



View of Freeport McMoRan's Climax mine in Colorado, US located at approximately 3,465m from the 4,314m summit of Mount Democrat

Trends in mine water treatment

HC Liang looks at recent trends in mine water treatment, including sulphate, selenium, arsenic and antimony removal

As requirements for removing contaminants in mine water treatment continue to evolve and become generally more stringent, stricter discharge limits on contaminants such as sulphate, selenium, arsenic and antimony have been imposed on many mine sites in recent years. Mine water-treatment processes for removing these constituents are summarised below.

SULPHATE

Although sulphate has traditionally been considered relatively harmless, regulations for sulphate in mine water discharge have become more common, with discharge limits sometimes as low as 10mg/L, but typically between 250mg/L and 1,000mg/L.

The rationales for imposing sulphate discharge limits range from more generally accepted aspects of limiting the total dissolved solids (TDS) or salinity contributions from high concentrations of sulphate, to more controversial aspects such as the putative effects of sulphate on mercury methylation by sulphate-reducing bacteria, or purported chronic aquatic toxicity.

Clean water is a precious resource throughout much of the world. Therefore, in addition to removing sulphate in water treatment to meet

discharge limits, treating water to remove sulphate may also be necessary to reuse water in mine operations, where lower sulphate concentrations may be necessary to mitigate scaling, to increase recovery in water treatment, or to improve other operational parameters.

The most common way to remove sulphate from mine water is to add hydrated lime to precipitate gypsum, which is a common practice to treat acid mine drainage (AMD) and acid rock drainage (ARD) that have low pH and high sulphate concentrations. Because of the solubility of gypsum in water, however, approximately 1,800mg/L or higher concentration of sulphate remains in solution in this process. Because of this, gypsum precipitation by itself is not sufficient to meet most of the more recent sulphate-discharge standards.

Another chemical-precipitation process for sulphate removal involves precipitating ettringite by adding calcium and aluminium reagents at high pH. This chemical precipitation process can decrease the sulphate concentration to below 250mg/L because of the low solubility of ettringite at high pH.

Questions remain about the practicality of the ettringite precipitation process in full-scale mine water-treat-

ment operations, however, based on concerns about scale formation on process equipment, the large amounts of sludge generated from the process, and the costs of the reagents.

Alternative ettringite precipitation processes have been developed that can recover aluminium from ettringite to lower both reagent costs and the amount of sludge that needs to be disposed of. These processes are complex and would be considerably more difficult to implement in full-scale water-treatment facilities compared with conventional chemical treatment processes typically used in mine water treatment.

Besides chemical precipitation, nanofiltration (NF) or reverse osmosis (RO) can also remove sulphate in mine water treatment. Although NF or RO treatment can typically remove sulphate to low concentrations, there are many considerations in deciding whether NF or RO is practical at a particular mine site. For example, if only sulphate needs to be removed in the mine water-treatment process, then NF or RO may not be the best option because NF or RO treatment generates a reject waste brine stream, and brine management can become a significant cost.

However, in certain circumstances, the NF or RO brine may be chemically treated for discharge along with the permeate. Extensive pre-treatment is also often required, especially for waters with high sulphate concentrations, to prevent the NF or RO membranes from scaling and to maximise the water recovery of the membrane treatment system.

Ion exchange (IX) is also a viable treatment option for sulphate removal, ►

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Hilltop mine, an abandoned silver mine, located at 3,948m on the slopes of Mount Sherman in Colorado, US



“There are no ‘one-size-fits-all’ mine water-treatment processes or technologies to remove contaminants”

► especially if sulphate is one of only a few contaminants of concern that needs to be removed in at a particular site. As with any IX process, there would be regeneration waste streams that would need to be managed.

Biological reduction of sulphate to sulphide has been proposed for mine water treatment; however, unlike selenium removal (more detail below), biological sulphate reduction would most likely not become practical for full-scale water-treatment facilities that need to treat high flow rates and high concentrations of sulphate.

SELENIUM

Selenium discharge criteria standards have been lowered to 5µg/L in some places based on its chronic aquatic toxicity, which is much lower than the US Environmental Protection Agency’s drinking-water maximum contaminant limit (MCL) of 50µg/L. Even though selenium is an essential nutrient for most organisms, including humans, it is bioaccumulative in the environment and can be toxic to fish, invertebrates and birds that consume fish.

