Remediation of Acid Mine Waters

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Abstract The formation of acid mine drainage (AMD) from pyrite and the contaminants associated with it are a major concern to the global mining industry and the environmental agencies of many nations. Available literature contains suggestions of many remediation techniques to address this concern that are based on knowledge of the chemistry of AMD. The choice of which remediation technique to apply often depends on which challenge has to be overcome. This research through a comprehensive review of the various techniques in the literature and operational manuals of some agencies has developed a guideline in the form of four flow chart diagrams as supporting tools to aid the rapid selection of the appropriate remediation technique. They address the management of AMD and technology selection through a systematic approach to chemical characterisation, the prevention of flow and the treatment required when flows are unpreventable.

Key Words Acid mine drainage, Management, Pyrite, Remediation

Introduction

Acid drainage, usually referred to as acid mine drainage (AMD) occurs as a result of naturally occurring chemical reactions of exposed sulphide containing minerals with water, oxygen and bacteria (Down and Stocks 1977). The bacteria known as Acidthiobacillus (formerly thiobacillus) ferrooxidans (Kelly and Wood 2000) acts as the catalyst in this case. Pyrite is the most common sulphide mineral associated with AMD.

The main objective of this work is to review existing works on acid mine remediation techniques, and then develop a practical tool for the remediation of acid mine drainage using flow chart methods for ease of understanding and clarity. This will provide a framework upon which decision makers, acting as either mine staff or regulators may quickly determine which method should be adopted to address the issue of acid mine drainage. The choice of a flow chart is to simplify a rather complicated technical process for easy use on mine sites.

Methodology

The method adopted for this paper is essentially a desktop literature review. This is the first logical step in understanding the problem and trying to resolve the issues. The methodology involves a number of different techniques or methods, including a critical review of literature across a wide spectrum of disciplines as shown by, but not limited to journals and book sources.

Based on the literature survey, four types of flow charts were then constructed to aid in the characterisation of mine drainage, and how to prevent the occurrence if possible. On the other hand, if the flow is unpreventable then there are two logical flow charts to guide the user in the selection of a particular treatment technology for the remediation of either net acidic or net alkaline mine waters.

Causes

AMD is formed when sulphide minerals e.g. pyrites react in the presence of oxygen, water and bacteria called Acidthiobacillus ferrooxidians. Figure 1 shows the equations as reported by Stumm and Morgan (1981).

Technology for the prevention of AMD

It is said that "prevention is better than cure", hence it is better to stop the occurrence of acid mine drainage in the first place. The objective of preventive techniques is to prevent the formation of acid effluent in a mine. In contrast, corrective techniques are those which treat acid water in mines in such a way that they cease to be a threat to the environment. When planning a mine, it is better to give priority to preventive techniques when possible. The preventative techniques as reported in various research papers can be grouped into about seven types as outlined in figure 2.

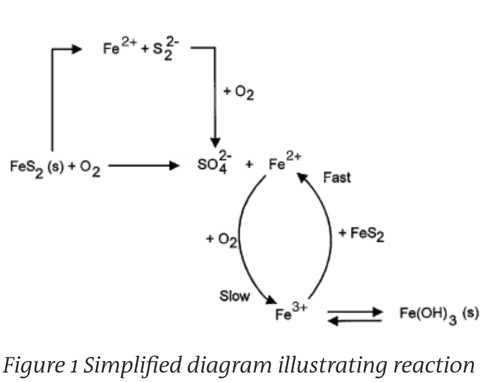

Figure 1 Simplified diagram illustrating reaction pathways for pyrite oxidation (Source: Stumm and Morgan 1981)

