# Prediction of Time Dependent Factors in Acid Mine Drainage

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ABSTRACT

This paper outlines the processes involved in acid generation from sulphides and the key factors in identifying and predicting time dependent changes in the nature of acid mine drainage (AMD). The initial characteristics of mine water; whether drainage from exposed mining faces, runoff and seepage from waste dumps or seepage from process tailings; do not necessarily reflect the long term potential for AMD. The ultimate quality of mine drainage is a function of the interaction of many chemical, physical, biological and engineering (operational) factors. Techniques are available that can predict the qualitative nature of acid generation and mine drainage quality but accurate quantitative predictions are essentially impossible at the present time. As more and more mining operations exploit sulphide ore, the AMD and acid waste issue will become a far greater concern. The significance of time dependent factors in the production of acid mine drainage is not just restricted to particular mine sites but needs to be recognised by the mining industry as a whole.

## INTRODUCTION

The quality of mine drainage has a major impact on water management systems. The quality determines whether or not water can be used as make-up in the process, discharged without treatment or the type of treatment required. Geochemical processes initiated following exposure of fresh rock to atmospheric conditions are the cause of water quality changes as a mine develops. This is a particular concern for mine developments in deposits which contain varying levels of sulphides such as base metals, precious metals and coal deposits.

The authors' direct project experience at operations in Australia, New Zealand, USA and South East Asia has confirmed that the major concern with mine drainage is the deterioration in quality due to sulphide generated acidity. The time for development of acid conditions can vary from less than 1 day to more than 50 years. Even in ore deposits containing 40 percent sulphur the generation of acid drainage may not occur for 10 to 20 years. On the other hand, material with less than 1% S can be immediately acid forming and release high concentrations of acid.

Recent expansion in gold mining throughout much of the world presents a potential medium to long term problem. In Australia, the gold industry renaissance thus far has concentrated on the exploitation of near surface deposits of oxide and other low sulphide ores. The industry is now beginning to move into a second phase targeting deep deposits many of which contain sulphide mineralisation and may be acid forming. The industry can expect sulphide generated acidity problems to become more prevalent and, if unchecked, costly remedial works and long term active post-mining maintenance will be required.

Two recent conferences; the 'Mine Drainage and Reclamation Conference' held in Pittsburgh, USA in April 1988 and the 'International Conference on Control of Environmental Problems at Metal Mines' held in Norway in June 1988, identified the increasing concern and increasing costs associated with the management and rehabilitation of sulphide mine wastes.

For example, the Canadians estimate that they have some 14,000 hectares of reactive sulphide mine wastes which will cost in excess of $C1,500,000,000 to rehabilitate over the next 15 years (1). Although the data is not readily available at this stage, it is highly probable that other countries, including Australia, could be faced with similar costs. It is therefore critical that new operations and expanding operations are designed and managed in a way that does not add to this industry cost by ensuring that acid mine drainage is controlled and sulphide wastes are disposed of in an environmentally acceptable manner.

Identification of potentially acid forming materials and development of appropriate management strategies is essential for designing an effective waste disposal and management strategy for the control of acid formation. The current state of knowledge is inadequate to fully assess the long term implications of acid forming materials in constructed waste dumps. However, the accepted strategy which involves placement of acid forming material in a manner that will prevent or minimise exposure to oxidised leaching is economical, practical and effective but requires close supervision and operational monitoring.

It is not simply a matter of burying the acid forming waste since convective transport of oxygen can result in sulphide oxidation occurring deep within a dump (2). It is essential that oxidised leaching through such an emplacement is controlled to reduce reaction rates and minimise the removal of oxidation products. This paper outlines the processes involved in acid generation and key factors in identifying and predicting time dependent changes in acid mine drainage.

## SOURCES AND GENERATION OF ACID MINE DRAINAGE

The major sources of acid mine drainage (AMD) at mining operations are:

1. Drainage from exposed mining faces in open pits and in underground operations;
2. Runoff and seepage from waste rock dumps; and
3. Seepage from process tailings.

