ANOXIC CATTAIL WETLAND FOR TREATMENT OF WATER ASSOCIATED WITH COAL MINING ACTIVITIES.[1]

by

K. N. Duddleston, E. Fritz, A. C. Hendricks, K. Roddenberry[2]

ABSTRACT. An experimental anoxic cattail wetland was constructed from an existing series of sediment ponds. Acid mine drainage from an inactive coal refuse disposal facility was collected and routed through the wetland. Prior to construction of the wetland, a conventional caustic soda treatment system was used to maintain compliance with National Pollutant Discharge Elimination System discharge coal mining point source parameters. Capital and operating costs for the wetland have been monitored for comparison with conventional water treatment costs. An existing sediment basin was converted to the wetland thus reducing initial costs. Long-term liability under SMCRA is anticipated to be reduced through bond reduction and eventual bond release.

Influent and effluent water samples were monitored from January 1991-February, 1992. The pH of both influent and effluent was 7.0. Iron concentration decreased from an average of 5 mg/l to 2mg/l, and manganese concentration decreased from an average of 4 mg/l to 1.5 mg/l as water passed through the wetland. Sulfate concentration decreased from 400 mg/l to 200 mg/l as well. Populations of sulfate reducing bacteria were enumerated from the wetland substrate. Samples taken once monthly from February 1991 through August 1991 show an increase of 1.2×10^4 to 3.7×10^5 microorganisms per gram dry substrate. Preliminary identification using phase contrast microscopy suggests the presence of Desulfovibrio species. Experimental wetland mesocosms have been constructed to test the effectiveness of different substrate types. A pine bark mulch substrate and a spent mushroom compost substrate will be compared on the basis of the number of sulfate reducing bacteria present and effluent concentrations of iron, manganese, and sulfate.

Additional Key Words: constructed wetlands, acid mine drainage, sulfate reduction

Introduction

Acid Mine Drainage (AMD) is a product of the coal mining industry that has come under considerable scrutiny. It is formed by the oxidation of pyritic minerals upon exposure to oxygen and water during the mining of coal or pyrite (Eq. 1).

$$4FeSO_4 + O_2 + 2H_2SO_4 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

$$Fe_2(SO_4)_3 \longrightarrow 2Fe(OH)_3 + 3H_2SO_4 \qquad (1)$$

These discharge waters are typically characterized as having a low pH and high levels of iron and manganese. High levels of sulfate are also commonly associated with AMD. Regulations have been established by federal and state authorities to monitor discharge quality. The state of Virginia requires a pH of 6.0-9.0, an instream iron concentration of 2 mg/L, and instream manganese of 1 mg/L. Traditional treatment methods involve the use of liquid caustic soda or lime to raise the pH, and the addition of other chemicals to remove metals. Constant monitoring and maintenance, chemical costs, and waste disposal make this a labor intensive and expensive means of treating AMD. The use of constructed wetlands as an alternative to traditional chemical treatment has often proven

[1]Paper presented at 1992 American Society for Surface Mining and Reclamation Meeting, Duluth, MN, June 15-18, 1992.

[2]K.N. Duddleston is a graduate student and A.C. Hendricks is an Associate Professor at V.P.I.& S.U., Blacksburg, VA 24060. E. Fritz is Manager of Surface Operations and K. Roddenberry is Senior Environmental Engineer for Westmoreland Coal Company, Big Stone Gap, VA 24219.

Proceedings America Society of Mining and Reclamation, 1992 pp 249-254
DOI: 10.21000/JASMR92010249

https://doi.org/10.21000/JASMR92010249

to be a cost effective and often more efficient means for mitigating AMD (Hedin et al., 1988; Weider et al., 1988).

Constructed wetlands are man made complexes similar to marshes or swamps that are built for treatment purposes (Hammer, 1989). They have been built to treat various types of waste water as well as AMD. Constructed wetlands utilize both biological and microbiological processes as a means for abatement of contaminated water. Microbial sulfate reduction in particular is an important process involved in treating AMD. Two metabolic end products of sulfate reduction, bicarbonate and H_2S, are responsible in part for the mitigation of AMD within constructed wetlands (Eq 2,3).

$$2CH_2O + SO_4^{2-} \text{------>} H_2S + 2HCO_3 \qquad (2)$$

$$Fe^{3+} + H_2S \text{-------->} FeS \qquad (3)$$

Bicarbonate adds alkalinity and increases the pH, and H_2S precipitates iron and other metals as metal monosulfides.

Sulfate reducing bacteria are anaerobes utilizing a small range of simple carbon sources as electron donors and sulfate as an electron acceptor. Wetlands constructed to enhance anaerobic conditions through subsurface water flow have been shown to increase water quality over those wetlands with surface flow only (McIntire et al., 1990). The purpose of this report is to present data collected from an anoxic subsurface flow wetland constructed to treat AMD through the enhancement of bacterial sulfate reduction.

