J. S. Afr. Inst. Min. Metall., vol. 90, no. 2.
Feb. 1990. pp. 45-49.

Biological pre-treatment for the recovery of gold from slimes dams*

by E.N. LAWSON†, J.L. TAYLOR‡, and G.A. HULSE†

SYNOPSIS

It is generally recognized that a large proportion of the gold remaining in the residues from metallurgical plants on the Witwatersrand is occluded in pyrite. The conventional flotation–roasting process typically recovers approximately 40 per cent of this gold. The process described here is an unconventional route involving bacterial oxidation, which can achieve a gold recovery of approximately 80 per cent.

The paper describes tests carried out in the laboratory, as well as on a slimes dam. The results show that the recovery of gold can be noticeably enhanced through the use of bacteria under conditions of controlled pH, moisture, and aeration. Biological oxidation of the pyrite releases the occluded gold, which then becomes amenable to cyanidation.

SAMEVATTING

Goud teenwoordig in the uitskot van Witwatersrandse goudaanlegte is ingeslote in piriet. Ongeveer 40 persent van bogenoemde goud word herwin tydens die gebruiklike piriet flotasie–roosterproses—daarenteen lewer 'n onkonvensionele bakteriese oksidasie proses, wat hier beskryf word, ongeveer 80 persent goudherwinning.

Laboratorium en slikdam studies word in hierdie verslag bespreek. Resultate toon dat goudherwinning merkbaar verhoog kan word deur van die toestande vir bakteriese aktiwiteit te optimaliseer naamlik, pH en vog kontrole en verbeterde belugting. Bakteriese oksidasie van piriet stel ingeslote goud vry wat vatbaar is vir die konvensionele sianideringsproses.

Introduction

Gold-mine tailings dumps or slimes dams are built up of fine particles that are mainly smaller than 150 μm. These become so compacted that only very slow percolation of water and air diffusion is possible. The material below the surface (which upon deposition is alkaline) is thus largely preserved in its original state. With time, rain leaches out the lime from the surface and sides of the dam, lowering the pH of the slimes, which allows the indigenous bacterial population to become active. The pyrite decomposes partially as a result of chemical oxidation, but is mainly mediated by the bacteria. The result is oxidized slimes and the familiar golden dumps. Although the gold content of tailings is low (0,2 to 1 g/t), the gold is more readily recoverable by cyanidation of the oxidized surface slimes than of the underlying unoxidized slimes. Thus, promoting the oxidation of pyrite by bacteria throughout the slimes dam releases gold, which can then be recovered by cyanidation.

Summary of Investigations

Preliminary investigations were carried out in four phases to determine the amenability and economic viability of gold recovery from a slimes dam by bacterial means.

Phase I consisted of laboratory-reactor tests in 3-litre batches of slime slurries with a liquid:solids ratio of 7,5:1 in the presence of the bacteria *Thiobacillus ferrooxidans*. This type of laboratory test is the usual method for showing the amenability of material to biological oxidation since such a test provides better operating conditions for the bacteria than do heap tests. A gold recovery of 81 per cent was achieved from the slimes, as compared with a recovery of 52,3 per cent without oxidation.

Phase II involved an assessment of the amenability to bacterial oxidation of a flotation concentrate produced from the slimes. A gold dissolution of 88,6 per cent was achieved (as against a gold recovery of 31,6 per cent without bio-oxidation). Since flotation recovered 60 to 65 per cent of the gold, an overall recovery of 53 to 57 per cent was obtained.

Phase III tested slimes heaps on a laboratory scale. Ten equivalent-sized heaps of 2 by 1,8 by 0,5 m (1,8 m^3) were constructed according to various formulations of oxidized and unoxidized slimes (described in detail in the next Section), together with bacterial nutrients and bacteria. The best results were obtained from a heap consisting of 1:1 oxidized and unoxidized slimes together with nutrients and added bacteria. The gold dissolution was 80 per cent.

In Phase IV, an on-site trial was run with prepared test strips on a slimes dam. The preparation involved ploughing, pH adjustment, and moisture maintenance. After a period of 70 days, an average gold dissolution of 72 per cent was achieved—some 8 per cent lower than that obtained in laboratory-scale heap tests.

Experimental

Phase IV is an extension of the work reported by Livesey-Goldblatt[1]. The process used involves the removal of a surface layer of oxidized material from a slimes dam, leaving behind sufficient oxidized slimes to inoculate the underlying layers with bacteria. After adjustment of the pH and loosening of the slimes for aeration, the oxidation process is allowed to proceed. The

* Paper presented at the Colloquium on Leaching, which was held by The South African Institute of Mining and Metallurgy in Randburg in November 1988.

