Can treatment and disposal costs be reduced through metal recovery?

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Abstract This paper describes a framework to conduct a "metal-recovery feasibility assessment" for mining influenced water (MIW) and associated treatment sludge. There are multiple considerations in such a determination, including the geologic/geochemical feasibility, market feasibility, technical feasibility, economic feasibility, and administrative feasibility. Each of these considerations needs to be evaluated to determine the practicality of metal recovery from a particular MIW.

Keywords metal recovery, copper, zinc, critical and strategic elements, economics, geoenvironmental models

Introduction

Most hard-rock operations will need to treat water at some point during the mining life cycle, and many mining influenced waters (MIWs) require treatment in perpetuity. Commonly, MIWs contain elevated concentrations of metals, such as copper and zinc, which could be potential economic resources to help offset treatment costs. Also, there is a growing interest in many trace elements that historically have had little economic significance but that are now increasingly being used in high-technology defense and green-energy applications (*e.g.* solar panels, wind turbines; Eggert *et al.* 2008; Jaffe *et al.* 2011). Many of these elements are recovered as byproducts of copper and zinc processing (see Bleiwas 2010), and hence may occur in MIWs. For example, tellurium and selenium are byproducts of copper production, gallium is a byproduct of zinc production, and cadmium and indium are byproducts of zinc and copper production (USGS 2013b). The recent prices of these trace elements (USGS 2013a) warrant investigation into their recovery as a byproduct in a metal treatment and recovery facility. Would the potential economic gains from metal recovery be adequate to reduce treatment costs of MIWs and reduce disposal costs of their associated sludge?

A "metal-recovery feasibility assessment" can be performed for an individual MIW or treatment sludge. The feasibility of economic metal recovery depends upon numerous factors that include (1) chemical/mineralogical composition and consistency, (2) amount and consistency of the available volume (seasonality) or mass, (3) existence, location, specifications, and terms of a potential buyer for the recovered metal(s), (4) availability of recovery technologies, (5) economic factors (*i.e.* total costs), and (6) regulatory and liability concerns. Fig. 1 summarizes some considerations involved in evaluating the feasibility of metal recovery from MIW and associated treatment sludge.

Geologic/Geochemical Feasibility

Characterization of the MIW is an important initial step in a metal-recovery feasibility as-

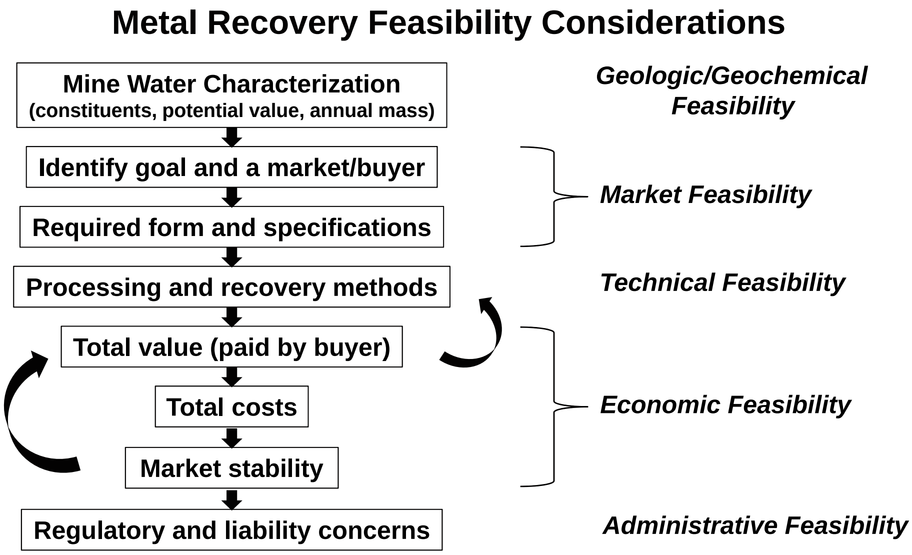

Fig. 1 *Considerations for the feasibility of metal recovery from mining influenced water and associated treatment sludge. Arrows indicate iterative steps. Transportation costs can be a deciding factor in the economic feasibility of metal recovery.*