Site Description

A 0.7 acre wetland was constructed near Norton, Virginia, by Westmoreland Coal Company in late summer 1990. It was built to treat seepage from an inactive coal refuse pile containing 4.5 million cubic yards of waste silt and rock material. Rain and spring water flowing through the refuse pile resulted in AMD flowing from its outer slopes and underground drains. Before chemical treatment the pH ranged from 3.5 to 9.1, the iron from 4.6 to 38.5 mg/L and manganese from 2.5 to 4.3 mg/L. The flow averaged 50 gpm. Prior to wetland construction, annual costs for chemical treatment were $7,200, including labor. After construction, annual costs averaged $1,000.

Three ponds located downstream from the refuse pile were used as sediment ponds for plant process water during active mining. The middle of these 3 ponds was converted to the wetland at a cost of $25,800. The AMD bypasses the first pond and flows directly into the wetland. From the wetland it flows into the third pond, where additional chemicals can be added if necessary, before it flows into Pine Branch, a tributary to the Powell River. The wetland itself consists of a bed of limestone, one foot deep, beneath one foot of weathered pine bark mulch. Six inch perforated pipes were placed in the limestone bed to serve as an underground drain (Fig. 1A). 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. The water level can be adjusted by raising or lowering the outlet pipe, and stand pipes were installed within the wetland to allow for cleaning of the drain pipes. Cattails (Typhas sp.) were planted in April, 1990 as shown in Figure 1B. This scheme allowed for comparisons of sulfate reducing bacteria population size between areas with and without cattails. Test boxes were constructed at the wetland site to compare treatment capability between different substrate types. Due to unforseen difficulties with the construction of the boxes and weather problems, no data is available from those boxes at this time.

