FOCUSING ON THE PROBLEM OF MINING WASTES: AN INTRODUCTION TO ACID MINE DRAINAGE

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Background

Mining waste, generated from active and inactive mining sites and from beneficiation activities, and its impact on human health and the environment are a continuing problem for government entities, private industry, and the general public. The nation's reported volume of mining waste is immense. A scoping study conducted by the Western Governors' Association Mine Waste Task Force (1) collected the following statistics on inactive and abandoned mines (IAMs) by state:

> Arizona -- 80,000 IAM sites covering 136,653 acres, pollution 200 miles of surface waterways.
> California -- 2,484 IAM sites, 1,685 mine openings, and 578 miles of polluted streams.
> Colorado -- 20,299 mine openings and 1,298 miles of affected streams.
> Idaho -- 27,543 acres affected by IAMs.
> Missouri -- 7,655 IAM sites covering 48,175 acres, with 109 miles of affected streams.
> Montana -- 20,000 IAM sites covering 153,800 acres, with 1,118 miles of stream damage.
> New Mexico -- 25,320 acres and 69 miles of stream affected by IAMs.
> Oklahoma -- 26,453 acres affected by IAMs.
> Utah -- 25,020 acres affected by IAMs, with 83 miles of polluted streams.

Of this total volume, approximately 85 percent is attributed to copper, iron ore, uranium, and phosphate mining and related activities. Approximately one-half of the waste generated is mining waste and one-third is tailings, with the balance consisting of dump/heap leaching wastes and mine water.

Because of the extent of these problems, the U.S. Environmental Protection Agency in conjunction with the U.S. Department of Energy organized a series of seminars to disseminate available information on approaches for addressing mine waste. This document presents papers written by the seminar presenters, for which this introductory paper provides a general context.

Definition and Chemistry of Acid Mine Drainage (AMD)

The types of mine waste problems are numerous, but the most difficult one to address is the acid mine drainage (AMD) that emanates from both surface and underground mine workings, waste and development rock, and tailings piles and ponds. AMD is defined as drainage that occurs as a result of sulfide oxidation in rock exposed to air and water. In the case of iron sulfide (pyrite/marcasite), the chemical reaction in the acid-generating process can be simplified to:

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O >>> Fe(OH)_3 + 2SO_4 + 4H$$

In the presence of oxygen and water, pyrite oxidizes to form iron hydroxide (commonly called "yellowboy"), sulfate, and hydrogen ions. The liberation of hydrogen ions causes acidity in water passing over the rock. Every mole of pyrite yields four moles of acidity.

AMD can be characterized by low pH and increased acidity, elevated heavy metals, sulfate, and total dissolved solids (TDS). The low pH water that results from acid generation is capable of solubilizing heavy metals contained within the waste rock. Most harmful to the environment is the high metals loading in the water emanating from the waste material. As AMD flows away from the acid-generating source and moves into the receiving environment where the pH is buffered, discoloration of the streambed or the material that the AMD is passing over often is caused due to precipitation of solid metal hydroxides.

Stages in the Development of AMD

The development of AMD involves a complex combination of organic and sometimes inorganic processes and reactions. In order to produce severe acid drainage, where the pH of the system drops below 3, sulfide minerals must create an optimum microenvironment for rapid oxidation and must continue to oxidize to oxidize for a sufficiently long time to exhaust all of the neutralization potential of the rock (2). The potential of sulfide rock to generate acid is strongly related to the amount of alkaline, often calcareous, material in the rock. For example, a rock containing 5 percent sulfide minerals may not generate acid due to an overabundance of calcite in the rock that is available for acid neutralization. Another rock, containing less than 2 percent sulfide minerals might generate a considerable amount of acid if no neutralizing minerals are present within it.

When reactive sulfide rock is initially exposed to flowing water and oxygen, sulfide oxidation and acid generation begins. Any calcium-based carbonate in the rock immediately neutralizes this small amount of acidity and maintains neutral to alkaline conditions in water passing over the rock (3). As acid generation continues and the neutralizing agent is consumed or is rendered ineffective in further neutralization, the pH of the water decreases, which in turn enhances the conditions for further acid generation. As the rate of acid generation accelerates, the pH progressively decreases in a step-like manner. Each plateau of relatively steady pH represents the dissolution of a neutralizing mineral that becomes soluble at that pH (3). If the rate of acid generation remains high enough to remove all of the neutralization potential in the rock, the pH values will drop below 3 and AMD will become severe. These various stages can last for weeks, months, or centuries until the sulfide minerals completely oxidize and the rock becomes inert, or until special waste management and AMD control actions are taken.

