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BACTERIAL LEACHING OF NICKEL AND COBALT FROM PENTLANDITE

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The influence of *Thiobacillus ferrooxidans* bacteria on efficiency of nickel and cobalt leaching from natural pentlandite $(Ni,Fe)_9S_8$ have been examined. The effect of pulp density, particle size and initial ferrous ion concentration in leaching solution on the leaching yield was also evaluated. It has been demonstrated that the presence of *T.ferrooxidans* bacteria in leaching system induced considerable increase in nickel and cobalt leaching from pentlandite. The decrease in efficiencies of nickel and cobalt bacterial leaching processes have been denoted in systems containing high amounts of ferrous ions. Initial Fe^{2+} concentration of 4.5 g/dm^3 seems to be the most favourable for pentlandite bioleaching. The 20% pulp density may be admitted to be optimum regarding both satisfactory yields of bioleaching process and high nickel and cobalt concentrations in leaching solutions. The obtained results showed that particle size of 90-125 μm was optimum for nickel and cobalt bioleaching from pentlandite.

Key words: thiobacillus ferrooxidans, bacterial leaching, nickel ions, cobalt ions

INTRODUCTION

Bacterial leaching is a method used in many countries for metals recovery from variety of materials, including low-grade ores and metaliferrous wastes (Lundgren and Silver, 1980; Karavaiko, 1985). During bioleaching, metals are extracted from

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insoluble compounds such as sulphides and oxides, which are transformed (mainly through oxidation processes) into soluble forms such as sulphates.

Microorganisms that are most often used in bioleaching processes are acidophilic, autotrophic sulphur bacteria belonging to *Thiobacillus ferrooxidans* species. This bacteria group derives energy for growth and multiplication from oxidation processes, in which both ferrous ions and/or inorganic sulphur compounds (including metal sulphides) may serve as substrates being oxidised.

Bacterial oxidation of ferrous ion to ferric form is very important because of oxidative agent (Fe(III)-ion) regeneration by this way. Bioleaching processes are usually carried out in acid environment, preferably at pH 1.7-2.4, where metal ions remain in solution (Karavaiko 1985). Important features of *T.ferrooxidans* bacteria are their abilities to tolerate high acidity as well as high concentrations of metal ions (Cwalina et al. 1998). Under such conditions, bacteria must be resistant to metal ions (Groudev 1979; Karavaiko 1985; Cwalina and Dzierżewicz, 1989, 1991). This resistance may be achieved, among others, by bacteria selection during adaptation processes (Cwalina 1994; Cwalina et al. 1998a).

Pentlandite $(Ni,Fe)_9S_8$ is one of the main nickel-containing minerals (Chodyniecka and Zawiślak 1987). Except nickel and iron, pentlandite often contains also cobalt. Its concentration in ore may achieve 25% and usually is 25-50-times lower than nickel concentration (Torma 1988).

Pentlandite leaching in the presence of bacteria *T.ferrooxidans* may proceed according to the reaction (Torma 1972):

$$(Ni,Fe)_9S_8 + 17{,}625\ O_2 + 3{,}25\ H_2SO_4 \rightarrow 4{,}5\ NiSO_4 + 2{,}25\ Fe_2(SO_4)_3 + 3{,}25\ H_2O \quad (1)$$

The aim of the present study was to examine the efficiency of nickel and cobalt leaching (in sterile systems and in the systems inoculated with *T.ferrooxidans* bacteria) from natural pentlandite. The influences of pulp density, particle size, and initial iron concentration in leaching solution on the leaching yield have also been evaluated.

MATERIALS AND METHODS

In the present study, the natural pentlandite ore containing 5.21% Ni, 51.10% Fe and 0.25% Co, originated from Sudbury (Canada) has been used. Using X-ray diffraction method it has been demonstrated that in this ore pentlandite $(Ni,Fe)_9S_8$ was accompanied by non-stoichiometric pyrrhotite Fe_7S_8 (Fischer 1997).

Bioleaching processes have been carried out using the strain *T.ferrooxidans* 583 obtained from the German collection of microorganisms and cell cultures (DSM;

Deutschen Sammlung von Mikroorganismen und Zellkulturen GmbH, Braunschweig, Germany). The strain was cultured in 9K nutrient medium (Silverman and Lundgren 1959) containing Fe^{2+} at concentration of 9 g/dm^3 (pH 2.5). Actively growing bacterial populations were used for inoculation the leaching systems.