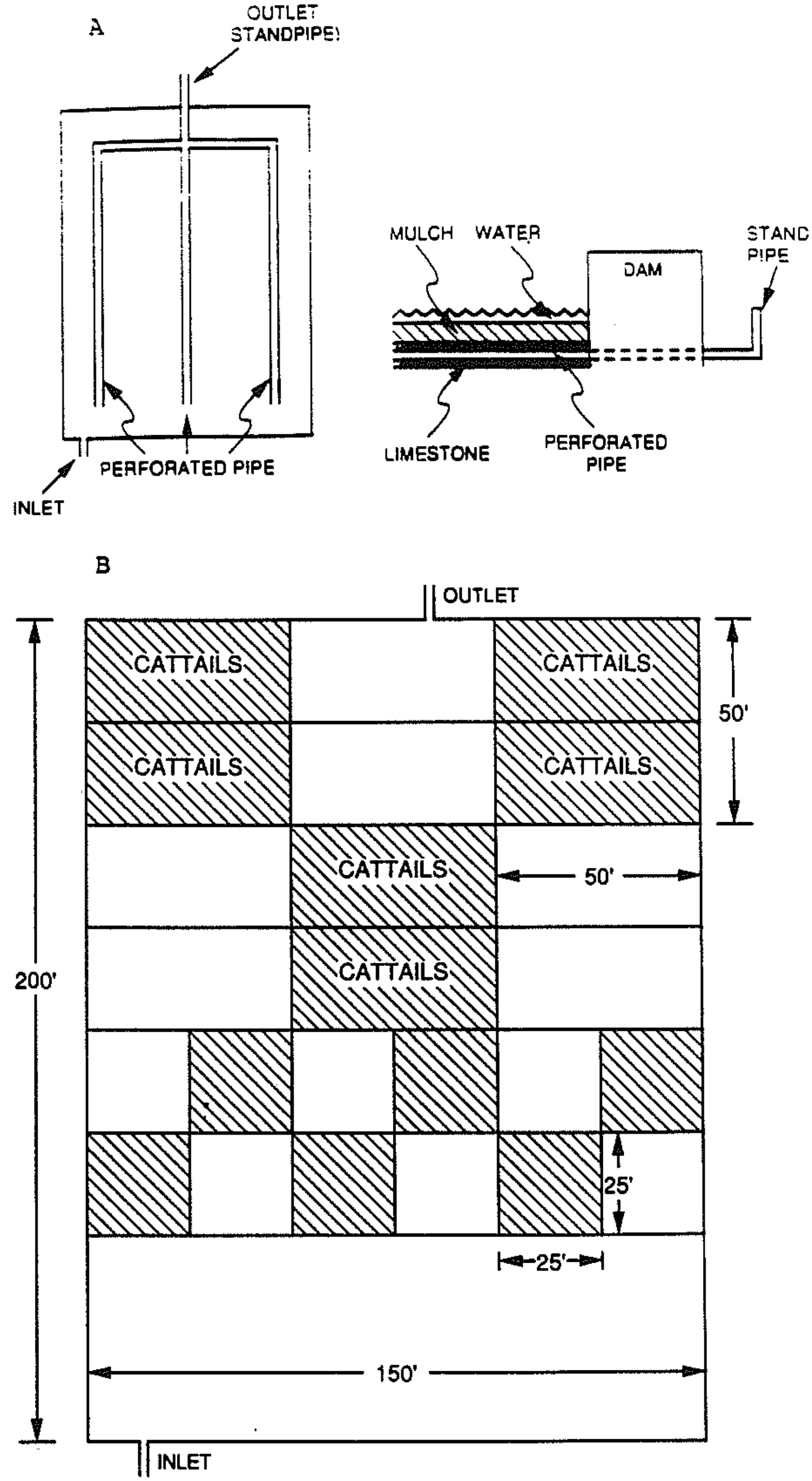
Materials and Methods

Water Chemistry

Inlet and Outlet water was analyzed for Fe, Mn and pH weekly by Environmental Monitoring Incorporated, Coeburn, Virginia. All other analysis were performed at VPI & SU. Samples were taken monthly for analysis of sulfates. Samples were held on ice during transport to laboratory and analyzed within 24 hours using $BaCl_2$ (Methods 1983).

Sulfate Reducing Bacteria

Substrate samples were taken monthly to enumerate sulfate reducing bacteria. Samples (50 grams) were taken from random areas within the wetland using a pitchfork. They were placed in Ziploc bags and held on ice during transport to the laboratory. Samples were analyzed within 24



<u>LAYOUT FOR CATTAIL PLANTINGS</u>

1) Shaded Areas are the Cattail Areas.
2) The Six Large PLots are 50' X 50'.
3) The Twelve Small Plots are 25' X 25'.

Fig. 1. Diagram of drainage system (A) and cattail plantings (B).

hours using the five tube most probable number method (Alexander 1982).

Results and Discussion

Water Chemistry

The pH (Fig 2A) was near neutral in both the inlet and outlet water. An increase in alkalinity occurred as the water passed through the wetland, and acidity was 0 for both inlet and outlet water (Data not shown). For the first 2 months, the wetland underwent an establishment period in which successful treatment of iron and manganese was not evident. After February however, the iron concentration was consistently reduced as the AMD passed through the wetland. The reduction in manganese concentration was extremely variable through March and again in June, but was consistent from June through November (Fig. 2C). It is expected that iron would be removed more effectively than manganese, as manganese has always been difficult to remove through wetland use. In all cases, however, pH, Fe, and Mn met instream compliance standards, and no additional chemical treatment was necessary. The reduction of sulfate was consistent over the sampling period, dropping an average of 360 mg/L as the AMD passed through the wetland (Fig. 3).

Sulfate Reducing Bacteria

The number of sulfate reducing bacteria present in the wetlands averaged 10^4 organisms/g dry substrate. Fluctuations occurred, with the highest number being reached through the warmer months of May through August. There was a drop in number in September, possibly due to a wash out during heavy rains right before sampling (Table 1).

In comparing the population size of sulfate reducers between areas with and without cattails, no significant difference could be found, with an average of 3.4×10^4 and 5.8×10^4 microorganisms/g dry substrate respectively. It should be noted that the method used for enumerating sulfate reducers is not an exact count, but rather an estimate. Also, the number of sulfate reducers present says nothing about their activity, and experimentation as such is ongoing at this time. There is good evidence of activity however, in that there has been a sulfide odor at the wetland site, and a reduction in the sulfate concentration of the AMD as it passed through the wetland.

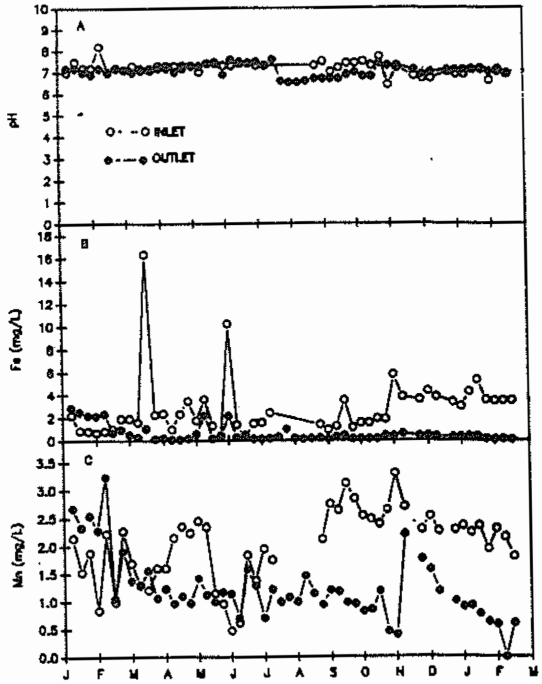


Figure 2. pH (A), Fe (B) and Mn (C) influent and effluent AMD (mg/L).

