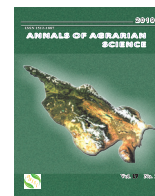




## Annals of Agrarian Science

Journal homepage: <http://journals-org.ge/index.php>



# Prospects for processing low-grade rebellious copper ores of the Madneuli deposit by heap bioleaching

N. Lomidze, M. Kandelaki, Sh. Malashkhia\*, N. Chubinidze, L. Chochia, T. Guruli, N. Chkhobadze

LEPL Independent Scientific and Research Unit, A. Tvalchrelidze Caucasus Institute of Mineral Resources of Ivane Javakhishvili Tbilisi State University; 11, Mindeli Str., Tbilisi, 0186, Georgia

Received: 20 January 2020; accepted: 25 February 2020

## ABSTRACT

Over 40 years of copper mining and processing in Madneuli Mine, millions of tonnes of overburden rocks, substandard ores and enrichment waste have been accumulated in mine dumps, which contains a significant amounts of useful components. Let alone the fact that these wastes occupy large areas of land, they are also hazardous to environment due to their sulfide content. The article presents the results of a study carried out as a laboratory simulation of the heap bacteriological- chemical leaching process. The test object was a low-grade rebellious sulfide and oxidized copper ore extracted from the mine dumps. The experiment was performed using acidophilic iron and sulfur-oxidizing bacteria isolated and activated from the Madneuli ore field microflora. In parallel with the process of ore heap bacteriological-chemical leaching, an acid leaching with diluted sulfuric acid solution was carried out under the same conditions. The studies have demonstrated that the method of copper heap bioleaching in ores of such type is advantageous in comparison with acid leaching. This method gives 27% higher copper recovery compared to the chemical leaching method.

**Keywords:** Bacterial, Heap, Leaching, Copper, Pyrite, Oxidation.

\*Corresponding author: Shalva Malashkhia; E-mail address: [shalvamalashkhia@mail.ru](mailto:shalvamalashkhia@mail.ru)

## Introduction

Recently, in all mining countries worldwide, special attention has been paid to the technogenic mineral raw material (solid minerals deposits) obtained in the process of ore extraction and processing. The rising prices for precious and nonferrous metals and the decrease in the number of rich, free-milling ores containing these metals have led to the actualization of the issue of exploiting technogenic ores.

A mining facility is a huge source of industrial waste, leading to the exponential increase in environmental pollution.

In environmental terms, sulfide-containing wastes fall into particularly hazardous category. In the process of mining and processing of ferrous ores, the residual sulfides, along with ferric sulphides undergo an oxidation process over time; Heavy metals are transformed into water-soluble salts (sulfates) followed by their leaching. Hypergenic

changes in technogenic products occur much faster than in natural geological conditions. One of the important factors in the intensification of processes is the increase of activation of the surface of sulfides in the braking and granulation process.

The terms “acid mine drainage” (AMD) and “acid rock drainage” (ARD) are used in foreign scientific literature, which refers to the problem of water contamination by the operation of mining industries. The process of sulfide oxidation is determined by several factors:

1. PH of the solutions which come in contact with sulfide minerals.
2. Surface and morphology of minerals.
3. Concentration of oxygen and trivalent iron in the solution.
4. Temperature.
5. Galvanic effect during the contact between different sulfides.
6. Bacterial exposure [1-3].

As far as century and a half ago, Louis Pasteur discovered the special role that microorganisms play in the process of substance exchange in environment. He was the first to prove the microbes are involved in the transformation of different elements. Louis Pasteur's researches laid the foundation for a new science - microbiology, which evolved in various directions, including technical and geological microbiology.

Elements such as sulfur, iron, copper, manganese, calcium, etc. fell into the scope of interests of Geological microbiology. For 70 years geomicrobiology was considered to be a purely theoretical discipline, but it was becoming increasingly apparent that a number of processes involving microbes were proceeding at such a pace that their implementation and management were actually feasible. Foremost, it concerned the microbiological oxidation of sulfides.

Bacterial processes in sulfide deposits can be used to intensify the hydrometallurgical processing of sulfide ores.

