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Geological and mineralogical study of ore tailings for bio-leaching

Adilkhan Baibatsha[1], Alma Bekbotayeva[2], Gauhar Turysbekova[3], Erkin Bektai[3], Gulnara Omarova[2]
[1] Innovative Geological and Mineralogical Laboratory, Kazakh National Research Technical University named after K.I. Satpayev
[2] Department of Geological Mapping, Mineral Deposits Search and Exploraton, Kazakh National Research Technical University named after K.I. Satpayev
[3] Department of Metallurgy Non-Ferrous Metals, Kazakh National Research Technical University named after K.I. Satpayev

ABSTRACT

In this paper, the geological conditions of accumulation and the material composition of the ore tailings from the processing plants of Kazakhstan were studied. The results of studying the material of unused tailings are presented. Accumulated tailings were studied on natural exposures and on the materials of cartographic wells. In the three tailing dumps of the Zhezkazgan enrichment plant, after processing, more than 1.2 billion tons of tailings are accumulated in the form of effluent pulp, of which about 1 billion tons are in two inactive tailing dumps, and the third tailing dump is operational. When the content of the main copper ore component in tailing dump is about 0.1-0.3%, the total geological reserves of metals can be at least 2.0 million tons. More than 630 million tons of ground material with a copper content of 0.1 to 0.4% is accumulated in the tailing site of another large facility – Balkhash enrichment plant. Thus, in the tailing ponds of only two considered processing plants, there are more than 1.5 billion tons of technogenic raw ore material, where the geological reserves of copper are about 3 million tons. Mineralogical studies provide a determination of the distribution and content of basic (copper, lead, zinc) and associated (noble and rare metals) useful components in the tailings. The tailings of the processing plant can be considered promising for processing technogenic deposits of mineral raw materials. This type of technogenic ore is underexplored from both a geological and technological point of view. In this regard, it was necessary to conduct full-scale scientific research in order to study the material composition of tailings as technogenic deposits with the establishment of variability in the distribution of useful components in them and the technological properties of their processing. The results of studying the chemical, mineral and granulometric content of the tailings can serve as reliable initial data for technological studies on the extraction of metals from this technogenic raw ore material. The mineral and granulometric content of copper ore processing tailings has been studied. Microscopic descriptions of polished sections made of loose tailings are given. Sulfide ore minerals are microscopic in size, they are distributed mainly inside the grains of the host rocks and are rush in nature. Using the results of geological studies, a methodology for technological research was selected and laboratory experiments were conducted on the bioleaching of copper from the tailings.

Keywords: Ore tailings, Sulfides, Non-ferrous metals, Technogenic ore, Concentration technology, Bioleaching.

Corresponding Author:

Adilkhan Baibatsha,
Innovative Geological and Mineralogical Laboratory,
Kazakh National Research Technical University named after K.I. Satpayev,
050013, 22a Satpaev Str., Almaty, Republic of Kazakhstan
E-mail: baibatsha5652@kaiost.cn

1. Introduction

There is a global tendency towards reduction of the natural resources of mineral raw materials and increase of their recycled waste, for example, in the form of refinement tailings of non-ferrous metal ores. Ore-containing tailings accumulated in large volumes in tailing processing plants can be considered as technogenic deposits that significantly replenish the reserves of the mineral resource base. Most of the reserves of explored and developed mineral deposits are in the later stages of development. At the same time, in recent years there have been no significant discoveries of new mineral deposits [1-8]. To ensure the uninterrupted operation of existing mining and enrichment enterprises, new sources of mineral raw materials are required. The solution to this problem can be considered as having great economic and social significance. The study of tailings of non-ferrous metal ores as accumulated technogenic ore raw materials in tailing dumps is of great importance.

The authors have conducted geological and mineralogical studies in the tailing dumps of the Zhezkazgan and Balkhash enrichment plants (Figure 1) [9-13], where more than 1.5 billion tons of processed copper ore tailings were accumulated in the total volume. These tailings can be processed as technogenic deposits of non-ferrous metals with accompanying valuable elements[14]. Ore minerals in tailings are represented mainly by sulfides of copper and other metals. The main metal content in the studied tails is: base - copper, lead, zinc; noble - gold, silver; rare and scattered elements - Zr, Se, Y, Yb. The presence of Ni, Co, Mo, Bi, Sb, Be in the tailings is of particular interest. The results of the research will serve as a reliable basis for further technological research on the selection of reagents and a rational scheme for the integrated processing of technogenic ore raw materials for the extraction of metals and non-metallic products[15-21].

