MICROBIAL EXTRACTION OF PRECIOUS METALS FROM A GRAVITY-FLOTATION CONCENTRATE

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ABSTRACT. The possibility for microbial extraction of precious metals from mineral and metal bearing raw materials and wastes is of special interest in the area of the mineral biotechnologies. Various processes of this type are known and the most important among them are the following: the preliminary oxidation of gold-bearing sulphide ores and concentrates by means of chemolithotrophic bacteria and archaea to liberate and expose the fine gold particles from the sulphide crystal structures; the direct extraction of gold from oxide mineral raw materials by leaching with solutions containing amino acids of microbial origin and suitable chemical oxidisers of the native gold; the leaching of gold by means of heterotrophic bacteria growing on suitable organic sources of carbon and energy in the presence of the mineral gold-bearing mineral raw materials being leached; selective change of the flotation properties of the gold-bearing sulphide minerals by short treatment with chemolithotrophic bacteria to facilitate the subsequent flotation and produce very clean gold-bearing concentrate.

Keywords: chemolithotrophs, leaching, valuable metals

МИКРОБИОЛОГИЧНО ИЗВЛИЧАНЕ НА БЛАГОРОДНИ МЕТАЛИ ОТ ФЛОТАЦИОННО-ГРАВИТАЦИОНЕН КОНЦЕНТРАТ

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РЕЗЮМЕ. Специален интерес в областта на минералните биотехнологии е възможността за микробно извличане на благородни метали от минерални и метал съдържащи суровини и отпадъци. Известни са различни процеси от този тип и най-важни сред тях са: предварителното окисление на златосъдържащите сулфидни руди и концентрати чрез хемолитотрофни бактерии и археи за освобождаване и излагане на фините златни частици от сулфидните кристални структури; директно извличане на злато от окисни минерални суровини чрез извличане с разтвори, съдържащи аминокиселини от микробен произход и подходящи химически окислители; извличане на злато с помощта на хетеротрофни бактерии, които растат върху подходящи органични източници на въглерод и енергия в присъствието на излугваните злато-съдържащи суровини; селективна промяна на флотационните свойства на златосъдържащите сулфидни минерали чрез краткотрайно третиране посредством хемолитотрофни бактерии за улесняване на последващата флотация за получаване на много чист злато-съдържащ концентрат.

Ключови думи: хемолитотрофи, излугване, ценни метали

Introduction

The ability of different microorganisms, mainly chemolithotrophic bacteria and archaea to leach precious metals from mineral substrates (ores, concentrates and wastes) is largely applied under real industrial conditions. The role of the microorganisms in these processes can be of different types:

- A preliminary oxidation of the gold-bearing sulphide ores and concentrates to reveal and liberate the fine gold particles from the sulphide crystal structures. In some cases the microbial oxidation of sulphides is performed together with the leaching of the precious metals by means of reagents which are non-toxic for microorganisms (such as thiourea and acidic medium);
- A direct extraction of gold from mineral oxides containing the precious metals by means of solutions of aminoacids of microbial origin and suitable chemical oxidants of the native gold (such as peroxides);
- Bioleaching by means of heterotrophic bacteria grown on suitable organic sources of carbon and energy in the presence of the leached gold-bearing substrate;
- A selective change of the flotation properties of the sulphide minerals present in the complex gold-bearing concentrates by means of a short treatment by chemolithotrophic bacteria and archaea. This treatment results in a change of the flotation properties of the gold-bearing concentrates.

This paper contains data about investigations on the microbial extraction of the precious metals from a sulphidic gold-bearing ore in the western part of Bulgaria.

Materials and Methods

The initial sample contained 7.1 g/t Au and 14.5 g/t Ag, 2.8% sulphur (from which 2.4% were sulphidic), 7.3% iron and 0.35% copper as the main components. The phase analysis of the gold in the ore was:

- Free Au 0.5%;
- Au in oxides and hydroxides 12.5%;

- Au finely disseminated in sulphides (mainly pyrite) 85.1%;
- Au finely disseminated in silicates 1.9%.

Most of the gold was finely disseminated in pyrite and a relatively small part – in chalcopyrite. The gold was present mainly as small (less than 1 micron) particles. The chalcopyrite was the main copper mineral in the ore but part of the copper was present in secondary sulphidic minerals, mainly in covellite and bornite. The quartz was the main mineral in the ore rock.

A gravity-flotation concentrate was obtained by processing of the initial ore sample. The pyrite was the main gold-bearing mineral in the concentrate. The gold was present in the pyrite as a fine isomorphic impurity. The galena was the main silver-bearing mineral and the silver was present also as isomorphic impurities. A portion of the silver was present in the pyrite.

Data about the concentrate are shown in Tables 1 and 2.

The bioleaching of concentrate was performed in agitated Erlenmeyer flasks of 300 ml volume each containing 100 ml leach solution with the composition of the 9K nutrient medium and different quantities of the mineral substrates used in this study with a particle size of minus 100 microns added in quantities to form the desired pulp density.

Table 1. *Data about the gravity-flotation concentrate*

Element	Content
S total	6.80 %
S sulphidic	6.17 %
Fe	8.04 %
Cu	1.64%
Zn	0.15 %
Pb	6.35 %
Au	28.4 g/t
Ag	1270 g/t

Table 2. *The phase composition of the precious metals in the concentrate*

Phase composition	Distribution, %	
	Au	Ag
Free exposed	12.5	-
Capsulated in iron oxides	31.4	20.3
Finely dispergated in sulphides	53.0	71.3
Finely injected in silicate	3.1	8.4
Total	100.0	100.0

Elemental analysis of the liquid samples from the leach systems was performed by atomic absorption spectrometry (AAS) and inductively coupled plasma spectrometry (ICP). The isolation, identification and enumeration of microorganisms were carried out by the classical physiological and biochemical tests and by the molecular PCR methods (Karavaiko et al., 1988; Attia, El-Zeky, 1989; Spasova et al., 1994; Groudev et al., 1996; Sanz, Köchling, 2007; Escobar et al., 2008; Dopson, Johnson, 2012).

