

## ACID MINE DRAINAGE RESEARCH: HYDROLOGY'S CRITICAL ROLE AND UNIFYING THEME

Frank T. Caruccio<sup>1</sup>

---

Abstract.--With some exceptions, in innovative treatment techniques many of the concepts and theories regarding acid mine drainage were postulated over 35 years ago. And much of the mine drainage related research currently performed should be integrated by a unifying concept and directed toward the solution of a principal objective - namely, the in-situ abatement of acid mine drainage. A central element which can provide a vehicle for unifying research directed toward this end and which is least understood and studied, is the hydrology of a backfill. A discussion is presented to justify soliciting proposals directed primarily toward and better understanding of the nature, occurrence and movement of water within spoil/backfill material.

---

Knowledge of the occurrence, distribution and description of water movement in a backfill, collectively defined by the hydrology, is critical to an understanding of the chemical evolution of water as it recharges the backfill and eventually emerges as a seep. The quality of the seep produced determines whether or not a bond is released, impacts the overall economics of the mining operation and affects the permitting decisions of future mines in that area. To date, few studies have addressed the hydrology of backfilled sites, primarily, I suspect, because of the difficulty of obtaining a hydrologic data base that requires drilling of the backfill material and properly installed wells and piezometers. Other than the ground water installations required to monitor quality, there is little incentive to drill costly monitoring wells in a backfill. Of the mine drainage issues, the hydrology of the system, although the most important part of the problem, remains the biggest unknown. If there is little incentive to drill and thoroughly explore an acid producing reclaimed site to determine what went wrong, imagine the incentive to

hydrologically explore a non-acid site to find out what was done right! Let's look first at the acid side of the issue.

From an historical perspective, acid mine drainage has been a persistent problem, plaguing and limiting coal development as a viable energy base. Although simple to explain, the problem has yet to be solved on a level whereby regulatory agencies may feel comfortable in granting permits to mine certain seams in certain areas. Indeed, during the last 30 years substantial progress has been made in the prediction methodology, understanding the nature of the problem and in treatment technology (particularly in reclamation of landscapes and treatment of acidic mine drainages). Yet, in those problem areas, acid waters continue to be produced and although recent mine plans are designed to minimize or contain underground the acid loads, the mining and reclamation strategy necessary to completely eliminate acid mine drainage continues to elude us.

Further, the cost of treating and controlling acid mine drainage has been estimated to be in excess of 5 billion dollars (1970 dollars)- one wonders how this entire scenario can be economically viable! The severance taxes and reclamation funds instituted by the Mining Act, that are currently being returned to the states, are beneficial but the

---

<sup>1</sup>Frank T. Caruccio is Professor of Geological Sciences, Department of Geological Sciences, University of South Carolina, Columbia, SC 29208.



reclamation efforts are usually directed toward alleviating mine related problems which remotely address acid water abatement. More often than not, considerable efforts are directed toward the revegetation of an abandoned mine site, with peripheral attempts toward water quality amelioration; in all fairness probably due to a lack of a demonstrated effective in-situ treatment rather than intent.

During my 25 years or so in acid mine drainage research I initially directed my efforts toward an understanding and prediction of acid mine water. Over the last ten years my efforts have been directed toward the mitigation of acid waters through the in-situ manipulation of the hydrology and geochemistry of infiltrating or recharge waters. As part of this overall effort, several ancillary studies developed with regard to prediction technology and the hydrology of a backfill. And over the past 15 years or so, through several committee appointments, I was able to periodically review the state of the art of acid mine drainage research, nationally as well as internationally. Based on what you are familiar with, consider the following concepts and their applications to the abatement of acid mine drainage:

1. The acidity of acid mine drainage originates not from free acid but from the hydrolysis of certain iron sulfates ( by products of pyrite oxidation).

2. The occurrence of the problem is geographically limited to certain parts of the bituminous coal field.

3. Concentrations of acidity vary with conditions of flow to produce variations in loads.

4. The primary source of acidity is pyrite or marcasite in the roof shales, binders and rider seams.

5. Acid formation is associated with the concurrent growth of iron-oxidizing bacteria and the bacteria serve as catalysts.

