
Conclusions

AMD is considered the greatest environmental challenge currently facing the mining industry (Mitchell, 1999). A large amount of research has been conducted in search of a cost-effective method for the prevention of AMD. A new method currently under development involves the stabilisation of sulphidic mine wastes with phosphate chemicals (Evangelou, 2001). Published research on this technique to date has been limited to studies on pure pyrite, pyrrhotite, pyritic coal waste and pyritic tailings. This study aimed to extend the phosphate stabilisation technique to polyminerallic, partly oxidised mine waste. The material used in the experiments was sourced from the abandoned, AMD generating Montalbion silver mine, Far North Queensland. In order to understand the processes occurring in the phosphate stabilisation experiments, an extensive characterisation of the Montalbion mining area was undertaken.

The Montalbion mining area contains several mineralogically and geochemically heterogeneous waste dumps. The steep slopes at the mine site promote erosion, allowing continuous oxidation of the waste material. The waste dumps contain high concentrations of Fe, Pb and S, minor As, Bi, Cu, Mn, Sb, Sn and Zn, and traces of Cd, Co, In, Se and W. The primary ore mineralogy of the waste dump consists of quartz and clays with 1-10 % sulphides (galena, tetrahedrite, sphalerite, chalcopyrite, pyrite and arsenopyrite). Extensive weathering of the sulphides has resulted in the formation of abundant secondary metal and/or alkali (hydrous) sulphates.

The oxidation of the sulphides, dissolution of soluble secondary efflorescences, desorption of H^+ from mineral surfaces and lack of acid neutralising material results in the generation of AMD at Montalbion. As a result the receiving surface waters of Oakey Creek are acidic (pH 3.3-4.1) and contain elevated concentrations of SO_4^{2-} , Al, Cd, Co, Cu, Fe, Mn, Ni and Zn. Oxygenation of the AMD waters promotes the precipitation of extensive, Fe-rich "yellow-boy" (amorphous Fe, schwertmannite, goethite) which has preferentially concentrated As, Sb, and In through adsorption/coprecipitation processes.

The chemistry of the mine drainage and Oakey Creek waters are strongly controlled by irregular rainfall events. During dry periods, evaporation leads to the formation of efflorescent sulphates in the waste dumps and on the edges of stagnant pools in Oakey Creek. Rainfall dissolves the soluble efflorescences in the waste dumps, resulting in acidic drainage waters with elevated SO_4^{2-} , Fe, Cu and Zn. Less soluble efflorescences retain Pb and As in the waste rock. Heavy rainfall flushes Oakey Creek with neutral pH waters, dissolving the streambed efflorescences and remobilising SO_4^{2-} , Al, Cd, Cu, Mn and Zn.

The waste used in the phosphate stabilisation experiments comprises a complex mixture of quartz, clays, sulphides, (hydr)oxides and sulphates. The presence of abundant secondary minerals, particularly soluble sulphates, has an important effect on the phosphate stabilisation experiments.

The phosphate stabilisation experiments demonstrated that the formation of phosphate coatings and precipitates can be induced in polyminerallic, sulphidic mine waste and partly oxidised, polyminerallic mine waste. Two forms of phosphate were formed: a) amorphous phosphate coatings, interpreted to be chemically attached to the sulphide substrate and; b) phosphate precipitates with a wide variety of chemistries and morphologies, interpreted to be physically attached to their substrates. Metal \pm alkali phosphate coatings developed on all sulphide minerals present in the waste of experiment 3 and all sulphide minerals except tetrahedrite of experiments 1 and 2.

The degree of phosphate development appeared to be dependent on cation availability. This was primarily controlled by the strength of oxidant in the coating solution, which controlled the degree of sacrificial sulphide oxidation. The dissolution of extensive soluble sulphates present in the mine waste provided abundant cations for reaction with the phosphate anions. This resulted in a greater degree of phosphate formation than when unoxidised mine waste was used (experiment 1). This is a promising result regarding the use of the phosphate stabilisation technique on abandoned, AMD generating mine sites such as Montalbion. The use of KMnO_4 and Trifos in experiment 3 provided

high concentrations of Mn and Ca in the coating solution, resulting in abundant Mn and Ca phosphate formation.

The development of phosphates inhibited acid generation and metal release in all columns. This was due to the inhibition of sulphide oxidation and probably due to the attenuation of dissolved metals into phosphate phases. The coatings formed using KMnO_4 and phosphate fertilisers were the most effective at inhibiting acid generation. This combination of oxidant and phosphate was also the cheapest and considered the most conducive for use in the field. The long-term ability of the phosphates to reduce dissolved metal concentrations in the leachate was likely dependent on the stability of the phases in the oxidising solution, though it is possible that metal concentrations were controlled by leachate pH alone. Fe and Pb phosphates were very stable, preventing the release of Fe and Pb into the leachates. In contrast, the Zn and Cu concentrations increased throughout the dissolution stage of experiments 1 and 2, likely due to gradual corrosion of the Cu and Zn phosphates. Dissolved metal concentrations were low in the coated column leachates of experiment 3 predominantly due to the stability of the amorphous Mn phosphates, which retained their incorporated metals. The concentrations of As and Sb were higher in the coated column leachates due to the greater mobility of these elements at higher pH.

The results of this study demonstrate that the phosphate stabilisation technique can inhibit sulphide oxidation and metal release in polyminerallic, partly oxidised mine wastes. Such processes are caused by the formation of stable phosphate coatings and precipitates. The phosphate stabilisation technique does have several potential limitations, including the release of sulphate and metalloids as by products of the coating process (Matlock et al., 2003). In addition, the long term stability of the coatings has been questioned (Jones et al., 2003). Further column experimentation and detailed field trials specifically targeting these potential limitations are required to determine whether the phosphate stabilisation technique can be used to remediate partly oxidised mine wastes in a cost-effective and environmentally sound manner.