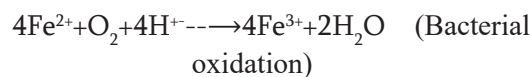
Thus the connection between geological and technical microbiology has developed and a new field of microbe use emerged, which made possible to apply this process in mining industry for the extraction of metals, primarily copper [4].

One of the modern alternative methods that does not involve the disadvantages of traditional pyro- and hydrometallurgical methods for sulfide ore processing is biogeotechnology. The use of biotechnology in non-ferrous metallurgy allows us to find new approach in solving such complex problems as processing of low-grade materials with particularly difficult enrichment properties (including dumps and substandard ores). However, the technological process is simplified to a significant degree, since instead of using roasting, acid leaching and other environmentally harmful processing methods, oxidative leaching can be carried out in environmentally friendly conditions [5, 6].

The method of metal bioleaching is based on the use of acidophilic chemolithotropic microorganisms, which in the process of evolution have acquired the ability to use the energy released in the process of oxidation of inorganic substances (divalent iron, elemental sulfur, etc.) for their vital activity, and act as catalysts in chemical reactions. For the synthesis of proteic substances, these microorganisms use carbon dioxide or inorganic carbonate compounds for autotrophic nutrition [7-9].

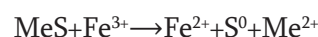
Acidithiobacillus ferrooxidans play the leading role among mesophilic acidophilic chemolithotro-

pic microorganisms used in biohydrometallurgy. Its use accelerates oxidation rate of divalent iron to trivalent iron by 100,000 and more. In the process of bacteria-catalyzed iron oxidation, which can be presented in a simplified form as shown below, energy is released (Gibbs energy change at pH = 2 is 33 kJ /mol).

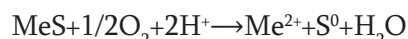


Microbiological oxidation of divalent iron produces a bioreagent - an oxidant, which is a compound of trivalent iron and bacteria-synthesized exopolysaccharides, the oxidation potential of which in sulfuric acid solutions is 80-120 mV higher compared to the pure ferric oxide sulfate under the same conditions [1, 2]. Thus, in accordance with modern views minerals are predominantly oxidized by bioreagents. The share of cellular enzymes interactions with minerals is negligible [10–15].

Oxidation reaction of sulfide minerals in simplified form:



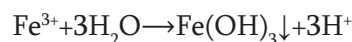
Oxidation of sulfide minerals with oxygen and acids proceeds very slowly with the following reaction:



The elemental sulfur produced by the oxidation of sulfides is oxidized by microorganisms to sulfuric acid:



With the decrease in the acidity of the solution, the hydrolysis of  $\text{Fe}_2(\text{SO}_4)_3$  results in the precipitation of ferric hydroxide and the release of protons, which makes it possible to control the concentration of ferric iron and the pH in the solution.



A. th. ferrooxidans and A.th. thiooxidans are aerobic bacteria, therefore they develop only in the presence of oxygen needed for endogenous respiration and iron oxidation. Oxygen and carbon dioxide concentrations in solutions are one of the main parameters determining the activity, growth and rate of the biooxidation process in bacteria.

0.14 kg of oxygen is required for oxidation of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  per kg of iron, and 2 kg of  $\text{O}_2$  for oxidation of 1 kg S to  $\text{SO}_4$ . Likewise, 1 kg of chalc-

pyrite requires 0,74kg of oxygen, that is, 2.13 kg of oxygen is required to extract 1 kg of copper from chalcopyrite. In 20°C water  $O_2$  is  $8 \cdot 10^{-4}$  gr/l, e.i., 6,4 kg per 1000 m<sup>3</sup> which is not enough, thus the role of aeration is important.

The role of the bacterial factor in the oxidation of sulfides was first studied in 1947 by Colmer and Hinkle. They found that *Acidithiobacillus ferrooxidans* caused the oxidation of the divalent iron to trivalent in acidic quarry waters of the Bingham pyrite-containing coal ore field. Trivalent iron is one of the most powerful oxidizers of sulfides and bacterial regeneration of trivalent iron is very important in the oxidation of sulfides and leaching of ferrous metals.