6. The key factors in the formation of acid mine drainage are the presence of finely divided pyrite which is exposed to the atmosphere and the oxidation of ferrous by bacteria.

7. The problem is related to the occurrence of sulfates of iron, aluminum and manganese.

Further, recommended research on control programs might be aimed at: (a) the control of the disposition of the iron sulfides, (b) prevention of contact of iron disulfide with air and water, (c) reduction of bacterial activity and (d) removal of the objectionable impurities from acid mine water.

Sound familiar? ALL of the above were gleaned from literature dated no recent than 1954! The classic works of S.A. Braley, L.V. Carpenter, R.L. Starkey, K.L. Temple and W.A. Koehler, to name a few, and my apologies to the other giants in the field who were not mentioned, go back to the early 1930's in publication dates. Other than the few major breakthroughs, primarily in treatment, what is the stage of our progress to date and since then, how have the overall research efforts been structured to build upon these concepts and observations reported over 35 years ago?

A review of the recent literature in acid mine drainage research shows that little has been added to the basic pool of knowledge central to the mitigation of acid formation at the pyrite site. Several breakthroughs have occurred in the treatment technology, notably, the wetlands treatment of acid waters, the surfactant bactericides developed to control the iron oxidizing bacterial activity and the large scale treatment facilities designed to handle large volumes of acidic water. However, how much closer are we toward solving the problem? It seems to me that the acid mine drainage problem which in itself is overwhelming, has been dissected into minute parcels of research, for funding expediency and/or clarity of thought, which have been taken independently away from the central objective related toward the solution of the problem. Today, with some notable exceptions, very little research is integrated into a unifying conceptual theme. Commonly, the results are reported to answer the objectives of the study and little is done to take the data and conclusions from that realm into the real world through the synthesis of ideas or integration into the other facets of the acid mine drainage problem. For example, the worth or value of a study that shows a chemical aspect of the acid problem would be greatly enhanced if the results of the study can be integrated into the hydrology of the site and further developed toward field application. Unfortunately, the research has been so finely refined that the trees become identified as not being part of the forest.

As a first step toward addressing the solution of the acid mine drainage problem through a perpetual and effective in-situ abatement technique let me suggest that future research in acid mine drainage abatement studies be structured to interrelate two or more aspects of the natural system and restrict funding to those projects that can demonstrate that the final results can be easily integrated into an ever expanding data base. The pyramid concept should be introduced with the keystone being the solution to the problem and supporting research constituting the building stones and blocks that establish the base, but at the

same time converge toward the central objective. It seems that today we continue to lay a broader and broader base with no sense of convergence occurring within the immediate future.

In soliciting proposals, funding agencies commonly call for studies within extremely broad categories the are related to the problem, but which do not provide convergence or direction toward addressing a central objective. Consider the RFP published in the September 18, 1987 Commerce Business Daily, soliciting research proposals "... to provide practical solutions to selected problems of abandoned coal mines. Proposed research must result in the development of innovative technologies, have wide regional application and be completed in a short time frame." The request then goes on to say that they are particularly interested in the areas of "...water quality, specifically abatement of acid mine drainage from a) underground mines, and b) refuse piles..."

Understandably the request is structured in the broadest description to encourage novel, innovative and unique approaches that may not as yet been conceptualized. I agree with this strategy. But at the same time could not part of the solicitation be line item specific, calling for directed research leading toward a specified objective. This may invoke a response from an expertise or talent, though not familiar with the overall problem of acid mine drainage, who may become involved in the research through directed efforts. For example, one of the key elements in the problem being discussed is the occurrence of water within a refuse pile or backfill and the critical role that it plays in the mass transfer and production of acidity and alkalinity. How is water recharged to the spoil, what is the distribution of the pores, what rock type generates the greatest porosity and provides the greatest alkaline/acid potential, what is the residence time of the water recharging the spoil, and how are the discharges controlled at the toe or outflow to produce seeps? Are the seeps an admixture of multi-channel flows or large reservoir bleeds? Each of these is a major unknown and must be addressed. In addition to the solicitation described above could not these research needs be specifically identified and targeted for proposals? A master plan must be organized that contains a convergence of studies and research efforts directed toward the solution of the problem.