Figure 1. Tailings pond of Balkhash enrichment plant

The accumulated tailings of the processing plants will provide an increase in the total resources of ore raw materials and provide a significant economic effect, since the total volume of marketable products in them is estimated $ 3.0 billion.

The conducted research showed that the mineral composition of the accumulated tailings is similar to the mineral composition of the initial cuprous sandstones of the Zhezkazgan stratiform deposit. The origin of the Zhezkazgan deposit is associated with a granitoid intrusion hidden at a depth that was formed as a result of the action of the mantle plume [22-27]. A study of the mineral composition of the accumulated tailings shows that the ores of Zhezkazgan's tailing dump are rush, ore minerals are very small and, in most cases, they are contained in siliceous grains [28; 29].

At the present time, in Kazakhstan, there is more than 6.0 billion tons of mining waste accumulated (tailings and sludge from processing, slag, cake, clinker, and other types of metallurgical waste) [7]. A significant proportion of this waste is accounted for by tailing dumps of ore processing, including copper-bearing ones. During the processing of non-ferrous metal ores, up to 95-98% of the rock mass in the form of tailings goes to dumps, with which up to 40% of metals recovered from the mines and carriers are lost [8; 9].

Under conditions of a progressing deficit of raw material, the tailing impoundments of processing plants can be an important source of replenishment [30-36]. One of the new approaches to solving these problems is the biogeotechnological method of metal mining, which proceeds at normal pressure and temperatures from 8 to 50 ° C. The leaching process of most metals is based on their opening and conversion from insoluble sulfide form to soluble [37-42].

To date, various companies in the countries of the USA and South America, Canada, Africa, Australia, etc. use bacterial-chemical technologies for producing copper, cobalt, nickel, gold, zinc, and uranium [43]. Experimental plants for bacterial leaching of copper ores are being built in China and Mexico. An analysis of the work of these enterprises indicates that with capital expenditures for the construction of a processing line of about $ 900 million, the cost of one ton of the product is less than $ 50 and the payback time of the installation is reduced to 18 months. That is, a year or two after the processing plant is established, net profit will be estimated $ 375 million [44-49]. This problem exists not only in Kazakhstan, it manifests itself in the global copper industry. Abroad (USA, Canada, Austria, South Africa, the Philippines, Finland, etc.), 22 plants for the extraction of copper from tailings are in operation [50-54]. Organizing waste processing is much less expensive than developing a new natural field. The cost of processing industrial waste, such as tailings, is 2-3 times less than the processing of natural raw materials. Extraction of metals from waste of primary processing and from substandard ores is widely used in the USA, Canada, France, Australia, Brazil and other countries [55-61].

In the 1970s, in the USA, at the largest copper-molybdenum factories Arthur and Magna with a total capacity of 100 thousand tons per day, two copper recovery plants were put into operation, processing 97.2 thousand tons of tailings per day. When processing sands with a content of about 0.09% copper, both plants produce 72 tons of low-grade copper concentrate per day, which made it possible to increase copper production in factories from 234 to 259 thousand tons per year [21]. At the Toledo factory (Philippines), tails contain 0.08% copper; up to 70% of the total copper losses with tailings are attributed to classes +74 microns. The factory operates a plant for refloatation of the sand part of the tailings containing 0.13% copper. In Chile, at the El Salvador factory with a capacity of 25 thousand tons per day, a section was built for additional extraction of copper from the sand fraction of the tailings containing 0.3% copper [62-68].

