



Biohydrometallurgical Processing Methods for Low-Grade Sulfide Ores in the Arctic

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Abstract

Microorganisms capable of oxidizing sulfide minerals were isolated for the bioleaching experiments. Ore samples from the Allarechensk mining waste dump and low-grade ore samples from the deposit Nud II were studied. The samples have a similar ore mineral composition – pyrrhotite, pentlandite, chalcopyrite, and magnetite. In the study, the solution was recycled to make the process environmentally friendly.

Keywords: *bioleaching, heap leaching, sulfide ores, non-ferrous metals*

Introduction

Multiple major deposits of the most important mineral resources are concentrated in Russia's Murmansk region. The study area is characterized by a unique combination of natural and anthropogenic factors – challenging climatic conditions and intensive industry growth. The exhaustion of the reserves of high-grade ores that can be concentrated by conventional methods raises the question concerning the prospects of the development of low-grade natural and anthropogenic mineral resources. At the same time, long-term storage of mining waste is a major environmental problem. Storage of the mining waste and concentration tailings of sulfide ores involves intense hypergene processes, in particular, the oxidation of sulfides. As a result, heavy metals pass into water-soluble salts and enter the soil, surface and groundwater, thereby polluting the environment. The total content of the valuable components accumulated in the waste has already reached a level comparable with commercial deposits, and the average grade sometimes exceeds that of many newly developed deposits. At the same time, mining waste and concentration tailings, as well as low-grade ores often remain unprocessed due to the lack of an efficient technology. Recovering non-ferrous metals contained in mining waste using microorganisms is a cost-effective alternative to conventional hydrometallurgical processes. The development of biohydrometallurgical processes for the recovery of non-ferrous metals from anthropogenic copper-nickel resources and low-grade copper-nickel ores will reduce the environmental footprint and solve the problem of mining waste storage in the Arctic.

The global experience with hydrometallurgical processes shows that heap leaching is a promising method for the further recovery of valuable components from low-grade off-balance ores (Brierley and Brierley, 2001; Watling, 2008; Khalezov, 2013). One of the developments in mineral processing is the use

of the combined processing technology, allowing to significantly improve the utilization level of the mineral resources, reduce processing costs, and ensure effective environmental protection. An example of such technology could be a combination of concentration and metallurgical processes with bacterial leaching, which is a biotechnology. The use of native bacterial strains adapted to the given environmental conditions is most appropriate.

The bioleaching technology has been commercially implemented in the recovery of copper and uranium, processing of gold ores and concentrates (Watling, 2006; Johnson, 2014; Wang et al., 2011). Henna et al. (2016) report experience with heap leaching at a polymetallic deposit in northern Finland.

Murmansk Region has a number of mineral resources, whose development requires the implementation of efficient processing methods. Such resources include the Monchepluton copper-nickel ores (Pripachkin, 2013). Anthropogenic resources that can potentially be processed include the copper-nickel concentration tailings at Kola MMC, as well as the Allarechensk waste dump composed of the mining wastes of the sulfide copper-nickel ores of the Allarechensk primary deposit.

The goal of this research was to conduct lab-scale bioleaching tests using native bacterial strains on the non-ferrous metals (copper and nickel) held in the concentration tailings from the waste dump at the Allarechensk deposit and in the low-grade ore of the Nud II deposit.

Materials and methods

The following mineral resources were chosen for this study: a) waste dumps of the Allarechensk deposit; b) low-grade ore of the Nud II copper-nickel ore deposit.

Allarechensk waste dump holds the mining waste of the sulfide copper-nickel deposit that was developed for 10 years

Tab. 1. The chemical composition of the Allarechensk ore sample preliminarily processed by magnetic separation

Tab. 1. Skład chemiczny próbki rudy z Allarachska, wstępnie poddanej procesowi separacji magnetycznej

Component	Content, %
Na ₂ O	0.069
MgO	8.138
Al ₂ O ₃	0.798
SiO ₂	14.653
S	24.962
CaO	1.756
TiO ₂	0.337
Cr ₂ O ₃	0.130
Fe ₂ O ₃	38.494
CoO	0.360
NiO	7.189
CuO	3.107

starting in the 1960s. The main ore minerals are pyrrhotite, pentlandite, and less often chalcopyrite, which are in close paragenetic association with magnetite. Since the average non-ferrous grade is estimated based on the average Ni grade and is 1%, the samples were pre-processed by magnetic separation. The chemical composition of the sample is given in Table 1.

