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Review

The chemistry of conventional and alternative treatment systems for the neutralization of acid mine drainage ☆

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Abstract

The oxidation of pyritic mining waste is a self-perpetuating corrosive process which generates acid mine drainage (AMD) effluent for centuries or longer. The chemical neutralization of these complex, buffered effluents result in unstable, metal-laden sludges, which require disposal to minimize long-term environmental consequences. A variety of passive treatment systems for AMD, developed in the past two decades, combine limestone and organic substrates in constructed wetlands. These systems work well initially but over the longer term fail due to clogging with and the depletion of available organic carbon. However, some ecologically engineered systems, which exploit the activities of acid reducing microbes in the sediment, rely on photosynthesis in the water column as a source of organic matter. The primary productivity in the water column, which also generates some alkalinity, provides electron donors for the microbial reduction processes in the sediment. In its consideration of 'passive' systems, the literature has placed undue emphasis on sulphate reduction; thermodynamical iron reduction is equally important as is the need to prevent iron oxidation. Secondary precipitates of iron play a significant role in sediment-driven biomineralization processes, which affect the anaerobic degradation of organic matter and the stability of the resulting metal sulfides. One such passive system, which utilized a floating root mass as a source of organic carbon, is described. An extensive review of the literature and the chemical and biogeochemical reactions of AMD treatment systems, lead to the conclusion, that sediment based ecological systems offer the greatest potential for the sustainable treatment of AMD.

Keywords: Acid mine drainage; Acid rock drainage; Passive treatment; Lime treatment; Ecological engineering; Microbial remediation

Contents

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1. Introduction

By definition, mining is not sustainable. Yet it is not unreasonable to ask if the treatment of mining wastes can be conducted in a sustainable manner. Ideally, a sustainable solution to any industrial problem is economically viable, generates little or no waste, is energy efficient and is not a source, in itself, of pollution. A growing body of evidence now suggests a causal relationship between the environmental and economic performance of companies since the reduction of pollution enhances profit by increasing efficiency, reducing compliance costs, and minimizing future liabilities (King and Lenox, 2001), economies that should all be of interest to the mining sector.

By general consensus, Acid Mine Drainage (AMD) is the most critical environmental problem created by mining. AMD is unique among industrial contaminants. Because of its leaching capacity, augmented by the activities of the bacteria it attracts, it is self-perpetuating. Nordstrom and Alpers (1999) estimate that without preventative measures the Richmond Mine, at California's Iron Mountain, would generate AMD, with $\mathrm{pH} < 1$ and containing several g L^{-1} of dissolved metals, for 3000 years. Kalin (2001) estimated, based on oxidation rates derived from tailings pore water samples, that the site of a small zinc/copper mine in northwest Ontario, Canada, would generate AMD for 1000 to 35,000 years. These may be extreme examples but it is not uncommon for base metal mines and their waste products to generate acid for more than 100 years. Since AMD is self-renewing, an ideal solution to it would also be self-perpetuating.

There are two distinct strategies for treating AMD. The conventional solution is to collect and chemically treat acidified effluents in a centralized treatment plant. Alternatively, effluents can be routed through natural or constructed wetlands within which microbial communities perform the same function. Such a passive treatment scenario meets the definition of sustainability. It is economical, non-polluting, and is not a source of secondary wastes. Moreover, a well-engineered passive treatment system is a closed ecological system and hence is self-renewing. But do such systems work? This paper will discuss the chemistry of both the conventional and alternative approach to the treatment of AMD.

2. The chemistry of conventional AMD treatment

The process of AMD generation is well understood. AMD is formed by the oxidation of metal sulphides, mainly pyrite and marcasite, which have been exposed to air and water during and following mining operations. AMD formation involves iron sulphide oxidation (1), ferrous iron oxidation (2), ferric iron hydrolysis (3), and the enhanced oxidation of ferric sulphide ions (4).

$$\mathrm{FeS_2} + 7/2\mathrm{O_2} + \mathrm{H_2O} \rightarrow \mathrm{Fe^{2+}} + 2\mathrm{SO_4^{2-}} + 2\mathrm{H^+} \quad (1)$$

$$\mathrm{Fe^{2+}} + 1/4\mathrm{O_2} + \mathrm{H^+} \rightarrow \mathrm{Fe^{3+}} + 1/2\mathrm{H_2O} \quad (2)$$

$$\mathrm{Fe^{3+}} + 3\mathrm{H_2O} \rightarrow \mathrm{Fe(OH)_3(s)} + 3\mathrm{H^+} \quad (3)$$

$$\mathrm{FeS_{2+}} + 14\mathrm{Fe^{3+}} + 8\mathrm{H_2O} \rightarrow 15\mathrm{Fe^{2+}} + 2\mathrm{SO_4^{2-}} + 16\mathrm{H^+} \quad (4)$$

In a conventional treatment system alkaline materials and other chemicals are added to the AMD to neutralize it and enhance hydroxide precipitation. A preferred alkaline material is quicklime CaO (5), which forms Ca hydroxide in the presence of water (6).

$$\mathrm{CaO} + \mathrm{H_2O} \rightarrow \mathrm{Ca(OH)_2} \quad (5)$$

$$\mathrm{Ca(OH)_2} \rightarrow \mathrm{Ca^{2+}} + 2\mathrm{OH^-} \quad (6)$$

Following dissolution of the hydrated lime, pH increases and metal ions precipitate as hydroxides as shown for Cu in Eq. (7).

$$\mathrm{Cu^{2+}} + 2\mathrm{OH^-} \rightarrow \mathrm{Cu(OH)_2} \quad (7)$$

Each metal in solution contributes a specific metal acidity to the AMD; additionally, specific metals precipitate at specific pH levels. For example,