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Wetlands: Mechanisms For Treating Acid Mine Drainage

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"Mechanisms For Treating Acid Mine Drainage"

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Introduction

A great deal of attention has been given to wetlands in recent years. Research suggests that natural and/or constructed wetlands may play a valuable role in flood flow moderation, sediment retention and stabilization, and waste water treatment while providing habitat for game and nongame wildlife. Only within the last 10 years have wetlands received serious attention in the treatment of acid mine drainage (AMD).

Large volumes of geologic material are exposed to the environment during the mining of coal and metal. Pyritic minerals (FeS_2) commonly associated with coal and metal deposits are subsequently exposed to air and water (oxidized and hydrolyzed) resulting in AMD. These discharge waters typically have a low pH and high levels of iron and sulfate. Due to the elevated acidity, increased solubility of other metals such as Al, Mn, Cu, and Zn associated with AMD has increased concern about possible toxic effects to plants, aquatic life, animals, and even humans in the coal regions of the Appalachian states. Regulations have been established by federal and state authorities to monitor discharge. Currently, Kentucky requires a pH of 6.0-9.0, and an average daily instream iron and manganese concentration not to exceed 3.5 and 2 ppm, respectively.

Traditional treatment of AMD involves collecting drainage in ponds and adding alkaline reagents such as caustic soda or lime and aeration to neutralize acidity and precipitate metals. This treatment method is costly in terms of equipment, chemicals, and manpower. In addition, this form of AMD treatment must be continued for an indefinite period. Estimates of this cost to the coal industry exceed $1 million per day (Kleinmann 1990).

Researchers at Wright State University and West Virginia University (WVU) independently noted that AMD from abandoned mine lands was improved in quality after passing through natural moss (Sphagnum) wetlands in Ohio and West Virginia (Huntsman et. al. 1978, Wieder and Lang 1982). Since then, investigators have been able to observed and document this process in constructed wetlands and greenhouse experiments. The following discussion focuses on our current understanding of the chemical and biological processes associated with AMD amelioration utilizing wetlands technologies.

Role of Wetland Plants and Substrates

Early attempts to duplicate natural wetlands receiving AMD simply involved planting cattails (*Typha* sp.) in existing sediment ponds on mined sites. The hypothesis was that the vegetation would spread and the discharge would be treated. In many cases, the vegetation either did not proliferate or died and the wetland remained ineffective in treating AMD. These failures prompted further research to characterize more thoroughly the substrates and vegetation most effective in treating AMD and to gain a better understanding of other important parameters in the biochemical process.

Cattails (*Typha* sp.) have been found to have a great tolerance to adverse environments. One of the reasons could be that the uptake and accumulation of metals into their tissue does not become detrimental to the plant. However, research indicates that metal uptake by cattails may account for less than 1% of the iron removed by a volunteer wetland treating AMD (Sencindiver and Bhumbia, 1988). Species such as *Sphagnum* moss also have a well-documented capacity to accumulate iron. Algae and a few other hydrophytic species have also received attention due to their increased metal removal affinity. Selection of hydrophytic species should first be based on the ability of the plant to survive local conditions. The use of exotic species for aesthetic reasons should be cautiously considered, even when they have been proven effective elsewhere.

Although the role of wetland plants is not completely understood, their most important role appears to be their ability to stimulate both aerobic and anaerobic microbial processes. This is accomplished by plants providing sites for microbial attachment, releasing oxygen from their roots, and supplying organic matter for heterotrophs (microorganisms requiring complex organic compounds of nitrogen and carbon for metabolic synthesis).

Wetland substrates also to vary in their ability to remove metals by exchange reactions, precipitation, and organic complexation. These abiotic (do not require microorganisms) chemical and physical processes could account for over 90% of the metal retention in wetlands treating AMD. Results of greenhouse experiments at the University of Kentucky, showed pine-needle and hay mixtures to be more efficient than peat, sphagnum moss and mine spoil mixtures in reducing acidity and Al, Cu, and Zn concentrations. The substrates (except the mine spoil mixture) showed similar efficiencies for Fe removal, but all substrates were a source rather than a sink for Mn (Figures 1 and 2).

Exchange reactions and the formation of organic complexes by substrates apparently are important processes for only a short time during the first stages of operation in a new wetland system when biological activity is limited. After these processes reach their stable level, precipitation processes dominate in forming hydroxide and secondarily in forming sulfate or sulfide forms.