sessment. Fig. 2 illustrates an approach that can be used to characterize MIW. Potential value in the Fig. represents 30 % of the late 2012 metal prices from the London Metal Exchange (LME; or from USGS 2013b; see http://minerals.usgs.gov/minerals) and can be a useful rough guide to prioritize selective recovery of particular metals. The 30 % factor is mentioned in the case study at Wellington-Oro discussed later in this paper and represents a more realistic price than the gross LME value. Although metal prices for many of the trace elements are considerably higher than those for the major/minor elements, the greater abundance of the major/minor elements provides a greater potential value relative to the trace elements. Nevertheless, if elements can be recovered as a byproduct, their recovery may enhance the overall recovery value if a market can be identified. It is also useful to consider each chemical element as a function of a basis, such as annual mass or the amount of MIW that can be treated during a given period of time. An example calculated from water composition reported for the Berkeley Pit, Butte, Montana, USA (Davis and Ashenberg 1989) and a 30 % factor reveals that treatment of one million liters of water could yield $US500 from copper recovery, $US300 from zinc recovery, and $US250 from magnesium recovery. Prior to water treatment, the Berkeley Pit was filling at a rate of 20 ML/d, and the associated Horseshoe Bend water treatment plant, when it is at full capacity, will be treating approximately 26.5 ML of pit water per day (www.pitwatch.org). Some copper currently is being recovered from the pit waters using scrap iron (via passive copper cementation), but these calculations indicate that the potential value of copper, zinc, and magnesium that could be extracted would be in excess of $US27,000 per day, assuming 100 % recovery and a value of 30 % of the LME price.

The presence of potentially recoverable elements in MIW can be predicted from the mineral-deposit type and identified mineral phases (Plumlee *et al.* 1999). Geoenvironmental models are data compilations of environmentally significant geologic and geochemical characteristics for different types of mineral deposits (du Bray 1995; Plumlee 1999). These models can help target specific mine sites, based on mineral-deposit type being mined,

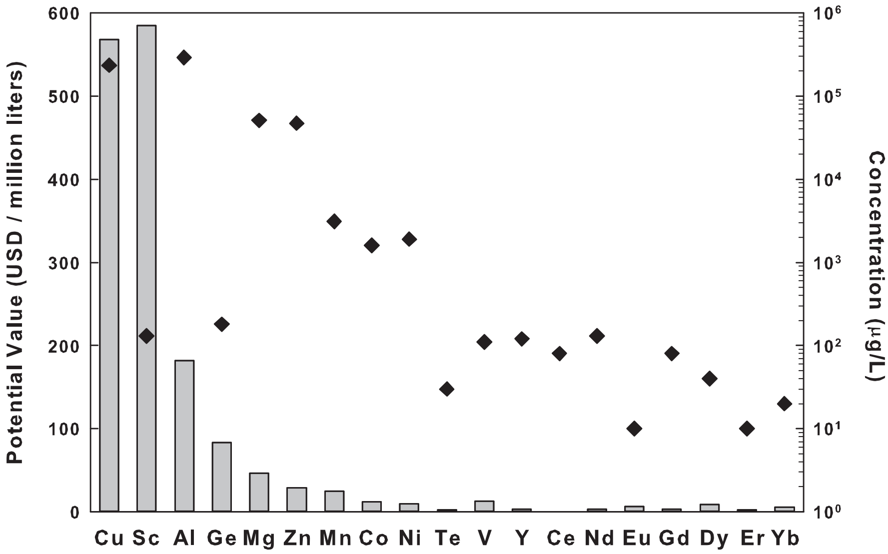

Fig. 2 *Example of mining influenced water characterization for a metal-recovery feasibility assessment. Concentrations (diamonds) are from unpublished 1993 data for the Reynolds Adit, Rio Grande County, Colorado, USA. Potential values (bars) are based on either 30 % of the late 2012 metal price from the London Metal Exchange or USGS (2013b) for each chemical element. Note that metal recovery rates vary depending upon the treatment and recovery technology used. Prior to installation of a bulkhead, peak flows at the Reynolds Adit were 3.3 to 4.9 ML per day with an estimated annual copper load of 65,000 kg (CDPHE 2010).*