Extraction of metals from low-grade ores, overburden and dump rocks by heap bacterial leaching is cost-effective, as sulfide oxidizing reagents are continuously regenerated by microorganisms. Heap bacterial leaching of copper ore began in 1958, after the US company Kennecot Mining patented the use of iron oxidizing bacterium *A.thiobacillus ferrooxidans* for copper extraction and applied this method to process low-grade ores of the Bingham Canyon Mine (USA) [16,17]. In 1982, in Chile, Sociedad Mineral Pudahuel first applied biotechnology to extract copper from Lo Agurre's low-grade ore deposits, and the SX-EW technology to recover copper from the solution.

Currently, the heap bacterial method accounts for 25% of the world's annual copper production, which is carried out at plants of Chile, Australia, the USA, Mexico, Peru, Bulgaria, Burma, China and other countries. In addition, several plants in Australia, Finland, China, Turkey apply this technology in the processing of copper-zinc ores. Recently, China has been actively conducting researches on

the application of heap bacterial leaching method in copper-zinc ore processing, and developed technologies are instantly introduced.

Foreign hydrometallurgical practices clearly show the prospects of heap bacterial leaching method, especially for the extraction of copper, uranium and gold in low-grade ores, mining and enrichment plant wastes.

The heap bacterial leaching technology is as follows: Solutions containing sulfuric acid, oxidants (oxygen, Fe (III), etc.) and microorganisms (*Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans*, *Leptospizilum ferrooxidans*, etc.) are introduced onto the surface of the heap or into the heap. Different methods are used for the process of solution distribution. The major part of solution coming out of heap, which is enriched with nonferrous metals, is collected and ferrous metals are recovered out of it with the use of various methods (cementation, extraction, etc.).

In world practice, copper heap leaching technology is mainly based on the leaching of secondary copper sulfides - chalcocite ( $Cu_2S$ ) and covellite ( $CuS$ ) in ores. Heap bacterial leaching of primary copper mineral chalcopyrite ( $SuFeS$ ) is often commercially restricted due to the residual products attributed to passivation of minerals during the oxidation process.

The issue of utilization of technogenic waste is relevant for Georgia too.

The largest copper deposit of Georgia is in the Madneuli sulfide ore field, where a quarry mining method was first introduced in 1958 and it has been operational since 1975 (Picture 1 shows a view of the mine quarry).

Copper ores in the mine are represented in the form of vein-type and disseminated deposits. Com-



**Fig. 1.** Madneuli Gold-Copper-Polymetallic Ore Quarry

position rocks - secondary quartzites, silicified tuffs, are main ore minerals: Primary - chalcopyrite, pyrite, rare sphalerite; Secondary- covelline, chalcosine, bornite, cuprite, insignificant amount of copper sulfates and carbonates. According to the mineralogical composition and technological characteristics, three types of copper are distinguished:

Chalcopyrite-pyrite - good enrichment properties

Chalcopyrite-covelline-chalcosine-pyrite - moderate enrichment properties

Covelline-chalcosine-pyrite - difficult enrichment properties

The average copper content in ores over the years indicates that (1975 - 1.2%; 1985 - 1.0%; 1995 - 0.83%; 2005 - 0.7%; 2015 - 0.65% and currently 0.50%) the deposit is gradually becoming poorer.

The ore deposits of the central and northeastern part of the Madneuli quarry are characterized by a complex geological genesis. In particular, the mineralogical composition of copper ores is heterogeneous, with the significant amounts of secondary copper sulfides (covelline, chalcosine, bornite), copper is also found in oxidized form (10-30%). Compound mineral rock formations are represented in hydrothermal alterations (silicification, kaolinisation, chloritization) of tuffs and tuffaceous aleurites. Ores of such areas are characterized by: containment of nonmetallic silt-forming minerals (kaolinite, sericite, alunite, chlorite, jarosite) and frequent tectonic faults, which makes them difficult to enrich.

At present, only a small portion of free-milling copper ores remains, and the demand for copper concentrates has not changed. There is a large amount of low-grade rebellious copper ores in the vicinity of the ore deposit (Table 1).

Their processing by traditional methods (gravity, flotation) is unviable, as it is impossible to obtain saleable copper concentrates. The copper content in the concentrate varies from 6.0 to 12.0%, which is an indicator of sub-standard concentrates and the low coefficient of economic parameters. Accord-

ing to today's market values, if copper is the major useful element in the concentrate, then its mineral content should be 14.0%, otherwise its market price is nonreimbursable. Therefore, there is a need to develop and implement other modern and innovative technologies for the processing of these ores, which will both expand the raw material base for copper production and allow rational use of non-renewable natural resources.

