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IMPROVING THE QUALITY OF MINE SERVICE WATERS IN GOLD MINES IN SOUTH AFRICA

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ABSTRACT

The gold mining industry in South Africa uses about 700,000 tons of lime per year worth 34 million rand (1 rand = 0,5 U.S. dollar). It is estimated that about ten percent of this is used to neutralise acidic-waters underground. A novel alternative means of countering the production of acidity in mine service waters and minimising the use of lime is discussed. The addition of sodium lauryl sulphate to mine water, used for wetting down operations on broken ore in a stope, reduced the acidity and sulphates in the return water from the stope. The decrease varied between 50 and 90 per cent depending on the number of times the rock was washed. The type of blasting explosive used had a significant effect on the amount of acidity produced.

1 INTRODUCTION

The gold mining industry in South Africa relies heavily on water for many purposes in order to exploit the gold bearing reefs present beneath the earth's crust. In a typical year the industry consumes about 338×10^6 m^3 of water or 16,5 m^3 for each ounce of gold produced. Figure 1 shows the proportion of water utilized by the various operating sectors of a gold mine. It is seen that underground operations use only about 18 per cent of the total water consumed, and this service water is used underground for numerous purposes including mine cooling, dust suppression, and recently, in a few mines to power hydraulic machinery, Middleton, Viljoen and Wymer (1985). The figure for underground consumption does not reflect the total amount of water in use because it excludes recycled water, and all gold mines, with only two minor exceptions, re-circulate vast quantities. It has been calculated, Schmitz (1984), that 3×10^6 m^3/day is circulated underground in South Africas' one gold mines and this gives a ratio of water flow to rock mined of about 12:1, a very large ratio.

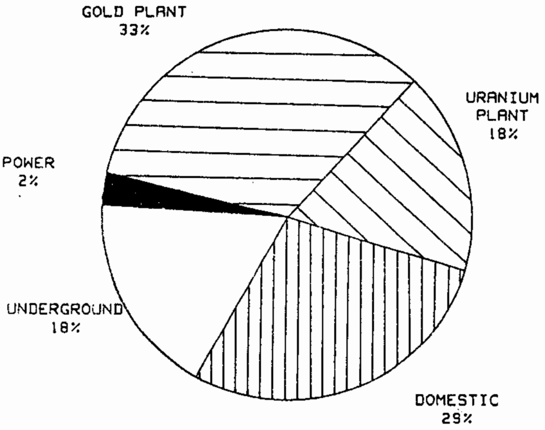

FIGURE 1: WATER USE IN THE MAJOR OPERATING SECTORS OF A GOLD MINE.

1.1 Water quality in recirculating circuits

When gold reefs containing sulphide minerals are exploited, acidity is present in the service water draining from the workings and this acidity dissolves certain constituents present in the reefs. Attempts have been made to utilize this fact to recover uranium and other metals from abandoned areas in gold mines with significant success, Cator (1969). However this acidity is generally a problem and results in corrosion of equipment and mineralization of the service water. Present practice to counter this acidity is to add lime at central treatment sites underground before the service water is clarified for re-use or pumped to surface. This addition of lime further increases the salt content of the water and also results in a potential scaling problem when the water is re-used. Since fresh water make up to these circuits is only about 5 per cent of the circulating load, pumps and pipe-lines have to be overdesigned to allow for scaling. Heat transfer surfaces are particularly prone to scaling when treated service water is chilled to achieve environmental cooling.

Because of these problems associated with the neutralisation of the acidity in mine service water with lime, alternative ways of dealing with the acidity are presently being examined. These include treating the water with an alkali other than lime such as soda-ash, and softening or desalinating the water after neutralization. These alternatives are considerably more costly than the use of lime and merely attempt to counter the consequences of the production of acidity without seeking to remedy the cause. This paper discusses work done to identify and eliminate the basic causes of the production of acidity and salinity in mine service water.

