

RESEARCH ON THE INHIBITION OF BACTERIAL OXIDATION OF PYRITE AND CONCOMITANT ACID MINE DRAINAGE

PART 1. INVESTIGATIONS ON GOLD MINE SAND DUMPS

EXECUTIVE SUMMARY

Concern about the production in mine waste dumps of acid drainage water containing high levels of sulphate and metal ions initiated the research of this project into the possibility of chemically inhibiting the bacteria responsible for the acid formation in the dumps. Research in the U.S.A. indicated that such treatment of dumps might be effective. Two types of dump have been investigated, namely, gold mine sand dumps and coal waste dumps. The project involved a contract of the Water Research Commission (responsible for finances) with the Department of Microbiology and the Institute for Polymer Science of the University of Stellenbosch (responsible for the research of the project) and the Chamber of Mines of South Africa (responsible for providing pilot scale experimental coal waste dumps and support services, including routine chemical analyses). The investigation was divided into two phases, namely, Phase I, comprising laboratory studies at the University of Stellenbosch, and Phase II, consisting of the pilot scale tests of chemical inhibitors on coal waste dumps, involving the Department of Microbiology at the University of Stellenbosch and the Chamber of Mines. The present final project report has been divided into three parts: Part 1 comprises all studies on the gold mine sand dumps (Phase I, Department of Microbiology), Part 2 all studies on coal waste dumps (Phases I and II, Department of Microbiology and Chamber of Mines) and Part 3 all studies on the development of slow-release systems for the inhibitor sodium lauryl sulphate (Phase I, Institute for Polymer Science). The remainder of this executive summary refers only to Part 1 of the report; Parts 2 and 3 have their own executive summaries.

The following are the main findings and conclusions from our evaluation of the possibility of inhibiting acid drainage-producing *Thiobacillus ferrooxidans* or other chemolithotrophic iron-oxidizing bacteria in gold mine sand dumps by treating the dumps with chemicals active against these bacteria.

1. The seepage of acid water from Witwatersrand gold mine sand dumps, which released an estimated 50 000 t of salts into the catchment of the Vaal Barrage during 1985 (Jones et al., 1988), showed the characteristics of acid drainage from mine waste deposits elsewhere in the world. The pH of the water was below pH 3, sulphate comprised a large proportion of the tonnage of salts in the acid drainage (Jones et al., 1988) and the brown colour of the seepage water and

precipitates in and around seepage pools indicated the presence of oxidized iron. That bacterially catalyzed iron oxidation was occurring in the seepage was indicated by the presence of populations of chemolithotrophic iron-oxidizing bacteria of ca. 10^6 to 10^7 /ml in drainage water and ca. 10^3 to 10^6 /g in the brown-coloured soil of a seepage area. It is presumed that the bacteria were *T. ferrooxidans* or contained a large proportion of *T. ferrooxidans* in a mixed population. These bacteria are the major iron-oxidizing bacteria of acid drainage elsewhere and the HJJ growth medium and conditions of incubation for the MPN estimates of the iron-oxidizing bacteria in sand dump seepage were selected for their suitability for *T. ferrooxidans*.

2. The gold mine sand dumps appeared to be a not very favourable growth environment for *T. ferrooxidans* and other possible iron-oxidizing chemolithotrophic bacteria of acid seepage. Increasing concentrations of an oxidized sand (i.e. in which the pyrite had been oxidized) increasingly retarded the growth of *T. ferrooxidans* in a favourable culture medium. The drying of mine dump sand resulted in the rapid destruction of large inoculum populations of *T. ferrooxidans* and iron-oxidizing bacteria from acid seepage, the destruction being more rapid in an oxidized sand than in an unoxidized sand containing pyrite substrate. However, high populations of *T. ferrooxidans* were maintained when the sands were kept moist.
3. Of the compounds tested in laboratory cultures as possible inhibitors of *T. ferrooxidans* and mixed populations of chemolithotrophic iron-oxidizing bacteria from sand dump acid drainage, the anionic detergent sodium lauryl sulphate (SLS) was the most effective. Inhibition of the most resistant cultures was achieved with 8 mg SLS/l in cultures containing no mine dump sand and with 20 mg SLS/l in cultures containing mine dump sand at 500 g/l. However, when the sand concentration was raised to 1000 g/l, 20 mg SLS/l only retarded ferrous iron oxidation by a less resistant *T. ferrooxidans* strain. Adsorption of the SLS by the sand can explain, or partly explain, this result. The sand-inhibitor interaction must receive further attention as a major factor determining the inhibitor dose and method of application for the control of acid drainage from sand dumps.
4. An anionic linear alkylbenzenesulphonate detergent (LAS) was almost as effective as SLS as an inhibitor of *T. ferrooxidans* and iron-oxidizing acid drainage bacteria in cultures without mine dump sand (LAS at 8 mg/l inhibited all cultures), but with 500 g/l sand in the cultures was less effective than SLS in that not all cultures were inhibited by 30 mg/l LAS. This result provides no grounds for considering LAS as an alternative inhibitor to SLS for the control of

acid drainage formation in sand dumps, but attention has not been given to economic considerations, which would also necessitate further comparison of the effectiveness of LAS and SLS.

