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Technical Note

The role of chemolitotrophic bacteria in an oxide copper ore heap leaching operation

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ABSTRACT

The role of chemolitotrophic bacteria in the oxidation of copper sulfide minerals in oxide copper ore heap leaching operation at Sarcheshmeh Copper Mine has been investigated. It was determined that about 34% of the heap copper content existed in the form of sulfide minerals, 1/3 of which has been leached quit naturally, and the remaining copper as oxide ores. As such, the heap considered in this study, consisted of a mixed sulfide and oxide copper ore. Previous samplings from PLS of the heap showed there were a significant amount of native chemolititrophic bacteria (more than 10^5cell/ml) which belonged to the genera Acidithiobacillus, Leptospirillum and Sulfobacillus. To investigate a probable relation between the existence of bacteria and the leached sulfide ores, several samples were taken from different depths of a newly leached pad and analyzed for their bacterial number, pH, oxidation-reduction potential (ORP), total soluble iron (TSI), pyretic iron and copper content. It was found that bacteria had an important effect on the heap pH, solution potential, and TSI from the top of the heap down to the depth where enough oxygen could diffuse. As these are very active oxidizing bacteria, they created favorable conditions (such as low pH and high ORP values) for copper sulfide ore oxidation. Copper extraction from sulfide ores in this chemical heap leach operation can then be attributed to the bacterial activity especially at the top levels of the heap. It is possible that the remaining sulfide copper ore in the heap can be leached biologically after completion of chemical leaching.

Keywords: Bioleaching; Sulfide minerals; Chemical leaching

1. INTRODUCTION

Natural bioleaching of sulfide minerals has been taking place as long as the history of the world, but it is only in the last several decades that we have realized that bioleaching is responsible for liberating some metals. The application of the bioleaching for the extraction of copper has been exploited and used to develop suitable methods to recover copper from copper bearing feedstock (Schnell, 1997).

Heap leaching of copper has been practiced for several decades, mostly with oxide ores. Probably bacteria aided some of these oxide operations, but this was without serious study. This is the subject of the current paper for determining the role of chemolitotrophic bacteria in the chemical (acid) heap leach operation at Sarcheshmeh Copper Mine. In this heap, permanent pads are constructed over each other so that the height of the heap has increased to about 80m at present. The copper ore used for the operation can be considered as an oxide/sulfide mixture which is typically composed of 66% copper in the form of oxide minerals and 34% as sulfide minerals mainly in the form of chalcocite and chalcopyrite. There are some industrial experiences of applying a process of chemical and then biological operation for such mixed oxide/sulfide copper ores (Acevedo and Jentina, 1993; Sen *et al.,* 1993). No considerations were taken for the biological operation part while Sarcheshmeh copper heap was constructing. Copper sulfide minerals are insoluble or partially soluble during the time (about 75 days) considered for dissolution of copper oxide ores, but studies in this project showed that about 30% of total copper in the form of sulfide minerals has been leached naturally.

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Several samplings from different parts of the heap showed there were a lot of indigenous bacteria (more than 10^5cell/ml) belong to the genera, *Acidithiobacillus*, *Leptospirillum* and *Sulfobacillus* (Seyed Baghery, 2001). These bacteria have also been identified in industrial copper bioheaps in which they accelerate copper mineral oxidation (Brierley, 2001). Hence, sulfide copper dissolution can be attributed to the bacterial activity and therefore it may be possible to recover the left copper (which amounts to about 28000 tones) from the buried sulfide minerals.

The main objective of this study was to determine the role of the above bacteria on some of the heap parameters and propose some processes that may be useful for recovering the residual copper in the heap.

2. EXPERIMENTAL

In order to find out the role of chemolitotrophic bacteria in the oxidation of sulfide ore fraction of the heap leaching operation at Sarcheshmeh Copper Mine (Iran), a newly finished irrigation pad was selected in the month of September. The typical temperature in this month at Sarcheshmeh Copper Mine is around 26.3ºC. After 2 days of finishing the operation, three sampling area, each with a distance of 20 meters were marked on the pad and then from the surface of the pad down to the depth to 2.75m, several samples (totally 36 samples) of the leached ore were taken, each at an interval of 0.25m. In order to measure the values for pH, oxidation-reduction potential (ORP), bacterial counts and total soluble iron concentration in the solid samples, 1kg of each sample was added to 1 liter of acidic (pH=1.9) distilled water in a 5 liter volume beaker and mixed thoroughly for 20 minutes. After settling, a sample of the clean solution was drawn for measuring the above parameters. The bacteria were counted microscopically using a slide counting chamber. The pH and ORP values were also measured using a WTW pH/Eh meter model 323. The total dissolved iron was analyzed by the atomic absorption method. The solids of each sample were washed, dried, pulverized and then analyzed for iron and copper. An average value of each parameter for distinct depths was considered to discuss about.