1.2 Use of surfactants to decrease acidity

Acidity is produced via the oxidation of sulphide minerals present in the reef horizons being mined. The main sulphide mineral is pyrite in its various morphological forms although pyrrhotite occurs in significant amounts near faults. In contact with air at ambient temperatures underground, these sulphide minerals oxidise at varying rates to produce acid conditions on the mineral surfaces. The rate at which this oxidation reaction takes place is accelerated more than twenty times in the presence of certain autotrophic bacteria, and this fact has been recognised both in South Africa, Matic and Mrost (1964) and overseas, Corrick and Sutton (1965). Thus if a means could be found to prevent the growth of these bacteria then a substantial reduction in the quantity of acid produced could be anticipated. Until recently a practical means of achieving this has not been available. However in a study carried out at the U.S. Bureau of Mines, Kleinman, Crerar and Pacelli (1981), various growth inhibitors of the bacterial species Thiobacillus ferrooxidans and Thiobacillus thiooxidans were evaluated and it was found that certain anionic wetting agents were the most cost effective, particulary at low pH values.The reasons for the effectiveness of this class of surfactants is not well understood but it appears that these compounds alter the normal properties of cell membranes in the bacteria. The most cost effective inhibitor found so far is sodium dodecyl sulphate (or sodium lauryl sulphate as it is commonly known). In laboratory studies a concentration of 30 mg/ℓ of this material was sufficient to prevent the oxidation of both pyrite and pyrrhotite present in various reefs, Greig (1985). This exploratory study indicated that the cost of treating mine service water in circulating systems would be about R0,18 per m^3 of water which is less than the present costs of lime treatment. The tonnages of material required to be transported and handled underground would be considerably less. On the basis of these and other potential advantages and the positive laboratory findings, it was decided to proceed with a trial underground.

2 UNDERGROUND TRIAL

An isolated wide reef panel of 23 m length was selected for the trial. The stoping width varied between 1,1 and 1,4 metres and the reef channel width between 0,7 and 1,1 metres. A spray system was designed so that the ore blasted in the stope could be evenly wetted. This system of sprays was fed from a pump supplying water with a low total dissolved solids (T.D.S.) content of about 400 mg/ℓ. Using this quality water, any buffering action of dissolved salts was minimised and small changes in the pH and T.D.S. could be readily measured. The return water from the stope was led into a plastic lined footwall drain in the reef drive from where it could be returned to the supply tank or drained to waste. Any coarse solids in the water settled in the drain. At no time did the water being used contact materials which could be attacked by acid - plastics and 316 stainless steel were used throughout as materials of construction.

Standard mining procedures were used throughout the trial and will not be described here. Twelve blasts were carried out, and the amount of rock broken each time was kept constant at 90 tons. Chip samples were taken on the face before each blast.

The following test procedure was used to examine the degree of acidity and mineralisation introduced into the service water. The broken rock in the stope was allowed to stand for a predetermined period of time after the blast. The supply tank was then filled with water and the sprays positioned on top of the broken rock. Altogether 21 spray nozzels were located along the total panel length which varied from 20 - 23 m.

The conductivity and pH of the water supply in the tank were measured. The water was then pumped from the tank over the rock pile at a rate of 7 m^3/hr for a period of two hours, wetting all the broken rock as evenly as possible.

The water draining out of the stope was sampled at 15 minute intervals over a period of 2,25 hours as it drained from the stope into the drain in the reef drive. pH and conductivity measurements on the water were made on site and again the following day on samples transported to the laboratory. Samples were taken both for chemical and bacteriological analysis. The quantity of water used to spray the broken rock was carefully controlled and measured, but the quantity of water draining out of the stope was difficult to measure accurately.

Spraying of the broken rock pile was repeated daily over a period of seven days, although this procedure could be varied depending on requirements. After a test run was completed, the broken rock was cleared with a scraper-winch, new support installed and chip samples taken every 5 m on strike before the cycle was repeated.

Four types of blasting explosives commonly used in gold mines were used in the trial to establish any effect of the different types of explosives on the water quality.