The purpose of the study was to determine the viability of copper extraction in low-grade rebellious copper ores by bacterial-chemical leaching in laboratory conditions.

## Objects and methods of the study

The test object was a low-grade rebellious sulfide and oxidized copper ore extracted from the mine dumps.

A low-cost method of processing poor copper-containing raw materials is application of heap leaching method.

Airlift percolators allow conducting studies of the bacterial leaching process in passive filtration (solid mass) mode, this is a laboratory model of ore heap leaching. The studies used the association of iron and sulfur-oxidizing bacterial cultures of *Acidithiobacillus ferrooxidans* (A.th.ferrooxidans) and *Acidithiobacillus thiooxidans* (A.th. Thiooxidans), separated and activated from the acidic quarry waters of Madneuli Mine.

For the preparation of nutrient media, we used the textbook of G. I. Karavaiko [5].

As the criterion of oxidizing activity of bacteria, we take the level of divalent iron's oxidation to the trivalent state in the 9K nutrient medium. We performed cultivation of bacteria on the laboratory shaker (180 r/min) on the 9K nutrient medium with the temperature of 28-30°C, solid-to-liquid=1:10.

pH and Eh was determined by means of electro-metric method on the laboratory pH-meter (pH-

**Table 1.** Information on Dumps for 2018

Dump N	Area (Ha)	Volume (m3)	State
1	76.5	32,657,500	Operational
2	78.0	52,801,800	Closed
3	90.0	31,826,800	Operational
4	60.5	16,469,900	Operational

340). We applied complexometric titration method with Trilon B to determine divalent and trivalent iron content in the solutions; copper content in solutions was determined by titration using sodium thiosulfate solution; and for the determination of copper content in the solid mass, we applied atomic absorption method (Perkin Elmer; AAnalyst 200).

**Results and review**

The substance content of the technological sample was determined by chemical, department, mineralogical, gravimetric analysis. The results of the tests are given in Tables 2, 3, 4.

The physical characteristics of the research subject were determined by volume weight - 2.47 g/cm<sup>3</sup>, relative density - 2.74 g/cm<sup>3</sup>, bulk density 1.25 g/cm<sup>3</sup>, 3.6% moisture absorption; Porosity (true) - 9.85%.

Department and mineralogical analysis have clearly shown that chalcosine is represented by a total group of minerals that develop at the expense of chalcopyrite and are found in a form of pure monolayers of pyrite and chalcopyrite grains.

Chalcopyrite-free grains are rarely found solely in small class and silts (0.015-0.08 mm).

Micro vein-type fractures in pyrite grains are filled with minerals of the chalcosine group, pyrite embedded with quartz is also coated with chalcosine-covelline layer. In thin class, most of the pyrite grains are covered by the monolayer resulting from the oxidation of chalcopyrite. The results of the physical analysis of the sample are shown in table ...

Such chalcosine-pyrite-oxidized copper ores belong to the rebellious ores, in which pyrite of the third generation, in contrast to the pyrite created at the earlier mineralization stage, intergrows with covelline and chalcosine into 0.001-0.01 mm smallest dense aggregates.

The above-mentioned dense aggregate of intergrown pyrite and secondary copper sulfides (covelline, bornite, chalcosine) significantly complicates the complete dissolution of minerals during the milling process, which results in a sharp decrease in the amount of copper recovered and the quality of concentrate.

A solution of 9K of nutrient medium has been added into the percolator containing a -10 + 0 mm

**Table 2.** *Chemical composition of rebellious copper sulfide ores*

Chemical composition, %, g/t													
Humidity	Heating loss	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	P <sub>2</sub> O <sub>5</sub>	Al <sub>2</sub> O <sub>3</sub>	SO <sub>3</sub>	S <sup>''</sup>	Na <sub>2</sub> O	K <sub>2</sub> O	Cu	Au
0.76	5.1	78.7	8.61	1.1	1.3	0.1	6.3	8.94	4.01	0.7	1.0	0.64	0.4