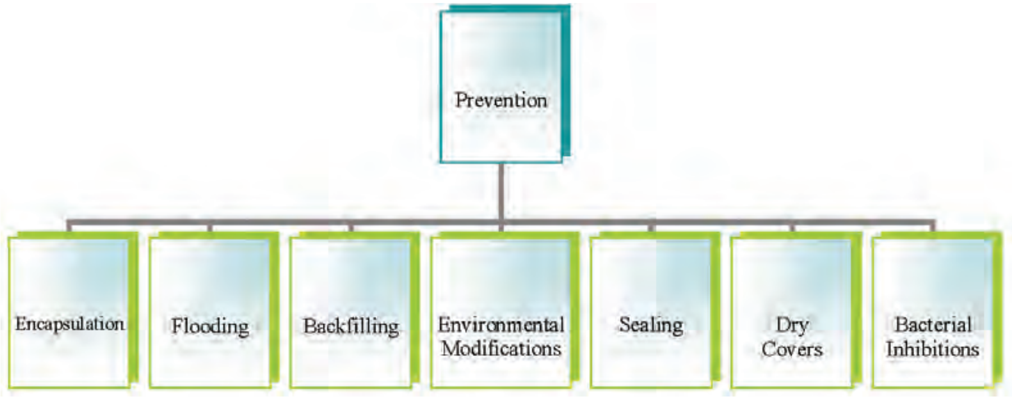

Figure 2 Various types of AMD prevention techniques.

Technology for the treatment of AMD

When the formation of acid mine drainage cannot be prevented or controlled, then collection and treatment is essential before the mine water can be discharged. The treatment can be active, making use of chemicals (Fripp *et al.* 2000) or passive, in the form of lagoons(rapid flow with significant hydraulic head or gradient) or cascades (rapid flow with significant hydraulic head or gradient) involving the use of natural substances and or biological processes.

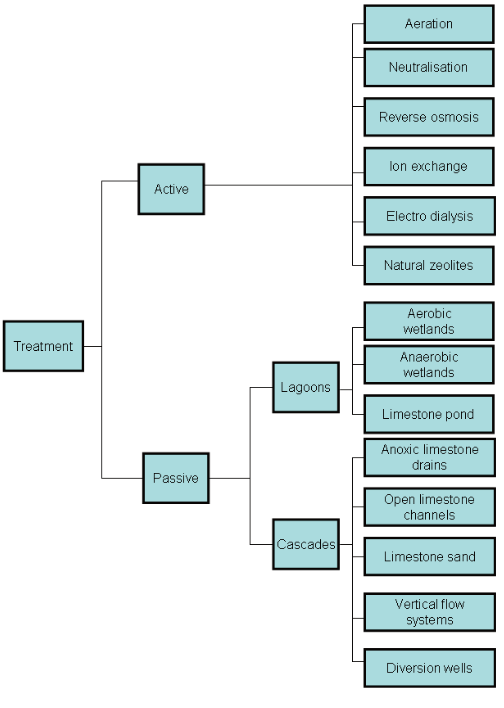

***Figure 3** Flow chart of options available for the treatment of AMD.*

An overview and categorisation of the techniques or technologies available for the treatment of AMD is outlined in figure 3. The important aspect to note regarding both active and passive systems, however, is that they require some degree of maintenance and monitoring.

Technology selection criteria

Based on the findings of the literature review, the selection of the type of treatment technology is not dependent only on the water chemistry, flow rate, and loadings, (Kepler and McCleary 1994; Hedin *et al.* 1994) but also topography, land availability, economics sustainability and climatic conditions.

These methods are looked up in the context of the proposed flow charts drawn. Included in it, is a short reflection of the additional factors that influence the selection criteria from the perspective of the decision maker. The most appropriate technologies require a provision of tools to all stakeholders such as the regulators, industry, vendors of technology and the general public. Many factors must be taken into consideration when selecting a remediation technology. Each AMD site is different; therefore, different methods or combinations may be effective when used for its remediation. These flow charts have been developed to aid all interested parties in evaluating sites as candidates for remediation of acid mine waters.

Local geochemistry

According to Skousen *et al.* (2000), the chemistry of AMD is a function of site hydrology and contact with acid producing (sulphide) and acid neutralising (carbonate) minerals. Hence, generally sulphide rich and carbonate poor sites produce acidic mine waters, while carbonate rich sites, even with significant sulphide concentrations would typically generate alkaline mine waters. The flow chart