Prediction of AMD

The prediction of AMD in particular, is a rapidly evolving science. Predictive tests specifically designed for sulfitic coal mine wastes have been around for decades. Significant advances in the predictive techniques applied to hard rock metal mine waste samples have been made in the past 5 to 10 years. Recent studies have been conducted comparing various predictive tests for hardrock samples (4,5). Accurate predictive testing, proper waste rock characterization, and proper interpretation of the resulting data are all of paramount importance in developing successful sulfide waste rock management techniques. Conducting proper predictive tests prior to developing waste management plans is the preferred choice from an environmental as well as an economic standpoint. Millions of dollars can be saved as a result of focusing on preventing AMD rather than reacting to problems it can cause.

Predictive analyses can range from simple comparisons to complex laboratory testing and computer modeling. A simple, but very useful, assessment might include comparing a proposed mining operation with geologically similar and/or nearby mines where acid generation is known to be a problem or not. Rock samples may undergo relatively inexpensive, short-term "static" predictive testing (e.g., acid/base accounting) in which the amount of acid-generating potential of the rock is weighed against the acid-neutralizing potential of the rock. Static tests are qualitative tests only. Rock types that undergo static tests that result in an indication for potential acid generation may undergo more expensive, long-term "kinetic" tests (e.g., humidity cells or column leach tests) in which actual weathering reactions are simulated in the laboratory. Kinetic tests are qualitative indicators of the rate and amount of acid that a given sample may generate.

Control of AMD

Much of the effort to control AMD in the past has been directed at treating the symptoms rather than controlling the problem at the source. In the early 1990's, significant research was undertaken to develop improved sulfide waste management techniques for hardrock mines. Control of acid generation can be achieved by removing one or more of the three essential components in the acid-generating process (i.e., sulfide, air, or water). Steps that can be taken to control AMD include:

Waste segregation and blending. This would include thoroughly blending the acid-generating rock with enough rock of a net neutralizing potential, that neutral pH levels within the waste system are maintained.

Base additives. Alkaline materials such as limestone, lime, and soda ash can be added to the sulfide rock upon disposal to buffer acid-generating reactions.

Covers and caps. Soil, clay, and synthetic covers can be placed over the acid-generating rock to minimize the infiltration of water and air into the system. Water covers at acid-generating tailings impoundments have been effective in controlling the problem.

Bactericides. The introduction of certain chemicals that reduce the bacteria (*Thiobacillus ferrooxidans*) that catalyze the acid-generating reactions have been effective in controlling AMD.

Collection and treatment of contaminants. In this case, AMD is collected and treated using active or passive treatment systems. Active treatment might include base additives to precipitate metals out of solution, remove the resulting sludge, and discharge the treated water. Passive treatment might include passing contaminated water through a constructed wetlands designed to remove contaminants. These control options are less attractive in the long term because they treat the symptoms of AMD rather than controlling the problem at the source.

Bioremediation. The use of microorganisms to remove metals from mine drainage.

Conclusions

AMD and the sources of its production are the legacy of over 100 years of mining in the western United States. AMD has been a problem in the eastern United States and throughout the world even longer. The presentations in this publication describe only a small fraction of the current thinking and ongoing research to address the issue of mining wastes in general, and AMD in particular, using comprehensive and cost-effective approaches. The problem of mining wastes is daunting. An all inclusive description of the types of environmental issues posed by mining wastes is beyond the scope of this document. Nonetheless, the case histories presented reflect common mine waste problems and provide insight to state-of-the-art management techniques. Although these techniques have been used to successfully address aspects of mine waste, they warrant further research and site application. For the country's best scientists and engineers, the challenge presented by mine wastes involves developing solutions to problems created in the past, while seeking ways to avoid these problems in the future.

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