**Table 3.** *Department analyses of rebellious copper sulfide ore*

Total composition of copper, %	Copper sulfides, %		Oxidized copper, %
	Primary	Secondary	
0.64	-	0.49	0.15
100.0	-	77.2	22.8

**Table 4.** *Gravimetric analyses of 10mm crushed rebellious copper sulfide ore*

Class, mm	Yield, %	Au, g/t	Extraction, %	Cu, %	Extraction, %
-10+5	52.9	0.33	48.5	0.58	47.9
-5.0+2.5	23.0	0.32	22.1	0.62	22.2
-2,5+1,25	10.2	0.29	8.9	0.73	9.9
-1.25+0.63	4.0	0.39	4.6	0.91	4.8
-0.63+0.315	3.3	0.39	3.9	1.04	4.5
-0.315+0.16	2.1	0.4	2.5	1.14	3.2
-0.16+0.08	1.4	0.47	2.0	1.23	2.7
-0.08+0	3.1	0.71	6.6	1.31	5.3
	100.0	0.36	100.0	0.64	100.0

thick ore. Nutrient medium consisted of: Ammonium sulfate - 0.15 g/L; Potassium chloride - 0.05 g/L; Magnesium sulfate - 0.5 g/L; One substituted potassium phosphoric acid - 0,1 g/L; Calcium nitrate - 0.01 g/L pH = 2.5. The nutrient medium contained 10% bacterial culture mixture. Bacterial titer  $10^4$  cell/ml.

Air was continuously supplied to the system by a compressor; the amount of air was regulated by special clamps. Such a system ensured multiple percolation of the solution and enrichment of the system by  $O_2$  and  $CO_2$ , which is essential for the microorganisms' vitality.

After each 7-day cycle, the solutions were drained off. The amounts of  $Cu^{2+}$ ,  $Fe^{3+}$ , and  $Fe^{2+}$  in the solution were determined. The pH of the solution was checked daily. If necessary, adjustments were made by adding sulfuric acid to 1.5-2.2 value.

The experiment was carried out at a temperature of 25-30°C (Fig.2).

Based on a series of tests performed in small (h-280 mm, d-25 mm) percolators, the optimal parameters for the process were determined. The impact of various factors on the copper leaching process has been studied: solid:liquid ratio, pH of solution; downtime between the active percolations.

Factors such as solid-to-liquid ratio are of great importance during the leaching process. The leaching process was studied at solid:liquid ratios of 1:

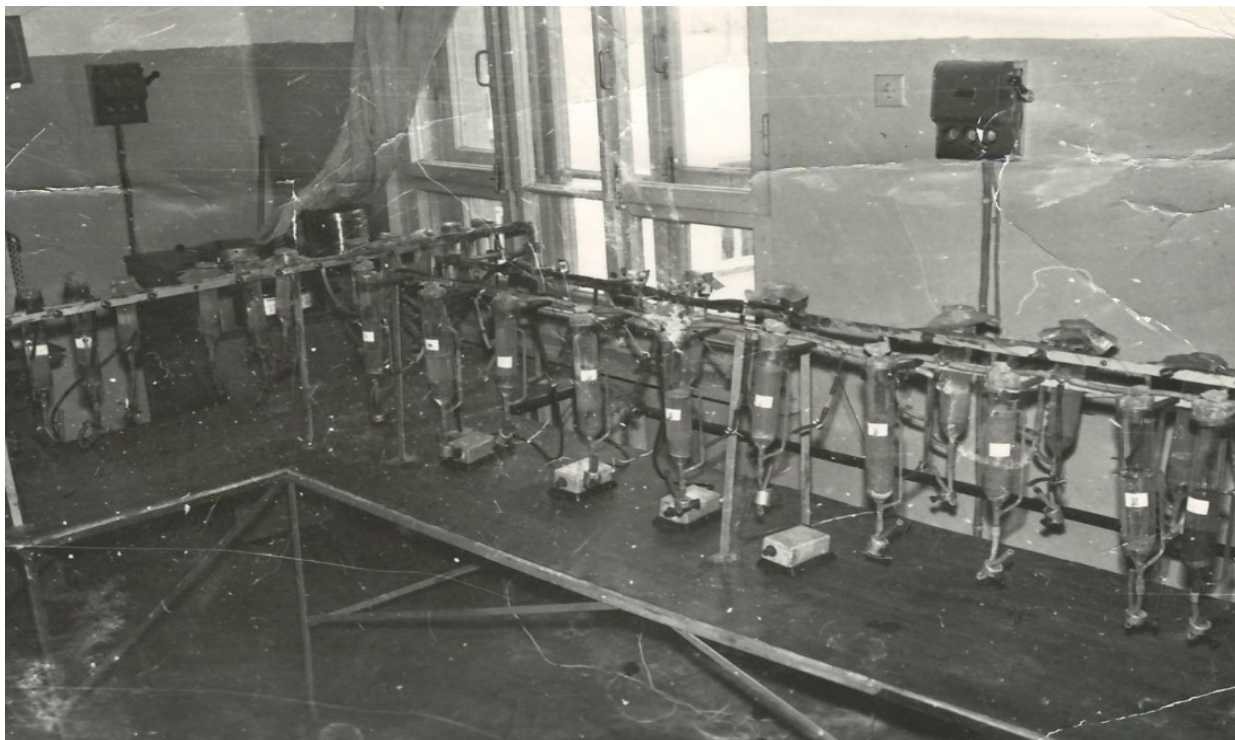
2; 1: 3,5 and 1: 5. The results of the tests are given in Table 5.

