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Rural Issues: Coal Mining and Abandoned Land Reclamation

ACID MINE DRAINAGE: SURFACE MINE TREATMENT AND IN-SITU ABATEMENT TECHNOLOGY

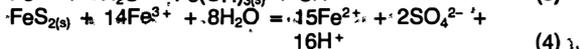
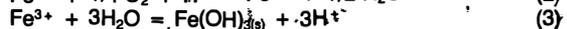
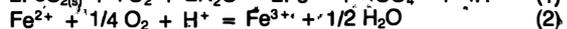
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STATEMENT AND NATURE OF THE PROBLEM

Large quantities of very thick, low sulfur coals are found at shallow depths in the western part of the United States. Many problems associated with these coals are primarily concerned with the high total dissolved solids (TDS) content of the drainages, the preservation of the fertile valleys, and the impact on the ground-water resources. In contrast, the major problems associated with the strip mines of the bituminous coal fields of Appalachia and the Midwest center about the instability of backfilled areas, the reclamation of backfilled mines, and acidic mine drainages. This paper addresses the last problem and outlines the technologies available for the reclamation of backfilled mines and acid water treatment.

Acid mine drainage forms under natural conditions when certain coal seams are mined and the associated strata exposed to a new oxidizing environment. During this process a variety of iron sulfides (FeS - FeS_2) are exposed to the atmosphere and oxidize in the presence of oxygen and water to form soluble hydrous iron sulfates. These compounds commonly appear as white and yellow salt crusts on the surface of weathered rock faces. Natural waters flowing over the weathered surfaces readily dissolve these compounds that hydrolyze in water, forming acidic, high sulfate, and high iron drainages. Ferrous and ferric oxyhydroxides impart the red and yellow color characteristic of acid mine drainage. Iron hydroxide usually precipitates and forms the "yellow boy" that is commonly observed in the streams and drainages of some coal mine areas (Caruccio and Geidel, 1978).

The general chemical reactions explaining the oxidation of FeS_2 and the production of acidity (H^+) are given by the following equations:



(Barnes and Romberger, 1968; Baker, 1975)

The stoichiometry of Eq. (1) shows that 1 mole of FeS_2 will produce 2 moles of H^+ (acidity). In turn, the Fe^{2+} generated by the reaction of Eq. (1) can readily oxidize into Fe^{3+} and produce an additional 3 moles of H^+ (Eq. (3)). In the references cited by Baker (1975), it has been shown that FeS_2 can also be oxidized in the presence of excess Fe^{3+} in solution with water and further hydrolyze to form 16 moles of H^+ (Eq. (4)).

The oxidation of Fe^{2+} to Fe^{3+} usually proceeds slowly under normal conditions, as in Eq. (2) and (3) (Singer and Stumm, 1970). However, certain bacteria act as catalysts and greatly enhance and accelerate the chemical reaction rate. Several workers investigating the oxidation rates of sterilized versus inoculated samples showed that certain iron bacteria do indeed catalyze the oxidation reactions involved in acid mine drainage formation and effectively increase the acidity produced (Klinemann et al. 1981; Walsh and Mitchell, 1972).

These bacteria are indigenous to aqueous environments with pH values that range from 2.8 to 3.2, and the pH of the ground water controls the occurrence and distribution of these bacteria (Walsh and Mitchell, 1972).

TREATMENT MECHANISMS

Large-scale Neutralization. When large flows and high acid loads are encountered, large-scale, manufactured treatment facilities may be used to neutralize the acidity, oxidize the iron, and generate a high-density settleable sludge. Many of these systems are available on a commercial basis.

Small-scale Chemical Neutralization. Because of the relatively simple and controlled aspects of dispensing a caustic medium, most mining operations routinely neutralize acidic mine drainages. Numerous acidic seeps are diverted into one flow channel which may be wired. The flow rate is measured by a modified Parschall flume; a float in tandem with a valve dispenses sodium hydroxide (caustic) directly into the acidic flow, the dosage rate being determined empirically. The pressure head is provided by locating the storage tanks at a higher elevation (and adjacent to roads to allow supply trucks easy access to refill). A narrow diameter (1–2 cm) PVC pipe conveys the caustic from the storage tank to the dispensing valve. This scheme does not require any electrical power and is well suited for treating acidic waters in remote parts of the mine. The viscosity of the caustic, however, is readily affected by temperature changes and the dosage rates must be continually monitored during the cold winter months. Further, during periods of heavy rainfall, runoff is channeled into the flow monitoring device, which activates additional caustic dispensing for flows that, in fact, have a lower acid load.

