OBSERVATIONS ON THE EVOLUTION OF Coal Mine Drainage Control

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Prior to the sixties, coal mine drainage control related to ecological implications through such approaches as dilution and defined "Clean Streams", or most commonly, was ignored. During the last twenty years, attention to Coal Mine Drainage Control has evolved through a series of approaches. In the mid-sixties, emphasis was placed upon treatment of discharges to achieve effluent guidelines which were based upon arbitrary standards. The parameters generally incorporated: pH, acidity, iron, suspended solids, and more recently) manganese, and settleable solids. This approach still remains with us.

Subsequently, amelioration efforts incorporated water diversion, "toxic" strata isolation, etc. These concepts were based mainly on isolation and minimization of contact of the reactants. It follows that reclamation and acid formation prevention were the logical extensions of amelioration. Here practical approaches centered upon abandoned mining operations - flooding of deep mines and civil engineering - one time "house cleaning" efforts for surface mining. Subsequently, there were distinct rumblings of identification of acid-producing seams which would not be permitted to be mined, the denial of mining permit applications, and rescinding of existing permits in certain areas. Now "unsuitability for mining" declarations are being issued.

To many of us, research-engineering philosophies of "prevention", center upon prevention of water quality degradation - not prevention of coal mining. Such concepts, fundamental and innovative, are based upon limited, but improving understanding of the description of complex natural equilibria: especially, application of the second law of thermodynamics - THE PIPER MUST BE PAID. Understandably, the price may be unacceptable.

This evolution proceeded from laws and regulation at all governmental levels, but the rate and direction of the evolution has seemed to respond by limited research efforts and by the industrially-utilized control procedures. Now, as ALL of these control approaches are being utilized, we find the task increasingly complex, costly , and uncertain. The current efforts seek, by premine planning, to predict the potential FOR, and extent OF, water quality degradation on the basis of overburden characterization, the total. hydrologic regime, and the total mining system (including rate) by a specific mining plan. Based upon this costly planning effort, the Federal-State laws requires a regulatory decision to be made whether the mining may proceed, as described, at. that site.

In potential water degradation by acids, the naturally-occurring system is identified: 1). solid phase iron sulfide species at fixed, highly disseminated locations. 2). Water - its quantity, quality, and flow rates into, through, and from the defined volume to be disturbed (by mining). 3). Air - specifically the oxygen component concentrations at specific locations. The fluid properties of oxygen and water make their location almost infinitely motile but highly variable due to strata permeability and porosity on the near surface of the earth.

THE IRON SULFIDE MINERALS ARE STABLE TO CHANGE FOR THIS SYSTEM IN AN ALKALINE, REDUCING ENVIRONMENT. They are unstable in an acid, oxidizing environment, thus subject to oxidation and hydrolysis to create different iron-sulfur-oxygen products, most of which are highly water soluble, thus water degrading. The propensity of iron sulfide instability increases with its: 1). concentration, dissemination, reactivity -especially surface area, etc. 2). time and magnitude of contact with the fluids - oxygen and water. 3). oxidation-reduction and hydronium-hydroxyl equilibrium ion environment. This propensity is HIGHLY VARIABLE WITH LOCATION AND WITH TIME.

Geologists seek to define the parameters controlling the "fixed" locations and characteristics of the iron sulfides in terms of their depostional origins - primarily marine versus fresh water. Geohydrologists seek to identify subsurface water quantity and movement via regime budgets. Hydrologists, using climatological and topographical data, define surface flows which establish recharge rates.. Engineers geek to determine the subsurface concentrations and movements of oxygen (can be gaseous and/or water borne) at locations relative to the sulfides. Chemists - geochemists seek to identify the sulfide reaction mechanisms and rates as a function of reactant concentrations and reaction tendency propensity.

What are the significances of control measure approaches?