3. RESULTS AND DISCUSSION

Regarding the environment temperature (around 26.3ºC) at the time of sampling, the dominant bacteria belonged to the genera *Acidithiobacillus* and *Leptospirillum*. In warmer months, moderately thermophiles were also isolated from this oxide heap (Seyed Baghery, 2001). The temperature at Sarcheshmeh Copper Mine changes from 6°C in the coldest month of the year, January, to about 28°C in July during days.

A theory of bacterial growth in a heap holds that the major area of bacterial growth is in the top 1.5 meters of a leach pile (Schnell, 1997). In this study, it was decided to take some samples from the top of the heap to a deeper depth of 2.75m to see how certain parameters change.

Figure 1 shows the number of bacteria and the ORP changes at different depth of the pad.

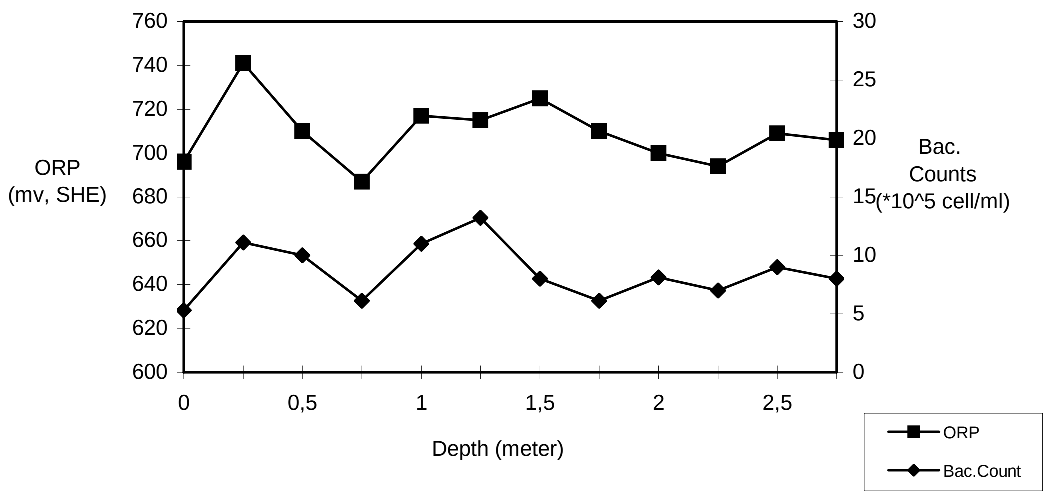

Figure 1. Bacterial count and ORP value changes in different depths of the pad

There is a close, direct relationship between these two factors. At the top of the heap, there are few bacteria and also low ORP value. This may be because of the rapid changes at the top of the heap such as different temperatures during days and nights, sunshine and the high evaporation of introducing solutions to the heap. Beneath the surface where the harsh environment conditions are disappeared, the number of bacteria and the ORP increased considerably. After that, down to the depth 0.75m, the above factors decreased for which a possible reason could be the insufficient energy supplies to support the bacterial growth. From the depth of 0.75 down to 1.25m, again the bacterial number and the ORP value increased. The lower depths showed a relatively constant number of bacteria that because of the insufficient oxygen concentration, just washed from the higher levels and they are not so active. The oxygen level at lower depths of 1.5m in a non-aerated heap (like the present case) drops to below 5% which is not enough to support the bacterial growth (Schnell, 1997). Redox potential is an important factor governing the dissolution of sulfide minerals and these results showed that the native thriving bacteria in this chemical heap were able to increase the redox to the level suitable for iron and copper bearing sulfide mineral oxidation (Brierley and Briggs, 2002; Yahya and Johnson, 2002; Sandström *et al.,* 2004).

A better understanding of the bacteria and their role in the heap can be deduced from Figure 2, which demonstrates the bacterial number and the pH value changes at different depths of the pad.