The prediction and monitoring of AMD must be based on a thorough knowledge of the process of formation. Unfortunately, the process is complex and not completely understood despite several decades of intense study. It is not intended in this paper to describe the detail of sulphide oxidation but it is necessary to outline the general principles.

When examining the potential for AMD it is important to appreciate that there are three main stages in the generation of acid mine drainage and the long term situation may be very different to those indicated by general laboratory testing or from the initial years of operation.

The first stage involves the chemical and/or biological oxidation of sulphide minerals which slowly produces acid. This acid may be neutralised by carbonates or other minerals and there is very little, if any, decrease in pH. The drainage remains neutral or alkaline although the level of dissolved solids may increase. This increase in dissolved solids is due to oxidation and neutralisation reactions. Stage 1 can be very short, less than 1 day or very long, more than 20 years, and testing programmes that monitor pH only will not identify sulphide oxidation in this stage of the process.

The second stage begins after the carbonates and other neutralising materials are consumed. When this occurs the pH begins to fall and the acidophillic bacteria begin to multiply. When the pH decreases to below about 3.5, bacterially catalysed sulphide oxidation becomes effective and stage 3 of the process begins. In this last stage the rate of acid generation is rapid and limited only by the concentration of ferric ion which is dependent on the availability of oxygen.

The chemistry of AMD is highly variable and depends on the reactivity of the sulphides, content of neutralising materials (eg carbonates) and the associated mineral assemblage. The pH and concentration of acid liberated can also vary significantly depending on these factors.

Pyrite ($FeS_2$) is the major and most common sulphide mineral associated with geological deposits. However, other sulphides such as pyrrhotite, which are generally a minor constituent relative to pyrite, can have a major impact on acid generation because of their very high reactivity and can stimulate the reaction rates of other sulphides leading to rapid stage 3 acid generating conditions.

In addition to the acid generating factors ( ie sulphide minerals, water, oxygen, iron-oxidising bacteria, ferric to ferrous iron ratio) and the acid neutralising factors (ie carbonate minerals etc), the physical and hydrological factors have a major impact on the generation of AMD. These factors are frequently overlooked even though the basis of engineering solutions to AMD are generally based on these factors. The ultimate quality of mine drainage is therefore a result of the interaction of many chemical, physical, biological and engineering (operational) factors.

## IDENTIFICATION OF ACID FORMING MATERIALS AND THE PREDICTION OF ACID MINE DRAINAGE

The general understanding of the complex AMD production process is improving and the key mechanisms have been identified. Techniques are available that can predict the qualitative nature of acid generation and mine drainage quality but accurate quantitative predictions are essentially impossible at the present time. There is uncertainty in the predictive methods and this must be acknowledged in all assessment studies. Sample selection and sample preparation is frequently a major source of error which can often result in incorrect conclusions. Even to the extent of concluding that a particular mine deposit is non-acid forming when in fact subsequent operational experience demonstrates the deposit contains acid forming materials. Incorrect sampling tends to bias the results towards underestimating the acid forming potential of materials in a particular deposit.

It is generally accepted that the acid-base account is an appropriate procedure for screening materials to determine the acid forming potential. Our experience supports this view and we routinely use a modification of the procedure in our assessment of all mining operations. The procedure is referred to as the 'Acid-Base Analysis' or 'Net Acid Producing Potential' (NAPP) and involves determination of the total sulphur content, acid neutralising capacity and the saturated pH and EC of the selected samples. Our experience has shown the the NAPP assessment is an essential tool for identifying the acid forming potential of mine rock and waste materials.