1. TREATMENT. A post de facto response. Most reliable, provides regulatory compliance, can be expensive, even continuous. Generally results in some form of water quality degradation, although not necessary precluding any particular water usage. High energy requirements, as used in flash distillation, reverse osmosis, etc. translate to high operating costs, thus prohibits total water quality restoration. However, the techniques are available.
2. RECLAMATION. A post de facto response. Partially effective, cost effective. Limited effectiveness may be inadequate to insure maintenance of regulatory standards and "acceptable" premining ecosystems despite greatly improved esthetics.
3. PREVENTION of water quality degradation during mining- Possibly excessive cost. Uncertainty of effectiveness. Needs further research and field testing. Regulatory agencies unwilling to approve procedures without fully demonstrated results. Offers best hope for most effective and lowest cost control.

    a. Segregation of reactive components. Helpful but of limited effectiveness. Can be expensive. Sensitivity involving movement of large strata volumes.
    b. Microbiological control - Lauryl sulfates, etc. Locally effective

with acceptable costs. Requires repeated application due to reagent instability. Potential side effects. Uncertainty whether effective response is truly microbiological control or from reaction environment control due to alkaline character of the reagent.

c. Control of reaction environment. (Inhibitors?) phosphates, ferric iron, etc. Maintenance of alkaline-reducing environment.

4. LIMITED or CESSATION of mining. Denies societies need for available, low cost energy source. Severe economic impacts. How to control which operation may proceed in an equitable manner? There are areas without mining where natural discharges still produce unacceptable quality water equivalent to coal mine drainage.

Each of the control approaches cited, including combinations thereof, have their merits and limitations. None is totally satisfactory to all concerned. In efforts to predict responses by premine planning procedures, a quote from a recent "Request For Proposal"(1) from. the US Bureau of Mines, may be helpful:"-quantitative prediction is impossible, primarily because of complications introduced by the relative kinetics of alkaline overburden dissolution and pyrite oxidation. --it is relatively simple to predict those sites at which acid drainage shall definitely not be a problem and where it shall definitely be a problem".

Despite the author's concurrence and acceptance of that quote, the implications are not clear. The criteria could be: 1). The total absence of iron sulfides (which would preclude all mining at the site), 2). Some arbitrarily defined iron sulfide concentration and distribution level. 3). The presence of some arbitrarily defined level of alkalinity source. 4). Other.

Such criteria imply consistency with the previous statement: IRON SULFIDE MINERALS ARE STABLE TO CHANGE IN AN ALKALINE, REDUCING ENVIRONMENT. Thus acid formation can be predicted and controlled by limitation of component concentration and/or maintenance of a non reactive environment based upon alkaline component availability.

If there are inadequate alkaline mineral components available within the mining site, it is not unreasonable that they can be introduced. The data needed for premine planning to minimize water quality degradation must center around iron sulfide and alkaline mineral (probably carbonates) concentrations, distributions, and characteristics. The existing approach of "acid-base" accounting by defined strata lithology (2)- which has evolved from the practices of the coal chemist, the water chemist, and the agronomist is fundamental.. continuing attempts to evaluate "rates" of acid-forming reactions under simulated, in situ, field conditions remain inadequate and possibly unreliable in interpretation and- application. These efforts date back before Braley, Hall, and Emrick (3) at The Pennsylvania Department of Health in the 1940 - 1960's.

OBSERVATIONS ON ACID-FORMATION RATES IN COAL MEASURES

Recently several sets of "weathering" data became available for study. The tests were responsibly carried out by experienced analysts, utilizing the approach that has evolved from Carruccio's thesis (4). most of the comments relate to all such attempts in a relative manner. Although proprietary considerations prevent citing any data, some generalizations regarding these and related results can be noted. Other experiences suggest the trends are not unique to any particular sample group. Most of the patterns have previously been observed. These comments are not offered as conclusions resulting from an extensive, designed experiment representing multifarious samples from many locations, which have been proven by statistical evaluation.

1. Many of the samples show "negative" acidity values. Such values have been treated by subtracting them from the cumulative acidity values. As an alkalinity component, it should be added to any observed alkalinity measured and thus related to "net" relationships, if desired. This is not simply a matter of "bookkeeping". The occurrence of such observations indicates a correlation with leachate pH, the values increasing linearly with pH to about 6.6. Above that level the increase approaches an exponential form. The "negative" acidities occur only when the sample leachate develops some alkalinity. There are several possible explanations for these results - possibly the absorption of atmospheric and local sources of carbon dioxide during the "aeration" cycle of the test which could enhance the strata dissolution.. The phenomena' may be an artifact of the test procedure, leading to uncertainty in interpretation. It is noted that the "leachate" is decanted through a filter paper, which, after draining is returned with the test solids to the test chamber. Accordingly, the paper surfaces along with the particle surfaces remain wetted with the dissolved solids from the dissolution step. The responses of abiabatic cooling - heating energy changes have not been explored.