Combinations of sodium carbonate briquettes, calcium oxide, potassium hydroxide, and various oxidizers (peroxide, sodium–calcium hypochlorite) may also be used as acid treatment. In all of these treatments a sludge develops which is retained in settling ponds. The ponds are eventually cleaned and the sludge disposed of at the mine site.

Wetlands. Several studies have demonstrated the effectiveness of wetlands in removing acidity, sulfate, and iron from mildly to moderately acidic mine drainages (Lang and Wieder, 1982). In these natural environments, sulfate is reduced to either bisulfide (with an attendant reduction in acidity) or pyrite (with the removal of iron). This technique impounds a low-lying area that gently slopes into a wetland, adding to it excessive amounts of organic matter (straw, hay, etc.). Following a brief period of decay, a sphagnum moss culture is introduced to the system.

The advantages of the treatment are the low maintenance (including cost) and the creation of an aesthetically pleasing treatment facility. However, the ecosystem providing the base of the treatment may occupy only certain natural niches. This treatment process is restricted to continuously wet areas at certain altitudes. Some researchers, however, have developed and selectively bred several moss species that may be used across a variety of conditions. Some question exists as to the levels of acidity and iron that the natural system may accommodate before being detrimentally affected by the acidic waters.

CONTROL MECHANISMS

This paper earlier demonstrated that the natural acid-producing elements are pyrite, oxygen, water (moisture), and the catalytic effects of bacteria and water geochemistry. All but the pyrite, which occurs as an intrinsic part of the rock matrix, may be directly affected through in-situ abatement techniques to reduce the flow rate and acid loads.

Detergents and Bactericidal Additives. Limiting the oxidation of ferrous to ferric irons effectively reduces the amount of acidity produced by almost half. Eventually, the

oxidation reaction will take place naturally and additional acidity will be produced. However, restricting the acid reactions to Equations (1) through (3) maintains the acid conditions which may be accommodated by bicarbonate alkalinity. Should the reaction expressed by Equation (4) begin, the rate of acid production will be greatly enhanced and overwhelm the low solubility limited calcareous-generated alkalinity. Thus, the addition of a suitable bactericide limits the rate of acid production and may be used to control the acid loads (Kleinmann and Enrickson, 1983).

This measure can be applied to active as well as abandoned mines. When used to complement other treatments, it is an effective control measure; because the bactericide is water soluble and entrained by the recharge events, it can penetrate deep within the backfill or mine portals and affect physically remote sections. Depending on the flow through rate/time, the application of the bactericide must be periodically repeated in severe situations. Where the acid levels are moderate, however, and may be neutralized by bicarbonate alkalinity, a single application of the bactericide may permanently reduce the acid levels to neutralizing bicarbonate concentrations. In this situation calcareous material must be present in the overburden of the mine setting.

Phosphate Complexes. The introduction of a phosphate compound (primarily in the form of pulverized apatite) into an acid system complexes the free iron radical and inhibits the hydrolysis reaction, thereby reducing the amount of acidity produced (Flynn, 1969). The phosphate is solubilized by only slightly acidic conditions and consequently must be physically juxtaposed to the pyrite reaction site. Some field tests using phosphate mine slurry have provided varying degrees of success and some failures have been linked to a mass transfer problem. Accordingly, the application of phosphate must coincide with the placement and be admixed with the acid spoil material (Meek, 1984).

If all reaction sites are affected, this treatment reduces, and in some cases eliminates, acidity. Because it is a complexing technique, acid sources associated with iron hydrolysis will be eliminated. The levels of acidity associated with the reaction (Eq. (1)), however, will continue to be produced.

Selective Placement of Toxic Material. Obviously, this strategy should be incorporated as part of the mine plan and must be implemented during the reclamation phase. The West Virginia Acid Mine Drainage Task Force advocates, in part, the placement of toxic spoil on top of a highly permeable inert material pad about 3–5 m thick. In turn, the acid material is capped with a clay seal, covered with 1 m of soil, and the surface is reclaimed. Soil in this case may be considered as the intensely weathered saprolitic profile above the bedrock. In a field test, a small (6 ha) hydrologically-isolated hill was reclaimed according to these recommendations. The clay seal effectively prevented infiltrating waters from contacting the toxic spoil, and the porous pad was instrumental in keeping the water table below and out of the influence of the acid material. Through a combination of bromide and iodide tracers and oxygen isotope data monitored over a 2-yr period, this method was demonstrated to be effective in preventing acid drainage formation (Geidel and Caruccio, 1984).

Plastic Liner. Reducing the flow of water through acid material effectively reduces the acid load of the system. In this technique the surface of the acid source is graded and covered with a 20- or 34-mil continuously sealed plastic liner (not unlike those routinely used in hazardous waste sites). To protect the plastic from ultraviolet ray exposure, which decomposes the plastic, a 1 m layer of soil is vegetated to afford mass stability.