To evaluate the efficiency of nickel leaching from pentlandite, the sulphide samples (particle size 36-63 μm, 90-125 μm, 200-250 μm or 63-200 μm) were introduced into Erlenmeyer flasks in amounts needed to obtain pulp densities of 1%, 5% or 20% w/v (weight per volume). The flasks were placed on thermostated (32°C) rotary shakers. As leaching solutions, the liquid medium 9K or its modifications (iron-free solution or liquid media containing Fe^{2+} at concentrations of 4.5 or 13.5 g/dm^3), both sterile (supplemented with 5 cm^3 of 2% thymol acting bacteriostatically) and inoculated with *T.ferrooxidans* bacteria (10^7 cells in 1 cm^3 of the leaching solution) have been used.

The concentrations of nickel and cobalt in the leaching solutions were determined by means of an atomic absorption spectrophotometer (AAS UNICAM 939).

RESULTS AND DISCUSSION

The changes in yields of nickel and cobalt leaching from pentlandite have been investigated under sterile conditions and in systems inoculated with *T.ferrooxidans* bacteria. Obtained results have been shown in Fig. 1 and Fig. 2, respectively for nickel and cobalt ions liberated into leaching solutions.

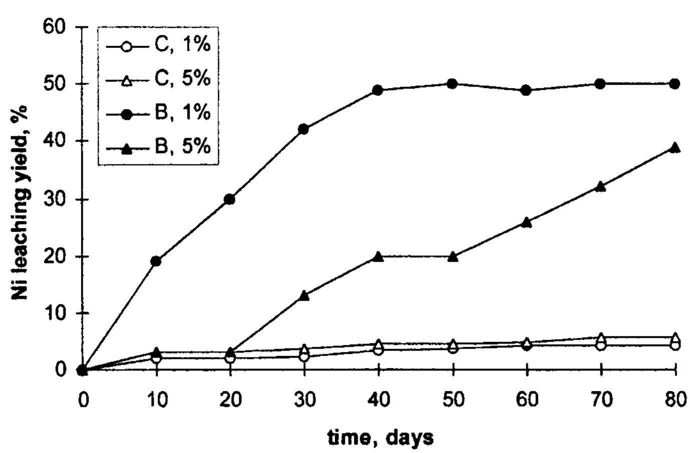

Fig. 1. The influence of pulp density (1%, 5%) on dynamics of chemical (C) and bacterial (B) leaching of nickel from pentlandite.

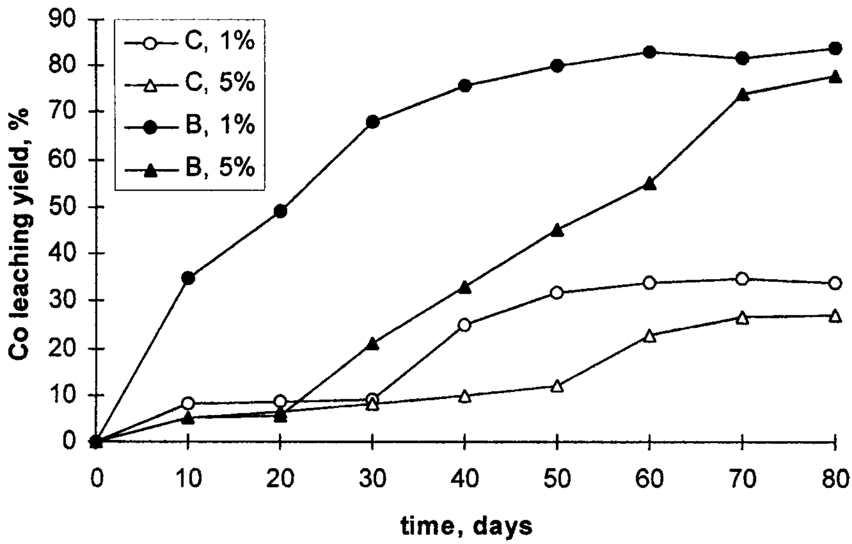

Fig. 2. The influence of pulp density (1%, 5%) on dynamics of chemical (C) and bacterial (B) leaching of cobalt from pentlandite.

It may be noticed that the maximum yields of nickel and cobalt leaching from pentlandite were usually obtained in slurries containing 1% w/v of ore, both sterile and containing microorganisms (Figs 1, 2). Only the nickel chemical leaching effects were very similar at pulp densities used (Fig.1). *T.ferrooxidans* bacteria caused considerable increase in the leaching efficiency (Figs 1, 2). The influences of bacteria and pulp densities on leaching yield were specially visible in case of the nickel solubilization, where the bacterial leaching processes proceeded with effectiveness 7-12-times higher as compared with respective processes carried out in the sterile systems (Fig. 1). After 80 days of process run, the 4% and 6% yields of nickel chemical leaching were attained at 1% and 5% pulp densities, respectively. Using the same the pulp densities, the bacterial leaching of nickel from pentlandite proceeded with the yields of about 50% and 40% (Fig. 1). Respective yields of cobalt leaching were 34% and 27% in the sterile systems as compared with 84% and 78% in the systems inoculated with bacteria (Fig. 2).