2. In utilizing these data, the dissolved alkalinity is not cumulatively treated, thus ignoring potential reaction environmental responses. Similarly, the results are considered in terms of mg CaCO3 per unit weight (grams) of sample tested and do not consider the actual concentration of acidity, alkalinity, iron, etc. in the leachate. Since the recovery of the leachate varies widely from extraction to extraction step and sample to sample, the leachate concentrations and thus the reaction environment, can be expected to vary - and does.

3. Since any solid-fluid phase reaction is dependent upon particle surface area, the variation in particle size distribution of the test sample can be expected (and does) vary with strata hardness, weathered condition, clay content, etc. The type and procedure of sample comminution is variable between laboratories and individuals. As the weathering tests continue, particle slacking may further enhance surface areas in some strata at rates' differently than others. Deviations from these causes of laboratory strata dissolution and reaction rates do not necessarily relate to in situ field conditions. These concerns also relate to alkaline earth carbonate solubility which varies with temperature, water quality, and existing carbon dioxide partial pressure.

4. The existence of a highly variable acid-formation induction period is observed. The indicated rates appear to be most uncertain in strata whose gross neutralization potentials is limited (thus responding very sensitively to the environmental conditions of the test) while strata with almost no neutralization potential but higher iron sulfide contents appears to be initiated at a higher rates which may or may not continue at that rate. This behavior may relate to in situ surface oxidation or surface oxidation between coring and testing. This could create a leachate water residue that could unduly enhance apparent acid-forming rates.

5. Data show that some strata may show significant rate reductions (responding as a

negative reaction rate ?) upon continued testing. These observations suggest uncertainty as to the appropriate time frame for the weathering tests. The technique used to establish the data curve slope may thus be uncertain. Manual drafting procedures and equation curve fitting by computer to some defined criterion seek to ascertain whether a correlateable, sustained curve slope has been achieved.

6. Strata developing ALKALINITY equivalent to 0.1 T CaCO3/1000 T or greater tend to show little propensity for acid formation. This observation is not to suggest a reduction in the more conservative 5 T CaCO3/1000T deficiency previously cited by Sobek et al and the West Virginia Task Force. Samples with smaller alkalinity and neutralization potential values always show a propensity to form acid, although considerable variations are indicated. The near lack of alkalinity and neutralization potential can be reasonably certain to produce' acidic drainage. The amount and/or rate of acid-formation does not necessarily relate to strata iron sulfide content but <u>the trend is </u>toward such a correlation.

7. In strata having low levels of neutralization potential, the tendency to use total sulfur content rather than iron sulfide values as a measure of acid production potential can be very misleading. The somewhat greater expense and time frame for the iron sulfide analyses more than justifies the availability of specific data.

8. The several chemical mechanisms which are believed to be involved in acid-formation in coal measures and related strata have drastically different reaction rates under different environmental conditions and between the several reactions. Since the environmental conditions of the weathering test are known to vary, it would be expected that different reactions and rates must result.

OTHER "RATE" MEASUREMENT APPROACHES

An attempt by the author to devise a laboratory procedure for measuring acid-formation rate for coal measures was abandoned although the approach was reported (5). It was sought to introduce as many of the multifarious parameters in a controllable manner as was feasible and hold others constant, (including counts of chemolithotrophic bacteria). The procedure became impracticably complex and tedious.

More recently, with Richardson (6) (7), we attempted to simplify the procedure by studying only isolated, relatively pure iron sulfide grains liberated and separated physically from a single coal (Clarion seam). They were controlled to limit the particle size range. Hopefully, the reaction was mostly limited to that between the mineral 8urface arid a ferric sulfate lixivant of constant concentration, temperature, and under sterile(?) conditions. A constant, reproducible reaction rate was measured for specific samples. Drastic rate differences were measured between samples due to variations in surface area, crystallinity, defect structure, and impurity levels among other parameters. Several other related studies now remain in limbo due to another rate phenomena - my retirement from University activities. Perhaps it will be feasible for them to resume in the future.

CONCLUSIONS:

If iron sulfide containing strata are contacted by alkaline waters, their propensity for acid-formation will be diminished, if not eliminated. This approach is based upon control of reaction conditions -NOT- neutralization of any acid which might be present. The natural conditions are too complex to suggest some minimum level of neutralization potential or water alkalinity. If the alkalinity is not available at the mine site naturally, to create an alkaline environment, it can be introduced. Cost, as usual, is the controlling factor. The significance of laboratory weathering tests as a predicitive tool remains uncertain.

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