August 2014
The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

Mining and water

Minimising the formation of acid rock drainage

A completed Water Research Commission (WRC) study aimed to establish feasible approaches to prevent the formation of acid rock drainage from mining wastes.

Background

The ideal approach to handling of sulphidic waste rock is to prevent the potential for generation of acid rock drainage (ARD) through the removal of the sulphide phase before its disposal, thus avoiding the need for long-term mitigation strategies. In the best case, this processing of waste rock prior to disposal should result in an increase in the recovery of values from the starting material and the re-allocation of waste material as feedstocks for other uses.

The search for feasible approaches

Current rock drainage prevention strategies focus on covers and coatings. While these have been shown to be effective, the lifespan of their effectiveness remains in question.

A previous WRC project (**Report No. 1831/1/11**) demonstrated the potential for the removal of sulphides from tailings. Both the removal of sulphide by separation and by reaction was demonstrated for the tailings and waste rock respectively, with the former showing the most promise.

In the latest project, the general application of sulphide removal by separation to reduce the risk of ARD generation is presented across tailings and finely divided mineral wastes from various sources, including a variety of coal fines and tailings from the gold industry. Demonstration of the removal of sulphide is presented in the final report with the associated reduction in potential for ARD generation.

Further, the cost implications and disposal routes for the sulphide and benign fractions removed are considered.

Review of rock drainage prevention strategies

Hydrology and mass transfer influence mineral bioleaching, and therefore impact ARD formation. Particularly, waste rock dumps are characterised by non-homogeneous flow and channelling.

The impact of particle size distribution and irrigation rate on preferential flow patterns is described in the report. Further, their influence on gas and heat transport impacts ARD formation.

Through review of the literature, it is clear that the hydrology studies available to provide useful insight into the interactions between flow patterns, microbial colonisation, and clogging, whether with heterotrophic microbial populations in soils or precipitates in waste rock dumps, are limited.

To date, most discussion of the hydrology of waste rock dumps and low grade mineral heaps for extraction is based on modelling studies. From the studies reported, the distribution of fluid in the heap between flowing liquid, stagnant liquid, particles and the gas phase is key.

In this report, the research to date with respect to mineral leaching ore beds is reviewed, indicating that current modelling approaches are limited owing to inappropriate assumptions of the nature of fluid flow in the ore bed and the resultant poor presentation of the non-uniform flow through the ore bed.

Two independent studies have demonstrated rivulet flow. Recently, in association collaborative projects of the University of Cape Town team, magnetic resonance imaging

and positron emission tomography have been used to investigate flow distribution in the ore bed to enhance the understanding of controlling factors.

Investigating new strategies

Strategies for limiting the permeability of waste rock dumps to restrict access of reactants were reviewed and extended. Two predominant approaches were found: provision of borders or covers, and reduction of bed permeability through the co-mining of waste rock with fine material.

An experimental study was conducted to establish methodology and provide proof of concept of the 'mingling' approach through analysis of flow. Here, permeability decreased, residence time increased, and degree of saturation increased with decreasing particle size for uniform sized particles.

Most importantly, the model system demonstrated that, by including a fraction of fine particles with the waste rock material in the dump, permeability can be manipulated and flow restricted, thereby restricting access of reactants to the reactive sulphide minerals present.

A substantial reduction in permeability resulting on homogeneous mixing of large waste rock particles with fines; however, the layering of fines (<2 mm) and waste rock provided a greater reduction. Leaching of a low grade base metal ore in such layers was compared to standard leach conditions using agglomerated ore and illustrated that the leach rate, under forced leaching conditions, was slowed, but not eradicated. Investigation of the co-mingling of waste coal with a benign waste tailings is recommended; however, it was not possible to source the appropriate inter-burden sample, with samples received being of inappropriate composition.

The impact of flow rate on colonisation and leaching was also studied experimentally. Here it was shown that rapid irrigation rates result in greater flow of microorganisms through the bed while reduced irrigation rates encourage microbial colonisation of the waste rock bed. Preliminary data on associated leach rates of low grade ore with irrigation rates are available.

Further irrigation of the waste rock bed from a single point demonstrated that regions of differing moisture content develop. In 'drier' regions, with moisture content around 7%, colonisation was not detected with methods used, whereas in higher moisture zones, of around 10%, colonisation was significant. This illustrates the importance of restricting moisture content for avoidance of ARD formation.

Recent studies on the removal of sulphide from tailings by separation were reviewed. This demonstrated that significant strides forward, independent of this study, have not been reported in the open literature since the completion of WRC K5/1831.