In a field test involving a 16 ha mine site where a 20 ml plastic liner was used, the net acid load emanating from two highly acidic seeps was reduced to a level sufficient to amortize the cost of the plastic liner within a 6-yr period (Caruccio and Geidel, 1983).

For this technique to be totally effective, the plastic liner must extend to the base of the spoil. The outcrops of most spoil banks are too steep to accommodate machinery or maintain slope stability necessary for soil retention, so that a significant portion of the mine is left exposed (unlined). Recharge avenues then exist; and under some climatic conditions, the head developed at the outcrop is enough to drive the recharge-wetting front under the plastic (temporarily reversing the hydraulic gradient). Subsequent acid leachates drain from beneath the plastic when the normal gradient is reestablished.

This technique is labor intensive and lends itself best to active operations. Although, if the acid material could be identified, concentrated in one area, and encapsulated in plastic, this procedure has merit in reclaiming abandoned mines.

Blanket (Surface) Application of Limestone. The geochemistry of the acid system indicates positive results (in the form of reduced acid loads) if the infiltrating (recharge) water source is rendered alkaline. Under these conditions, the elevated pH displaces the bacteria, and pyrite oxidation is inhibited. One possible and economically feasible method of changing the water chemistry is the application of limestone in the form of a blanket veneer on the surface of the mine. Rainwater or snowmelt, in contact with the limestone, is rendered mildly alkaline and creates an alkaline wetting front. But, because of the limited solubility of calcareous material, the amount of bicarbonate produced is much lower than the amount of acid generated by pyrite oxidation. As a result, the initial alkaline wetting front has a negligible effect on the total acid system, and the mitigation of acid flow is not recognized until several recharge events, spanning as much as 2 or 3 years, have occurred. (Geidel and Caruccio, 1982).

This technique is best suited to highly permeable surfaces and mildly acidic drainages. In areas where the slopes are too steep for normal reclamation methods, helicopters may dispense the limestone on inaccessible areas while four-wheel drive lime spreaders are used throughout the remainder of the mine.

Induced Alkaline Recharge Zones. The blanket application of limestone has two disadvantages that detract from the treatment's effectiveness. First, the ameliorant is not concentrated in the major recharge areas. Consequently, unless the surface is highly permeable, the major flow paths do not intercept a large portion of the limestone. Second, the limited solubility of the limestone produces minor amounts of alkalinity not immediately affecting the more soluble acidic systems.

The mechanisms designed to overcome these two deficiencies (the hydrologic uncertainty and the low alkalinity produced by the limestone) are incorporated in the induced alkaline recharge zones technique. Here, major surface water flows are intercepted by shallow (1-m) trenches that are lined with a bottom layer of sodium bicarbonate briquettes (applied at a rate of 1 kg per 0.5 m²) and covered with 0.3 m of agriculture limestone reject material. Surface runoff is then converted into highly alkaline (the effect from the briquettes), high flow (hence, large alkaline loads) that may easily overwhelm the acidic systems. The catalyzing bacteria are then displaced, the acid system neutralized, and the pyrite oxidation stabilized. The strongly alkaline system lasts only until the briquettes are completely dissolved. Normally, this should take about 6 months, during which time the acidic system is rendered

and maintained alkaline. Once achieved, the limestone should provide sufficient alkalinity to maintain the non-acidic state (Caruccio and Geidel, 1984).

This technique may easily be applied to abandoned mined lands with a minimum amount of earth moving effort. Also, the alkaline ameliorant is most effectively used. However, should the major recharge areas intercepting the acid-producing horizons in the backfill not be affected by the alkaline flow lines (as might occur if the hydrology is not well understood and the trenches improperly oriented), large amounts of acidity will be produced and the problem exacerbated. Further, the trenches must be located in permeable zones to preclude trench flooding that will contaminate adjacent areas with sodium, killing vegetation.

SUMMARY

Many treatment and control measures are available to mitigate and abate acid mine drainage from surface mines. The technique deemed most appropriate for a particular mine site depends on the age of the mine site, the permeability and character of the mine surface, the degree of vegetation, the degree of calcareous material present in the overburden, the availability of a chosen ameliorant, accessibility of the site by equipment, and the source (physical and hydrologic) of the acidic seeps in the backfill or mine regime. Those are but a few considerations to be examined in choosing an effective treatment technique. The problem site must be explored by drilling; the hydrogeochemical system must be understood and the acid source identified before the treatment technology is implemented.