The extraction of non-ferrous metals from mixed and oxidized ores from the tailings of the Sadonsky, Kalmakyrsky and Zhezkazgan deposits was experimentally studied and the combined technology was recommended (Gintsvetmet et al.) [69; 70]. The extraction of copper from sulphate solutions is used at the following enterprises: Baghdad, Johnson, Twin-Butts (USA), Erdenetiin-Ovoo (Mongolia) [71-75]. In Chile, Bulgaria, Canada, the USA, etc., uranium, copper, gold, and other metals are isolated by biotechnological leaching. The use of biotechnology allows a cost-effective and simple method to extract copper and other useful elements from the refuse. As a result of studies conducted in the hydrometallurgical laboratory of the Technological Institute named after S. Otgonbileg, it was found that for the processing of floatation tailings containing 0.15-0.50% copper, it is possible to use the biohydrometallurgical method [76].

Heap leaching at different periods was used to extract copper from quarry dumps and mixed ores at Balkhash, Almalyk and Ural mining and enrichment plants and others [77-85]. Heap leaching of metals from tailings of processing and metallurgy on an industrial scale extracts gold, copper and sometimes other metals. For example, for more than 15 years, the Manybay deposit (Northern Kazakhstan) has been processing the tailing dumps with acidic solutions on a hydrometallurgical plant with a volume of 1.5 million tons. However, heap leaching (like secondary floatation) is not widely used due to the length of the leaching time and the low level of copper recovery (less than 50%), the need for the construction of complex technological facilities and the lack of a guarantee for the complete extraction of metals upon completion of the process [86-88].

This brief review shows the relevance of the existing problem of processing tailings of enrichment plants. Acid leaching of metals from refractory and microscopic technogenic ores does not provide the proper level of their extraction. Biotechnology can provide the extraction of metals from the studied tailings at a relatively lower cost, a relatively high level of processing and high completeness of metal extraction under favorable environmental conditions. The essence of the proposed technology for the extraction of metals is to use various options for bacterial-chemical leaching of waste. The method itself has been known for a long time, but in the technology offered by the authors, a new approach will be used for the processing of refractory tail ore, associated with an increased number of bacteria in the bioreactor, which significantly intensifies the leaching process. According to preliminary experimental data, the recoverability of copper from the tailings exceeds 60% and can be brought up to 90%. These results were obtained during laboratory studies on tailings samples from the Zhezkazgan enrichment plant. Therefore, in order to achieve satisfactory production results, it is necessary to further develop research work on the selection of reagents and technological schemes for the rational and integrated processing of accumulated tailings as technogenic mineral deposits [89-94].

Existing both domestic and foreign technologies are mainly aimed at the study and use of natural mineral deposits. As geological ore reserves are exhausted, involvement in the use of technogenic types of mineral raw materials will become more attractive and relevant. The use of refuse accumulated in huge volumes in the tailing dumps of Zhezkazgan and other single-industry towns can significantly strengthen the country's mineral and raw material base and solve an important social problem related to employment [95].

The use of tailings is cost-effective. For example, the practical use of only accumulated tails of Zhezkazgan enrichment plant, the total amount of which is only 1 billion tons in Zhezkazgan alone, provides for the production of marketable products in the form of metals, valuable alloys and building materials. To achieve these indicators, it is possible to organize a new production with operation duration of decades.

2. Materials and methods

The methodology of scientific research is aimed at obtaining maximum geological information about the studied tailings of the enrichment of non-ferrous metal ores for successful laboratory technological experiments. Mineralogical descriptions of polished sections were carried out using an AxioScope A1 HAL 50 polarizing laboratory microscope, Carl Zeiss, HAL 100 / HBO, 5xHD / DIC models with a camera that allows a quantitative mineralogical description of polished sections made from the studied ore tailings to reveal microscopic grains of ore minerals from magnification up to 1,500 times and conduct high-quality photo documentation of the sample. The manufacture of thin sections and polished sections from loose material was carried out according to the author's method in the sample preparation laboratory of the National Research Technical University [96-99].

The content of copper in the tails varies in the range 0.1-0.3%, increases in fine fractions up to 0.5%. To study the distribution of useful components of the tailings and changes in their content with the depth of deposition, coring wells were drilled and core samples were taken for laboratory research. The mineralogical description of polished sections made from selected tailings samples shows that they contain substantially copper sulfides (chalcopyrite, bornite, chalcocite, covellite) up to 5-7%. Pyrite, rutile, magnetite is rarely present. Native gold is also found [100] (Figure 2).