Chemical and Biological Oxidation/Reduction Reactions

Constructed wetlands utilize both chemical and biological processes as a means of ameliorating AMD. Microbial sulfate reduction is an important process in treating AMD which requires a source of sulfate, carbon (organic matter) and a reducing environment.

Sulfate reducing bacteria are anaerobes that live in the absence of free oxygen and utilize a small range of simple carbon sources provided by plants and substrates. Sulfate, released into mine drainage as a result of pyrite (FeS_2) oxidation, is subsequently reduced to sulfide. Two products of sulfate reduction, hydrogen sulfide (H_2S) and bicarbonate (HCO_3), are responsible in part for the mitigation of AMD within constructed wetlands. Bicarbonate adds alkalinity and increases the pH and H_2S precipitates iron and other metals. In addition to its metal removal potential, sulfate reduction consumes acidity (H^+) and raises water pH. Likewise, some iron compounds which form as a result of pyrite weathering, can be reduced by anaerobic iron reducing bacteria in the wetland.

For these processes to progress, the wetlands must be constructed to enhance anaerobic conditions and contain a suitable population of sulfate and iron reducing bacteria. Preliminary results from a constructed wetlands study at Virginia Tech suggest that seasonal fluctuations in biological activity may reduce the effectiveness of wetlands to treat AMD year round (Table 1). Significant fluctuations in sulfate reducing bacteria populations occurred between February and June with the highest numbers present during the warmer months. Virginia Tech researchers also found no difference in sulfate reducing bacteria population size between areas with and without cattails.

If dissolved oxygen concentrations present in wetland surface waters are favorable for pyrite minerals to oxidize, discharge waters may actually increase in acidity. Therefore, by exposing the AMD in the open environment (prevalent aerobic conditions) we initiate metal oxidation/precipitation reactions. At the same time, we induce metal hydrolysis reactions which generate more acidity. It is important then to maintain the AMD anaerobic and increase alkalinity before the AMD is exposed to the open environment.

Constructed Wetlands Design

Limited research has lead to considerable debate concerning proper design criteria for treatment of AMD in constructed wetlands. However, there appears to be some agreement about the basic conditions that must be in place. A wetland should be constructed to increase the residence time and interaction of the AMD with the substrate material where microbial transformations and oxidation/ reduction reactions occur. This may involve installing baffles, regulating flow rates, and establishing subsurface flow through the wetlands.

Alkalinity generation in a wetland is important for precipitating metals and raising pH especially in the early stages of treatment so that enough buffer is generated to counteract the expected increase in acidity resulting from the aerobic stages of treatment. One method of generating alkalinity is by placing a bed of limestone beneath the layer of substrate with a perforated pipe serving as an underground drain. This type of drainage system prevents channeling, increases the retention time of the water and forces the water through the anaerobic zone of the wetland. However, efficient generation of alkalinity from the dissolution of limestone is often reduced in an oxygenated environment with time due to iron and manganese oxidation and precipitation reactions that coat or armor the limestone surface. More recent approaches utilize anoxic limestone drains (ALD's) which add alkalinity to AMD by keeping limestone and mine water anoxic (containing low levels of dissolved oxygen).

These (ALDs) consist of high quality limestone buried in a trench, underdrain, or cell. Anoxic drains intercept acid water while it is underground and direct it into a buried trench of limestone. By keeping the limestone and mine water anoxic, limestone can continue to dissolve without becoming armored. The water can then be diverted into a wetland where oxidation, hydrolysis and precipitation reactions can occur. Current approaches attempt to reduce inherent Fe^{3+} and dissolved oxygen levels in AMD by utilizing anaerobic lagoons before directing the AMD through the ALD. This approach appears promising as a water pretreatment, however, more research is needed to determine the long-term effectiveness of ALDs.

Summary

Acid mine drainage is a common problem where coal and other minerals are mined. Treatment of AMD by chemical methods are effective but costly, whereas constructed wetland systems offer a low cost, natural approach alternative. Several important factors should be considered when treating AMD by wetlands. They are: (1) flow rate and water chemistry; (2) wetland substrate; (3) wetland vegetation; and (4) microbial composition and activity. Based on current knowledge, wetland technologies could provide sufficient treatment for many AMD discharges. However, since the biochemical treatment processes involved in those systems are not well understood, long-term efficiency predictions need to be cautiously evaluated by additional research under field conditions.

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