

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

PART 2. INVESTIGATIONS ON COAL WASTE DUMPS

EXECUTIVE SUMMARY

Little information is available on the extent and environmental impact of acid mine drainage from coal waste dumps in South Africa. The only two reported investigations, for river systems in Natal (Kemp, 1962; Rudd, 1973), show high concentrations of total dissolved solids, in particular sulphate, in rivers leaving coalfields, but limited declines in the pH of the initially mildly alkaline water and reductions in the salt concentrations downstream following dilution and self purification. However, with the large-scale development of open-pit mines, particularly on the Transvaal highveld for electricity generation and the mining of export coal, the acid drainage problem and its prevention must receive continuous attention. At all costs, the extensive acidification of rivers, as has occurred in the eastern U.S.A., must be avoided.

The following are the main findings and conclusions from our investigation of the possibility of inhibiting acid drainage-producing *Thiobacillus ferrooxidans* or other chemolithotrophic iron-oxidizing bacteria in coal waste dumps by treating the dumps with chemicals active against these bacteria. The initial basic laboratory studies (1 to 4 below) formed part of Phase I of the research, while the pilot scale dump and associated laboratory studies (5 to 8 below) formed Phase II. Phase II was conducted with the collaboration of the Chamber of Mines.

1. A limited study of coal waste dumps near Witbank showed the occurrence of acid drainage water in the lower parts of the dumps and in a pool alongside one of the dumps, associated with the presence of large populations of chemolithotrophic ferrous iron-oxidizing bacteria, presumed to be *T. ferrooxidans*. Thus a drainage water sample of pH 2,40 and three coal waste samples of pH 2,40 to 3,88 from the Douglas Colliery dump contained  $4,64 \times 10^3$  to  $2,83 \times 10^6$  iron-oxidizing bacteria/ml or g. These samples were from an acid drainage pool, a waterlogged bank near the drainage pool and from the bottom of a rubble slope. Four of seven samples from a dump on the Wolvekrans Section of the Douglas Colliery also contained iron-oxidizing bacterial populations ( $3,00 \times 10^{-1}$  to  $2,80 \times 10^6$ /g). The four samples were coal waste of pH 2,85 to 7,54 from a flat drainage area at the toe of the dump, the bottom of the dump slope,

15 m (vertical height) up the slope and from ore with a high pyrite content on the top of the dump. No iron-oxidizing bacteria were detected in freshly deposited coal waste of pH 6,98 or drainage water of pH 7,99 from the Wolvekrans dump or in burned waste of pH 12,30 from the Douglas dump. If the iron-oxidizing bacteria and the associated oxidation of pyrite, which produces the acid mine drainage, are restricted mainly to the outer 25 to 30 cm of the dumps as is the situation elsewhere (Dugan, 1975; Good et al., 1970), the possibility exists for inhibiting acid mine drainage formation by the application of suitable antibacterial chemicals.

2. While developing a suitable experimental system for testing the inhibition of *T. ferrooxidans* cultures by chemicals in the presence of coal waste, we found that coal waste fractions of differing particle size up to 11,5 mm diameter, had a profound effect on the ferrous iron concentration and pH of the growth medium necessitating the inclusion in growth and inhibition experiments of uninoculated medium controls containing the coal fraction under study. The almost neutral (pH 6,34) coal waste fractions raised the pH of the medium and catalysed the disappearance of ferrous iron. Culture growth in the absence of inhibitors was adversely influenced by the pH increases caused by these fractions, but also by additional inhibitory effects of the coal waste.
3. In the presence of 500 g/l coal discard fractions of differing particle size (0,425 to 1,18, 2,00 to 2,80, 4,00 to 4,75 and 8,00 to 9,50 mm diameter), two *T. ferrooxidans* strains were inhibited by SLS at 70 to 90 mg/l, added at the beginning of culture incubation or during the exponential phase of culture growth. These concentrations were very much higher than the inhibitory concentrations of 2 to 4 mg/l SLS for cultures not containing coal waste. In the presence of the 2,00 to 2,80, 4,00 to 4,75, 8,00 to 9,50 mm coal waste fractions and a 10,0 to 11,5 mm fraction, sodium benzoate and sorbic acid were both inhibitory at 40 to 75 mg/l when added at the beginning or during the exponential phase of growth. In the absence of coal waste, the inhibitory concentrations of sodium benzoate were 15 to 30 mg/l and those of sorbic acid 15 to 20 mg/l. The various coal waste fractions had little or no differential effect on the inhibitory concentrations. These experiments showed that sodium benzoate and sorbic acid might be even better than SLS for the inhibition of *T. ferrooxidans* and the associated formation of acid in coal waste. Sodium benzoate has the additional advantage of being a much cheaper chemical than the

other two (about half the price of SLS and less than one third of the price of sorbic acid).

