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BIOTECHNOLOGY ISSUES FOR DEVELOPING COUNTRIES

Present and future of bioleaching in developing countries

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Nowadays bioleaching occupies an increasingly important place among the available mining technologies. Today bioleaching is no longer a promising technology but an actual economical alternative for treating specific mineral ores. An important number of the current large-scale bioleaching operations are located in developing countries. This situation is determined by the fact that several developing countries have significant mineral reserves and by the characteristics of bioleaching that makes this technique especially suitable for developing countries because of its simplicity and low capital cost requirement.

The current situation of commercial-size bioleaching operations and ongoing projects in developing countries is presented and discussed with especial reference to copper and gold mining. It is concluded that this technology can significantly contribute to the economic and social development of these countries.

In our days, at the beginning of the XXI century, bioleaching occupies an increasingly important place among the available mining technologies. The situation is now quite different than was 25 years ago, when the first international meeting on the subject took place in Socorro, New Mexico (Murr et al. 1978), initiating the now traditional International Biohydrometallurgy Symposia. Today bioleaching is no longer a promising technology but an actual economical alternative for treating specific mineral ores.

Examination of the current large-scale bioleaching operations reveals that an important number of them are located in developing countries. This is not purely accidental but the necessary result of two important factors: for one thing, many developing countries have significant mineral reserves and mining constitutes one of their main sources of income; on the other hand, bioleaching is a technique especially suitable for developing countries because of its simplicity and low capital cost requirement (DaSilva, 1981; DaSilva, 1982; Gentina and Acevedo, 1985; Warhurst, 1985; Acharya, 1990; Acevedo et al. 1993). This is the case for countries like Chile, Indonesia, Mexico, Peru and Zambia. As can be seen in Table 1, these developing countries share over 50% of the world copper production.

Table 1. World copper production (thousands of tonnes)[a].

Country	1998	1999	2000
Australia	607.0	711.0	829.0
Canada	705.8	620.1	634.2
Chile	3,6869	4,391.6	4,602.0
China	486.0	520.0	588.5
Indonesia	809.1	790.3	1,005.5
Mexico	384.3	381.2	344.6
Peru	483.3	563.3	553.9
Poland	436.2	463.6	463.2
Russia	518.0	510.0	510.0
United States	1,860.0	1,601.0	1,480.0
Zambia	378.8	271.0	320.1
Others	1,932.7	1,915.9	1,912.7
World	12,288.1	12,712.0	13,243.7

[a] USGS Minerals Yearbook at http://minerals.usgs.gov/minerals/pubs/commodity/myb

In the case of gold mining, Brazil, Chile, Ghana, Indonesia, Papua New Guinea, Peru and Uzbekistan rank among the 13 top producer countries with 33% of the world production, as shown in Table 2.

Historical development

It is recognized that microorganisms have contributed to the solubilisation of metal sulphides since ancient times and that Romans benefited from their action long before Christ. It has been pointed out that the copper mine of Río Tinto in Spain was probably the first large-scale operation in which microorganism played a major role (Brierley, 1978; Brierley, 1982).

Table 2. World gold production (tonnes)[a].

Country	1998	1999	2000
Australia	310,1	301.1	296.4
Brazil	49.6	52.6	52.0
Canada	165.6	157.6	153.8
Chile	45.0	45.7	54.1
China	178.0	173.0	180.0
Ghana	72.5	79.9	72.1
Indonesia	124.0	127.1	124.6
Papua New Guinea	64.1	61.3	74.0
Peru	94.2	128.5	132.6
Russia	114.9	125.9	140.0
South Africa	464.7	451.3	430.8
United States	366.6	341.0	353.0
Uzbekistan	80.0	85.0	85.0
World	2,510.0	2,550.0	2,550.0

[a] USGS Minerals Yearbook at http://minerals.usgs.gov/minerals/pubs/commodity/myb

The role that microorganisms play in this process was demonstrated only in 1947 when Colmer and Hinkle isolated from acid mine waters bacteria belonging to the *Thiobacillus* genus (Le Roux, 1970). Later, *Thiobacillus ferrooxidans* (Temple and Colmer, 1951) and *Thiobacillus thiooxidans* (Temple and Delchamps, 1953)were isolated and characterised. *Thiobacillus ferrooxidans* has been recently reclassified as *Acidithiobacillus ferrooxidans* (Kelly and Wood, 2000).

In the period of 1950 to 1980, bioleaching was thought mostly as an appropriate technology for the recovery of copper and other metals from damps and low-grade ores. Probably the most important operations in those days were in the copper mines of Río Tinto, Spain and Cananea, Mexico. Río Tinto had a dump bioleaching operation, that produced 8,000 tonnes of copper per year, while Cananea produced 9,000 tonnes/year in its dump and *in-situ* operations (Gentina and Acevedo, 1985).