The influence of pulp density on nickel and cobalt concentrations in the solutions obtained after chemical and bacterial leaching of pentlandite is shown in Fig. 3.

The results presented in Fig. 3 indicate that the concentrations of both leached metals were considerable higher in the leaching solutions obtained in the systems with higher the pulp densities, although increased the pulp densities caused decrease in the bioleaching yields (Figs. 1 and 2).

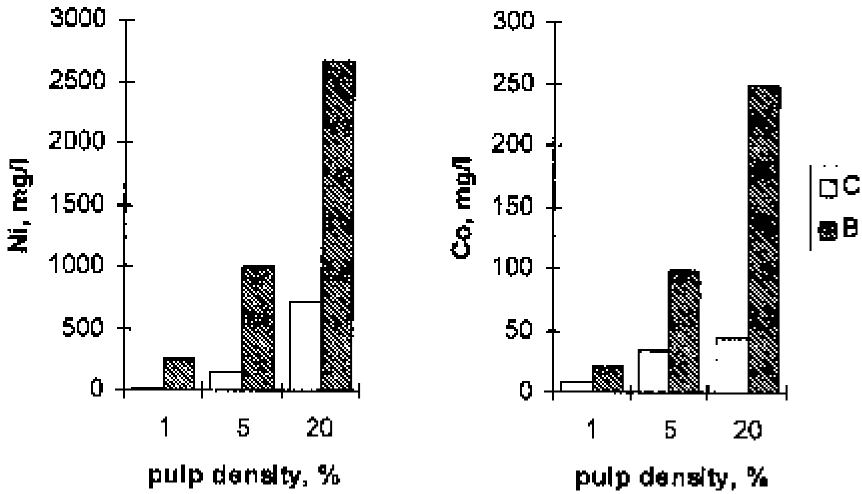

Fig. 3. The influence of pulp density on nickel and cobalt concentrations in the solutions obtained after chemical (C) and bacterial (B) leaching of pentlandite.

The results of investigations carried out to evaluate the effect of ore break-up on nickel and cobalt bioleaching yields are presented respectively in Fig. 4 and Fig. 5.

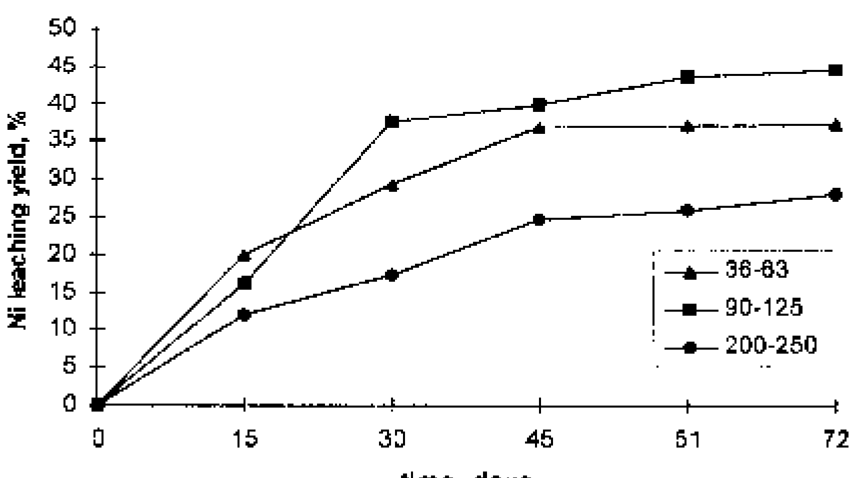

Fig. 4. The influence of particle size (36-63 μm, 90-125 μm, 200-250 μm) on nickel bacterial leaching from pentlandite.

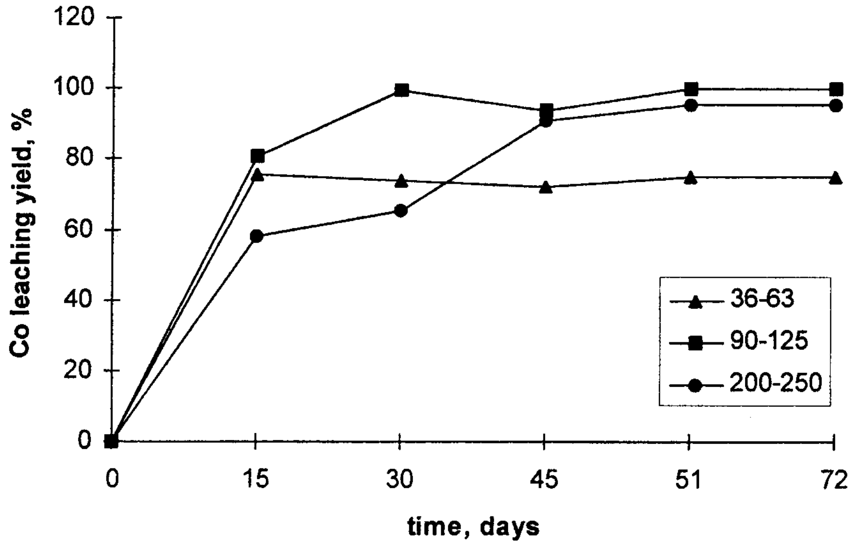

Fig. 5. The influence of particle size (36-63 μm, 90-125 μm, 200-250 μm) on cobalt bacterial leaching from pentlandite.