In sterile control (bacteria-free nutrient medium), copper extraction was 2.5% over the same period of time.

It is known that for the development of iron- and sulfur-oxidizer thiobacterium *A.th.ferrooxidans* and *A.th. thiooxidans* an acidic medium of pH = 1.5-2.5 is required. During the oxidation of sulfide minerals, especially pyrite, sulfuric acid is formed causing a decrease of the pH value. If the bacteria are not adapted to such conditions, then their activity decreases. Therefore, the impact of pH on bacterial activity was studied in two variants - pH = 1.5 and pH = 2.0; solid: liquid = 1: 5 and solid: liquid= 1: 2. The results of the tests are given in Table 6.

The effect of downtime between the active percolations on the quality of copper leaching.

In order to study this parameter of the leaching process, the experiment was conducted at pH = 2.0-2.1, since previous experiments have shown that the maximum copper extraction reaches its peak on the 49th day, and then decreases during the following days, we considered 1 full cycle for 49 days and chose this period as the duration of the trial. The downtime between the percolations varied: 1 day, 2 days, 3 days and 4 days. Solid:liquid ratio 1:2 and 1:5 The results of the trial are given in Table 7.



**Fig. 2.** Small airlift percolators

**Table 5.** Effect of solid-to-liquid ratio on the quality of copper leaching by percolation in low-grade copper ore

№	Percolator №	Solid-to-liquid ratio	Nutrient medium volume, ml	Inoculant volume, ml	Number of samples, g	Bacterium pH	Copper extraction in 7 days, %														
							7	14	21	28	35	42	49	56	63	70	77	84	91	Average daily copper extraction, %	
1	1	1:2	180	20	100.0	A. th. ferrooxidans, A.th. thiooxidans	2.14	3.3	7.0	10.3	14.3	20.1	26.8	34.4	38.1	42.3	45.3	48.4	51.1	53.1	0.41
2	2	1:3:5	160.0	18	50.0	A. th. ferrooxidans, A.th. thiooxidans	2.2	4.0	8.2	12.7	17.6	25.3	32.5	40.1	46.8	52.0	57.8	60.1	62.5	64.8	0.50
3	3	1:5	250	25	50.0	A. th. ferrooxidans, A.th. thiooxidans	2.1	5.3	8.8	13.2	20.0	28.1	38.2	50.2	56.0	59.3	63.0	68.1	70.0	72.3	0.556
4	K	1:1	100	-	100.0		2.2	0.3	0.6	0.8	0.9	1.0	1.2	1.6	1.73	1.81	1.84	1.92	1.97	2.5	0.03