3 RESULTS OF UNDERGROUND TRIAL

3.1 Analysis of chip samples

The results of the analysis of chip samples taken on each face before blasting are summarised in Table 1. The statistical treatment of the results is based on the pyrite being distributed log-normally in the reef and follows established practices for this type of distribution.

Obviously the mineral concentration in the broken rock would be related to the values in the chip samples from the two faces before and after each blast. It is difficult to compare the means of transformed distributions statistically, but the results in Table 1

Table 1 PYRITE VALUES OF THE ADVANCING FACE PRIOR TO BLASTING

FACE NO	SULPHIDE kg Fe S_2/t		
		90% CONF. LIMIT	
	MEAN	UPPER	LOWER
1	2,73	3,80	1,79
2	2,33	3,55	1,49
3	2,31	3,36	1,35
4	2,99	4,12	2,10
5	2,57	3,61	1,61
6	2,60	3,65	1,65
7	2,97	4,03	2,02
8	2,47	3,55	1,54
9	2,06	3,19	1,16
10	2,22	3,20	1,18
11	2,09	3,19	1,17
12	2,45	3,53	1,52

indicate that any differences in grade between broken rock present after any two blasts would be small and can be neglected for present purposes. Thus any differences found between tests on broken rock from different blasts would not be due to variations in the pyrite content of the rock but to other factors.

The rate at which water was pumped through the spray system was constant at 7,0 m^3/hr for a period of two hours. Apart from a period of a few minutes at the commencement and end of each spray cycle, the return water from the stope flowed at a constant rate of 2,8 m^3/hr for a period of 2,25 hours. Thus the water recovery was only about 44 per cent. This recovery was more or less constant irrespective of the period of time between spray cycles or the rate of spraying. While some water losses can be expected through cracks in the footwall, the magnitude of the effect makes it unlikely that losses of this nature can contribute more than a small fraction of the low water recovery observed. Rather the effect is considered to be due to the necessity to establish a continuous hydrostatic head to cause the water to flow through the porous rockpile. With about 90 tons of broken rock in the stope, calculations indicate that a water input of about 8 m^3 is not unrealistic to establish this head and cause flow through the system.

3.3 Rate of Removal of Nitrates and Sulphates from the Broken Rock in the Stope

The flowrate and salt content of the water entering and leaving the stope are known, thus the rate of removal of a particular salt from the broken rock can be calculated.

The rate of removal of nitrates and sulphates from the broken rock in the stope in successive two hour wash periods is indicated in Figure 2. As is seen, the rate of removal of nitrates from the broken rock decreases in an exponential manner. The experimental values obtained fitted an equation of the form $y=ae^{bx}$, the correlation coefficients being above 0,95 in all cases. This is consistant with the hypothesis that the nitrates are introduced solely from the explosives used in mining. Anfex was shown to produce the highest concentration of nitrates in the broken rock, followed by 60 % Ammonium Dynamite, Dynagel and finally Tovex, with values of 95, 26, 15 and 12 g nitrates/ton broken rock respectively. Throughout the study an exponential removal rate was obtained in the case for nitrates irrespective of the period of standing between washes and nitrates were completely removed after 3 washes.

In contrast, the pattern for the rate of removal of sulphates differed greatly from that for nitrates. High rates for the removal of sulphates were always obtained initially in any wash period, the actual value depending on the period of time which had elapsed since the previous wash.

When sodium lauryl sulphate was added to the feed water, similar washout curves for nitrates were obtained. However the addition of this chemical to the water altered the sulphate washout curves, and this is illustrated clearly in Figure 3. During the first wash similar sulphate removal rates were obtained in all cases, whether sodium lauryl sulphate was present or not. This is to be expected since the latter is only introduced during this wash. However from the second wash onwards a smaller quantity of sulphates was washed out of the broken rock in all cases where sodium lauryl sulphate was present. This is indicated in Figure 3 by the lower removal rates at the start of a wash, as a result of the smaller amount of sulphates present. The high rate of removal of sulphates obtained initially in any wash period was used to investigate the effect of soldium lauryl sulphate on the rate of formation of sulphates and acidity during dormant periods between washes. From equation (1) values for the increase in sulphates formation rate between each succesive wash were calculated.