that would be good candidates for recovery of particular chemical elements from MIW. For example, deposit types that produce highly acidic MIW with the highest concentrations of copper, zinc, aluminum, and magnesium include volcanogenic massive sulfide, epithermal quartz-alunite, and some porphyry copper deposits. All of these deposit types have relatively high concentrations of iron and copper sulfides and relatively low concentrations of carbonate minerals in the ores, wastes, or host rocks compared to other deposit types. These deposits types are potential targets for consideration of copper and zinc recovery. Some energy-critical trace elements that may be enriched in porphyry copper systems include tellurium, cobalt, nickel, gallium, indium, silver, and cadmium (Yano *et al.* 2013). MIW from mined porphyry copper deposits may therefore be potential targets for the recovery of these trace elements. Rare earth elements (REEs) can be enriched in some deposit types that generate low-pH conditions, such as volcanogenic massive sulfide and epithermal quartz-alunite deposit types (USGS, unpublished data), so MIW in these deposit types may be potential candidates for recovery of REEs.

Technical Feasibility

Recent increases in the prices of many metal commodities have revived questions as to whether metals can be economically recovered from MIW. Determining which metals might be present in sufficient concentrations to be economically recoverable (and the form and purity of the concentrate required by the market) can help prioritize research into which current technologies can be applied and which new technologies need to be developed for metal recovery. Zinck (2005) reports that the two main approaches for metal recovery from mining wastes are hydrometallurgical (*e.g.* leaching followed by solvent extraction or ion exchange) and pyrometallurgical (*e.g.* smelting). Mosher (1994) describes an industry approach that used MIW treatment sludge as a smelter feedstock, recovering incidental saleable metals, and producing non-hazardous products.

The primary treatment technology for MIW is hydroxide precipitation. The resulting sludge from this type of treatment results in a metal mixture that generally is not suitable for any market specifications. Sulfide precipitation is an alternate treatment technology. In sulfide precipitation, some metals (*e.g.* ZnS) can be selectively removed. Sulfide precipitation lends the possibility of selective recovery due to different solubility products for different metals.

Case Study: Wellington-Oro Water Treatment Plant

The Wellington-Oro mining complex is located near the town of Breckenridge, Summit County, Colorado, USA. The water treatment plant, which began operation in late 2008, uses a sulfide precipitation process to remove zinc and trace cadmium as sulfides in a mixed concentrate. Other metals, such as iron, primarily remain in solution. The water treatment plant has the potential to produce 40,000 kg of zinc per year (based on the design flow of 820,000 L/d and influent zinc concentration of 134 mg/L). The filtercake contains approximately 50 to 57 % zinc on a dry weight basis (unpublished data 2009 and 2011) and is classified as a nonhazardous waste (Bratty *et al.* 2008). This treatment technology allows for the selective recovery of zinc that is suitable to send to a smelter. The zinc sulfide sludge produced has been purchased by Nyrstar, Clarksville, Tennessee (the primary zinc producer in the United States). Nyrstar covered the shipping costs ($US0.31 per kg of zinc content) and reportedly paid the town of Breckenridge $US0.33 per kg of zinc content (personal communication). In this case, the smelter's cost to obtain the zinc was about 30 % of the average 2010 LME price.

Additional treatment technologies exist for MIW. Gusek and Figueroa (2009) provide an overview of MIW treatment technologies. Some alternative technologies include solvent extraction, ion exchange, biosorption (using microorganisms and aquatic and terrestrial plants), electrowinning, and copper cementation (copper reduction on iron metal). Some of these technologies, or hybrids of these technologies, may lend themselves to the selective recovery of metals and trace elements. Different technologies need to be systematically evaluated for their technical, economical, and environmental benefits for metal recovery from different types of MIW.