† Genmin Process Research, Private Bag X3, West Rand, 1746 Transvaal.

‡ Union Corporation Building, 74/78 Marshall Street, Johannesburg 2001.

© The South African Institute of Mining and Metallurgy, 1988. SA
ISSN 0038-223X/3.00 + 0.00.

slimes can be removed within three months so that the process can be repeated in the underlying layer.

The slimes dam chosen for the tests exhibited the following characteristics:

(a) pH values of 2,4 for naturally oxidized slimes and 7,6 for unoxidized slimes,
(b) a surface moisture content of 7,5 per cent, increasing to 14 per cent at a depth of 1 m,
(c) a pyritic sulphur content varying from 1,2 to 1,6 per cent, and
(d) a gold content varying from 0,2 to 0,65 g/t.

Phase I

Bacterial oxidation of the slimes was carried out in the laboratory in 3-litre batches, 9K nutrients (Silverman and Lundgren[2]) being provided in a slurry of 7,5:1 liquid: solid ratio.

Two sets of experiments were initiated: the first without the addition of iron, and the second with iron added. In both experiments the other 9K nutrients were present. A series of five bacterial oxidations were carried out over a period of 0 to 27 days. At intervals of approximately 5 days, individual oxidations were terminated progressively and the slurries were filtered. The residual slimes were then washed, repulped, filtered again, washed, and dried.

For cyanidation, samples from well-homogenized residues were slurried at a ratio of 2:1 with tap water. After the pH value had been adjusted to 12 by the bulk addition of lime, cyanide was added in the form of NaCN and the slurry was leached with aeration for 24 hours. The cyanidation slurries were filtered and washed well before being dried, and the head and tailings were analysed for gold.

Phase II

To test the amenability of a pyrite flotation concentrate to bacterial oxidation, slurries with a liquid-to-solid ratio of 6:1 were prepared. The higher solids content was chosen for economic reasons.

Each batch contained 500 g of concentrate and 3 litres of nutrient medium. The pH of the slurries was adjusted to 1,6 before receiving the bacterial inoculum. The tests were carried out for 4, 10, 15, 22, and 25 days, while the bio-oxidation progress was monitored by means of pH and redox measurements and by ferrous and ferric iron titrations[3] using barium diphenylamine sulphonate as the indicator solution. The bio-oxidation was considered to be progressing well when the concentration of ferrous ions decreased to 0 and the redox potential increased to above 650 mV. On completion of each batch, the slimes were treated as described in Phase I.

Phase III

From bulk samples of oxidized and unoxidized slimes, ten equivalent-sized heaps 2 by 1,8 by 0,5 m (1,8 m^3) were constructed (Fig. 1).

The test heaps were arranged as follows:

1. Control, 'unoxidized' only, with moisture content adjusted
2. 'Unoxidized' + 40 litres of bacterial inoculum, pH adjusted to 2
3. 50% 'oxidized' + 50% 'unoxidized' slimes (without any adjustment, the pH value was already close to 2)

Fig. 1—The ten heaps were separated from one another by concrete walls to prevent intermixing of the slimes

4. 50% 'oxidized' + 75% 'unoxidized' slimes, pH adjusted to 2
5. 25% 'oxidized' + 75% 'unoxidized' slimes, pH adjusted to 2
6. 50% 'oxidized' + 50% 'unoxidized' slimes + 40 litres of bacterial inoculum, pH 2
7. 50% 'oxidized' + 50% 'unoxidized' slimes + 40 litres of bacterial inoculum, pH 2 + N and P nutrients + 9K iron
8. 50% 'oxidized' + 50% 'unoxidized' slimes + 40 litres of bacterial inoculum, pH 2 + N and P nutrients
9. 'Unoxidized' + 40 litres of bacterial inoculum, pH 2 + N and P nutrients + 9K iron
10. As test 9, but ferrous iron addition of only 20%.

All the heaps were maintained at a moisture content of 15 per cent—the 'field holding capacity' of the slimes. They were also monitored daily for pH and Fe^{2+} and Fe^{3+} contents. Samples were collected at 10-day intervals for cyanidation and assays of gold dissolution, which were later compared with that obtained on Day 0.

Field holding capacity refers to the amount of water that can be retained by the slimes. The water is not readily lost by gravitational or evaporative forces, and tends to be equivalent to the equilibrium moisture under normal circumstances. This was determined experimentally by the use of dry slimes held in perforated containers to which water was added and maintained in an atmosphere of 60 per cent humidity. The field holding capacity was then obtained by measurement of the moisture content once the slimes had reached constant weight.