4. In inhibition experiments with no coal waste in the culture medium, fresh solutions of 1-bromo-3-dichloro-5,5-dimethylhydantoin (H900) inhibited *T. ferrooxidans* at 6 to 10 mg/l. Ageing had a detrimental effect on the inhibitory concentration, so that not even 14 mg/l of a 6-month-old solution was inhibitory. The instability of H900 over time makes it unsuitable for use in coal discard. Combinations of SLS with sodium benzoate, sorbic acid and H900 and of sodium benzoate with sorbic acid caused no substantial reductions in the inhibitory concentrations of any of the inhibitors tested.
5. The treatment of pilot-scale dumps containing 55 t of coal waste at the Wolvekrans mine by the application of 1 kg dissolved SLS and 0, 5, 10 or 15 kg natural or polyisoprene rubber pellets containing 35% SLS was inadequate to inhibit acidification, which occurred in all dumps within 3 months. Further treatment of the dumps after about 15 months with much higher doses of SLS and SLS-rubber pellets (5 kg dissolved SLS and 0, 10, 30 and 60 kg of the natural or polyisoprene rubber pellets with 35% SLS, to give total SLS treatments of 6,00, 11,25, 20,00 and 32,25 kg SLS/dump) failed to inhibit the acid, dissolved iron and sulphate production through the following 21 months. Very little of the applied SLS left the dumps and the concentrations in the effluents, which reached a maximum of only about 30 mg/l, were inadequate to prevent the survival or possibly development of high populations of chemolithotrophic iron-oxidizing bacteria in the effluent water.
6. Investigations of factors possibly responsible for the lack of success of the SLS treatments in controlling acidification of the pilot scale coal waste dumps, showed the presence in the dump effluents of populations of iron-oxidizing bacteria with resistance to 12 to 14 mg/l SLS, and the ability of cultures of *T. ferrooxidans* to greatly increase their resistance to SLS (from being inhibited by 2 or 4 mg/l to growing in medium with 8 or 18 mg/l, depending on the *T. ferrooxidans* strain). The acid effluents from the dumps also contained heterotrophic filamentous fungi and yeasts, among which SLS-degrading yeasts were detected. Slow or very slow release of SLS from the SLS-rubber pellets and a slow downward movement of the inhibitor in the dumps, presumably involving adsorption, resulted in only low concentrations of SLS in the coal waste (< 14 mg water-extractable SLS/kg) in the lower 0,7 to 1,5 m of dumps 2 and 3 with

natural rubber pellets and throughout the dumps with SLS-polyisoprene rubber pellets. These low SLS concentrations permitted the iron-oxidizing bacteria to establish populations of ca.  $10^2$  to  $10^6$ /g in the coal waste. By contrast, in the upper 0,45 to 0,55 m of dumps 2 and 3, where the water-extractable SLS concentrations were  $> 40$  mg/kg, no or very few iron-oxidizing bacteria were found. This result shows that application of SLS at a rate of 20 kg/dump or 0,6 kg/m<sup>2</sup> could inhibit iron-oxidizing bacteria in the coal waste to a depth of ca. 0,5 m, hence may be an adequate treatment for a dump with an oxygen barrier at  $\leq 0,5$  m depth. However, the cost of the SLS, excluding transport and application, for this treatment at the 1990 price would be R58 080/ha.

7. In a further pilot scale study, SLS and sodium benzoate were compared as inhibitors of acid drainage production by the 55-t coal waste dumps at the Wolvekrans mine. Treatments were the addition of 2 kg SLS or 0,2 or 2 kg sodium benzoate/dump every 2 weeks for ca. 10 months. From 188 days, the dumps receiving SLS and the high dose of sodium benzoate appeared to have their adsorption sites for the inhibitors saturated, as indicated by (with few exceptions) high levels of inhibitor in the effluents. Most of these effluents showed no iron-oxidizing bacteria, in contrast to high populations (mainly  $10^2$  to  $10^6$ /ml) before 188 days and continuing high populations in the effluents from the dumps receiving the low benzoate dose or water only. The amounts of SLS and sodium benzoate giving the presumed saturation were, respectively, 600 and 500 mg/kg coal waste. If one third of these doses were applied to large dumps to saturate the outer 0,5 m of coal waste (to inhibit acidification outside the oxygen barrier) the application rates would be ca. 3 000 and 2 600 kg/ha and the cost of the chemicals (transport and application costs excluded) at 1990 prices R29 040 and R12 922/ha for SLS and sodium benzoate, respectively. However, none of the dumps showed clear evidence of reduced acidification resulting from the inhibitor treatments, although the dump receiving the high dose of benzoate yielded lower levels of dissolved iron and sulphate than the other dumps (unfortunately from the beginning of the experiment, with no change when the dump became saturated with benzoate).
8. Limited basic studies of the adsorption of SLS and sodium benzoate by coal waste showed higher levels of SLS adsorption than benzoate adsorption, except perhaps at SLS concentrations below 40 to 50 mg/100 g coal waste of diameter 2,0 to 10,0 mm in 100 ml water or HJJ medium. Under these conditions less SLS was adsorbed than remained in solution, but with higher SLS concentrations

supplied, the adsorption ranged from 72 to 86%. With a smaller coal fraction (1,18 to 2,00 mm), more than 68% of the SLS was adsorbed at all concentrations supplied. By contrast, less sodium benzoate was adsorbed by a 2,80 to 4,00 mm coal waste fraction than remained in solution with all sodium benzoate-coal waste combinations that we tested. Adsorption to coal waste can explain the effect of the waste on the minimum inhibitory concentrations of sodium benzoate for two *T. ferrooxidans* strains in the culture inhibition experiments, but not the much greater effect of the waste on the minimum inhibitory concentrations of SLS. Further comparative studies of the adsorption of SLS and benzoate to coal waste are required, as possible lower levels of adsorption of sodium benzoate may be another reason for choosing it as an inhibitor in preference to SLS.

9. The overall conclusion from these laboratory and pilot scale studies on coal waste is that sodium benzoate seems to have the best potential of the inhibitors studied to inhibit acidification of the pyrite. However, the 1990 price of sufficient chemical, without transport and application, would be about R12 922/ha and the effectiveness of the treatment remains to be proved.

#### REFERENCES

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