The mineralized rocks of the Nud II deposit are mainly meso- and leucocratic norites and gabbro-norites, forming a series of alternating layers with gradual transitions. The main ore minerals are pyrrhotite, pentlandite, chalcopyrite, magnetite. Pyrite, mackinawite, violarite, molybdenite are also found. Sulfides are characterized by dissemination, nodes, schlierens, and veins (Pripachkin, 2013).

The chemical composition of the sample is given in Table 2.

To study the leaching processes of the anthropogenic and natural mineral materials, water samples were taken in a swamp below the Allarechensk waste dump. The pH of the samples was 3.59, which is considered favorable for the growth of acidophilic microorganisms. A wide range of liquid and solid nutrient media was used to isolate bacteria: Towson (with agar), Liske agar medium; sulfur bacteria medium (using the recipe recommended by the American Public Health Association), Postgate, Leten, Silverman, and Lundgren 9K. In the samples, iron and sulfur-oxidizing acidophilic microorganisms promoting leaching of sulfide ores were found.

For the further research, in a biostat at a temperature of 27°C and continuous aeration, a bacterial biomass was obtained with a population density of 109 cells/ml. The bacterial population was measured by fluorescence microscopy using polycarbonate membrane filters.

The samples from the Allarechensk waste dump were used in an experiment with a circulating solution feed (bacterial solution and 2% sulfuric acid). Ore size was -5+2 mm, percolator charge 800 g, ore bed height 16 cm, column diameter 5 cm. Two columns were operated: A1 – bioleaching with a circulating bacterial solution, A2 – leaching with circulating 2% sulfuric acid. On the first day, the columns were moistened. The solutions were fed 2 times a week into each column.

Nud II ore size was -5+1 mm, percolator charge 200 g, ore bed height 12 cm, column diameter 3 cm. Two columns were

Tab. 2. The chemical composition of the Nud II ore sample

Tab. 2. Skład chemiczny próbki rudy z Nud II

Component	Content, %
Na ₂ O	0.025
MgO	7.282
Al ₂ O ₃	2.348
SiO ₂	32.340
S	14.930
CaO	4.576
TiO ₂	0.301
Cr ₂ O ₃	0.147
Fe ₂ O ₃	33.191
CoO	0.261
NiO	2.417
CuO	2.175

operated: H1 – bioleaching with a circulating bacterial solution, H2 – leaching with circulating 2% sulfuric acid. On the first day of the experiment, the ore was moistened. Then, the leaching solutions were fed twice weekly.

During the experiment, the parameters of the leaching and spent solutions were constantly monitored: pH, Eh, ferrous and ferric iron ion concentrations. At the outlet of the columns, the solutions were examined by atomic absorption spectrometry using the spectrophotometer SF-2000.

Results and discussion

Pregnant solution parameters are shown in Figure 1.

As can be seen from the presented results, the pH of the bacterial medium ranged throughout the experiment from 1.8 to 2.3, the pH of the sulfuric acid solution ranged from 0.7 to 1.1. The high pH values of 5.8 indicate saturation of the ore with moisture. The Allarechensk samples were found to have a higher pH value of the solutions due to the high content of pyrrhotite in the ore, which actively consumes acid. The concentration of ferric iron in the bacterial solutions (A1, H1), which at the beginning of the experiment was 12.9 g/l, increased by the end of the experiment to 16.4 g/l, while the concentration of ferrous iron decreased. In the sulfuric acid solutions (A2, H2), the content of ferrous and ferric iron increased throughout the experiment (Table 3).