Phase IV

The site on the slimes dam chosen for the testwork was easily accessible to heavy vehicles. Two strips approximately 9 by 50 m running perpendicular to the dam wall but about 100 m from it were marked out. An area of 15 m in width was left between the strips.

Oxidized slimes to a depth of 1,2 m were removed and stockpiled, leaving behind approximately 0,1 m of oxidized slimes. The test strips were ploughed with a double mouldboard plough (Fig. 2) to a depth of 0,46 m to give a mixture of approximately 22 per cent oxidized slimes and 78 per cent unoxidized slimes. In each of the test strips, three areas of 20 by 6 m were marked off and an irrigation system consisting of storage tanks for pH 2

Fig. 2—The plough breaks up the compacted slimes and at the same time mixes oxidized with unoxidized slimes

water and 15 sprays per strip was erected (Fig. 3).

Nitrogen and phosphate were found to be beneficial in the laboratory-scale slimes heaps, and these elements were therefore added to the test areas.

The full treatments were as follows.

Strip B had site B1 untreated, B2 with nutrients and pH adjustment by the addition of sulphuric acid, and B3 identical to B2 except that an additional ploughing stage was carried out to provide a more thorough acid mix to the site on day 0.

Strip A had sites A1, A2, and A3 treated in a similar manner to the corresponding B sites, the difference being that bacterial inoculum was also added to sites A2 and A3.

The inclusion of untreated sites was to have areas available for further tests should these become necessary during the investigation, as well as providing a control area.

The treated sites were routinely monitored for pH, Fe^{2+}, Fe^{3+}, moisture content (maintained at 15 per cent), pyritic sulphur, and gold dissolution. Environmental factors such as temperature and rainfall, although not reported here, were also recorded.

Results

Phase I

Bacterial oxidation of slimes slurries with no added iron gave the results shown in Table I, while Table II shows the results with iron added.

These results indicate that bacterial breakdown of pyrite in the slimes led to a considerable improvement in the gold dissolution—from approximately 50 per cent to over 80 per cent. Additional iron appeared to enhance the bacterial activity, giving rise to maximum gold dissolution in approximately 20 days. When no iron was added, the gold dissolution was still improved by bacterial oxidation, but the maximum value was reached after a longer time.

Phase II

Bacterial oxidation of pyrite flotation concentrate gave the results shown in Table III. An average gold recovery of 60 to 65 per cent was obtained during the flotation of the slimes material. The overall gold recovery was thus in the region of 53 to 57 per cent.

TABLE I
BACTERIAL OXIDATION WITHOUT ADDED LIME

Oxidation d	Gold dissolution %	Pyritic S in slime %
0	52,3	1,2
4	72,4	–
10	73,7	0,8
15	78,5	0,76
23	81,0	0,44

TABLE II
BACTERIAL OXIDATION WITH ADDED IRON

Oxidation d	Gold dissolution %	Pyritic S in slime %
0	47,7	1,2
5	77,7	0,5
7	80,7	0,3
14	82,7	0,3
21	84,9	0,1
27	84,4	0,1

TABLE III
BACTERIAL OXIDATION OF FLOTATION CONCENTRATE

Oxidation d	Gold dissolution %	Pyritic S in concentrate %
0	31,6	25,6
4	51,9	23,5
10	63,9	20,8
15	69,5	20,8
22	80,4	12,8
25	88,6	7,7

Phase III

The test results on laboratory-scale slimes heaps over a 100-day period are shown in Table IV.

As can be seen, the gold dissolutions increased in all the heap experiments. This is particularly evident in the unoxidized slimes (heaps 2, 9, and 10), in which more pyrite was present for bacterial attack. This is further underlined by heap 5, which consisted of 75 per cent unoxidized slimes in contrast to all the other heaps with only 50 per cent unoxidized slimes.

The highest gold dissolution—close to 80 per cent—was achieved in heap 8, which had bacteria and nutrients added. Added iron did not enhance the gold dissolution (as shown by heap 7) probably because the iron nutrient detracted from the utilization and breakdown of the pyrite.

