

# ARD in waste rock: preventive methods

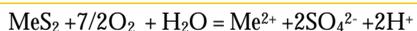
A major issue with the disposal of sulphide-rich mine waste is the release of acid rock drainage (ARD). Often the course of action taken is 'end-of-pipe' treatment, however this action is undesirable due to high cost and continued liability. The environmental problem of ARD has long been recognised as being deleterious to the surrounding environment and is, as a consequence, a major financial burden to the mining industry.

In 1995, in the US, in excess of US\$1 million/d was spent to combat the problem. With ever increasing restrictive legislation being enacted globally, the control of ARD is paramount to the mining industry. It must also be noted, however, that there are limitations as to the level of control achievable due to cost implications, and BATNEEC (best available technology not entailing excess cost) is generally the accepted solution. To date, the physical and chemical control of acid generating waste is typically categorised as being:

- ◆ source control, which attempts to reduce the rate of, or prevent, sulphide oxidation. In practice the former is more practical;
- ◆ migration control, which aims to chemically or physically contain the products of ARD from being mobilised away from the site of generation, for example a geosynthetic liner or clay cap; and
- ◆ discharge control methods, which aim to treat an effluent so as to remove the ARD products thus preventing environmental impact from dispersion (for example a chemical treatment plant).

The latter control mechanisms permit the generation of ARD but with different response actions. Source control, in contrast, has the potential to offer the best long-term solution, as it attempts to prevent or restrict the generation of ARD. It also has the advantage that the economics of prevention often outweigh those of a long-term cure.

The process of sulphide oxidation involves an electrochemical reaction in which one sulphide acts as an anode and another less conductive solid acts as a cathode. The reaction essentially occurs as:



Where Me equals a divalent metal cation, such as Fe in pyrite, or a combination of metals, such as FeCu in chalcopyrite. This releases metals, sulphate and possibly hydrogen ions, which leads to a fall in pH. The reaction is dramatically enhanced in the presence of a cata-

lyst, such as *Thiobacilli bacteria*, or an oxidising reagent, such as ferric iron in solution.

## CONTROL OF SULPHIDE OXIDATION

Traditionally, attempts have been made to remove or reduce oxygen and moisture by the placement of thick barriers over the waste. Such a barrier could include a geomembrane or geofabric cover (figure 1). Fine-grained covers rely on the moisture-retaining characteris-



Figure 1: Synthetic and geofabric cover over a sulphide waste rock pile, Y Fan mine, Wales.

tics of these materials to maintain high moisture contents above the water table. Naturally formed covers can be encouraged by intentional formation of 'hard pans'. These are analogues to lateritic iron accumulation in tropical soils. The hard pan can comprise a ferricrete (iron-rich cement), silicrete (silica-rich cement), a gypcrete (gypsum-cemented zone) or calcrete (calcite cemented zone).

Exclusion of bacteria may also significantly reduce sulphide oxidation and this involves the use of bactericides, either as an intimate mixture with tailings or back-fill material or applied directly onto sulphide surfaces. However, such treatment requires continual re-application based on currently available bactericides and is only suitable as a short-term option.

Table 1: Efficiency in reducing effluent impact by various source control treatments.

Treatment	Percentage reduction in metal release <sup>1</sup>	Percentage reduction in acid release <sup>2</sup>
Silica encapsulation	94	98
Bitumen	93	96
Bactericide	81	70
Phosphate	69	72
Limestone	48	68
Lime	33	48
Clay cover	44	31

<sup>1</sup> Calculated against humidity cell test data for untreated waste for the metals Fe<sup>+</sup> Cu<sup>+</sup> Zn<sup>+</sup> Cd<sup>+</sup> Mn<sup>+</sup> Ag<sup>+</sup> Co<sup>+</sup> Ni

<sup>2</sup> Calculated against humidity cell test data for untreated waste for [H<sup>+</sup>] based on field pH measurements

More recent research by SRK Consulting and the Department of Materials and Minerals, Cardiff University, UK, has focused on exclusion of the sulphides by precipitation of an insoluble, non-reactive precipitate thereby isolating the sulphide from oxidants.

Ferric phosphates and oxyhydroxides have been proposed previously and the rate of sulphide oxidation has been observed to decrease in samples amended with phosphate.

However, in field studies the presence of alteration products on sulphides has not led to a significant decrease in acid generation. A more promising barrier is to encapsulate the sulphide waste in bitumen or silica gel.

To assess the relative methods, continuous leaching studies have been conducted on samples of sulphide-rich mine waste subject to the control options outlined in table 1. The results of cyclic leaching in humidity cells revealed that silica encapsulation was the most effective method for control of metals and acid generation. This

method has the benefit of being an 'add-on' process to an existing operation (figure 2) and can generate mine waste, such as tailings, that has considerably greater environmental stability than untreated waste.