**Table 6.** Effect of pH on the quality of copper leaching by percolation in copper ore

№	Percolator №	Solid-to-liquid ratio	Nutrient medium volume, ml	Inoculant volume, ml	Sample quantity, g	Culture used	pH	Copper extraction in 7 days, %													
								7	14	21	28	35	42	49	56	63	70	77	84	91	Average daily copper extraction, %
1	5	1:2	180.0	20.0	100.0	A. th. ferrooxidans, A.th. thiooxidans	2.1	3.3	7.0	10.3	14.3	20.1	25.8	34.4	38.1	42.3	45.3	48.4	51.1	53.1	0.41
2	6	1:2	180.0	20.0	100.0	A. th. ferrooxidans, A.th. thiooxidans	1.5	4.1	9.1	12.0	16.2	22.4	30.3	38.5	44.5	48.9	52.5	53.7	56.8	58.0	0.45
3	7	1:5	225.0	25.0	50.0	A. th. ferrooxidans, A.th. thiooxidans	2.1	5.3	8.8	13.2	20.0	28.1	38.2	50.2	56.0	59.3	63.0	68.1	70.0	72.3	0.56
4	8	1:5	225.0	25.0	50.0	A. th. ferrooxidans, A.th. thiooxidans	1.5	5.2	9.0	14.7	22.6	32.0	42.4	54.1	59.1	63.8	67.4	72.2	74.1	75.5	0.58

**Table 7.** The effect of downtime between the active percolations on the quality of copper leaching

№	Percolator №	Number of tailings, in g	Nutrient medium volume, ml	Microorganisms used	Solid:liquid	pH	Cycle duration, days	Copper extraction in 7 days, %							
								I	II	III	IV	V	VI	VII	Average daily copper extraction, %
1	10	100.0	180.0	A. th.ferrooxidans, A.th. thiooxidans	1:2	2.1	7+1+7	3.7	8.1	14.3	20.1	27.3	32.0	40.1	0.82
2	11	100.0	180.0		1:2	2.0	7+2+7	4.3	11.5	17.5	25.0	35.1	40.0	47.3	0.97
3	12	100.0	180.0		1:2	2.0	7+3+7	4.2	12.8	18.5	24.1	33.3	41.3	51.8	1.06
4	13	100.0	180.0		1:2	2.1	7+4+7	4.3	13.1	20.8	28.5	26.1	43.3	52.5	1.07
5	14	50.0	225.0		1:5	2.0	7+4+7	7.2	18.8	29.5	38.2	46.3	55.6	65.3	133

For comparison purposes, the test subject underwent a heap chemical leaching with a diluted sulfuric acid solution (2.53 g/L) under the following conditions: Solid-to-liquid ratio 1:5, pH-2,1, trail period 91 days, cycle - 7 days. The results of the test are given in Table 8.

Thus, the experiment demonstrated the viability of bacterial-chemical leaching of low-grade rebellious sulfide and oxidized copper ores in Madneuli deposit, as well as its advantage compared to the acid heap leaching method. The experiment has demonstrated that under the same conditions, the amount of copper transferred to solution by bacterial-chemical leaching was 27.0% higher than by pure chemical leaching.

**Conclusion**

The composition of medium technological samples taken from the Madneuli copper ore deposit dumps is studied by chemical, mineralogical, deportment, gravimetric analysis. This sample consists of: Cu – 0,64%; S<sub>sulf</sub> - 4,01%; SO<sub>3</sub> – 0,1%; SO<sub>3</sub> – 8,94%; Fe – 8,6%; SiO<sub>2</sub> – 78,7%

Copper is represented in the forms of secondary sulfides (covelline, chalcosine) and as oxidized sulfide, 77.2% and 22.8%, respectively.

The viability of copper extraction in low-grade rebellious copper ores by bacterial-chemical leaching in laboratory conditions has been established. In airlift percolators, under different conditions (solid

**Table 8.** The results of copper ore heap bacterial and chemical leaching

Copper mineral state	Copper content in ore, %		Leaching type	Copper extraction in solution, %
	Initial	Final		
Oxidized	0.15	0.02	Bacterial-chemical	85.0
Secondary	0.48	0.16		66.6
Primary	-	-		-
Total	0.64	0.18		72.3
Oxidized	0.15	0.06	Chemical (sulphuric acid 5g/L)	60.0
Secondary	0.48	0.29		39.7
Primary	-	-		-
Total	0.64	0.35		45.3

and liquid phase ratio, pH of solution, downtime between the active percolations), during the 91 days period, with 1: 5 solid-to-liquid ratio and pH = 2.1, the amount of copper transferred from the ore to the solution is 72.3% (of which 66.6% is from secondary sulfides and 85.0% - from oxidized minerals).