I am a firm believer in the value of basic research. Certainly, it is through this avenue that data bases are developed, which, in turn, are synthesized into hypotheses and become foundations for applied and pragmatic research. But, realistically, how much closer are we toward solving the problem than we were twenty five years ago. Over the years,

and especially within the last ten years, a substantial amount of time, effort and money has been spent on the acid mine drainage problem. From my perspective, the data and conceptual base has been expanded, tremendously. Developments in predictive technology have provided insight into the nature and character of sulfide reactivity, reclamation efforts have provided insight into the nature of the pore gases and their evolution giving us a better understanding of the hydrogeochemistry of the problem. Treatment technology advances have given us a variety of mitigative applications that may or may not be site specific, but certainly are restricted to specific settings within the backfill or spoil pile (i.e. in order to be effective, phosphate amendments must be juxtaposed to reactive sulfide sites--consequently are limited in application to active or reconstructed sites). And numerous studies characterizing the physical aspects and geometries of the problem sites have yielded broad insights into the chemistry, hydrology and biology of the problem. The time has come to reexamine the broad base of completed studies that are laterally distributed and to recognize a common element upon which the vertical development and integration of the results can proceed and upon which a strategy for directed research can be developed..

If the principal objective addresses mine drainage quality then it appears logical to link the studies by a water related concept and, as a unifying theme, integrated by interpreting the results of the study within the vehicle of the hydrologic cycle. Consider the pathways of a drop of water as it enters the cycle as precipitation. And, depending upon the time of the year and the intensity and duration of the event, it will either run off and reflect the quality of the precipitation and surface chemistry, penetrate the near surface and reflect the quality of an actively leached horizon, or recharge deep within the backfill and reflect a quality of deep interior reactive spoil. Within each profile the variations in the degree of saturation and pore gas composition greatly affect the kinetics of alkalinity and acidity formation. Further, the physical character of the litho type, coupled with the method of mining, will control the pathway of water movement within the spoil (i.e., bouldery material will provide enhanced porosity and permeability, whereas clayey, friable material will inhibit water flow) and, in turn, the chemistry of the litho type will control the quality of the flow path. Most mine drainage quality predictions, based exclusively on overburden analyses, assume a uniform wetting front and ubiquitous water flow within the spoil, when, in fact, water flow is preferentially oriented along the more permeable zones (determined by the rock's physical characteristics) which may be either acidic or alkaline. In so doing, the

majority of the water flow comprising the seep (and its quality) comes in contact with a small portion of the total backfill or spoil material.

Extending this concept further to reclamation and in-situ acid abatement technology, to affect changes in chemical reactions, the chemistry of the water flow within the mine setting must be completely modified and controlled, an engineering challenge because, as discussed above, the runoff-infiltration ratios vary according to time of the year and nature of the precipitation. Accordingly, manipulation of the physical dimension is the only viable alternative. The number of studies providing for an understanding of this regime are remarkably few. At this stage of development we strive to chemically control a flow path by chemically altering the recharge point. However, within 1 meter of penetrating the surface of a spoil, the direction and movement of water is completely unknown, confusing the

evaluation of the efficacy of treatment. Did the treatment adequately intercept the targeted zones, was the treatment of sufficient magnitude, has the treatment gotten there yet?

At what time will we see a call for innovative studies designed to stabilize reactive pyrites, to characterize the hydrology of acid producing sites leading toward water manipulation to control seep quality, to evaluate the interaction between revegetation, soil development and pores gas changes to ascertain at what time in the future the acidity will become self treating, novel ideas for the reconstruction of an abandoned mined land engineered to increase alkaline loads and reduce acid loads. At this level the unifying theme of the hydrologic cycle links together several elements of the mine drainage problem and begins to integrate results leading toward a central objective. Alternatively, do we still proceed to corroborate the works of Braley, Carpenter, Temple, Koehler, Starky,.....

