Comment on:

NENGOVHELA AC, YIBAS B and OGOLA JS (2006) Characterisation of gold tailings dams of the Witwatersrand Basin with reference to their acid mine drainage potential, Johannesburg, South Africa (*Water SA* 32 (4) 499-506)

by
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Introduction

Some features of the Witwatersrand tailings dams emerged, first during the development of methods for their vegetation (largely to prevent erosion by wind), and secondly during the development of bacterial leaching techniques for the recovery of uranium, that assist in understanding how the products of the oxidation of pyrite migrate into the biosphere. The paper by Nengovhela et al. (2006) gives an excellent framework, and I believe that if the additional features that are presented here are added to their framework, the result will be a reasonably complete picture.

The oxidation of pyrite

Nengovhela et al. (2006) summarise the basic chemistry well. However, they overlook the critical role of bacteria. *Thiobacillus* spp. play a major role in the oxidation of the Witwatersrand pyrite once the pH has reached the range where they are active. Pyrite can be preserved almost indefinitely in the presence of adequate alkaline minerals such as limestone (Campkin and Lloyd, 1970).

The bacteria play a number of interesting roles. The tailings, when first deposited, are essentially sterile. The arrival of the bacteria is the first indicator of life, and the fixed nitrogen they provide is used by all subsequent life forms. It was not initially realised that they were indeed nitrogen fixers, but work carried out in association with the British microbiological research establishment at Porton Down proved that they used atmospheric nitrogen as their source (Kuenen and Beudeker, 1982).

This was confirmed in practice when the injection of air into the tailings deposits was studied. The purpose of the experiment was to try to oxidise the pyrite in the depths of the tailings deposit, so that any oxidation products could be removed by processing rather than being lost slowly to the environment. Gas samples showed (Watts, 1971) that the air was essentially depleted in oxygen and carbon dioxide, and enriched in argon and other inert gases. The enrichment was proof of the nitrogen metabolism of the bacteria.

Availability of oxygen

As Nengovhela et al. (2006) observed, the zone over which the pyrite is oxidised is only a few metres at most. This is generally true of the finer-grained slimes, arising from milling processes that reduce the size to about 75% <75 µm. Sand dumps arising from a now-outdated process are much more porous, and gold mining residues of this type are usually oxidised throughout their entire depth.

These observations strongly suggest that there is a significant restriction on oxygen flow into the slimes dams. As Nengovhela et al. (2006) observed, the ingress of water does not carry adequate dissolved oxygen to oxidise much pyrite. Several hypotheses were examined before the primary mechanism by which oxygen entered the slimes was identified. It was finally found that, in every slimes dam examined, there was a clear phreatic surface in the dam. In the zone above that, the gas expanded and contracted with changes in the barometric pressure, and this drew fresh air into pores as the pressure increased, and drove depleted air from the pores as the pressure dropped. Changes in the oxygen content of the upper layers were readily tracked as the barometric changes occurred.

Seasonal phenomena

Nengovhela et al. (2006) observed some changes in the moisture content of the tailings dams, but failed to correlate this with any observable phenomena. We studied it over several years (Lloyd, 1980) and found that during the Highveld dry season, the moisture content of the upper layers of the tailings dams dropped and soluble salts migrated towards the surface. In places crystals of gypsum and other soluble sulphates could be seen. The first rains resulted in a short pulse of pollution into streams and rivers. Then continued rains drove the soluble salts back into the deeper levels of the tailings. Towards the end of the rainy season, the surface layers were almost devoid of soluble salts, which now peaked about a metre below the surface. In an experiment that extended over nearly 2 years, we harvested soluble salts from a 5ha site at East Geduld by mining the surface at 10 cm depth per month. During the wet summer months, the mined material was almost devoid of soluble material; during the dry winter months it contained nearly twice the average level.

These findings clearly have considerable bearing on the release of acid and soluble sulphates from the tailings dams.