The amount of copper transferred to the solution by acid leaching method is 27.0% lower than the amount achieved with the bioleaching method, performed under the same condition (60.0% from oxidized minerals, and 39.7% - from secondary sulfides) - 45.3%.

In the bioleaching process, a mix of acidophilic iron and sulfur-oxidizing bacteria *A.th.ferrooxidans* and *A.th. thiooxidans*, isolated from the acidic quarry waters of the Madneuli deposit was used.

### Acknowledgement

The study was performed with the support of Shota Rustaveli National Science Foundation of Georgia [FR-18-6322]

### References

- [1] V.N. Makarov, T.N. Vasilieva and etc., Potential environmental hazard of copper-nickel ore dressing tailings storage facilities removed from operation, *Chemistry for the interests of sustainable development*, #1, V.13 (2005) 85-93 (in Russian) .
- [2] N. N.Orekhova, I.V. Shadrunkova, Ecological and economic aspects processing of technogenic hydromineral raw materials, *Mining informational analytical bulletin*, # 5(2014) 161-179 (in Russian).
- [3] D.B. Jonson, Biomining-biotechnologies for extracting metals from ores and waste materials, *Current opinion in biotechnology*, 30 ( 2014) 24-31.
- [4] I.A. Brierly, C.L. Brierly, Present and future Commercial application of biohydrometallurgy, *Hidrometallurgy*, 59 (2001) 233-239.
- [5] G.I.Karavaiko, G.Rossi, A.Agate and others, *Biogeotechnology of metals*, Centre for International projects, Moscow, 1989 (in Russian).
- [6] C.G. Kashuba, M.I. Leskov, Heap leaching in Russian practice , a review of experience and analysis of perspective, *Gold and technology*, 1, 23 (2014) 10-14 (in Russian).
- [7] V.I. Culebiackin, *Bacterial leaching of sulfide ores*, Nauka, Cibirian branch, Novosibirsk, 1978 (in Russian).
- [8] C.L. Braerly, Bioproduction mineral raw materials gold mining transfer from English.,<http://Zolotodob.ru/articles/metallurgy.lixiviation/> , 11188 [in Russian]
- [9] A.R. Colmer, M.E. Hincle, The role of microorganisms in acid mine drainage: a preliminary report *Science*, # 106 , (1947) 253-256.
- [10] M. Gericke Y., Govender A., Pinches, Tank bioleaching of low-grade chalcopyrite concentrates using redox control, *Hidrometallurgy*, 104 ( 2010) 414-419.
- [11] K. Third, R. Cord-Ruwisch, H. Watling, The role of ironoxidizing bacteria in stimulation in inhibition of chalcopyrite bioleaching, *Hidrometallurgy*, 57 (2000 ) 225-233.
- [12] N.V. Fomchenko, Two-stage bacterial-chemical oxidation of sulfide concentrates of gold and non-ferrous metals, Abstract dissertation. Moscow, 2012 (in Russian).
- [13] Chjen Chjihun, Improvement of the heap bio-leaching process of sulfide ore based on the intensification of the synthesis of the bioreagent immobilize by microorganisms, Abstract dissertation, Moscow, 2016 (in Russian).
- [14] R.Yuan, Bioleaching study for zijinshan copper mine , *Non-ferrous metal*, 52 (2000) 159-161.
- [15] N.N. Lomidze, Sh.S. Malashkhia, I.R. Kvatashidze, M.G. Baghnashvili, Study on the possibility of utilization of bioreagent for processing of stored tails of copper-pyrite ore flotation, in: *Book of abstracts 5 th International Scientific-practical Conference on Up-to-date Problems of Geology*, Tbilisi, 2019, pp. 71-73.
- [16] N.N. Lomidze, Z.L. Arabidze, Analysis of bio-hidrometallurgical technologies use by possessing of dressing of waste material of copper and gold contained sulfide ores, *Mining journal* 1(32) ( 2014 ) 58-61 (in Georgian).
- [17] V.V. Lodeishikov, Processing of nickel-containing ores by the method of heap bacterial leaching, <http://solotodobicha.ru/articles//mittalurgi.lixiviation/> ,10151.