The Net Acid Producing Potential (NAPP) is calculated from the total sulphur content and the inherent acid neutralising capacity (ANC) of a material. The total sulphur is stoichiometrically converted to a maximum potential acidity and expressed as %$CaCO_3$ equivalents to be consistent with the units of ANC. The NAPP is therefore defined as follows:

$$NAPP(\%CaCO_3) = \%S \times 3.125 - ANC(\%CaCO_3)$$

The '%$CaCO_3$ equivalent' is the conventional unit for relating the neutralising capacity of a material to standard $CaCO_3$ (limestone).

Therefore using this NAPP approach, a negative (-ve) NAPP value indicates that there is excess neutralising capacity available and that the material will be non-acid forming irrespective of the total S level present. Whereas a positive (+ve) NAPP value indicates that the material may be inherently acid or potentially acid forming.

As a routine part of the acid-base analysis, the pH and electrical conductivity (EC) of a saturated paste of crushed (<2mm) material are also determined to support the NAPP classifications and in particular identify inherently acid or saline materials.

The procedure is used to classify rock types into the key geochemical types as follows:

<u>Acid Forming</u> : material with inherent pH less than 4 and also acid generating (NAPP > 0);

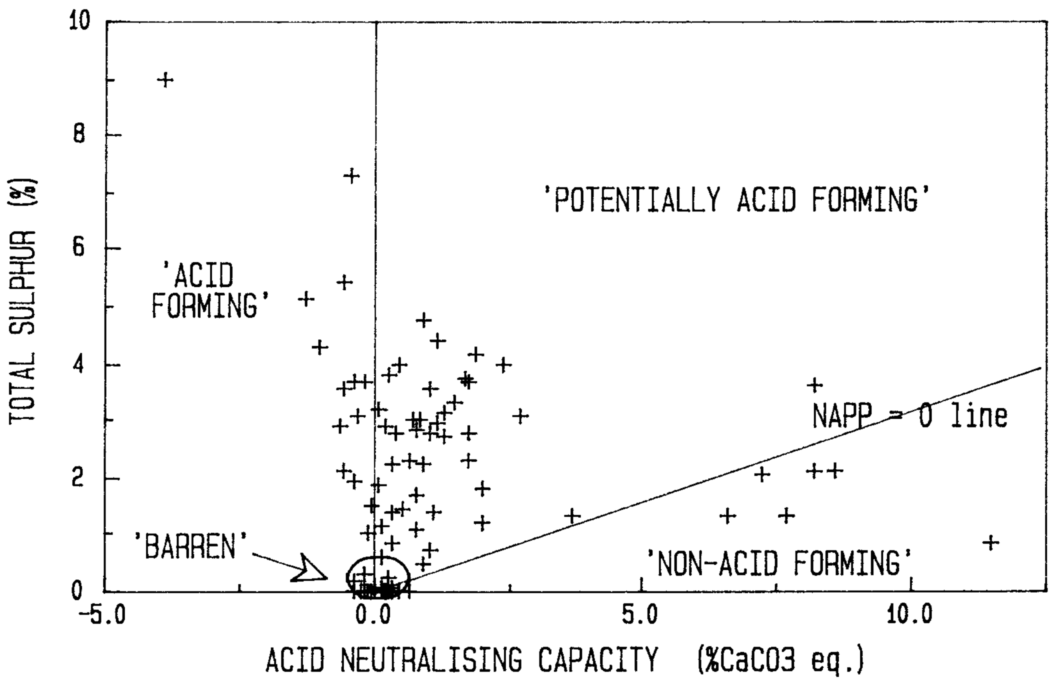
<u>Potentially Acid Forming</u> : material with inherent pH greater than 4 but potential for acid production, (NAPP > 0);

Non-Acid Forming : material with inherent pH greater than 4 and NAPP $\leq$ 0;

Barren : material essentially devoid of sulphur and neutralising minerals.

The results of the NAPP assessment can be presented graphically as shown on Figure 1. Figure 1 depicts actual data for a large gold project and identifies the various geochemical waste types.