The role of sulfate reducing bacteria is a pivotal one in the reduction of metals in wetlands (Hedin, et al., 1988; Hammack and Hedin, 1989; Dvorak, 1991), yet there are still a number of important aspects of this role that require more research. From a biological view, a determination of optimum bacterial densities for the removal of metals, how these densities can be achieved, and information about the environmental requirements that regulate their activities is needed. Knowing that these bacteria are present in the wetland is important. However, it is also important to know how efficiently they are performing, and how and what conditions can be changed to enhance their efficiency.

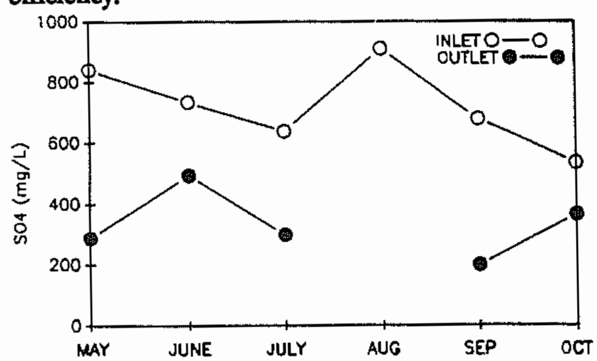


Figure 3. Sulfate concentration of influent and effluent AMD (mg/L).

TABLE 1: Enumeration of Sulfate Reducing Bacteria, Pine Branch Wetland, Norton Virginia.

Sample Date	@ # Sulfate Reducers per gram dry substrate ($x10^4$)
Feb 12, 1991	1.17
March 21, 1991	0.49
May 30, 1991	5.44
July 10, 1991	7.60
August 21, 1991	37.0
Sep 30, 1991	0.7

@ average of three or more samples

It is also important that the best wetland design is utilized in order to take advantage of the sulfate reducing capacity of these wetlands. Is strictly surface flow the best design? Or, is it better to utilize the entire volume of the wetland by sending the water from the surface to the bottom (or from the bottom to the top), before discharging? The latter design forces all the water to become anaerobic for a period of time, and exposes all the metals to the sulfides generated by the sulfate reducers. This concept has been used successfully by Dvorak, et al., (1991) and Hendricks, (1991), and continued research and exploitation of this anaerobic phase of treatment is needed.

Literature Cited

Alexander, M. 1982. Most probablen number method for microbial opulations. pp813-820. In Page, A. L., Miller, R. H., and D. R. Keney (eds). Methods of Soil Analysis, Pt 2. Am. Soc. of Agr., Inc. and Soil Sci. of Amer., Inc. Madison Wisconsin.

Dvorak, D. H., Hedin, R. S., Edenborn, H. M. and S. L. Gustafson. 1991. Treatment of metal-contaminated water using bacterial sulfate reduction: results from pilot-scale reactors. Second International Conference on the Abatement of Acidic Drainage. Tome 1. Sept. 1991. Montreal.

Hammach, R. W. and R. S. Hedin. 1989. Microbial sulfate reduction for the treatment of acid mine drainage: a laboratory Study. In Proceedings, Ninth Annual West Virginia Surface Mine Drainage Task Force Symposium, April 25-26, 1989. Morgantown, West Virginia.

Hammer, D. A. and R. K. Bastain. 1989. Wetlands as ecosystems: natural water purifiers? pp5-20. In Constructed Wetlands for Waste Water Treatment. D. A. Hammer (ed). Lewis Publishers, Chelsea, MI.

Hedin, R. S., Hyman, D. M. and R. W. Hammack. 1988. Implication of sulfate reduction and pyrite formation processes for water quality in a constructed wetlands: preliminary observation. pp382-388. In Mine Drainage and Surface Mine Reclamation, Bureau of Mines Information Circular 9183, Vol. I.

http://dx.doi.org/10.21000/JASMR88010382

Hendricks, A. 1991. The use of an artificial wetland to treat acid mine drainage. Second International Conference on the Abatement of Acidic Drainage. Tome 3. Sept. 1991. Montreal.

Methods for Chemical Analyses of Water and Wastes. 1983. USEPA Environmental Monitoring and Support Lab. Cincinnati, OH.

Weider, R. K. 1988. Determining the capacity for metal retention in man-made wetlands constructed for coal mine drainage. pp375-381. In Mine Drainage and Surface Mine Reclamation, U.S. Bureau of Mines Information Circular 9183, Vol. I.

http://dx.doi.org/10.21000/JASMR88010375