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COAL INDUSTRY PERSPECTIVES ON NONPOINT SOURCE POLLUTION

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The objective of the 1972 Federal Water Pollution Control Act was to "... restore and maintain the chemical, physical, and biological integrity of the Nation's waters." To achieve this objective Congress declared as one of its national goals "... that the discharge of pollutants into navigable waters be eliminated by 1985." Since pollution abatement was a high priority objective, much attention was given to point sources of pollution and to methods of controlling and regulating them. It is now 1985 and achievement of the national goal, although not 100 percent satisfied, has realized tremendous gains toward that end.

Attention has now turned to the more subtle offender, nonpoint source pollution. Nonpoint source pollutants are those that enter ground and surface waters from nonspecific or unidentified sources. At least one-third of the pollutants entering U.S. waters is estimated to come from nonpoint sources. According to the February 1985 draft Operating Guidance prepared by the U.S. Environmental Protection Agency's Office of Water and circulated among State authorities, EPA has promised that by the end of the year it will issue a status report on nonpoint sources (U.S. Environ. Prot. Agency, 1985).

In the overall abatement effort nonpoint source pollutants must be dealt with just as arduously as their more obvious counterparts. The 1972 Act (section 304(e)) recognized this need and required the EPA administrator to provide guidelines that would identify and evaluate nonpoint source pollutants and methods of controlling them. In the effort to satisfy this directive, EPA has discovered that both nature and man have contributed to the problem and that nonpoint source pollutants are less amenable to treatments than are point sources.

Those nonpoint sources that result from man's activities fall, generally, into four categories: agriculture, forestry, construction, and mining (Ashton, 1975). Though the coal mining industry is primarily concerned with the fourth category, its exploration and reclamation activities involve it, to some extent, in all four categories. The common thread that binds all four activities, of course, is the problem of sediment pollution. In addition to sediment, nonpoint source pollution resulting from surface mining may include acid mine drainage and highly mineralized water.

Discharges from active coal mining sites must be directed through sediment control structures and are considered, therefore, point sources. Since all active mining sites are heavily regulated under the Surface Mining Control and Reclamation Act of 1977, and since NPDES permits are required for all point source discharges, all active coal mines are virtually free of nonpoint source pollution. Potential nonpoint sources are quickly converted to point sources by constructing pipes, channels, ditches, conduits, etc. The coal industry's major concern with nonpoint sources, then, is with abandoned mines. If the abandoned mine is a surface mine, sediment will sometimes result from erosion; if underground, there may be acid mine drainage. In fact, over half of all acid problems are directly or indirectly related to inactive underground mines (Hill, 1975).

The potential for erosion is created early in the opening of a surface mine. As soon as roads are constructed to facilitate prospecting and mining activities, the vegetative cover is removed and bare soil is exposed to rain and wind action. The mining process itself creates an even greater area of vulnerability. However, the mining industry recognizes the impact of its actions and is quick to rectify the situation. Reclamation is contemporaneous and effective. Coal mining operates under one of the strictest regulations of any industry, so corrective measures are assured. This has not always been the case, however. There was a time when the remuneration for coal was so small that it was not possible to undertake the expensive reclamation practices that are now so common.

The coal mining industry is unique in that a mechanism for amelioration of past practices is in place. Title IV, Abandoned Mine Reclamation, of the 1977 Surface Mining Control and Reclamation Act required that a fee collection program be established for reclamation of abandoned mined areas. The objectives of this fund were to protect public health, safety, general welfare, and property from extreme danger of adverse effects of coal mining practices and to restore land and water resources degraded by the mining process.

All coal that is mined in this country is assessed a fee—15 cents per ton for underground mined coal, 35 cents per ton for surface mined coal, and 10 cents per ton for lignite. These fees, collected quarterly from coal mine operators, are the primary source of revenue for the Abandoned Mine Reclamation Fund through which the program is financed. After the money is collected, it must be appropriated by Congress. The allocation of monies is made annually according to priorities established by the agency (State, Indian Tribe, Federal Government) responsible for the regulatory program of the State or reservation. The fee collection system became effective October 1, 1977, and will continue through 1992. Walter Heine, OSM's first director, stated that the "Abandoned Mine Land Reclamation program is one of the most important and far-reaching environmental initiatives ever developed by the Federal Government" (U.S. Dep. Inter., 1978).

The Nation's first Abandoned Mine Lands Reclamation Conference was held in Pittsburgh on Sept. 19 and 20, 1978. Its purposes were to assess the current state of the art in reclaiming orphaned coal lands; to develop reclamation plans, regulatory requirements, and fish and wildlife programs; and to consider technical aspects of such problems as subsidence, acid drainage, and reclamation of refuse and gob piles.

It was obvious from the beginning that a large amount of money would be involved. Even before a model State plan had been developed, about \$104 million had been collected. There were no guidelines for this new program, so the Appalachian Regional Commission was charged with developing a plan to serve this need. OSM issued its final regulations to implement the abandoned mine reclamation programs and published them in the Federal Register on Oct. 25, 1978.