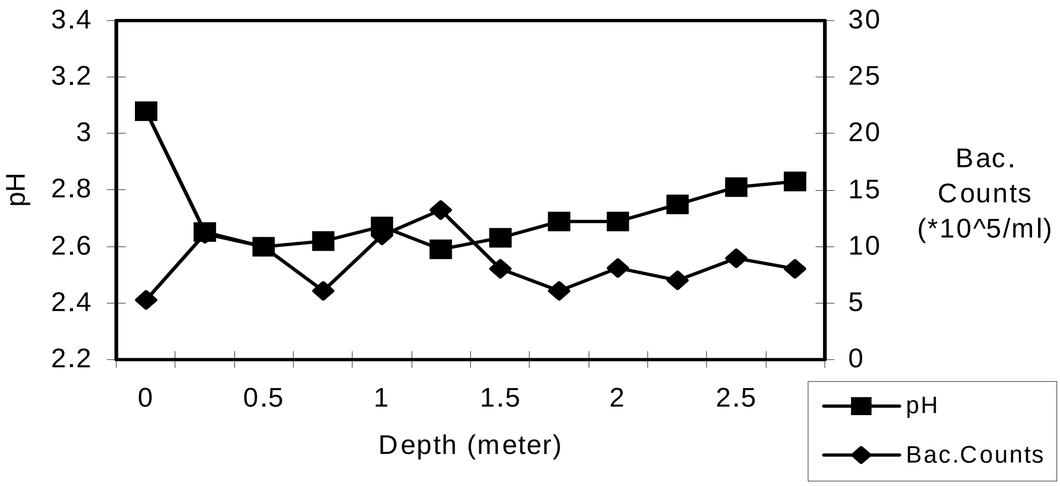

Figure. 2. Bacterial count and pH value changes in different depths of the pad

At the top of the pad, the pH of the leached ore was high together with few bacteria. Beneath the surface, down to the depth 1.25m, there were more active acid producing bacteria growing at the pH around 2.5 to 2.6 which is a suitable pH for mesophilic bacteria. From this point down to the lower depths, the pH value started to increase gradually as a consequence of the lack of enough oxygen for the bacteria.

The pH value has an important role on the solubility of ferric ion, which is a key factor for sulfide mineral oxidation; furthermore, its precipitation in the form of jarocite in a heap can reduce the permeability as well as final metal recovery (Figure 3). There is a counter-relation between these two factors. The low concentration of total soluble iron (TSI) was due to the long time irrigation of the pad. During that time, the iron in the acid soluble form has been leached chemically, and the total soluble iron produced after 48 hours from the time irrigation was finished, could be attributed to the bacteria which had oxidized iron mostly in the form of pyrite.

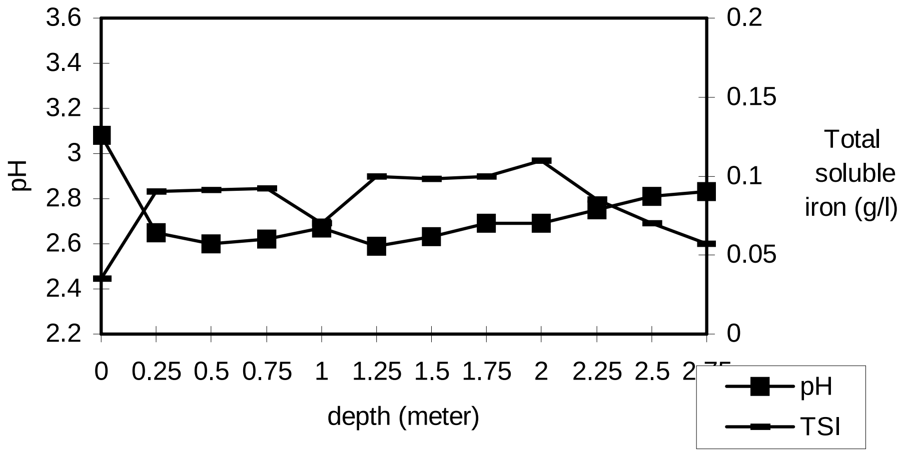

Figure 3. TSI concentration and pH value changes in different depths of the pad

The result of bacterial growth on the oxidation of pyrite has been shown in Figure 4. Supposing the homogeneous distribution of pyrite, one can conclude that following bacterial growth, ferric ion was produced and down to the depth to 1.25m, pyrite has been oxidized. Blow this depth, bacterial growth has been ceased and the iron content of the ore which is mostly in the form of pyrite, started to increase gradually. It can be concluded that where there have been active bacteria, the amount of pyrite has decreased.