It may be seen that the bioleaching process was the most effective when the ore particle sizes were in range of 90-125 μm. All early described experiments have been carried out in 9K solution containing Fe^{2+} at concentration of about 9g/dm^3. It was interesting to examine the influence of this ion concentration on bioleaching yield. Results have been presented in Table 1.

Table 1. The influence of Fe^{2+} initial concentrations in the leaching solutions on the efficiency of nickel and cobalt leaching from pentlandite; C - control systems (sterile); B - bacterial systems (inoculated with *T.ferrooxidans*).

Fe^{2+} [g/dm^3]	Leaching yield [%]			
	Ni^{2+}		Co^{2+}	
	C	B	C	B
0	4,6	49,6	38,5	87,9
4,5	9,2	49,2	21,4	100,0
9,0	16,8	38,4	43,3	79,2
13,5	18,3	16,9	38,3	39,8

It may be stated that the efficiency of chemical leaching of nickel was higher with higher ferrous ion initial concentration in the leaching solution. Similar dependence was not observed in the case of chemical leaching of cobalt. Bioleaching efficiencies of both tested metals decreased with increasing Fe^{2+} initial concentrations. Using X-ray diffraction method it has been found that under such conditions, the formation of insoluble hydroxy-compounds, such as goethite FeO(OH), from hydroxy-sulphates $Fe_3(SO_4)_2(OH)_5 \cdot 2H_2O$, $(NH_4)Fe_3(SO_4)_2(OH)_6$ and jarosites $KFe_3(SO_4)_2(OH)_6$ took place (Fischer, 1997). These compounds covered surface of leached ore and thus lowered bioleaching efficiency.

CONCLUSIONS

It has been demonstrated that the presence of *Thiobacillus ferrooxidans* bacteria in the leaching system induced considerable increase in nickel and cobalt leaching from pentlandite. The decrease in efficiencies of nickel and cobalt bacterial leaching processes have been noticed in the systems containing higher initial amounts of Fe^{2+}. This ion concentration of 4.5 g/dm^3 seems to be the most favourable for the pentlandite bioleaching.

The 20% pulp density can be assumed as the optimum value as far as satisfactory yield of the pentlandite bioleaching process as well as the highest nickel and cobalt concentrations in the leaching solutions are concerned.

The obtained results have shown that the particle size of 90-125 μm was optimum for nickel and cobalt bioleaching from the pentlandite.

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Cwalina B., Fischer H., Ledakowicz S., Bakteryjne ługowanie niklu i kobaltu z pentlandytu. Fizykochemiczne Problemy Mineralurgii 34 (2000), 17 – 24, (w jęz. angielskim)

Badano wpływ bakterii *Thiobacillus ferrooxidans* na efektywność ługowania niklu i kobaltu z naturalnego pentlandytu $(Ni,Fe)_9S_8$, zawierającego 5.21% Ni, 51.10% Fe i 0.25% Co. Oceniano także wpływ gęstości pulpy (1%, 5%, 20%), rozmiaru ziaren (36-63 µm, 90–125 µm, 200–250 µm, 63-200 µm) i początkowego stężenia jonu żelazawego Fe(II) w roztworze ługującym (4.5 g/dm^3, 9.0 g/dm^3, 13.5 g/dm^3) na wydajność ługowania. Wykazano, że obecność bakterii *T. ferrooxidans* w układzie ługującym powodowała istotne zwiększenie wyługowania niklu i kobaltu z pentlandytu. W układach zawierających wysokie stężenia jonów żelazawych (≥9 g/dm^3) odnotowano zmniejszenie efektywności procesów bakteryjnego ługowania niklu i kobaltu. Wydaje się, że najbardziej korzystne dla biołogowania pentlandytu jest początkowe stężenie Fe(II) wynoszące 4.5 g/dm^3. Biorąc pod uwagę zarówno satysfakcjonujące wydajności procesów biołogowania, jak i wysokie stężenia niklu i kobaltu w roztworach ługujących, można przyjąć 20%-ową gęstość pulpy jako optymalną. Wielkość ziaren pentlandytu, optymalna dla biołogowania niklu i kobaltu z tego minerału, powinna mieścić się w zakresie 90–125 µm.