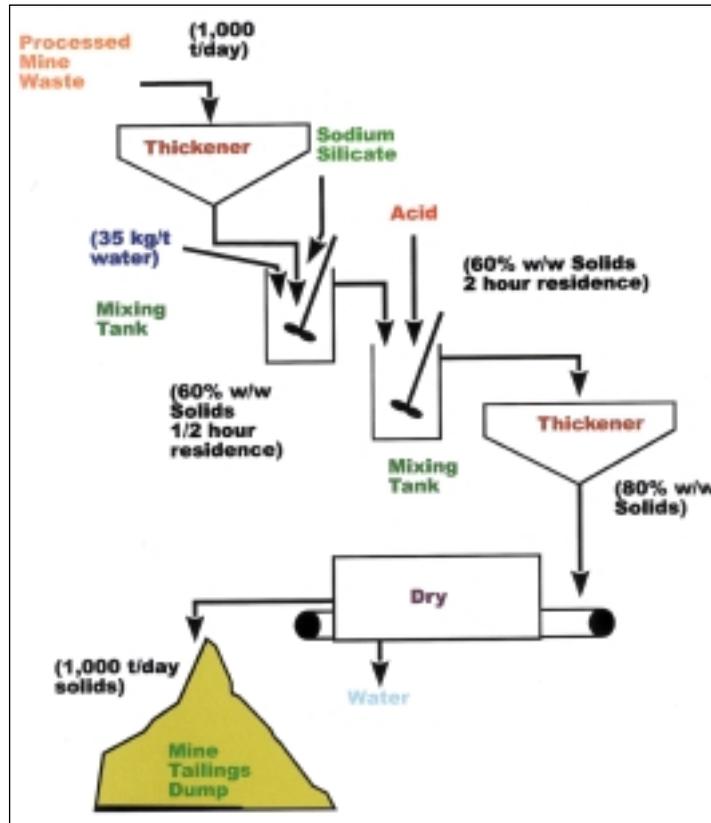
Phosphate treatment, although not as good, also produced reasonable control of metals, sulphate and pH. The fresh limestone proved a better ameliorate than the previously weathered lime with lower metals production, although Ca and sulphate were still very high. A clay soil cover had little effect on the control of metals, sulphate or pH as entrained moisture within the waste contains sufficient oxygen to initiate oxidation.

With the exception of the silica encapsulation, the first three flushes of all the other cells released an initial high peak in metal salts as the partially oxidised mine waste was rinsed of the previously formed salts. This dissolution of

# TREATMENT

secondary minerals has an important implication in that, with a change in pH, these salts are readily released leading to a secondary source of acid generation. These secondary minerals are often temporarily stored in the old mine waste and their behaviour is much less predictable than primary sulphide oxidation. This did not occur in the silica-encapsulated cell, as the preparation of the cell required the waste material to be thoroughly mixed in an alkali solution, which was subsequently neutralised, filtered and the solids dried. The metal salts removed by this treatment are potentially very stable, as they will also be micro-silica encapsulated.

Bactericides are highly variable in efficiency as often they present a bigger potential environmental impact than the waste. Equally, bactericides tend to be genera specific and so it is essential to adequately characterise the acid promoting bacteria prior to amelioration.



generation with low potential for metal leaching, such as in many coal mine drainage cases, limestone treatment is adequate and generally cost effective, being the cheapest option, although this may not be a viable long-term option. However, a surprising result was that lime, which is more expensive than limestone, did not offer significantly greater control than limestone. Further, the resulting high pH from lime neutralisation promoted arsenic solubility and increased the concentration of arsenate in leachate waters.

Thus, it can be seen that the control of sulphide oxidation presents an economic, realistic approach to reducing the impacts of ARD. It is unlikely that on an operational scale such measures will completely prevent ARD, but they could reduce the rate and volume of ARD products produced at any given time such that the receiving environment is not adversely impacted.

As with all control options,

the final adoption of any method will be dependent on site geology, hydrology, the geochemistry and mineralogy of waste material, economics and nature of the receiving environment in terms of sensitivity and future use.

## PRACTICAL ASSESSMENT

Relative costs for each of the methods are given in table 2, along side the relative percentage effectiveness of the method to reduce the rate of sulphate release, used here as a chemical marker for acid generation.

From the results it can be observed that silica encapsulation is the most beneficial in controlling metal-sulphate rich ARD, but is also, potentially, the most expensive treatment. However, the method may be useful for highly reactive mine waste such as that generated from high sulphidation precious metal deposits or massive sulphide mine waste, such as in the Iberian pyrite belt.

Additionally, the cost can be reduced by removing the filtering and drying stages and by replacing expensive reagents in the scheme, such as sulphuric acid, by less expensive alternatives. This would make the resulting product more selective.

Above: Figure 2 - Conceptual flow sheet of silicate treatment as part of a mineral processing system

Below: Table 2 - Estimated cost implications of treatments, expressed as US\$ per tonne of material treated.

Treatment	Cost
Silica encapsulation	\$5.00 - \$10.00 /t
Bitumen encapsulation	\$4.00 - \$ 6.00 /t
Phosphate coating	\$2.00 - \$ 4.50 /t
Bactericide treatment	\$3.00 - \$ 7.00 /t
Lime treatment	\$1.60 - \$ 4.00 /t
Limestone cover	\$0.20 - \$ 1.00 /t
Clay cover	\$0.18 - \$ 0.85 /t

Phosphate treatment offers a similar potential to control high ARD, although may not be as reliable. Where the main concern is acid

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