The inventory to identify the Nation's many acres of abandoned coal mined lands started in March 1979. Oak

Ridge National Laboratory carried out this initial phase of the survey. The second phase involved collecting and storing spatial data in the computer and selecting study areas for demonstration and testing purposes. Phases three and four consisted of analyzing, maintaining, and updating functions.

Once the abandoned sites were identified, the States made plans to reclaim them. Upon signing a cooperative agreement with OSM, funds were advanced to coal-producing States to help them plan their abandoned mine land programs. However, States were not eligible to receive their allocation, which was half the amount collected, until they had approved reclamation and regulatory programs in place. It was mid-1980 before any sizeable amount was made available to them.

As a followup to the regulations published in 1978, OSM developed guidelines to help States set their priorities for work to be performed. Problem areas considered were toxic mine drainage, active or potential slides, erosion and sedimentation, vegetation, toxic materials, hydrologic balance, public safety and health, aesthetic values, fish and wildlife values, air quality, and site characteristics (U.S. Dep. Inter., 1979). Since OSM's policy was to address first those problems which involved "extreme danger," most of the early projects were concerned with open mine shafts, subsidence, fires, floods, and landslides.

In addition to OSM's general guidelines, each State imposed its own priorities into the system. For example, one of Illinois' rules was that, initially, no projects would be

done on land presently owned by coal companies. First consideration would be given to publicly-owned land; second, to privately-owned land; and last, to land currently owned by coal companies (Aband. Mine Land, 1985).

Seven years after the Abandoned Mine Land program was established, with most of the extreme hazard cases taken care of, work is finally beginning on nonpoint source problems. So far, there has been a spirit of cooperation between most coal companies and AML offices to attack the problems together. The coal industry looks forward to a continuation of that good working relationship and expects to see that the efforts of filling voids, grading, seeding, channeling, and stream restoration result in a marked improvement of our environment.

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TRENDS IN POST-MINING LAND USES—ARE WE DOING OUR CHILDREN JUSTICE?

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By the end of June 1977, the mineral industry had disturbed an estimated 5.7 million acres in the United States. Approximately 1 million of the 2.7 million acres disturbed by the coal industry needed reclamation (U.S. Dep. Agric., 1979). Excluding coal operations, the mining industry reclaimed only 22 percent of the land it used from 1930 to 1980. The coal industry reclaimed 75 percent of the land used from 1930 to 1980 (Adam, 1982). The coal mining industry is far ahead of the other mining industries in terms of mined land reclamation. The major difference in reclamation efforts stems in large part from Federal control over coal mining and reclamation activities—including the abandoned mined land reclamation program.

Projections for new mine development and expansion from 1981 to 1990 show 151 new surface coal mines. Surface mines will produce a 3 to 1 proportion of overall production (Coal Mining Proc., 1982). Therefore, surface mining for coal is not expected to decrease in its impact on the land. Since surface mining will continue at the present level for the next 5 years, we should examine nonpoint source pollution from mines and the most reliable practices for its reduction and elimination.

ELEMENTS OF NONPOINT SOURCE POLLUTION

During the mining process, massive amounts of overburden is moved and broken or pulverized. Many fresh elements are continually exposed to oxidation and other weathering processes. Mineralization occurs, freeing these elements to run off. Unfortunately, some overburden contains elements that are not desirable for release into the hydrologic system.

One of the more commonly recognized elements of nonpoint source pollution from coal mines is acid mine drainage. Other possible components of nonpoint source pollution from abandoned and active coal mine sites are manganese, boron, arsenic, selenium, sodium and magnesium salts, and last but not least, sedimentation.

An important step in recognizing and locating potential sources of pollution is sampling and testing overburden prior to the mining operation. Overburden sampling allows the coal mine operator to plan for proper handling and isolation of toxic materials during the mining and reclamation processes. Many of the unreclaimed abandoned lands today are the direct result of improper analysis and planning for handling potentially harmful elements contained in the overburden. These derelict sites are some of the major contributors to nonpoint pollution today.

PREVENTION PRACTICES

Thanks to improved technology, active reclamation research programs, and a more conscientious coal industry, many innovative techniques have been developed to eliminate the perils of unwanted elements infiltrating the surface and ground water systems. Techniques used to control nonpoint source pollution from abandoned mined

lands and active surface mine sites include surfactants on coal wastes and slurry sites, organic compost or municipal/industrial wastes, tailored plant/tree seedling inoculants, water treatment techniques, flooding, clay caps, plastic liners, isolation of toxic materials in reconstructed spoil, sediment ponds, terracing and diversion, and permanent ponds or impoundments.