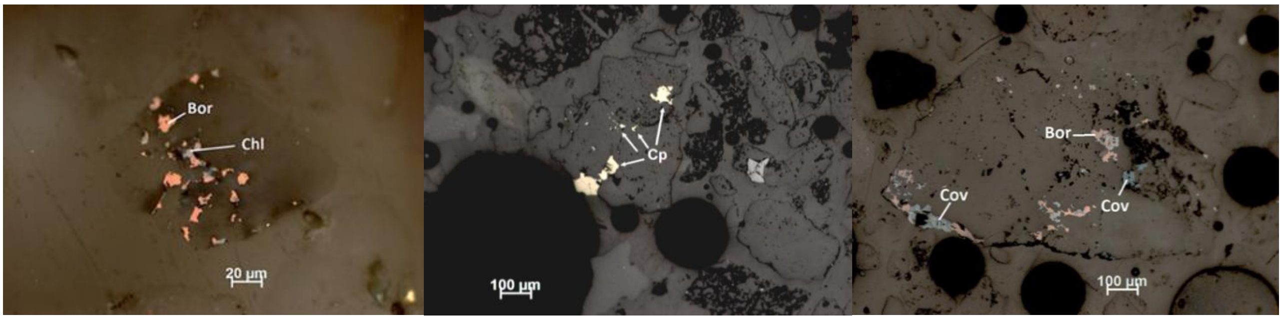

Figure 2. Mineral composition of the tailings of the Zhezkazgan ore ores: boronite (Bor), chalcocite (Chl), chalcopyrite (Cp) and covellite (Cov) in the host siliceous grains

The results of the study of cemented thin sections from samples taken from the tailings of the Zhezkazgan enrichment factory made it possible to determine the composition of ore minerals, their size and location relative to ore-containing rock grains. It has been established that the main ore minerals are copper sulfides: chalcopyrite, chalcocite, covellite, and bornite [101-107]. Also present are galena, sphalerite and even native gold. Under the microscope, more than 50 polished sections were examined. Ore minerals are represented by sulfides and have the following characteristics.

Chalcopyrite is the most common copper mineral and the number of grains in cemented sections can vary from 10 to 95. It is rare in free form, usually from 1 to 6 grains, ranging in size from 0.01-0.07 mm, sometimes up to 0.1 mm. The vast majority of chalcopyrite is enclosed in quartz grains (5-60 grains), with a basic size of 0.01-0.07 mm, rarely up to 0.06x0.17 mm [108; 109]. Chalcopyrite is sometimes located along the edge of quartz grains, the size of the mineral is from 0.01-0.5 mm, rarely up to 0.07-0.1 mm. Chalcopyrite along the edge of quartz grains is found in the form of single grains and their clusters, streaky formations, sometimes in intergrowths with boronite and faded ore. In addition, there are grains of quartz, in which chalcopyrite is in the form of fine impregnations with a size of 0.002-0.02 mm. In isolated cases, small fragments of quartz (1x1.3 mm) with a dissemination of chalcopyrite can be found. Chalcopyrite is rarely found in intergrowths with quartz (from 0.05 to 0.12 x 0.35 mm) and around quartz grains (up to 0.01 x 0.1 mm) [110-112].

Bornite, like covellite, is important among copper minerals and the number of its grains in cemented sections from 4 to 82. In its free form is rare, usually from 1 to 5 grains (0.01-0.07, rarely up to 0.1 mm). In the overwhelming majority of cases, like other copper minerals, it is enclosed in quartz grains (from 2 to 22 grains), with a size of 0.01-0.07 mm, rarely up to 0.1 mm, splices with chalcocite, covellite, and bornite are noted and less commonly with chalcopyrite and faded ore (up to 0.1x0.2 mm) and along the edge of quartz grains (from 1 to 29 grains) with grain sizes of 0.01-0.06 mm, rarely up to 0.1x0.2 mm. Its intergrowths with