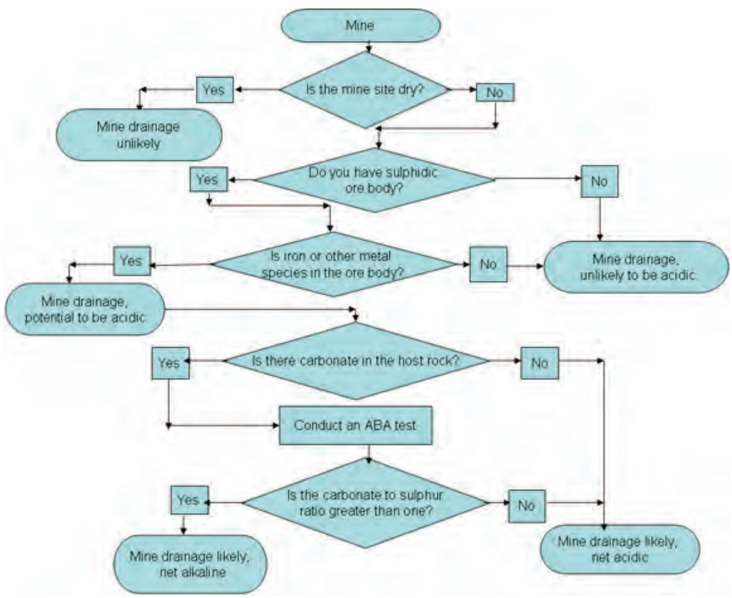

Figure 4 Chemical characterisation of AMD.

shown in figure 4 identifies the characterisation of AMD and figure 5 gives preventive techniques. On the other hand figures 6 and 7 suggest the treatment options.

The set of simple questions for interested parties to address leading to an understanding of the potential for AMD and its likely classification of net acidic and net alkaline.

Prevention
As shown in figure 4, if you identify that your mine has AMD then you can use the logical flow chart illustrated in figure 5 to find out which preventive technologies that may be applied in order to curtail the environmental impacts of acid mine drainage. From the review there are five major ways of preventing acidic mine waters and they are encapsulation, environmental improvement, flooding, sealing and the backfilling of mine pits. Figure 5 sets out a series of questions to help identify suitable preventive technologies or establish that the flow is unpreventable.

Treatment options
When the mine water cannot be prevented as might be concluded from figure 5, then the remaining option is to treat it making use of either active or passive technologies to meet environ-

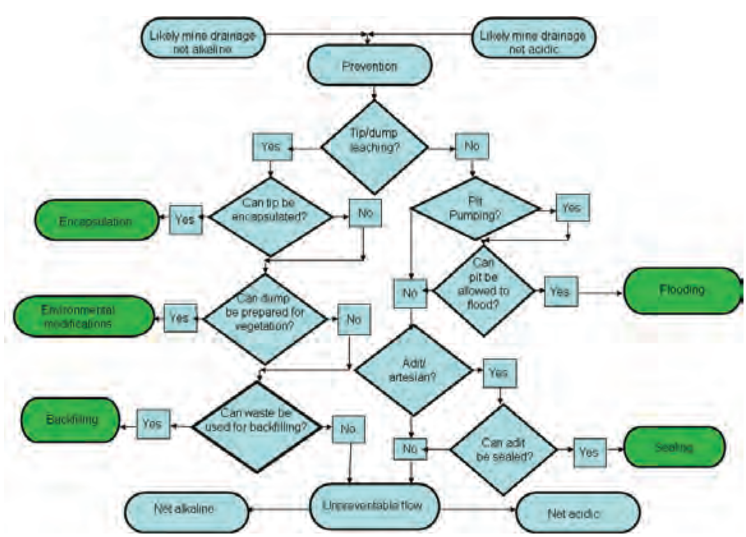

Figure 5 Flow chart for selecting preventive techniques.

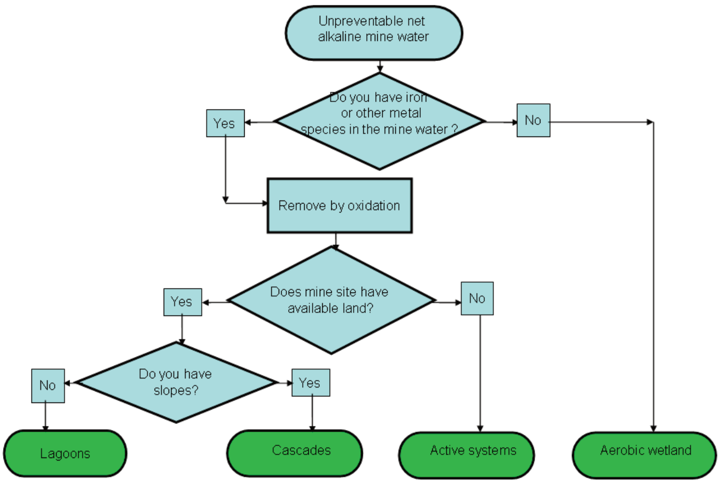

Figure 6 *Flow chart giving the decision logic for selecting remediation technologies for net alkaline waters.*

mental effluent standards before discharge.