Results and discussion

The direct chemical leaching of the precious metals from the sulphide concentrate used in this study was not efficient (Table 3) due to the fine dissemination of these metals in the sulphide minerals. The thiosulphate was the main attractive leach agent due to its relatively low toxicity and efficient leaching ability which was very close to that of the very toxic cyanide. The combination of thiosulphate with a protein hydrolysate was even more efficient than the leaching ability of the cyanide. The combination of thiosulphate with a protein hydrolysate was even more efficient than the leaching ability of the cyanide. However, all these reagents were not able to penetrate through the sulphide matrix and to establish a direct contact with the precious metals finely disseminated in the sulphide minerals (mainly in the pyrite) of the concentrate. The addition of some chemical oxidisers (mainly of KMnO4) to the leach solutions increased considerably the level of extraction of these metals. However, the most efficient extraction of the precious metals was achieved by means of the preliminary sulphide oxidation on the relevant concentrate by chemolithotrophic bacteria and archaea able to expose the precious metals and to make them accessible to the reagents suitable for their solubilisation.

Table 3. *Leaching of precious metals from the flotation concentrate by different reagents before and after its pre-treatment by means of microbial oxidation*

Leach solutions	The initial concentrate		The pretreated concentrate	
	Au	Ag	Au	Ag
	Extraction, %			
Protein hydrolysate	8.6	4.1	14.5	7.3
Protein hydrolysate + $KMnO_4$	32.7	14.5	89.4	72.1
Protein hydrolysate + thiosulphate	40.4	21.2	91.8	75.6
Thiosulphate	35.8	17.8	90.1	72.5
NaCN	38.7	20.3	90.5	72.1

A large number of chemolithotrophic microorganisms able to oxidise sulphide minerals (including the most stable pyrite and chalcopyrite) were tested for their ability to oxidise these sulphide minerals (Table 4). It was found that the different chemolithotrophs, even such related to one and the same taxonomic species, can differ considerably from each other with respect to this ability. The most efficient oxidisers were some strains of the extreme thermophilic archaea of the species *Sulfolobus metallicus* and *Thermoplasma acidophilum* at 86°C but at relatively low pulp densities (up to 10-20%). Other strains of these species and some strains of the species *Metallosphaera sedula* were the most efficient at relatively higher pulp densities (14-20%) at 75°C. Some mixed cultures of extreme thermophilic archaea were also very active at these temperatures.

The moderate thermophilic bacteria, mainly such of the species *Sulfobacillus thermosulphidooxidans* and *Alicyclobacillus tolerans*, were also very active at lower temperatures (50-59°C) and pulp densities of 15-20%.

The comparative experiments during this study revealed that the most efficient oxidisers of the sulphide ore and the sulphide concentrate were the chemolithotrophs possessing only the ability to oxidise the ferrous iron but not the elemental sulphur (S^0). The most efficient in this respect were the members of the genus *Leptospirillum*, such as the mesophilic *L. ferrooxidans* and the moderate thermophilic *L. ferriphilum*.

These microorganisms acted according to the well-known indirect oxidative mechanism and their role consisted in the oxidation of the ferrous iron to the ferric state. The ferrous ions were generated in the leach system as a result of the oxidation of the sulphides by the ferric ions.

Table 4. *Extraction of precious metals from the flotation concentrate pre-treatment by means of chemolithotrophic microorganisms related to different taxonomic species and different strains from each taxonomic species*

Pretreated by means of different microorganisms	Extraction of precious metals after pre-treatment, %		Number of strains tested
	Au	Ag	
Mesophilic bacteria			
Acidithiobacillus ferrooxidans	82 – 93	68 – 77	12
Leptospirillum ferrooxidans	78 – 91	64 – 71	8
Acidithiobacillus ferrivorans	75 – 88	57 – 68	4
Moderate thermophilic bacteria			
Sulfobacillus thermosulfidooxidans	80 – 95	65 – 79	8
Alycyclobacillus tolerans	77 – 90	62 – 71	4
Leptospirillum ferriphilum	75 – 86	57 – 71	4
Extreme thermophilic archaea			
Sulfolobus metallicus	84 – 95	68 – 82	8
Metalosphaera sedula	77 – 91	64 – 78	6
Acidianus infernus	73 – 84	60 – 80	6
Thermoplasma acidophilum	71 – 80	59 – 74	4

Note: The duration of the pre-treatment was up to 168 hours at the relevant temperature: 37 and 55°C for the mesophilic and moderate thermophilic bacteria, respectively, and at 75 and 86°C for the extreme thermophilic archaea, at 20 % pulp density.

On the other side, some microbial species possessing only sulphur-oxidising ability but not able to oxidise the ferrous iron (such as the mesophilic *At. thiooxidans* and the extreme thermophilic *Sulfolobus acidocaldarius* and *S. solfatarium*) were able to leach the sulphides but usually at relatively lower rates.

It must be noted also that at higher temperatures (over 60 – 65°C) there was some chemical oxidation of the ferrous iron to the ferric state by means of the oxygen dissolved in the leach solutions. The ferric ions generated in this way were also involved in the oxidation of sulphides. However, the role of the chemolithotrophic microorganisms mentioned above was considerably more essential than the chemical oxidation of the sulphidic concentrate used in this study.

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