The results of the experiments on the ore sample after magnetic separation demonstrate that the grade of the filtrates after leaching with a bacterial solution significantly exceeds the grade of the filtrates when leached with a weakly acidic sulfuric solution (Fig. 2). The average nickel grade of the filtrates of the column treated with the bacterial solution was 679.1 mg/l, with a maximum value of 1.55 g/l on the 40th day of the experiment. The average copper grade was 83.9 mg/l, with a maximum value of 211 mg/l on the 49th day of the experiment. Leaching with a 2% sulfuric acid solution produced the following results: the average Ni grade was 349.1 mg/l, with a maximum value of 1.67 g/l on the 7th day; the average Cu grade was 17.3 mg/l, with a maximum value of 111.2 mg/l on the 7th day.

The results of the heap leaching experiments on the low-grade ore sample demonstrate that the grade in the filtrates af-

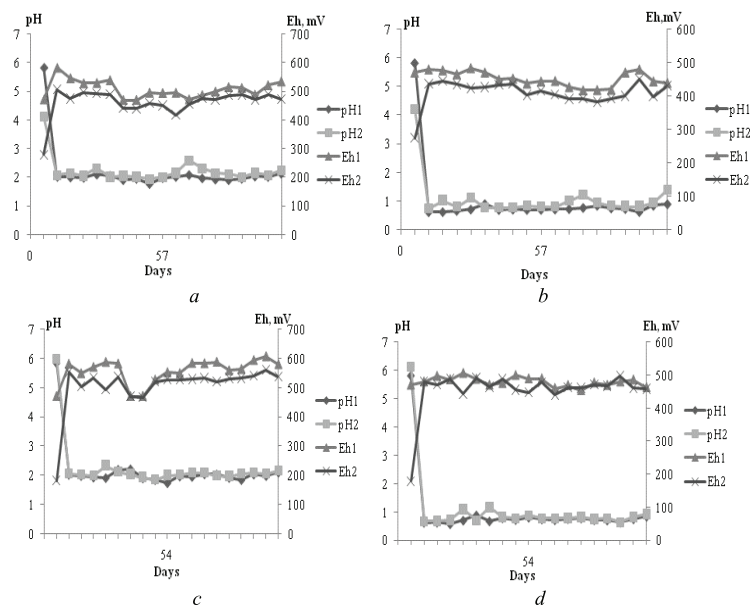


Fig. 1. Parameters of solutions: 1 – before, 2 – after: a – bioleaching of the samples from the Allarechensk waste dump, b – sulfuric acid leaching of the samples from the Allarechensk waste dump, c – bioleaching of the ore from the Nud II deposit, d – sulfuric acid leaching of the ore from the Nud II deposit
 Rys. 1. Parametry roztworów: 1- stan przed, 2 – stan po: a – bioługowanie próbek ze składowiska odpadów Allarachenski, b – ługowanie kwasem siarkowym próbek ze składowiska odpadów Allarachenski, c – bioługowanie rudy ze złoża Nud II, d – ługowanie kwasem siarkowym rudy ze złoża Nud II

Tab. 3. Iron ion concentrations in the pregnant solutions
 Tab. 3. Stężenia jonowe żelaza w roztworach dominujących

	Fe ²⁺ , g/l	Fe ³⁺ , g/l
A1	1,4 - 3	12,9 -16,48
A2	0 - 1,8	0 - 2,4
H1	0,9 - 1,79	12,9-16,41
H2	0,77 - 1,1	0 - 1,2

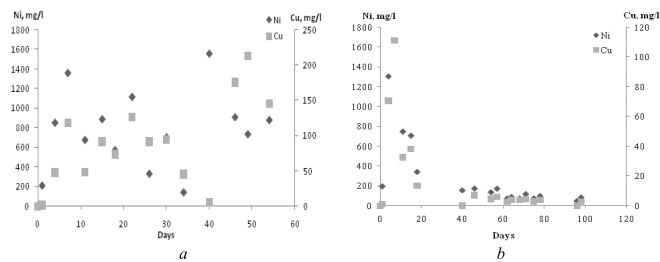


Fig. 2. Metals grade of the circulating solutions in the leaching experiment on the samples from the Allarechensk waste dump after magnetic separation. a – 2% H₂SO₄ solution; b – bacterial solution