Dissolved selenium in mine waters typically exists as either selenite (selenium(IV)) or selenate (selenium(VI)), depending mostly on the oxidation-reduction potential (ORP) of the water, but also on the pH.

Although selenate and sulphate share similar chemical properties, practical solutions in water treatment differ between these two because of the large differences in the concentrations of sulphate versus selenium that are typically found in mine waters.

For example, while biological reduction of sulphate is not viable for most mine waters due to the high sulphate concentrations involved, it has become increasingly common for mine water-treatment plants to utilise biological selenium reduction to achieve adequate selenium removal.

In biological selenium removal, selenite and selenate are reduced to insoluble elemental selenium by microbes that utilise the selenium ions as terminal electron acceptors, and organic carbon is supplied as a source of electrons for the selenium reduction. IX has also been applied for selenium

removal at many mine water-treatment facilities and is a viable process, particularly for waters in which not many other contaminants of concern need to be removed.

Selenium can also be removed by RO. However, the same considerations for RO mentioned in the sulphate section also apply for selenium removal. Typically, if only one or a few contaminants need to be removed in mine water treatment, RO would not be the most practical treatment process.

If many different contaminants that have highly disparate chemical properties need to be removed, which would require many different chemical treatment processes for adequate removal, then RO becomes a much more attractive option because it can simultaneously remove most contaminants of concern.

When most of the selenium in the mine water is selenite, it may also be possible to add a ferric coagulant to adsorb and remove selenite by the precipitated ferric hydroxide (ferric coagulation/adsorption).

Selenate is not removed well by ferric coagulation/adsorption and would need to be reduced to selenite first to undergo significant removal using a ferric reagent. Removal of selenite using a ferric reagent typically does not achieve as high a removal percentage as biological reduction, IX or RO, and therefore may not achieve the low discharge limits being imposed in some areas.

ARSENIC

In recent years, arsenic discharge standards at many mine sites have been lowered to 10µg/L, which is the same as the current drinking-water MCL in the US. Arsenic is both an acute and chronic toxicant, and long-term exposure to low concentrations of arsenic increases cancer risks. Similar to selenium, arsenic is found in mine waters in two common

oxidation states: arsenite (arsenic(III)) and arsenate (arsenic(V)).

Arsenate is removed readily by coagulation/adsorption using ferric reagents followed by clarification or filtration. But arsenite is not removed well by this process and needs to be oxidised to arsenate first for good removal.

Ferric coagulation/adsorption is one of the most common arsenic-removal processes at mine water-treatment facilities. With the proper dosages and under optimal reaction conditions such as high ORP and neutral or lower pH, ferric coagulation/adsorption followed by filtration can reliably remove arsenic in most mine waters down to 10µg/L or below.

IX or adsorptive media such as granular ferric hydroxide (GFH) and activated alumina (AA) can also be used to remove arsenate in mine water treatment.

As with ferric coagulation/adsorption, an oxidant would need to be added to oxidise arsenite to arsenate for influent waters containing mostly arsenite to work more effectively, and GFH works

better over a wider pH range than AA. Similarly, RO also rejects arsenate better than arsenite. IX, GFH, AA and RO are used less often than ferric coagulation/adsorption for arsenic removal in mine water treatment.

ANTIMONY

Antimony is in the same chemical group as arsenic and has similar chemical properties. Long-term chronic exposure to low levels of antimony has been associated with blood disorders. Analogous to arsenic, antimony is found in mine waters as either antimony(III) or antimony(V).

At many sites, antimony discharge standards have been lowered to 6µg/L, which is the same as the drinking-water MCL in the US. Similar to arsenic removal, a common antimony removal process in mine water treatment is ferric coagulation/adsorption followed by filtration.

Unlike arsenic, however, antimony removal using ferric coagulation/adsorption is much more effective at approximately pH 5 than at neutral pH. RO can also remove antimony, but is not

often used for antimony removal alone in mine water treatment.

SUMMARY

There are no 'one-size-fits-all' mine water-treatment processes or technologies to remove contaminants, and every mine water-treatment design needs to be evaluated carefully for the particular water chemistry of the mine water to be treated, the treatment goals and requirements, and practical aspects such as operational ease and functionality. ▼

Reverse osmosis (RO) treatment system at mine water treatment facility



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