chalcocite, covellite, as well as boronite with chalcopyrite up to 0.1 mm in size are noted. It is rarely found with covellite in intergrowths with quartz (up to 0.1 mm) and other copper minerals (up to 0.07 mm) [113].
Chalcocite is a sulfide rich in copper composition, it is less common and the number of grains in cemented thin sections from rare to 87. However, it should be noted that grains included small impregnations in individual quartz grains (from 10 to 40 small inclusions, size 0.002-0.02 mm). Among copper minerals, it is precisely for chalcocite that the presence of fine silica in individual grains of quartz is most characteristic. Free chalcocite is rare, usually from 1 to 4 grains (sizes 0.01-0.05, rarely up to 0.07 mm) [114-118]. In the overwhelming majority of cases, chalcopyrite is enclosed in quartz grains (from rare grains to 22 grains), with a size of 0.01-0.06 mm, rarely up to 0.1 mm, splices with covellite and bornite and along the edge are noted quartz grains (from 1 to 15 grains), with a grain size of 0.01-0.06 mm, rarely up to 0.1 mm. Rarely, chalcocite is found in intergrowths with quartz (up to 0.15 mm) and around quartz grains (up to 0.05 x 0.2 mm).
Covellite among copper minerals has a subordinate distribution and the number of its grains in cemented thin sections from rare to 114. In its free form, it is rare, usually from 1 to 7 grains (0.01-0.07, rarely up to 0.1 mm). Just like chalcopyrite and chalcocite, in the overwhelming majority of cases it is enclosed in quartz grains (from 1 to 34 grains) with a size of 0.01-0.07 mm, rarely up to 0.1 mm. Its intergrowths with chalcocite and bornite (size up to 0.3 mm) and along the edge of quartz grains (from 1 to 10 grains) with a grain size of 0.01-0.06 mm are noted. Splices with chalcocite and bornite up to 0.1 mm in size are also noted. Rarely, covellite is found in intergrowths with quartz (up to 0.1 mm) and other copper minerals (up to 0.1 x 0.2 mm) [119;120].

Table 1. Composition and weight of the fraction of samples taken from the tailing dump Osnovnoe.

No. of wells	Sample No.	Size (μm) and fraction content (g) in samples					
		500	250	125	63	-63	Σ
1	1-1	166.0	2588.81	1558.51	365.5	7334	12012.82
	1-2	428.56	2320.0	3750.0	1090.62	326.3	7915.48
	1-3	685.73	1471.36	5915.32	253.38	534.6	8860.39
2	2-1	220.38	4090.32	4467.66	877.85	178.1	9834.31
	2-2	192.52	2803.81	4477.66	784.02	153.1	8411.11
	2-3	269.63	2501.47	4663.81	840.33	191.5	8466.74
	2-4	279.67	1626.78	5445.32	207.42	223.93	7783.12
	2-5	208.6	3258.81	2978.81	589.89	102.92	7139.03
	2-6	450.18	1179.65	3313.79	1209.04	375.91	6528.57
	2-7	348.11	1056.06	3878.79	921.86	224.85	6429.67
	2-8	626.55	845.82	3658.81	1647.68	352.3	7131.16
	2-9	477.17	464.09	1434.09	1695.88	622.44	4693.67
	2-10	701.12	777.92	1726.64	1352.38	451.97	5010.03
	2-11	380.77	331.81	2034.78	2508.0	654.43	5909.79
	2-12	308.07	265.75	1226.99	921.45	242.29	2964.55
3	3-1	1043.32	5347.66	2628.81	581.07	155.5	9756.36
	3-2	858.31	3215.0	2040.33	380.86	57.10	6551.6
	3-3	319.37	2723.78	3508.78	692.09	144.74	7388.76
	3-4	532.89	3163.81	2563.81	678.03	143.94	7082.48
	3-5	1064.87	4823.81	3168.81	856.92	175.97	10090.38
	3-6	452.28	2450.8	3070.0	689.07	132.17	6794.32
4	4-1	505.41	176.1	2520.0	568.87	292.66	4063.04
	4-2	980.6	4646.47	2049.29	603.49	8228	16507.85
	4-3	1142.57	2685.0	4010.0	468.24	5919	14224.81

