allows for precipitation at a lower pH value, which in turn significantly reduces the sludge generated. Also, the precipitation of metal oxides is typically 1 to 2 orders of magnitude in lower solubility. The combination of

Sample Effluent Water Quality Results

Turbidity	0-2 NTU
Total Dissolved Solids	0-10 ppm
Arsenic	66.4% removal
Cadmium	99.98% removal
Calcium	78.27% removal
Calcium, dissolved	78.79% removal
Chromium	99.35% removal
Copper	99.95% removal
Lead	99.95% removal
Manganese	99.8% removal
Manganese, dissolved	99.76% removal
Nickel	99.75% removal
Silver	99.8% removal
Zinc	99.95% removal
Zinc, dissolved	99.93% removal

***Table 1**. Water Quality Results*

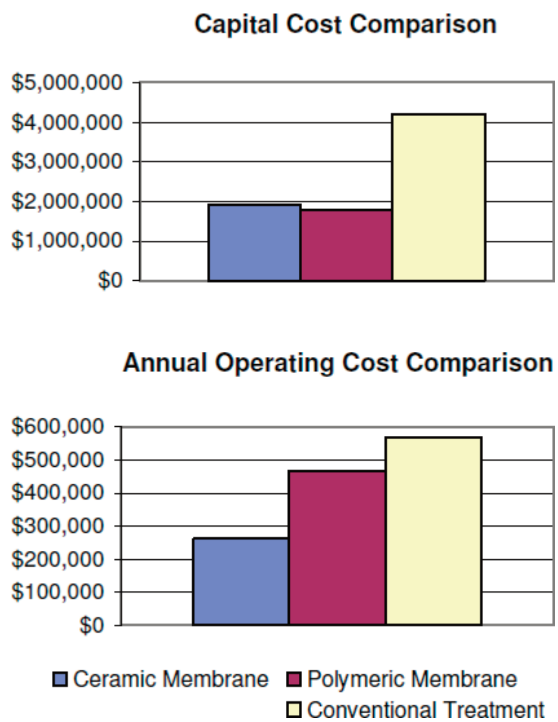

***Fig. 7** Capital and O&M Cost Comparison*

these factors typically will result in lower operating costs. At the present time, there are not any EC systems of sufficient size to gage their usefulness in the field. However, due to its cost effective at small scale operations, this should be considered as an option for the mining industry.

The other option to reduce costs is a high shear reactor. In the treatment of AMD, it is very important to encourage reaction kinetics. The high shear reactors appear to reduce the time needed for reaction kinetics. The cost of these systems is fairly low and therefore inclusion will typically improve chemical treatment.

Controlling Factors

Earlier in this paper, we discussed the lowest total cost of ownership. This can be achieved by controlling labor, chemistry, and power. As noted above, the cost of labor associated with operating the membrane system is significantly lower when compared to the HDS. The membrane system can utilize three control factors of pressure, turbidity, and pH to control the system. If these parameters are in spec, then the system will be in compliance and will fall directly on the solubility curve. Therefore, the operator only needs to be present to ensure the instruments are working properly and to handle the sludge generated by the system.

The chemistry can be performed at a lower pH due to iron co-precipitation. In addition, if EC is used, this chemistry can be enhanced. The high shear reactor will also improve reaction kinetics and will therefore increase the efficiency of the system.

The power requirements are reduced by utilizing low-pressure systems. The ceramic microfilters allow for treatment at a low pressure of 241 kPa, resulting in low power costs. All of these parameters will decrease the financial costs of treatment. The system's overall metals removal efficiency also benefits the environmental and social values of triple bottom line accounting. These benefits are: (1) environment benefits from the lower levels of pollution and (2) social aspect benefits from reusing clean water discharges.

Conclusions

The conclusions of this paper are as follows: (1) the use of membranes can benefit the mining industry by lowering the total cost of ownership, and (2) membrane system performance provides superior efficiency compared to alternatives in the removal of metals from AMD.

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