FIGURE 1: ACID FORMING POTENTIAL - GOLD PROJECT




'NON-ACID FORMING' and 'BARREN' materials are suitable for general construction works and covering layers in waste dumps. These rock types are unlikely to adversely affect mine water quality depending on the nature of their other geochemical constituents. The 'ACID FORMING' materials are immediately acid and must be isolated from any oxidised leaching. In underground operations these materials will adversely affect mine water quality and special treatment or engineering works may be necessary.

The 'POTENTIALLY ACID FORMING' materials have a potential to generate acid if exposed to oxidised leaching. These are the materials of greatest concern because they can cause long term deterioration in mine water quality and result in long term acid generation in mine waste. The period of oxidised leaching required to generate acid conditions increases substantially as the ANC increases (ie. as the lag period increases). Also, the potential duration and intensity of acid generation increases with increasing sulphur content. Detailed leaching and mineralogical tests are necessary to determine if these materials are acid forming and to provide an estimate of the 'lag period' or exposure period required for establishment of the acid conditions.

Leaching tests, carried on the major geochemical waste types for a deposit, are used to provide design and management criteria for controlling acid generation. Column and batch leaching tests are commonly used, and where possible, field trials are also utilised. Our approach is to use coarse (<25mm) size material in columns and leach under simulated rainfall conditions. This provides an indication of leachate quality, weathering behaviour and incorporates the effect of the kinetics of the acid generation and acid neutralisation processes.

Batch (humidity cell) leaching tests are generally carried out following the reaction of any inherent acid neutralising capacity with sulphuric acid to create conditions under which potential acid formation can be fully assessed. Samples in these tests are also innoculated with a mixed bacteria culture to ensure that biological oxidation of the sulphides is encouraged.

The objectives of the leaching test are to provide an indication of the reactivity of sulphides (column and batch leaching); the presence and likely scale of any lag period for acid generation (column leaching); the ability of the material to generate acid and support bacterially catalysed oxidation (batch leaching); and the nature of short term leachates (column leaching).

It is essential that the NAPP classification procedure is based on individual samples and NOT composite samples of specific geological or geotechnical rock types. The variation in acid forming potential can be as great within one particular rock type as between all rock types and analysis of composite samples generates biased results which may result in failure to identify acid forming material.

## CONCLUSIONS

As more mining operations exploit sulphide ore, the AMD and acid waste issue will become a far greater concern. Short term control measures are effective and low cost as long as the acid forming materials are identified and managed correctly. However, the industry must appreciate the need for on-going operational management to prevent any subsequent long term problems. Post-operational remedial works and treatment costs are far higher than management solutions which can be integrated into the mining and waste disposal operation during the life of a project.

The industry now has the tools and knowledge to identify acid forming rock and to take appropriate action to prevent adverse environmental impacts and achieve regulatory 'walk away' approval at the end of mine life. The engineering implications of the occurrence of acid forming materials are generally straight forward but require on going operational monitoring and management to be effective. The long term financial costs, environmental costs and public support costs of incorrectly managed acidic waste materials are totally unacceptable. Therefore the industry must accept and adopt the operational implications associated with the mining and processing of sulphide ores, particularly with the increasing development of sulphide deposits.

The significance of time dependent factors in the production of acid mine drainage is not just restricted to particular mine sites but impacts on the industry as a whole. The increasing exploitation of sulphide deposits will expose a greater quantity and greater proportion of sulphide material with the potential for a general deterioration in mine water quality on an industry wide basis. The objective of this paper was to emphasis the following issues and major pitfalls for those investigating the nature of mine wastes and time dependent changes in the nature of acid mine drainage:

1. The quantity of potentially acid forming sulphide mine rock, waste rock and tailings will increase in the future and problems associated with the management of these materials will become far more significant;

2. Identification of potentially acid forming material is possible but sample selection and consideration of the 'lag period' are critical for accurate assessment and classification of geochemical waste types within a deposit;

3. Operational management solutions are effective and practical but require a deliberate commitment by the operator to ensure effective long term control and 'walk away' approval at decommissioning.

## REFERENCES

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