$$\frac{\text{Change in removal rate of sulphates (mg/sec)}}{\text{Period between successive washes (hr)}} \quad .... \ (1)$$

These values are plotted in Figures 4 and 5. Values for Figure 4 were without sodium lauryl sulphate and show the effect of the different explosive used. It can be seen that there is a significant difference between explosives, but in all cases the rate at which sulphate was being formed during the period between washes was constant within the limits of experimental error. From these values a mean rate of formation was calculated for each explosive. Expressing these rates in terms of the contamination of service water during these simulated washing down operations gives the following results:-

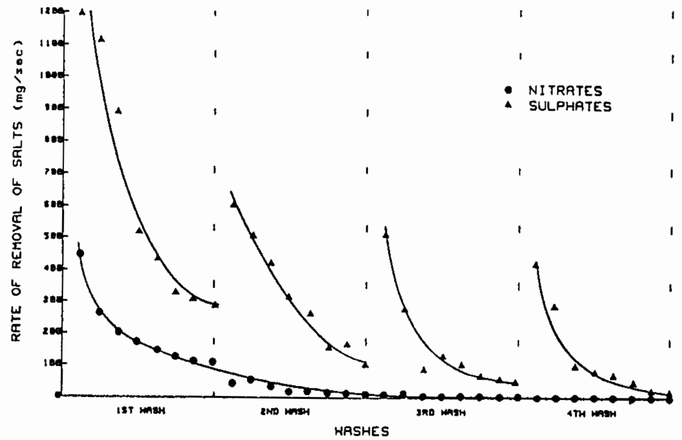

FIGURE 2: RATE OF REMOVAL OF NITRATES AND SULPHATES IN SUCCESSIVE TWO HOUR WASH PERIODS.

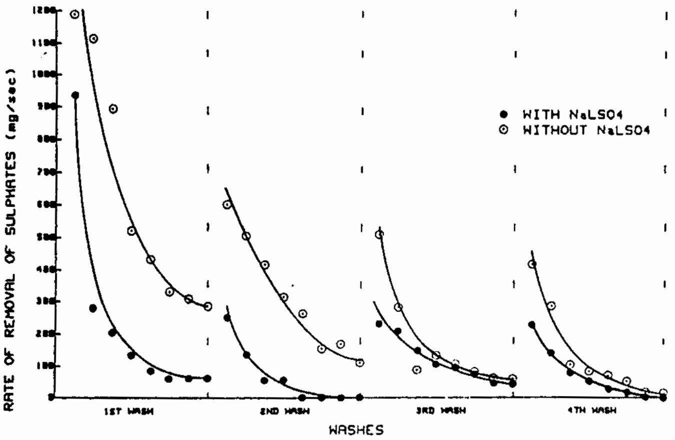

FIGURE 3: EFFECT OF SODIUM LAURYL SULPHATE ON THE RATE OF REMOVAL OF SULPHATES.

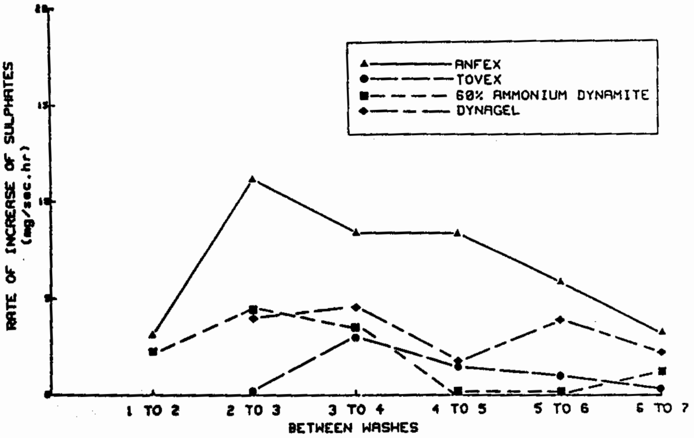

FIGURE 4: EFFECT OF TYPE OF EXPLOSIVE ON THE RATE OF INCREASE OF SULPHATES IN THE BROKEN ROCK.