	4-4	550.42	3423.81	331.47	791.53	178.23	5275.46
	4-5	442.52	4456.47	5056.47	1285.04	233.94	11474.44
	4-6	593.06	2428.79	3368.79	929.36	255.45	7575.45
	4-7	455,76	1605.22	1471.64	535.81	72.8	4141.23
	4-8	400	1036	3965.0	640.55	93.0	6134.55
	4-9	553.3	2214.74	4120.32	857.32	204.31	7949.99
	4-10	383.4	794.37	2448.8	810.56	222.04	4659.17
	4-11	465.73	715.18	1556.89	824.28	242.5	3804.58
	4-12	244.66	629.22	1896.27	731.14	183.8	3685.09
	4-13	305.01	583.09	2953.77	901.72	275.79	5019.38
5	K-1	44.14	377.1	435.22	111.84	16.31	984.61
Σ		17080.68	73078.88	103695.5	29203.09	29195.89	252254.00
%		6.77	28.97	41.11	11.58	11.57	100.00

The study of the particle size distribution of the tailings was carried out using an AS 200 series sieving Machine (made in Germany) and the fractional composition was analyzed according to size classes with high accuracy. As a result of the performed granulometric analysis, the prevailing sizes of the crushed particles were established, which range from 0.5 to less than 0.063 mm (Table 1). As can be seen from the data in Table 1, the content of fractions increases from 500 μm towards the minimum size of 63 μm. Of all the isolated fractions, particles with sizes of 250 and 125 μm prevail, the percentage of which is respectively 28.97 and 41.11% of the total sample volume. The minimum content corresponds to a fraction of 0.5 mm and its share is 6.77%. The smallest contents accounted for fractions with sizes of 63 and -63 μm, respectively, they make up about the same amount of approximately the same amount of 11.58 and 11.57%, respectively.
The results of the analysis are important initial data for conducting laboratory experiments on technological studies of stale tailings of non-ferrous metal ore tailings [121].

3. Results and discussion

Laboratory experiments were performed to extract copper from the accumulated tailings of ore in the Zhezkazgan deposit of cuprous sandstones. When leaching products in dense pulps, the mode of mixing and aeration of the pulp is of great importance, the optimization of which allows to create the most favorable solution composition when saturated with oxygen and carbon dioxide. The most optimal mixing of dense pulps is created in the Pachuca tank devices with the use of air. At the same time, in Pachuca tanks, the pulp is effectively mixed and the solid part of the pulp is kept in suspension without sudden changes in pulp density. The presence of finely disseminated copper minerals in quartz and fragments of siliceous rocks requires additional grinding for their disclosure, which requires significant costs. To solve the problem, measures to destroy the grains of quartz and siliceous rocks are necessary in order to release finely disseminated copper minerals.
For tailings processing, copper leaching technology is efficient in terms of capital and operating costs. In the experiment, the task was to develop a technology for involving accumulated tails in the processing. Given the data of mineralogical and X-ray fluorescence analysis of samples, the presence of sulfide minerals of copper, the presence of total sulfur, the content of which reached 5-7%, laboratory studies were carried out by two methods: 1) percolation leaching; 2) propagation leaching [122-124].
Percolation leaching. Experimental conditions: the size of the crushed ore grains is from -1 to -0.074 mm; leaching time – 98 hours (4 days); the composition of the leach solution is 5 g/l H2SO4; the content of ferrous iron - + 4-6 g/l Fe2+; cell concentration – 106 cells/ml (Th.ferrooxidans). During research, the solution leaked partially, over time, the leakage slowed down. Percolation was carried out to verify the applicability of heap leaching of the tailings of the processing plant. Percolation was difficult on the basis of the obtained finely ground sample material (-0.074 mm) in the presence of a clay component (clay component at Al up to 4%). During percolation, the solution leaked very slowly and the results were low.
Agitation leaching. In laboratory conditions, a sample with a subsample of 200 g was leached in the activator (with the ratio of solid fraction (S) to liquid (L), i.e., S: L = 1: 4, with a H2SO4 content (5 g/l), pH = 2) for 96

hours in four flasks with different samples. The leach cake was sent for chemical analysis. In chemical agitation leaching (without the addition of bacteria), the necessary extraction parameters were not achieved. Copper recovery was 30% for 72 hours [76-79]. To intensify the process, bacterial leaching with Th.ferrooxidans bacteria strains was used. Bioleaching is known to accelerate the dissolution of chalcopyrite by a factor of 12, arsenopyrite and sphalerite by a factor of 7, covellite and boron, by a factor of 18 compared to conventional chemical methods. The data of mineralogical analysis of the presented samples confirm the presence of such minerals in the studied tails [1-5].

