

ACID MINE DRAINAGE AT MOUNT MORGAN, QUEENSLAND (AUSTRALIA): EXPERIMENTAL SIMULATION AND GEOCHEMICAL MODELLING OF BUFFERING REACTIONS

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Abstract

The Mount Morgan mine in Central Queensland, Australia, is a heavily impacted site with over 100 million tonnes of sulphide-rich waste rock accumulated during more than a century of gold and copper mining. Concern over the potential dispersal of acid mine drainage (AMD) into the surrounding environment prompted the construction of a water treatment plant in 2006.

In this study we performed some column leaching experiments and developed a geochemical model to simulate the generation of AMD and reactions between the AMD and lime [CaO], the buffering agent used in the water treatment plant. Our results show that although the use of lime is effective in reducing acidity and contaminant levels in the water, extremely large amounts of metal-rich sludge will be generated, and the precipitation of large amounts of gypsum [CaSO₄·2H₂O] following the reaction between the lime and the AMD is likely to cause problems in the treatment plant and associated pipelines. The treatment process itself may have some negative consequences on the chemical stability of the rock waste: the reduction in acidity may lead to the dissolution of jarosite [KFe₃(SO₄)₂(OH)₆], a stable phase in the tailings under current pH conditions, and the release of contained metals into the system. We demonstrate that some relatively simple experiments and geochemical models can predict very accurately the outcomes of treatment/remediation strategies, but only if the geochemistry and the geology of the site are well known.

Introduction

AMD and trace metals derived from mining activities can be hazardous to humans, animals, and most plant species, and a great deal of public apprehension revolves around their impact on ecosystems and their potential effects on human health. This concern has triggered extensive research and remediation actions at many sites in Australia and worldwide in the last thirty years (e.g., Banwart and Malmstrom, 2001; Ciccu et al., 2003; Cidu et al., 1997; Concas et al., 2006; Cravotta and Trahan, 1999; Doye and Duchesne, 2003; Johnson and Hallberg, 2005; Jurjovec et al., 2002; Malmstrom et al., 2006; Romano et al., 2003), but expensive remediation and rehabilitation actions are often perceived as failures, and large resources are often invested in strategies that may be unnecessary and/or ineffective. All too often remediation strategies and treatment procedures are chosen without a sufficient knowledge of the range of chemical and physical processes involved with contaminant transport at mine sites.

The Mount Morgan Cu-Au mine was operational for over a century from 1882 to 1991, and during this time it produced a total of 247 t of Au, 37 t of Ag, and 387,000 t of Cu, and over 100 Mt of sulphide-rich waste rock (Edraki et al., 2005). Sulphide minerals in the waste rock include pyrite (typically 5-10% by volume, but up to 50%), pyrrhotite, chalcopyrite, and sphalerite (Ulrich et al., 2002; Wels et al., 2006). To date, the oxidation of these minerals has resulted in the production of 90,00 ML of AMD (pH 1.9 to 3.8) rich in Al, Fe, Cu, and Zn, and conservative models indicate that AMD will be generated for at least the next 500 years (Gasparon, unpublished). As stated by Boyle (2002) the site is “a historian’s paradise, an industrial archaeologist’s dream, but a heritage conservationist’s nightmare.”

The main AMD storage area is the “Open Cut Pit” which has a capacity of 11,555 ML (Taylor et al., 2002). A detailed rehabilitation plan for the Mount Morgan mine site over a ten year period found that a short-medium term water treatment plant was needed to treat the AMD directly from the Open Cut Pit via a series of pumps, and release the treated water directly into the nearby Dee River (Unger et al., 2003). A lime dosing water treatment plant was commissioned and built in May 2006. Different materials were tested to reduce acidity and remove metals, namely quicklime, lime kiln dust, magnesium oxide, and red mud (Jones et al., 2003). It was found that at pH 7.5 Al, Fe, Cu, and Zn were removed successfully by both the quicklime and the lime kiln dust, however quicklime was more effective in the removal of Mn, Mg, and SO₄²⁻.

In this study we will report some of the results of experimental AMD-lime reactions, and will discuss a geochemical model of the buffering reactions, and its implications for the chemical stability of the waste rocks and for the efficiency and sustainability of the water treatment plant.