TRENDS IN POST-MINING LAND USES

Through years of practicing soil and water conservation in America, one lesson we have learned well is to control the volume and velocity of water. If these two ingredients are left uncontrolled, then erosion and sedimentation are sure to occur.

Contour diversions, riprapped waterways and retention structures are commonly used to control the velocity and volume of water on the mine site. Conservation measures are particularly valuable where final steep or long slopes occur. Unfortunately, unless these practices are stipulated in the post-mining land use provisions of the mine permit, they must be destroyed before bonding may be returned. In other words, the conservation practices are removed before the land is returned to surface owner use. In Pennsylvania, the soil and water conservation districts have been very active in assisting land owners design their post-mining options and in specifying the needed soil and water conservation measures. Adequately addressing post-mining land use needs allows watershed protection to be built into long-term land management.

Another potential source of nonpoint pollution is selection of improper post-mining land use. In 1982, 13 eastern States permitted 480,000 acres for surface mining. Of those 480,000 acres, approximately 280,000 acres of forest land will be mined. An estimated 90 percent of the 280,000 acres of mined forest land will be converted to pastureland. Admittedly, many of the mountain areas need additional space for housing and grazing. However, such wholesale conversion to grazing land may mean that many steep slopes will not be reclaimed to a land use that will provide long-term watershed protection. Many of the State Regulatory Authorities need to closely examine their apparent permission of wholesale conversion of forest land to pasture. The reality of the situation becomes more apparent when acre upon acre of pasture is never fenced.

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FACTORS AND TREATMENT OF ABANDONED ACID MINE LANDS FOR CONTROLLING NONPOINT SOURCE POLLUTION

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INTRODUCTION

Generally, a spoil is a heterogeneous mass of geologic material composed of sandstone, shale, and siltstone at different stages of physical and chemical weathering. In this mass, one may find varying amounts of sand, silt, and clay, depending on the state of physical weathering, and from very little to large amounts of topsoil that have been incorporated into the spoil during the grading process (Evangelou, 1983).

Chemical classification of spoils has always been used as a means of determining potential nonpoint source pollution. In the past, the practice has been to chemically classify spoils according to their pH and acid or neutralization potential. Table 1 shows this classification as proposed by the Soil Conservation Service.

Such a classification commonly misrepresents mine spoil material because it assumes that pH is the main obstacle to reclamation. The data in Table 2 point out information that further classifies spoils, especially acid spoils that have been abandoned for a number of years.

Summarizing the data in Table 3, it can be said that abandoned acid mine spoils can be divided into four general chemical classifications based on electrical conductivity and pH of the spoil solution.

The following information will show in some detail: (1) the factors that cause abandoned mine spoils to become acid and saline-gypsiferous; (2) the influences that acidity and salinity have on reclamation; (3) the proper frequency and chemical tests that need to be run to identify a spoil's proper classification; and (4) ways to approach the solution of the abandoned acid mine land reclamation problem.

Table 1.—Chemical classification of coal mine spoils (U.S.D.A., 1980).

1. Alkaline and calcareous	pH above 7.3
2. Medium acid to neutral	pH 5.6–7.3
3. Acid	pH 3.5–5.5
4. Extremely acid	pH below 3.6
5. Alkaline-acid	Complex of 1 & 3 above.
6. Alkaline-extremely acid	Complex of 1 & 4 above.
7. Neutral-extremely acid	Complex of 2 & 4 above.

FACTORS CAUSING ACIDITY AND SALINITY

Abandoned acid mine spoils have three types of acidity: pyritic, exchangeable, and solution. Agricultural soils have mainly exchangeable acidity (solution acidity is considered negligible because of the fact that soils rarely have a water pH below 4). Upon pyrite oxidation the spoil solution becomes enriched with iron (Fe), manganese (Mn), and aluminum (Al) at levels that are toxic to plants and other biological systems as pH often drops below 4. Under such conditions disintegration of clay minerals can enrich the solution with many other metals, having as a source the

clay structural components. These metals may include Ca, Mg, Na, and K along with Mn, Cu, Zn, and Al. Then, advanced or long-term oxidation of pyrite (as in abandoned acid mine lands) leads to a buildup of exchangeable acidity, solution acidity, and sulfate salts, mainly calcium sulfate, magnesium sulfate, iron sulfate, manganese sulfate, and at times, aluminum sulfate (Evangelou, 1983). Spoils of this nature are easily identifiable by studying composition of the solution phase. Table 4 shows the solution composition of saturation extracts of unreclaimed acid spoils of western Kentucky and Missouri.