5. Among the cationic surface-active compounds tested, the low pH antimicrobial quaternary pyridinium compound Ceepryn was more effective than SLS against *T. ferrooxidans* ATCC 19859 in cultures without sand (2 mg Ceepryn/l inhibited all cultures), but was considerably less effective in cultures containing 500 g/l sand, with 20 to 40 mg/l the minimum inhibitory concentration (in contrast to 8 mg SLS/l for the same *T. ferrooxidans* strain). The quaternary ammonium formulation Hyamine 3500 showed only partial or temporary inhibition of *T. ferrooxidans* and the acid drainage bacteria at the highest concentration tested (128 mg/l), even in cultures without mine dump sand. However, acidity is known to be highly detrimental to the activity of quaternary ammonium compounds. Adsorption to surfaces is a general characteristic of the quaternary pyridinium and ammonium compounds, reducing their antimicrobial activity, thus the reduction of the effectiveness of Ceepryn shown in the cultures with 500 g/l sand would likely be greatly enhanced in a sand dump. Evidence available to date provides no grounds for considering Ceepryn as a possible alternative to SLS for the combatting of acid drainage in sand dumps.
6. The food preservative organic acid inhibitors, benzoic and sorbic acid, are inherently less effective inhibitors of *T. ferrooxidans* in respect of minimum inhibitory concentrations than the surface-active chemicals, SLS, LAS and Ceepryn. The minimum inhibitory concentrations of sodium benzoate and sorbic acid in cultures without mine dump sand were 15 to 30 and 15 to 20 mg/l, respectively; these concentrations increased to 25 to 35 and 20 to 30 mg/l when 500 g/l mine dump sand was included in the cultures. The limited reduction of their effectiveness in the presence of the sand indicates that they have the advantage of little adsorption to the sand. It appears that doses of benzoic or sorbic acid to inhibit *T. ferrooxidans* in sand dumps would need to be about four times that of SLS, making even the cheaper benzoic acid probably not an economical alternative inhibitor to SLS.
7. Sodium lignosulphonate and polyacrylic acid had such limited activity against *T. ferrooxidans* that they cannot be regarded as possible inhibitors of acid drainage formation in sand dumps.
8. Investigations of the distribution of chemolithotrophic iron-oxidizing bacteria in sand dumps showed large populations only in wet regions where acid drainage

water was seeping through the sand at the base of the dump and emerging at the surface or in the interior grey-coloured sand exposed on excavated faces where the pyrite had not yet been oxidized to sulphate and yellow or orange oxidized forms of iron. The outer orange-coloured layer of sand dumps away from seepage zones contained almost no iron-oxidizing bacteria nor sulphur, both observations indicating that the pyrite substrate on which the bacteria grow had been lost from this part of the dumps during more than half a century of oxidation. As this process has proceeded to depths of ca. 10 m in sand dumps, the iron-oxidizing bacteria must be catalysing pyrite oxidation at or beyond this depth. Bacterial inhibitors to control acid production in the dumps must therefore be delivered in inhibitory concentrations to at least this depth. The absence of iron-oxidizing bacteria from most winter samples from the exposed face of the excavated dump, in contrast to their abundance in similar (but moister) grey-coloured samples in summer, suggests that pyrite oxidation is seasonal. It is possibly negligible in winter as drying of the dump sand results in rapid death of the iron-oxidizing bacteria.

9. The delivery of an inhibitor such as SLS to the sites of pyrite oxidation at least 10 m deep in sand dumps and the effectiveness of the inhibitor in the presence of the sand will be influenced by adsorption of the inhibitor to the sand. Although mine dump sand (50 or 100 g) adsorbed most of the SLS supplied in 100 ml water at concentrations of 1,0 to 6,0 mg/g sand, less than half the SLS supplied at below ca. 0,1 to 0,6 mg/g sand was adsorbed. Inhibitory SLS concentrations in laboratory cultures were below the latter concentrations, thus in the presence of sand at 500 g/l were only about double the inhibitory concentrations in the cultures without sand. Inhibitor delivery strategy will have to take into account adsorption and movement of the inhibitor in the sand dump. Continuous dosing of the dump from a slow-release formulation (Immeiman, 1987; this report, part 3) is one possible strategy and dosing in repeated pulses another. Continuous dosing with SLS would require an estimated total application of more than 115 kg/ha mine dump surface and possibly more than 460 kg/ha. The cost of the SLS as priced in 1990 (transport and application excluded) would be at least R1113/ha and possibly greater than R4453/ha. Whether such applications are justified in view of the probable complete reprocessing of the sand dumps during the next 20 years, is questionable. However, more research is needed on the adsorption and movement of potential inhibitors in sand dumps for a reliable comparative assessment of the two strategies for any specific inhibitor.

REFERENCES

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