Although not completely successful, the pilot operation at Toromocho, Peru, can be cited as an important contribution to the development of bioleaching technology. In the mid-seventies, heaps and dumps up to 36 thousand tones of ore of 0,4% Cu were operated and evaluated. Although the copper recovery was lower than expected, the economic evaluation of a full-scale operation was positive (Zegarra, 1979; Warhurst, 1985).

A major multidisciplinary and multiinstitutional Chilean project on bacterial leaching of copper ore is also considered a landmark in bioleaching technology. The project, funded by the Chilean government and the United Nations Development Program – UNDP, started in 1985 with the participation of scientists and engineers from universities, research institutes and mining companies. Their activities covered a wide spectrum of topics, from basic biological aspects to the operation of small pilot heaps (Badilla-Ohlbaum et al. 1991). Its contribution to basic and applied knowledge in the area was recognised by the United Nations Industrial Development Organization–UNIDO (Anonymous, 1987).

A breakthrough in bioleaching practice was the establishment of the first copper mine exploited solely by bacterial technology. This goal was achieved in Minera Pudahuel in Chile, when in the mid-eighties they switch from a mixed acid and bacterial leaching to full heap bacterial leaching of an ore containing 1 to 2% copper, rendering 14,000 tonnes of fine copper per year (Acevedo et al. 1993). The process consisted in crushing, agglomeration, heap bioleaching, solvent extraction and electrowinning. It is worth noting that Pudahuel's biotechnology was totally developed in Chile.

Current bioleaching operations and projects in developing countries

Soon after the start-up of the Pudahuel process, several other copper bioleaching operations were established in Chile, as shown in Table 3.

Table 3. Copper bioleaching operations in Chile.

Mine	Production, tonnes/year
Heap leaching	
Lo Aguirre	14,000
Quebrada Blanca	75,000
Cerro Colorado	100,000
Zaldívar	150,000
Iván-Zar	12,000
Andacollo-Cobre	21,000
Dump leaching	
Chuquicamata	over 15,000
Los Bronces	n.d
Zaldívar	n.d

n.d: no data available

A number of copper bioleaching projects are at this time under study and development. Perhaps the most meaningful one is being carried on jointly by the Chuquicamata Division of CODELCO (Chilean National Copper Corporation) and BHP Billiton. This project aims to the

large-scale operation of a plant for the bioleaching of copper concentrates in continuous stirred tank reactors using thermophilic microorganisms. The project involves the construction of a US$ 60 million large pilot plant able to produce 20,000 tonnes of copper cathodes/year (Anonymous, 2002a; Anonymous, 2002b).
Another exciting experience is being carried on in Mexico. Peñoles S.A., in association with Mintek, has been able to produce several tonnes of copper cathodes in their demonstration plant in Monterrey. The plant is an integrated tank bioleaching, solvent extraction, electrowinning facility capable of producing 500 kg of copper per day (Anonymous, 2001a).

Bioleaching is also successfully applied in gold mining, when the metal is covered with a film of insoluble metal sulphides that difficult the extraction of gold with cyanide solutions. In this case, the sulphide film must be removed in order to obtain satisfactory gold recoveries, and bioleaching is presently the alternative of choice for such pre-treatment step. Ten large-scale gold biooxidation facilities are known to operate today, four of them located in developing countries, as shown in Table 4.

Table 4. Large-scale gold concentrates biooxidation plants in developing countries[a].

Plant	Capacity	Commisioned
São Bento, Brazil	150 tonnes gold concentrate/d	1990
Ashanti, Ghana	1.000 tonnes gold concentrate/d	1994
Sansu, Ghana	1.000 tonnes gold concentrate/d	1994
Tamboraque, Peru	260.000 tonnes zinc flotation tailings	1999

[a] Acevedo, 2000

A series demonstration plant was commissioned on February 2002 in the Hutti Gold Mines in the Karnataka state in India. The plant was designed for treating gold and silver bearing concentrates, but it can be used for the bioleaching of copper, zinc, nickel and other base-metal concentrates (Anonymous, 2002c). Another ongoing project is a heap bioleaching plant to treat zinc sulphide concentrates that is being developed in the Kumba's Rosh Pinah mine in Namibia (Anonymous, 2001b).

Looking forward

The current panorama of bioleaching in developing countries is encouraging. It is expected that in the coming years several new commercial-size bioleaching plants will be installed. It is likely that heap leaching will continue to be the choice for low-grade ores and tailings, while tank bioleaching technology will probably increase its application for gold, copper and other base-metal concentrates. The use of thermophilic bacteria and archea will be a major contribution, increasing the leaching rates and metal recoveries and allowing for the treatment of recalcitrant ores such as chalcopyrite.

Developing countries should increase their efforts in research and development in bioleaching technology, as they have comparative and competitive advantages in this area. International cooperation should also be considered in the establishment of new operations that can significantly contribute to the economic and social development of these countries.

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