Market Feasibility

Smelters may be an important market for metal recovered from MIW, but their practicality depends on the physical and chemical properties of the metal-containing concentrate recovered from MIW and also on factors such as the quantities of concentrate generated, distance to the nearest smelter that will accept the concentrate, transportation costs, and contaminants present in the concentrate. In addition to smelters, other possible markets also need to be considered. For example, the fertilizer industry has been a secondary market for zinc recovered from waste sources (USEPA 1999), and a pigment manufacturer has been identified as a secondary market for iron-oxide sludge recovered from abandoned coal mines (Hedin 2003; Silva *et al.* 2011). Zinck (2005) discusses several sludge reuse options including utilization in construction materials, agricultural land applications, metal adsorbents, and carbon dioxide sequestration. Each market has specific requirements for the forms and purity of the concentrate that they will accept. Marketability must be considered when evaluating the specifications of the potential product(s) produced by the treatment plant.

Economic Feasibility

Economic considerations help drive the interest in metal recovery. Metal prices are published by numerous sources and are based on numerous factors that include specifications, contractual agreements, and other criteria, and are summarized in USGS (2013a). The value of metals contained in MIW concentrates and sludge generally is a fraction of the prices listed for global or domestic markets (see Wellington-Oro case study above). Therefore, total costs (including treatment costs), market values, and potential return on investments need to be (1) estimated prior to making investments, and (2) weighed against the value received from the recovered product(s). Zinck and Griffith (2013) conducted a broad survey of MIW treatment facilities and reported that the average cost to treat one cubic meter of MIW is $CN1.54. Price fluctuation of metals also impacts the economic feasibility of metal recovery. For example, smelter contracts can vary over time with electric, fuel, and transportation costs and with the changes in metal prices.

Costs that need to be considered include such items as acquisition of capital and working capital, bond, labor costs, maintenance, infrastructure, reagents, insurance, interest, detailed engineering studies, and fees. Additional, less quantitative economic considerations for metal recovery from MIW include (1) energy required to recover the metal compared with the energy required to mine the ore, (2) costs of obtaining required permits for treatment and discharge, (3) preservation of land resources that might otherwise be disturbed by mining, (4) value of clean water as a result of MIW treatment, and (5) reduction in liability and disposal costs when potentially toxic metals are recovered. Even if not currently economic, metal recovery from MIWs can be used to offset treatment and disposal costs, and to reduce liability. Also, treated water may be used at the mining site, which would reduce the costs of acquiring water from other sources.

Administrative Feasibility

Administrative feasibility incorporates concerns related to regulatory and liability matters. There are several regulatory and potential liability concerns (in particular with the Clean Water Act and the Comprehensive Environmental Response, Compensation, and Liability Act—CERCLA, also known as "Superfund") that address metal recovery from MIW, as well as mining facilities as a whole. Recently, some of the potential liability concerns have been addressed through the U.S. Environmental Protection Agency's (USEPA) Good Samaritan Initiative, which is "an agency-wide initiative to accelerate restoration of watersheds and fisheries threatened by abandoned hard rock mine runoff by encouraging voluntary cleanups by parties that do not own the property and are not responsible for the property's environmental conditions" (see http://water.epa.gov/action/goodsamaritan). The USEPA made clarifications to the Good Samaritan legislation in December 2012 (view the memorandum at http://water.epa.gov/action/goodsamaritan). USEPA considers proposals to demonstrate the viability of metals recovery using the Good Samaritan policies for both CERCLA and the Clean Water Act (Carol Russell, USEPA, personal communication).

Conclusions

Most mining operations treat MIWs that commonly contain elevated concentrations of metals, which could contribute revenues to offset treatment and disposal costs. MIWs traditionally have been considered as a waste that must be treated and waste treatment byproducts (*e.g.* sludge) be sent for disposal (either as hazardous or non-hazardous waste). The feasibility of metal recovery from MIWs needs to be evaluated on a case-by-case basis. Even if not currently economic, metal recovery from MIWs has the potential to be used to offset treatment and disposal costs and to reduce liability.

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