Tailings structure

Nengovhela et al. (2006) reported some average particle sizes on the sites they studied, but they appear to have overlooked an important structural consideration that arises from the way in which the tailings dams are constructed. Tailings are led onto different parts of the dam at different times, and left to settle and consolidate before being covered by another layer. The result is a strongly layered structure, with dense minerals tending to concentrate near the bottom of each lift, and fine, light minerals near the top. There is a marked anisotropy, with horizontal permeability typically an order of magnitude greater than the vertical permeability.

Because the pyrite tends to concentrate near the bottom of each lift, as the dams age and the pyrite oxidises, the resultant iron oxides form a hard layer that reflects the layered structure

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originally created. This layer expands slightly, which further enhances the horizontal permeability.

The long term

As the surface layers age, the sulphide minerals in them are first oxidised and then migrate into the environment by the seasonal processes I have outlined above. But, of course, there is only limited penetration of oxygen into the bulk of the tailings, so there is limited oxidation of the pyrite. Old dams have a characteristic oxidised layer a few metres thick on the outer surface, in which pyrite levels are very low and most of the soluble salts have been removed by the processes I described above. There is a zone of limited oxidation, and then the sulphide minerals remain intact. Provided the dams maintain their physical integrity, there is no further release of the soluble salts that are the result of pyrite oxidation.

Outwardly, the flow of acids and soluble salts that the tailings initially contributed ceases once the dam has reached this state. However, the potential to pollute still resides within the dam. If the walls are breached by erosion, for instance, or collapse due to foundation failure or for any other reason, then the oxidation can proceed and salts will continue to be released into the environment. This clearly occurred during the Merriespruit disaster in February 1994, for instance (Dept of Water Affairs and Forestry, 2000).

It is for this reason that there must be ongoing monitoring of the state of the dam walls. One must question whether Regulation 7(d) of the National Water Act, 1998 (Act 36 of 1998):

> *design, modify, construct, maintain and use any dam or any residue deposit or stockpile used for the disposal or storage of mineral tailings, slimes, ash or other hydraulic transported substances, so that the water or waste therein, or falling therein, will not result in the failure thereof or impair the stability thereof;*

goes far enough. I have heard arguments that 'maintain' in this sense means 'maintain during operation'. This clearly is inappropriate, but perhaps the Regulation needs to refer to Section 39(4)(a)iii of the Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002) to make it clear that the owner of the slimes dam must manage this particular potential negative impact on the environment.

Ultimately many of the slimes dams will be removed and processed to remove the residual pyrite along with any gold and uranium present. The waste dams such as the two huge Ergo dams on the East Rand appear to be final resting places that will indeed have minimal long-term environmental risks.

References

NENGOVHELA AC, YIBAS B and OGOLA JS (2006) Characterisation of gold tailings dams of the Witwatersrand Basin with reference to their acid mine drainage potential, Johannesburg, South Africa. *Water SA* **32** (4) 499-506.

CAMPKIN JC and LLOYD PJ (1970) Prevention of bacterial attack on pyrite. *JSA Inst. Mining Metall.* **70** 206.

KUENEN KG and BEUDEKER RF (1982) Microbiology of thiobacilli and other sulphur-oxidizing mixotrophs and heterotrophs. *Phil. Trans. R. Soc.* **B298** 473-497.

WATTS PJ (1971) The Injection of Air into Witwatersrand Slimes. M.Sc. Thesis, Dept. Chemical Engineering, University of the Witwatersrand.

LLOYD PJD (1980) Ninety year's experience in the preservation of uranium ore dumps. *Proc. 1st Int Conf. Uranium Mine Waste Disposal.*, Vancouver, Canada. AIME New York. 33-42.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (2000) Operational Guideline No. M6.1. Guideline Document for the Implementation of Regulations on Use of Water for Mining and Related Activities Aimed at the Protection of Water Resources. (2nd edn.).

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