Acid Mine Drainage: An Overview

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Abstract

In the United States, acid mine water adversely affects over 6,500 km (4,000 miles) of rivers and streams. This is, however, a significant improvement over the situation two decades ago. Case studies document the nature of this improvement. Recently developed technology provide options for further improvement.

Introduction

In the United States, mining adversely affects over 19,300 km (12,000 miles) of rivers and streams and over 730 km^2 (180,000 acres) of lakes and reservoirs. At least a third of this contamination is due to acidic water generated by the exposure and weathering of pyrite.

Comparing recent data[2] with that compiled 20 years ago by the Appalachian Regional Commission (1969), the adverse impact of AMD in the U.S. appears to have decreased by about 1/3 (Fig. 1). This comparison is vulnerable to differences in the intensity of sampling and the criteria used to classify a stream as degraded, but the general trend is certainly valid. Most of this improvement is due to chemical neutralization at active, or recently active, mining operations. The cost of this chemical treatment, nationwide, is estimated to exceed $1,000,000 a day. In the rest of this paper, case studies will be used to document the improvement that has occurred in AMD-contaminated watersheds, and then new technology that has been developed to combat the AMD problem will be discussed.

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[2] Compiled by the author from 305-B reports from mining-affected states, supplemented by personal communications with various state agencies.

Water Quality in Mined Watersheds

        Twenty years ago, more than half of the U.S.
streams degraded by AMD were in Pennsylvania. About 2/3
of these streams are no longer seriously affected by AMD
(Fig. 1).   For example, in western Pennsylvania, water
samples collected at the junction of the Monongahela and
Youghiogheny Rivers indicate that in 1934, the Yough-
iogheny River had an acidity of 80 mg/L (as $CaCO_3$). By
1960, the acidity had decreased to about 18 mg/L (Clark,
1965).   A recently-completed analysis of water quality
records indicates that acidity has continued to decrease,
averaging 12.2 from 1965 to 1967, 9.0 from 1976 to 1977,
6.5 from 1978 to 1984 and 1.8 from 1985 to 1987. Most of
this subsequent improvement is probably due to enactment
and enforcement of effluent limits for the area's active
mines.

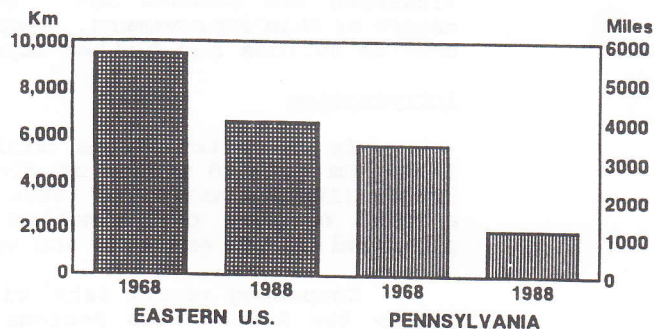## RIVERS AND STREAMS ADVERSELY AFFECTED BY ACID MINE DRAINAGE

FIGURE 1

        As an example of water quality improvement
unrelated to chemical treatment, one can look at the water
quality in eastern Pennsylvania, where the mining of
anthracite coal was once a thriving industry.   The old
mines were abandoned and allowed to flood over 30 years
ago. To protect surface structures, near-surface drainage
tunnels, known as outfalls, were constructed to limit the
recovery of the water table.   The Askam, Buttonwood and
South Wilkes-Barre outfalls now drain a mine pool
estimated to contain 6×10^7 m^3 $(1.6 \times 10^{10}$ gal) of water,
and together discharge about 2 m^3/s (32,000 gal/min) of
untreated acidic water into the Susquehanna River (Ladwig
et al., 1984). The inundation curtailed pyrite oxidation
by limiting atmospheric contact.   Though acidic water
already formed must be flushed out, very little new AMD
is forming.   Acidity at the outfalls decreased 74% and
sulfate concentrations decreased 49% during the period
1968 to 1979. (The latter indicates that the improvement
is not simply caused by neutralization). The pH observed

ranged from 3.3 to 5.6 in 1968; by 1979, this had improved to 5.8 to 6.2. Sampling of water in the flooded workings indicated that the water quality at the outfalls should continue to improve, for 93% of the mine shaft water samples collected were alkaline, with pH's as high as 7.8 (ibid).

A third Pennsylvania example documents the effect of natural amelioration. The Turtle Creek watershed encompasses 381 km^2 (147 square miles). Despite its name, 26 km (16 miles) of the creek was essentially barren due to AMD. Estimates on what would be required to restore a fluvial ecosystem in the watershed exceeded $11,000,000. Actual expenditures totalled less than $1,000,000. Even so, water quality improved during the 1970's and early 1980's, to the point that fish and turtles can now once again live there. Most of this improvement is due to natural causes, as the most readily oxidized pyrite was gradually consumed.

New Control Technology

The effect of AMD on stream water quality, though only 2/3 of what it was approximately a decade ago, continues to be a major problem for the U.S. It is now principally associated with old abandoned mines; if these sources are to be controlled, it will be at public expense. In addition, the long-term liability of water treatment has become a significant expense that affects commodity prices and operable reserves. Nevertheless, research developments provide some basis for optimism.