The favourable influence of iron on bacterial oxidation in the laboratory-reaction tests, as opposed to the negative effect of iron in the heap leaches, underlines the differences created by environment on the activity of the bacteria. In agitated and aerated slimes slurries, additional iron promotes bacterial growth, which enhances the breakdown of pyrite. In slimes heaps, lack of moisture deters bacterial movement. Survival mechanisms presumably push the bacteria to reach the pyrite, their only source of energy. This push is not so strong when iron has been added to the heaps since iron is an alternative

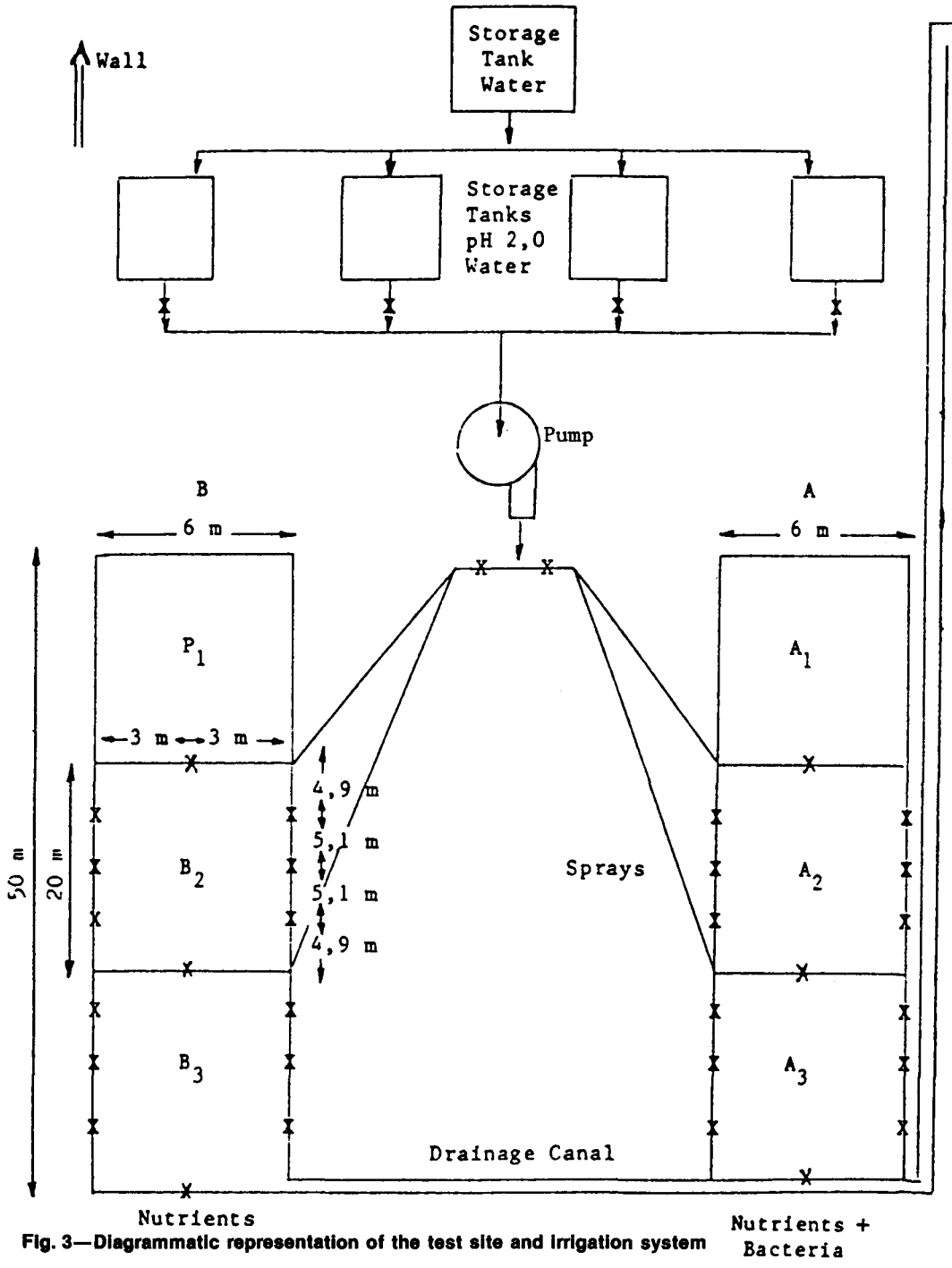

Fig. 3—Diagrammatic representation of the test site and irrigation system

TABLE IV
GOLD DISSOLUTION IN LABORATORY TESTS

Heap no.	Description	Dissolution in days, %									
		0	10	20	30	40	50	60	70	80	100
1	Control	35,9	35,9	35,9	35,9	35,0	35,9	35,9	–	38,5	41,0
2	Unox	41,0	46,2	48,7	52,0	55,0	59,0	61,5	64,1	66,7	69,2
3	50/50	50,0	55,9	61,8	64,7	67,6	67,6	70,6	70,6	73,5	73,5
4	50/50	52,9	55,9	61,8	64,7	67,6	70,6	–	–	70,6	–
5	25/75	47,0	50,0	58,3	61,1	64,0	–	66,7	75,0	75,0	–
6	50/50	55,9	58,9	58,9	61,8	64,7	70,6	70,6	–	72,5	–
7	50/50 + Fe	53,0	58,0	61,8	64,7	67,0	70,6	70,6	70,6	73,5	73,5
8	50/50	52,9	55,9	61,8	64,7	67,6	73,5	76,5	79,4	–	79,4
9	Unox + Fe	36,0	48,7	51,3	55,0	59,0	61,5	–	61,5	64,1	69,2
10	Unox + Fe	35,9	44,0	51,3	55,0	59,0	61,5	66,7	74,4	74,4	74,4

source of energy.

The results from the control heap show the necessity of bacteria (either added or present in oxidized slimes) and low pH for successful increase in gold dissolution.

Phase IV

In the case of sites A2 and B2, a significant increase in gold dissolution was noticeable only after the pH had been adjusted correctly throughout the depth of the ploughed slimes. This was achieved only with reploughing after day 42. Sites A3 and B3 had their pH adjusted by reploughing on day 0.

Tables V and VI compare the gold dissolution and pyritic sulphur content of areas A2, B2, A3, and B3, and show a definite relationship between the disappearance of pyritic sulphur and an increase in gold dissolution. The necessity for the correct pH (pH 2) was clear.

TABLE V
RESULTS FOR HEAPS A2 AND B2

	A2 (bacteria + nutrients)		B2 (nutrients)	
Oxidation d	Au dissolution %	Pyritic S %	Au dissolution %	Pyritic S %
0	46	–	49	–
42	55	–	48	–
62	60	1,00	63	1,00
82	71	0,79	78	0,77
112	71	0,68	76	0,57

TABLE VI
RESULTS FOR HEAPS A3 AND B3

	A3 (bacteria + nutrients)		B3 (nutrients)	