In this study, we have extended the sulphide removal studies to a range of finely divided materials, including the tailings from the preparation of pyritic gold ore concentrate, the BIOX tailings, and coal fines. In addition to demonstrating the preparation of the bulk of the material for disposal such that the ARD generation potential is small, potential uses for the residues are considered, as is the process costing.

Using a series of five samples of coal fines, the proof of concept was demonstrated of sulphide removal from the bulk of the waste tailings by separation, in this case flotation, in order to eliminate or decrease ARD generation potential. Further, it was demonstrated that biodegradable oleic acid was an excellent collector, yielding improved performance over dodecane.

A similar study on tailings from the gold industry has illustrated mixed results. Using flotation to upgrade the tailings from the laboratory bioleaching of pyritic gold concentrates has been successful with decreased sulphide grades reporting to the bulk tailings.

Here ARD generation potential was reduced but not eliminated as with other mineral systems. On treatment of the tailings (collected from the tailings dam) from the concentrator circuit by further flotation, no significant upgrading was achieved; however the sulphide associated with the solid tailings was already low.

The study of gold tailings samples was limited by those samples attainable. It is recommended that further representative samples be sourced for study to further assess the generalised nature of the findings Potential uses for both the sulphide-rich and sulphide lean tailings samples have been identified and illustrate a range of potential applications.

For the use of the sulphide rich stream, consideration is required for the quality of material needed as well as the impact of associated gangue fractions. To address this, the development of flowsheets for handling these streams and a system for their rating in selection of use is underway.

In order to establish a framework for the economic costing of the sulphide removal from tailings and fine waste materials, a flotation desulphurisation flowsheet has been proposed to follow the traditional coal processing flowsheet.

This has been used as the basis for an order of magnitude estimate of a new fine coal desulphurisation plant.

Based on assumptions specified, this preliminary costing has suggested potential for economic viability. A sensitivity analysis is presented which targets, among others, value of the resource recovered, yield and reagent costs as key considerations for optimisation of the approach.

A survey was done of studies on the removal of sulphide by reaction. In particular, the limited work on accelerated bioleaching was reviewed. Most notably the use of potassium ferrate as an oxidising agent and use of the Fenton reaction provide interesting approaches.

The recent report on the Fenton reaction is confirmatory of work conducted at CeBER, UCT with respect to bioleaching and opens a new and potentially fruitful avenue for consideration.

Main insights emanating from the study

- In the absence of removal of the sulphide from waste rock and tailings, it is unlikely that ARD generation can be avoided in perpetuity.
- The introduction of fines through co-mingling or establishment of layers within or on top of the waste rock dump reduces the permeability through the dump, but does not restrict leaching completely, under conditions of forced irrigation (worst case illustration) once microbial colonisation has been established. The rate of this leaching is affected by the ore packing.
- The poor understanding of the fluid path through a heterogeneous bed under unsaturated conditions compromises the modelling approach on which most prediction of ARD formation from waste rock dumps has been based.
- Where microbial colonisation of the waste rock dump occurs, the formation of ARD is continuous in time, de-coupled from the supply of irrigant. In this case, the irrigant serves to flush out the already formed ARD from the rock dump. The rate of flow of this irrigant (through dry and wet periods) influences both the flushing of ARD achieved and the colonisation of the rock surface.
- With tailings or fine waste rock / coal, proof of concept has been shown across a variety of feed materials that removal of sulphide through separation using, for example, flotation may result in a bulk tailings sample which is benign with respect to ARD generation. The minority stream is enriched with the sulphide material and requires contained disposal or use.
- A wide range of potential uses exist for both the sulphide rich stream and the sulphide lean stream resulting from the flotation separation. These include the generation of products such as sulphuric acid and cover materials, respectively, for which there is significant demand in South Africa, amongst others.

  A framework has been established for the costing of the separation approach. Preliminary analysis under specified conditions suggests potential for viability. Further sensitivity analyses highlight the cost of resource recovered, yield and reagent costs as key variables to be studied further.

  The limitation of the suite of characterisation methods for ARD is noted. Static tests lack a kinetic framework. Biokinetic tests require refinement to consider the flow through environment and reduction in labour intensity. Humidity cell tests are too time consuming, requiring data collection for over a year.

Further reading:
To order the report, ***Evaluating approaches to and benefits of minimising the formation of acid rock drainage through management of the disposal of sulphidic waste rock and tailings*** (**Report No. 2015/1/13**) contact Publications at Tel: (012) 330-0340, Email: orders@wrc.org.za or Visit: www.wrc.org.za to download a free copy.