Experimental setup and analytical methods

To experimentally simulate the processes governing AMD generation and buffering we used some purpose-built polystyrene columns (“leaching columns”) with a volume of 400 cm³. The columns were filled with the desired solid material (e.g., waste rock) and flushed at specific time intervals with the desired solution (e.g., uncontaminated surface water from the mine catchment). At the base and top of each column a 3 mm thick Teflon disk with 1.59 mm Ø holes and 4 mm spacing was used to hold the column filling material in the column. At the base of each column a nylon membrane was placed in between the filling material and the disk to prevent the removal of particles with a diameter <1.59 mm. Once each column was set up, the filling material was saturated from the base with the desired stock solution to ensure complete saturation. After the desired time intervals (typically 1 to 35 days), the leachate was collected from the base of the column. An oxidizing environment was maintained throughout the experiment, and the procedure was designed to simulate the interaction between surface water and waste rock, and the generation of AMD in the upper part of the waste rock pile.

Electrical conductivity and pH were measured using a conventional hand-held meter, and elemental (Fe, S, Cu, and Zn) concentrations were measured by inductively coupled plasma - optical emission spectroscopy (ICP-OES), and inductively coupled plasma - mass spectrometry (ICP-MS), using a Perkin Elmer Optima 3300 DV and a Thermo X7 series, respectively. Blanks and spiked samples were run with each batch of analyses for quality control purposes.

Results and Discussion

1. Experimental generation of AMD

The waste rock material was flushed with surface water collected at the site to simulate the process of AMD generation. Typically the Mount Morgan waste rocks and tailings contain variable amounts of quartz [SiO₂], pyrite [FeS₂], and jarosite [KFe₃(SO₄)₂(OH)₆], with minor kaolinite [Al₂Si₂O₅(OH)₄], and albite [NaAlSi₃O₈]. Pyrite was a major component (50% by volume) of the waste rock used for this experiment.

The experimental simulation yielded an AMD with pH and S concentrations similar to those observed in the field (Table 1), but with notable differences in Fe and metal concentrations. This solution was very unstable, and bright red-orange amorphous Fe-(hydr)oxides extremely rich in Fe and all metals, particularly Zn, precipitated after less than one hour. A 0.5 cm-thick layer of the same material is visible in the Open Cut Pit and elsewhere in AMD channels and ponds. It is therefore reasonable to conclude that our experimental simulation was able to reproduce the AMD and the Fe-rich precipitate observed at the mine site.

Table 1. Comparison between pH, Fe, S, Cu, and Zn values measured in AMD from the open pit and in the leachates.

Parameter	Observed Open Cut Pit	Measured leachate before Fe-(hydr)oxide precipitation
pH	2.68	2.86
Fe (mg L ⁻¹)	271	4447
S (mg L ⁻¹)	3902	3818
Cu (mg L ⁻¹)	39.8	64.8
Zn (mg L ⁻¹)	31.8	57.0

Our experimental AMD simulation at the Mount Morgan mine site predicted that for each litre of water that falls on the waste dumps each year, 1.725 cm³ of sulphide minerals react to form a solution with 13,430 mg L⁻¹ of SO₄²⁻, 42.5 mg L⁻¹ of Cu, 40.5 mg L⁻¹ of Zn, and 3,902 mg L⁻¹ of Fe. This solution then equilibrates in the oxidizing environment to form AMD and a precipitate of Fe-(hydr)oxides. Using existing data on rainfall, mineralogy, and volume of waste rock, we further calculated that it would take over 400 years to consume the acid-generating capacity of the waste rock pile.

2. Mount Morgan buffering simulations

Two columns were set up to simulate the buffering process. The experiments were designed to simulate the use of alkaline covers over waste dumps, and the blending of alkaline material with the waste. The aim of a cover is to exclude either or both oxygen and water from infiltrating through the waste dumps, hence preventing oxidation. In the first column (Column A) we placed a thick layer (approximately 0.65 cm) of lime over some crushed pyrite-rich waste rock. In the second column (Column B), the same pyrite-rich waste rock was thoroughly mixed with the same amount of lime (lime:rock ~ 1:20 by volume) as in Column A. Both columns were saturated from the base, and flushed at regular intervals with surface water collected from the site. The aim

of layering the buffering agent was to determine if it acts as an impermeable boundary and/or if it dissolves and forms a coating over the sulphide grains, both preventing oxidation.

It was found that the lime in Column A reacted violently as soon as the saturation front came into contact with it, resulting in the formation of a dense barrier. No solution could pass through the column and therefore no further analysis or results were obtained from Column A.

Conversely, equilibrium was reached quickly in Column B. The pH remained constant at ~ 12.5 , and the concentrations of Al, Fe, Cu, and Zn in the effluent were two to three orders of magnitude lower than those measured in the non-buffered effluent. Over time gypsum precipitated in the pore spaces until the system was completely clogged up and the effluent flow stopped.