Oxidation d	Au dissolution %	Pyritic S %	Au dissolution %	Pyritic S %
0	39	1,10	40	1,380
20	55	1,08	60	1,300
40	69	0,81	69	1,250
70	72	–	73	0,738

Conclusions

The tests showed that gold can be recovered from slimes dam material with the help of a population of *Thiobacillus* bacteria composed mainly of *Thiobacillus ferrooxidans*. These obtain energy for growth by oxidizing pyrite into soluble iron and sulphur compounds, releasing the gold occluded in the pyrite.

The initial part of the investigation, which focused on the use of bacteria in vessel-reactors with slurries of slimes and slimes flotation concentrate, indicated that, by oxidizing the pyrite, the bacteria released approximately 29 per cent of the gold to give a total gold recovery of 81 per cent. Although the amount of gold released by the bacteria increased to 57 per cent for the flotation concentrate, the overall recovery was less. As flotation is an expensive process, it is not justified by the low gold content of the slimes; nor is the building of large reactors economically feasible.

It is concluded that the bacterial *in situ* process is an attractive alternative to the flotation–roasting process (being practised for the recovery of gold from slimes dams) both economically and in its simplicity. Also, since noxious gases are produced during roasting[4], the bacterial process has less potential for environmental pollution.

Acknowledgements

The permission from General Mining Metals & Minerals Limited to publish this paper is gratefully acknowledged, as is the help and advice received from Messrs T.H. Tunley, P.R. Bailey, and C.M. Olën and the mine personnel involved in this project.

References

1. LIVESEY-GOLDBLATT, E. Bacterial leaching of gold, uranium, pyrite compacted mine tailing slimes. *Fundamental and applied biohydrometallurgy, Proceedings of the Sixth International Symposium on Biohydrometallurgy, Canada 1986.* pp. 89–96.
2. SILVERMAN, M.P., and LUNDGREN, D.G. Studies on the chemoautotrophic iron bacterium *Ferrobacillus ferrooxidans T.* An improved medium and a harvesting procedure for securing high cell yields. *J Bacteriol.*, vol. 877. 1959. pp. 642–647.
3. FURMAN, N.H. (ed.). Determination of iron in ores and metallurgical products. *Scotts standard methods of chemical analysis*, vol. I. New York, Van Nostrand Co., 1956. pp. 471–474.
4. GOSSMAN, G.I. Pyrometallurgy of gold. *The extractive metallurgy of gold in South Africa*, vol. 1. SAIMM monograph series M7. 1987. pp. 345–352.