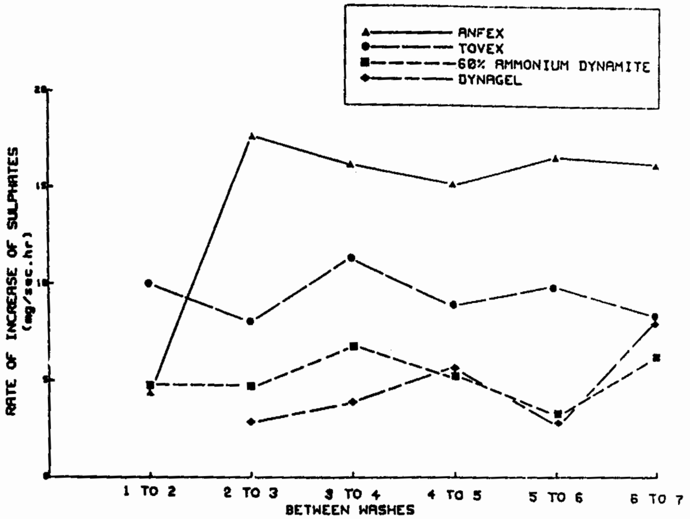

FIGURE 5: EFFECT OF SODIUM LAURYL SULPHATE ON THE RATE OF INCREASE OF SULPHATES IN THE BROKEN ROCK.

ANFEX : 16,3 mg/sec/hour of standing
TOVEX : 9,5 mg/sec/hour of standing
60 % AMMONIUM DYNAMITE : 5,1 mg/sec/hour of standing
DYNAGEL : 4,6 mg/sec/hour of standing

Thus the explosive used in breaking the rock had a significant effect on the rate of oxidation of sulphide minerals in the broken ore in the stope.

The addition of sodium lauryl sulphate reduced the amount of sulphate produced between washes as shown in Figure 5. Furthermore a definite downward trend is evident in the rate of formation of sulphates from the sulphide minerals which is independant of the explosive used. By comparison with Figure 4, Figure 5 shows that sodium lauryl sulphate was more effective in reducing the build up of sulphates after a number of wahsings. In fact, depending on the explosive used and the number of washes, the reduction achieved ranged from a minimum of 50 per cent to a maximum of close to 90 per cent.

3.4 Effect on bacteria

Bacterial counts made during the trials showed that large numbers of Thiobacillus ferrooxidans and T. thiooxidans were present in the water leaving the stope when no sodium lauryl sulphate was present. These numbers were significantly reduced when 30 mg/ℓ of sodium lauryl sulphate was added to the intake water.

3.5 Effect on pH

The pH of the water pumped over the broken ore in the stope varied between 6,5 and 8,0. The water draining from the stope during the first wash had a pH of between 2,6 and 3,5 irrespective of the explosive used or the presence of sodium lauryl sulphate.

In all subsequent washes, where sodium lauryl sulphate was not present in the wash water, the pH increased slightly to between 3,5 and 4. However when the surfactant was present the pH was consistently in the range 5,0 to 5,5 indicating a significant reduction in acidity.

4 COSTS

While no definitive information on costs is presently available, it is likely that the cost of treating mine service water with this chemical will be less than the cost of present treatment procedures. However, the costs are critically dependant on the exchange rate for the local currency against the U.S. dollar, since the raw materials to produce sodium lauryl sulphate are petroleum based.

5 CONCLUSIONS

The addition of 30 mg/ℓ of sodium lauryl sulphate to the mine service water has been effective in reducing the formation of both acidity and and soluble sulphates from pyrite present in broken rock in stopes. The pH of the water leaving a working stope increased from below 3 to above 5 and the sulphate content decreased by 50 to 90 per cent depending on the wash procedure used. However, the amount of acidity and nitrates produced from the explosives used in mining were not affected by the presence of sodium lauryl sulphate.

6 ACKNOWLEDGEMENT

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