In addition to the factors already considered by most researchers the following information is also required to select potentially effective technologies in mine drainage source characterisation: acid and metal loading, geochemistry and flow rates, site characterisation: climate, land availability and topography, environmental goals: discharge standards, human or ecological risk and contaminants of concern and available technologies (prevention, active or passive treatment).

The flow diagrams in figures 6 and 7 for net acid and net alkaline AMD attempt to take these considerations into account.

Net alkaline mine waters

The following flow chart sets out a logical sequence of questions that will guide the interested parties to the selection of appropriate technologies for the treatment of AMD in their location.

According to Johnson and Wright (2003), net alkaline mine water have low metallic salts due to their low solubility at high pH. Thus treating them is not of a problem like that of net acidic mine waters.

Net acidic mine waters

Once a mine has an unpreventable net acidic mine water, a method must be identified to treat it to meet environmental effluent discharge standards before it is discharged into nearby creeks, streams or rivers.

This suggested simple flow chart has been designed to aid mine operators and advisors in the selection of remediation technology options. From the review carried out most published flow

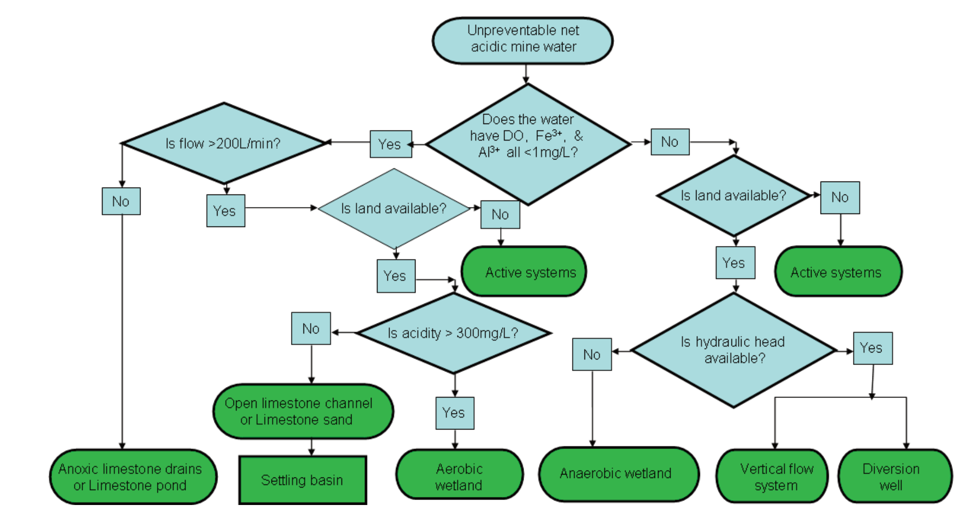

Figure 7 *Flow chart giving the decision logic for selecting remediation technologies for net acidic waters.*

charts (Hedin *et al.* 1994; Kepler and McCleary 1994) do not guide the one with the problem to make a remediation technology choice as they are prescriptive and limited in scope.

Discussion of proposed technologies

In this poster a systematic method of characterising the problem of AMD has been presented, making use of traditional flow charts to characterise the water then identify methods of prevention and finally methods of treating unpreventable flows.

Most of the selection flow charts that are reported or used in research are based solely on analysing the chemistry of water, flow and loadings (Kepler and McCleary 1994; Hedin *et al.* 1994; Ziemkiewicz *et al.* 2003). These methods offer no advice regarding the topography, availability of land and sustainability in the choice of a remediation technology.

Conclusions

A systematic approach to the selection of technology for the management of AMD has been presented in this paper. AMD may be characterised into two types and they are net acidic and net alkaline. Prevention of AMD needs to start at the early stages of the mine life and does not need detail characterisation of the water. The selection of the most appropriate treatment technology for mine water should be based on the raw mine water quality as well as the final effluent quality desired to be met.

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