One such development is the discovery that wetlands can be established in acidic mine water, and that these wetlands actually help to purify the water. As a result, during the past few years, over 400 small wetlands have been constructed on mined lands for the primary purpose of water treatment. In general, they consist of a series of shallow ponds planted with cattails (Typha). Most of these biological treatment systems have been constructed by active mining operations to reduce their water treatment costs; in general, the wetlands have paid for their construction costs in less than a year. In addition, an increasing number are being constructed by state agencies at abandoned sites, where improvements in effluent quality can directly affect the quality of receiving streams.

The principal treatment process in most of the wetland systems is bacterial oxidation of iron, and to a lesser extent, manganese. Some neutralization also occurs, due to sulfate reduction and dissolution of limestone in the anaerobic zone.

The Bureau of Mines is developing sizing criteria, based on iron removal, that takes into account water chemistry as well as flow rates. If the influent water has a pH of 6, 250 ft^2 will remove a pound of iron a day. If the influent pH is 4-5, twice as much space is required. At a pH of 3.0-3.5, at least 12,000 ft^2 is required to remove the same iron load. Finally, if the wetland is also expected to improve pH and/or lower manganese concentrations, even more space is required.

Another passive technique to treat acid mine drainage, anoxic alkaline drains, has recently been developed. Water that is low in oxygen, with iron in the ferrous (Fe^{2+}) rather than the ferric (Fe^{3+}) form, is intercepted by a limestone-filled trench. The limestone is isolated from the atmosphere by plastic sheeting and a clay cap to prevent iron oxidation and armoring of the limestone by ferric hydroxide. Dissolution of the limestone has raised pH from less than 4 to over 6 at several field sites (Turner and McCoy, 1990). Longevity of treatment is an obvious concern; to date, the oldest test system has been functioning for about 2 years. This is, however, already 3 times as long as previous similar systems that did not contain the plastic sheeting, giving some reason for optimism. As already noted, the efficiency of constructed wetlands is directly affected by influent pH. Anoxic alkaline drains would therefore appear to be a useful initial step for a biological treatment system; the Tennessee Valley Authority (TVA) has already begun to combine the two systems in that manner (Brodie, 1990).

Currently, Bureau of Mines scientists are focusing on optimizing the activity of sulfate reducing bacteria that thrive in the wetlands' anaerobic zone. Not only does the activity of these bacteria consume acidity, the hydrogen sulfide they produce reacts with most heavy metals to produce virtually insoluble precipitates. This would greatly increase water treatment efficiency, avoid the problem of sludge accumulation associated with the oxidation and hydrolysis reactions and extend the applicability of biological treatment to metal mines (Hammack and Hedin, 1989; Kleinmann and Hedin, 1989; McIntire and Edenborn, 1990).

An alternative to treating the acidic water is to abate acid generation. The generally accepted method of doing so is to inundate the pyritic material, thereby virtually eliminating pyrite oxidation. This has proven to be successful if inundation is complete, such as in the anthracite example cited earlier. Incomplete inundation, usually caused by the dip of the mined seam or water table fluctuations, simply moves the active oxidation zone to

a higher elevation in the mine or spoil without reducing acid formation.

An alternative approach, developed by Bureau researchers several years ago, involves the inhibition of the iron-oxidizing bacteria responsible for the rapidity of pyrite oxidation. Anionic surfactants can be used to decrease the activity of these bacteria and thereby retard pyrite oxidation. This approach is most applicable to coal refuse piles, where acid production has been reduced 60-95% (Kleinmann and Erickson, 1983). The surfactant can be sprayed on (3 times a year) or applied in controlled-release formulations that inhibit pyrite oxidation for 5 to 10 years. Both approaches are now commercially available. Research is planned on possible ways to extend this technology for use underground.

Other approaches to at-source control utilize chemical additions to provide neutralization in place and to retard pyrite oxidation by armoring or precipitating reactants. Typically, an alkaline compound is used; one problem is that the volume of acidic water represents a large acid load that must all be neutralized. Alkaline injection has generally proven inapplicable for surface mines, due to the relatively short-lived residence time and heterogeneous flow, but Bureau researchers are now considering its applicability for underground mines, where large pools of acid water could be periodically neutralized. Alternatively, at surface mines, surface application of alkalinity can be effective at sites where acid formation rates are modest. Also, university researchers at West Virginia and Montana State are evaluating the economics of using phosphate rock to form iron phosphates, thereby curtailing pyrite oxidation.

Reducing pyrite-water contact can also reduce the volume of AMD that forms. One recent development reduces the volume of water that leaks into underground mines from streams by 90 pct or more. Leaking zones are pinpointed using terrain conductivity (a simple and rapid geophysical technique) and verified by conventional gaging methods. The fractured streambed is then mended using a polyurethane grout injected beneath the sediment-water interface. The cost per linear foot is as low as half that of conventional stream repair, in addition to the savings realized by specifically targeting the water loss zones. Tests in streams above active longwall operations and an old, abandoned room-and-pillar mine have been extremely successful (Ackman and Jones, 1988).

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