Rys. 2. Zawartość metali w roztworach będących w obiegu podczas eksperymentu ługowania próbek ze składowiska odpadów Allarachenski po przeprowadzeniu separacji magnetycznej. a – 2% roztwór H₂SO₄; b – roztwór bakteryjny

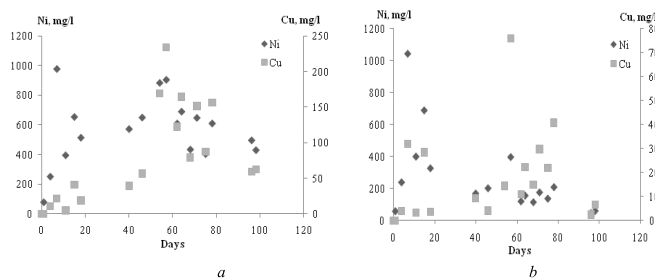


Fig. 3. Metals grade of the circulating solutions in the leaching experiment on the samples from the Nud II deposit. a – 2% H₂SO₄ solution; b – bacterial solution

Rys. 3. Zawartość metali w roztworach będących w obiegu podczas eksperymentu ługowania próbek ze złoża Nud II. A – 2% roztwór H₂SO₄; b – roztwór bakteryjny

ter leaching with a bacterial solution significantly exceeds the grade of the filtrates when leached with a weakly acidic sulfuric solution, similarly to the magnetically separated ore (Fig. 3).

The average nickel grade of the filtrates of the column treated with the bacterial solution was 566.8 mg/l, with a maximum value of 904.8 mg/l on the 57th day of the experiment. The average copper grade was 81.8 mg/l, with a maximum value of 233 mg/l on the 57th day of the experiment. Leaching with a 2% sulfuric acid solution produced the following results: the average Ni grade was 364.5 mg/l, with a maximum value of 1.04 g/l on the 7th day; the average Cu grade was 18 mg/l, with a maximum value of 75.9 mg/l on the 57th day.

Conclusion

The leaching experiments on samples of open-cut mining waste and low-grade ores demonstrated the advantages of using native iron-oxidizing microorganisms over the use of a sulfuric acid solution.

For instance, the average copper grade of the pregnant solutions after bioleaching exceeded that after leaching with a sulfuric acid solution by a factor of 4.5, the average nickel grade – by a factor of 2.

Over the 100 days of the experiment, 5.5% of nickel and 0.98% of copper was recovered into the bacterial solution, and only 2.26% and 0.18%, respectively, into the sulfuric acid solution. It should be noted that further improvements in the recovery of non-ferrous metals into the solution can potentially be achieved by tank leaching. In the leaching experiment on the Nud II low-grade ores, 31.35% of nickel and 16.31% of copper was recovered into the bacterial solution, and only 11.9% and 1.96%, respectively, into the sulfuric acid solution.

Heap leaching appears to be a promising process for the recovery of metals in the Arctic, allowing to reduce the negative impact of heavy metals on the fragile arctic ecosystems. When designing process flows for heap leaching in the arctic climate, it should be taken into account that the oxidation of sulfides contributes to the heating of the heap, which, in turn, increases the efficiency of the process by preventing the solution from freezing.

Acknowledgments

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Biohydrometalurgiczne metody przeróbki dla ubogich siarczkowych rud w Arktyce

Mikroorganizmy zdolne do utleniania minerałów siarczkowych zostały wyizolowane w celu przeprowadzenia eksperymentów biologicznego. Próbkę rudy ze składowiska odpadów pogórnictwa Allarechensk, jak również próbki rudy ze złoża Nud II zostały zbadane. Próbkę mają podobny skład mineralny – pirotyt, pentlandyt, chalkopiryt oraz magnetyt. W badaniu zastosowano recykling, aby proces był przyjazny dla środowiska.

Słowa kluczowe: *biologiczne, wycinanie odpadów, rudy siarczkowe, metale ciężkie*