TYPES OF ACIDITY TESTS AND INTERPRETATION

Techniques for assessing the fertility status of agricultural soils have also been used to assess coal spoils. Although the practice is justifiable for neutral spoils, for pyritic spoils it is questionable. The most important aspects of pyritic spoils are degree of acidity and pH. The pH measurements are usually made on a 1:1 soil:water suspension. This measurement will have some interpretive value as long as the pH is equal to or greater than 4 and electrical conductance is less than approximately 2 mmhos cm^{-1} . For spoils with a water pH less than 4, oxidizable pyrite is considered likely to be present.

In terms of acidity, three types of spoils are identified: (1) spoils of low water pH but of relatively low acidity; (2) spoils that may have low water pH (not less than 4) and very high exchangeable acidity; and (3) spoils that contain pyrite. Spoils of low water pH but of relatively low acidity are usually sandy and do not contain pyrite. Often such spoils are limed on water pH because the SMP buffer does not show any need for lime, even though the water pH may be lower than 5.

For spoils with low pH (normally higher than 4) and high concentrations of exchangeable acidity, the most appropriate test is one that can measure solution acidity plus exchangeable acidity. Such results are available from either the Woodruff Buffer Method or the Shoemaker, McLean and Pratt (SMP) buffer pH method (Table 5).

Finally, for pyritic spoils that have been abandoned for some time, and may have a water pH below 4, the test most commonly used to determine acidity is that using peroxide. The pyritic tests are often unreliable no matter what procedure is followed. The rates of lime reacting with the acidity (Roberts et al. 1984) and the byproducts formed, may create conditions in the field that are very different from the laboratory conditions (Evangelou et al. 1982). For these highly pyritic spoils one should take the wait and see approach. First, apply the lime as split applications, and before proceeding with vegetative seeding, recheck the pH. Secondly, check the soluble salts by the saturation extract method.

Often, laboratories sum the ammonium acetate extractable cations and refer to them as cation exchange capacity. This practice is applicable to agricultural soils but not to

Table 2.—Chemical composition of interpre water from coal mine spoils at saturation (Evangelou, 1983).

Identification	Classification	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	pH	EC
		meq/l					
1. Kentucky	Acid Gypsiferous	18.9	13.6	0.2	1.2	3.6	2.6
2. Kentucky	Neutral	19.1	8.1	0.4	0.5	7.1	2.1
3. Kentucky	Acid-Saline-Gypsiferous	24.4	93.7	<0.1	<0.1	4.0	7.0
4. Kentucky	Saline-Gypsiferous-Neutral	19.3	94.7	0.1	0.4	7.5	7.9
5. Kentucky	Gypsiferous	20.2	22.9	0.1	0.2	4.6	3.3
6. Missouri	Acid	20.1	4.5	—	0.5	5.4	1.9

Table 3.—Chemical classification of abandoned mine land coal spoils.

Class	Chemical characteristics	EC range (mm hos cm ⁻¹)	pH range
I	Acid	Below 2.25	Below 6
II	Acid-gypsiferous	2.25-2.50	Below 6
III	Acid-saline-gypsiferous	Greater than 2.5	Below 6
IV	Saline-gypsiferous	Greater than 2.5	Above 6

Table 4.—Solution composition of saturation extract of Kentucky and Missouri acid mine spoils versus a Kentucky productive soil (Evangelou, 1984).

Location	Ca	Mg	Na	Mn	pH	EC
	ppm					mm hos cm ⁻¹
Kentucky	550	1,130	10.4	221	2.5	12.4
Kentucky	273	5,480	56.6	910	3.3	23.6
Missouri	520	1,540	5.7	78	2.6	13.0
Missouri	550	503	14.0	61	2.9	7.0
Average Kentucky productive soil	80	10	10.0	0	6.0	0.8

spoils that have a saturation extract electrical conductance value of greater than 2 mmhos cm⁻¹. The saturation extract test should not be used in lieu of acidity determination tests but is supplementary to the pyritic acidity test. If the electrical conductance is less than 2.2 mmhos cm⁻¹ and the pH of the saturation extract is greater than 3, then neutralization of exchangeable acidity and pyritic acidity by adding the laboratory-determined amount of lime will be adequate.

The information presented in Table 6 summarizes the course of action after obtaining laboratory test results for acidity and the saturation extract. For a degree of difficulty greater than ++ use a temporary cover such as barley, which is highly resistant to salts. If the barley grows successfully, than a grasslike fescue may become established. Legumes are highly sensitive to low pH and salts, and their establishment in such spoil is always questionable.

In general, woodbark and wood chips at the rate of 27–31.5 metric tons/ha (30–35 tons/acre) give good results when mixed with the necessary plant nutrients, either as animal wastes (manure) or chemical fertilizers. Seeding with hydromulching can adversely affect vegetative establishment on dry soils. Although seeds may germinate in the ideal environment of the mulch, the dry environment of the spoils can result in poor seedling survival.