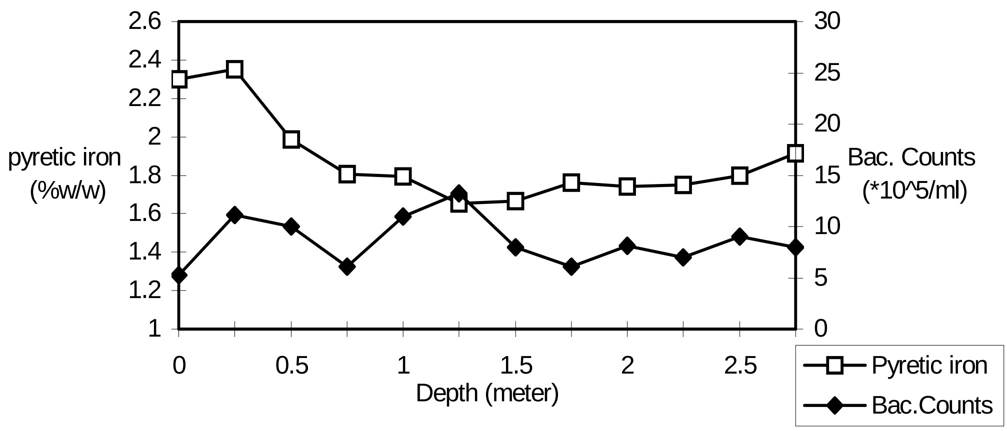

Figure 4. Changes of bacterial count and iron content of the ore in different depths of the pad

The test pad was irrigated for about 90 days, therefore, it is anticipated that the copper in the form of oxide minerals, mostly as malachite, has been leached totally and only the sulfide copper minerals have been left. Figure 5 shows the sulfide copper content of the ore which is decreasing in the area where active bacteria are present and after that, the copper was going to increase gradually. It can then be concluded that the observed copper recovery from sulfide fraction (which amounts to 30%) during the acid irrigation of the heap, is restricted to the top levels of the pads where aerobic bacteria and their products (especially Fe^{3+} and acid) create a suitable condition for sulfide mineral dissolution.

Figure 5. Changes of the copper content of the ore in different depths of the pad

4. CONCLUSIONS

- There were a considerable amount of chemolitotrophic bacteria in this oxide copper ore heap that grew down to the depth where enough oxygen could diffuse.
- The bacteria had a significant role on the values of ORP, pH and TSI all of which are important parameters in sulfide mineral oxidation.
- Comparing the iron and the copper content in the upper and lower parts of the residue ore in the test pad showed a more reduced mount of these elements in the top 1.25m where active aerobic bacteria and their products create favorable conditions for sulfide mineral dissolution.
- It should be noted that the results above came from a chemical heap leach operation in which no preparations were made to assist bacterial activity.
- It is possible for the buried copper in the heap, which exists mostly in the form of sulfide minerals, to be recovered by the following methods for which further studies in necessary to be carry out:
  - Bioleaching of the upper 1.5 m of the heap, removing it and then treat the next1.5 m and doing this to reach the bottom of the heap
  - Performing an indirect bioleach process in which bacterial products (especially Fe^{3+}) being produced out of the heap biologically in a separate process (Gomez *et al.*, 2000) and then introducing them to the heap.

REFERENCES

Acevedo, F., Jentina, J.C., Bioleaching of minerals - a valid alternative for developing countries. Journal of Biotechnology., 1993, 31, 115-123

Brierley, C.L., Bacterial succession in bioheap leaching. Hydrometallurgy, 2001, 59, 249-255.

Brierley, C.L., Briggs, A.P., Selection and sizing of biooxidation equipment and circuits. Mineral Processing Plant Design, Practice and Control, eds. Mular, A.L., Halbe, D.N., Barratt, D.J., Society of Mining Engineers, Littleton, Colorado, 2002, 1540-1568.

Gomez, J.M., Cantero, D., Webb, C., Immobilisation of Thiobacilus ferroxidans cells on nickel alloy fiber for ferrous sulfate oxidation. Applied Microbial Biotechnology, 2000, 54 (3), 335-340.

Sandström, A., Shchukarev, A., Paul, J., XPS characterisation of chalcopyrite chemically and bio-leached at high and low redox potential. Minerals Engineering, 2004, Article in Press, Corrected Proof.

Schnell, H.A., Bioleaching of copper. in: Rawlings, D.E., (ed.) Biomining: Theory, Microbes and Industrial Processes, 1997, 21-43.

Sen, A., Gupta, R.C., Prasad, M.S., Ramesh, N., Ray, S. K., Pal, K., Biohydrometallurgical Operations. in: Torma, A.E., Way, J.E., Lakshmanan, V.I. (eds.), Biohydrometallurgical Technologies, 1993, Vol. 1, 185-194.

Seyed Baghery, S.A., Isolation and preliminary identification of some iron - and - sulfur oxidizing bacteria from the Sarcheshmeh Copper Complex. in: Ciminelli, S. T., and Garcia Jr. O., (eds.), Biohydrometallurgy: Fundamentals, Technology and Sustainable Development, 2001, Part A, 393-396.

Yahya, A., and Johnson, D.B., Bioleaching of pyrite at low pH and low redox potentials by novel mesophilic Gram-positive bacteria. Hydrometallurgy, 2002, 63 (2), 181-188.