3. Geochemical model

The buffering capacity of lime and any problems associated with the AMD-lime reaction were modelled using the 'Geochemists Workbench' package (Bethke, 1998).

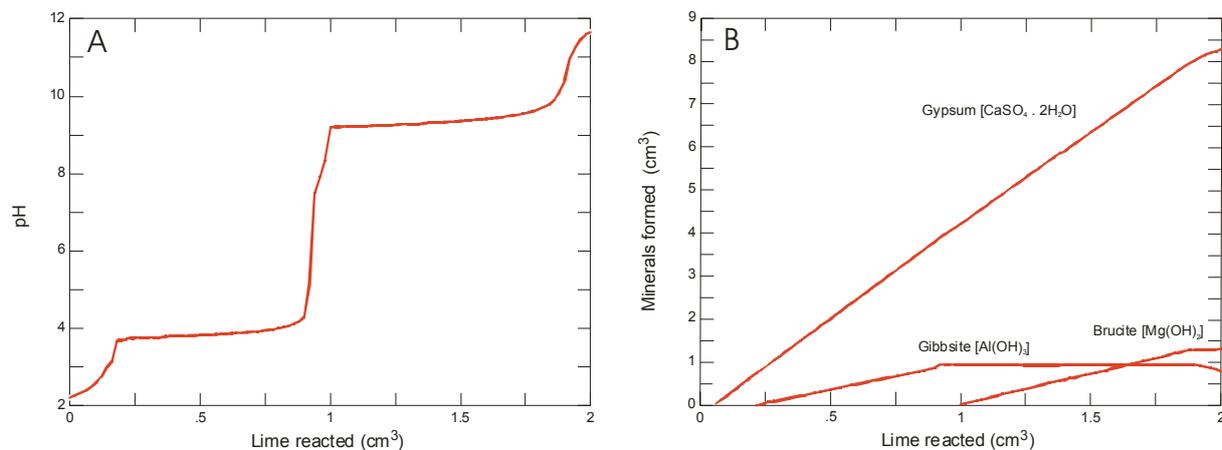


Figure 1. Results of geochemical modeling. A) Changes in pH as the lime reacted with the AMD. B) Volumes of minerals that formed in the system as the lime reacted with the AMD.

Two cm^3 of lime were completely dissolved in 1 L of AMD, and at the end of the reaction path the solution had 101 mg L^{-1} of Al and $2,784 \text{ mg L}^{-1}$ SO_4^{2-} . The pH level of the final solution was 11.7 (Fig. 1A) and concentrations of Fe, Cu, and Zn were all below 0.001 mg L^{-1} . Balancing of the AMD solution resulted in a reduction of Fe concentration to 40.91 mg L^{-1} (from 259 mg L^{-1} in the AMD), consistent with the precipitation of Fe (hydr)oxides. At the end of the reactions 8.29 cm^3 of gypsum were precipitated (Fig. 1B), with the total volume of precipitates being 10.57 cm^3 . Given that Open Pit has a storage capacity of 11,555 ML, this is equivalent to the potential production of over 122,000 m^3 of gypsum-rich sludge.

The precipitation of gypsum is consistent with the reduction in hydraulic conductivity observed in Column B. The large amount of sludge formed as a result of the reaction has serious implications for the effectiveness of the Mount Morgan water treatment plant.

The reduction of acidity in the treated water could have paradoxically negative consequences if the water is pumped back into the open pit. Under current low pH conditions, jarosite [$\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$] is a stable and abundant mineral phase in the tailings, capable of immobilizing some of the metals released from the waste material during the AMD generation process. Under higher pH conditions (>2.5), jarosite would become unstable, and this could lead to the release of metals into the pit water.

Conclusions

Our work has shown that the lime treatment of AMD at the Mount Morgan mine would be successful in simultaneously reducing acidity (pH increased from 3 to 12) and removing metals (Cu, Fe, and Zn) from the contaminated water. However, it would also generate large quantities of gypsum and other sludge materials which could cause clogging of pipelines, and ultimately cause the treatment system to malfunction. Furthermore, if this treated water is pumped back into the open pit, the decrease in acidity may cause the dissolution of jarosite and the re-mobilization of contained metal species. Based on existing rainfall and mineralogical data, and the amount of waste rock present at the site, we estimate that it might take over 400 years to consume the acid-generating capacity of the waste rock.

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