Be aware that mulches do not have a longlasting effect on vegetative cover. Use them initially only when conditions in the spoils make it necessary. For example, consider mulching when revegetating spoils with a waterholding capacity (available water) of less than 10 percent, especially if seeding later in spring or if the site has a southern aspect. When mixed with manures, mulches reduce aluminum toxicities to plants that occur at relatively low pH's since the organic matter tends to tie up soluble aluminum.

Generally, the following information should be kept in mind when revegetating abandoned mine lands composed of pyritic spoils.

1. Use calcitic lime in neutralizing pyritic spoils and apply lime as quickly as possible after spoil exposure to minimize dissolution.

2. Select a plant species exhibiting salt tolerance (see Table 9). When possible, use a winter annual or cool season perennial that is dormant in summer. This reduces transpirative demand and upward salt flux during the water-deficient summer months.

3. Seed during optimum germination conditions (relatively warm seed bed with maximum possible moisture). Germination delays allow salt migration into the seed, which kills sensitive, developing seedlings.

4. Leave the spoil surface rough, or deep till (rip) the upper part of the spoils profile and create furrows parallel to the slope. This traps water in depressions and encour-

Table 5.—Limestone rates for spoil buffer pH readings based on SMP¹ (Barnhisel, 1976).

SMP buffer pH readings	Agricultural limestone (metric tons/acre) required to adjust to pH 6.4 ¹
6.8-6.3	1.8-3.6 (2-4)
6.3-5.9	3.6-5.4 (4-6)
5.9-5.3	5.4-7.2 (6-8)
5.3-5.0	7.2-9.9 (8-11)
5.0-4.5	9.9-13.5 (11-15)
4.5-4.0	13.5-22.5 (15-25)

¹When lime rates are 25 or more (English) tons/acre, the "neutralization potential" test should be used to determine the actual amount of limestone needed.

Table 6.—Interpretation of pyritic abandoned mine land spoil chemical characteristics.

Class of coal spoils (Table 5)	Degree of reclamation difficulty ¹	Liming	Mulch	Water saving practices
I	+	Add according to test results.	Depends on soil texture and amount of acidity present.	Leave spoil rough.
II	++	Add according to test results	Depends on soil texture and amount of acidity present.	Leave spoil rough; build furrows 60–75 cm deep and 90–120 cm wide after mulching.
III	++++	Add according to test results.	Always add 27–32 metric tons of woodbark or wood chips and incorporate.	Leave spoil rough; build furrows 60–75 cm deep and 90–120 cm wide after mulching.
IV	+++++	No.	Always add 27–32 metric tons of woodbark or wood chips and incorporate.	Leave spoil rough; build furrows 60–75 cm deep and 90–120 cm wide after mulching.

+ Low degree of difficulty
+++++ Highest degree of difficulty

Table 7.—Crop sensitivity to salts based on the saturation extract test (Ayers, 1977).

Crop	Expected yield reduction			
	0%	10%	25%	50%
	(Electrical conductivity in mmhos/cm)			
Tall wheat grass	7.5	9.9	13.3	19.4
Wheat grass	7.5	9.0	11.0	15.0
Bermuda	6.9	8.5	10.8	14.7
Barley	6.0	7.4	9.5	13.0
Perennial rye grass	5.6	6.9	8.9	12.2
Trefoil, birdsfoot narrow leaf	5.0	6.0	7.5	10.0
Tall fescue	3.9	5.8	8.6	13.3
Vetch	3.0	3.9	5.3	7.6
Trefoil, big	2.3	2.8	3.6	4.9
Alfalfa	2.0	3.4	5.4	8.8
Lovegrass	2.0	3.2	5.2	8.0
Corn (forage)	1.8	3.2	5.2	8.6
Orchard grass	1.5	3.1	5.5	9.6
Clover, alsike, ladino, red, strawberry	1.5	2.3	3.6	5.7

ages water movement (hence salt leaching) through the spoil:

5. Apply surface mulches that increase infiltration and percolation of rainfall and decrease evaporation rates. Light colored mulches reflect a greater portion of the sunlight, reducing surface soil temperature heat load and evaporative demand. As mulch materials decompose, additional organic cation exchange capacity is created, tending to reduce solution salt levels. Avoid the use of salty mulches containing poultry manure on salt-affected spoil.

CONCLUSIONS

Abandoned acid mine spoils have a complex chemistry, making their reclamation difficult. To assure success, one needs to carry through the following tasks:

1. Be careful to obtain a representative sample.
2. Carry out the proper chemical tests to identify the problem: is it pH alone or high acidity, pyrite, or salinity. Fertility tests should be run only after the acid component has been identified, quantified, and corrected as discussed in this paper.

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