The study of bacterial-chemical leaching of samples. The most important factor in bacterial leaching is the rapid regeneration of ferric sulphate by thionic bacteria, which accelerates the oxidation and leaching process. On an industrial scale, bacterial leaching is used for heap leaching of minerals (copper and uranium) from ores at the site of their occurrence. It is economically feasible to extract copper from off-balance sulfide ores using bacterial leaching. This is carried out with aqueous solutions of ferric iron in the presence of iron-oxidizing bacteria.

The simplicity of the equipment for bacterial leaching and the ability to quickly multiply bacteria, especially when returned to the process of spent solutions containing bacteria, provides an opportunity not only to reduce the cost of metal extraction, but also to significantly increase the resources of mineral raw materials through the use of poor, off-balance ores, as well as enrichment waste and tails. Under the conditions of bacterial leaching of tails, microorganisms adapted and activated for the extraction of metals play an important role. Studies and extensive practical experience of foreign application of heap leaching of tailings showed that the technology of bacterial-chemical leaching is effective by reducing capital costs and reducing operating costs [6-12].

Iron oxidizing bacteria involved in the leaching of metals are chemoautotrophic according to their type of nutrition, to produce energy that catalysis chemical redox reactions and assimilates carbon dioxide for constructive cell metabolism, i.e., eating autonomously without the use of organics. Autotrophic microorganisms are not pathogenic, like some heterotrophs or paratrophs. Studies have established that the main role of iron-oxidizing bacteria for leaching is to oxidize ferrous iron (in a solution of sulfuric acid with oxygen) to a trivalent form, which oxidizes sulfides. Also, the use of iron-oxidizing bacteria for leaching is determined by the chemical action of ferric iron on minerals of ore raw materials [125].

The mechanism of oxidation of metal sulfides. There are two main mechanisms of bacterial oxidation of sulfides: indirect and direct. Thionic bacteria are chemoautotrophs, that is, the only source of energy for their life is the oxidation of ferrous iron, sulfides of various metals and elemental sulfur. This energy is spent on the absorption of carbon dioxide released from the atmosphere or from ore. The resulting carbon is used to build bacterial cell tissue. AFerrooxidans oxidize sulfide minerals to sulphates directly and indirectly. The indirect oxidation mechanism of metal sulfides proceeds according to the following scheme (1-2):

$$2FeSO_4+0,5O_2+H_2SO_4 \rightarrow Fe_2(SO_4)_3+H_20; \quad (1)$$

$$Fe_2(SO_4) +MeS \rightarrow MeSO_4+FeSO_4+S^o. \quad (2)$$

The direct mechanism of sulfide oxidation. This mechanism is based on the attachment of bacteria to sulfides and due to processes in the extracellular surface layer, sulfides are oxidized. In the practice of heap leaching during bio-oxidation, heaps of ore and dumps can generate a high temperature inside it as a result of oxidation of sulfides. But when leaching tailings with a low sulfide content, this effect is not so significant. With a high sulfide content, heap leaching control can be used to maintain temperature by regulating the biological activity of the used bacterial culture and maximizing heat storage in the heap. When conducting research, 9K medium (Silverman and Lundgren) was used. The concentration of bacteria in the solution was 106 cells/ml, which allowed the achievement of an optimum bioprocessing of the material. To conduct bacterial leaching, A.Ferrooxidans bacteria biomass was grown for 5 days. The culture medium of A.Ferrooxidans consists of: FeSO4 - 5 g/l; NH4SO4 - 1.5 g/l; MgSO4 - 0.5 g/l; K2HPO4 - 0.5 g/l; H2SO4 - 1 g/l.

Agitation bacterial leaching of the tails was carried out on a sample weighing 200 g at a ratio of S:L = 1:4, temperature 25 °C, 250 rpm. Washing sample H2SO4 (1%) + bacterial unsealing. By weight 200 g of the sample was leached in 1000 ml of a solution containing up to 10 g/l of sulfuric acid. After acid treatment, bacterial leaching was performed. Bacterial leaching was performed for 120 hours with a bacterial solution of A.Ferrooxidans. The content of ferric iron Fe3+ was 3 g/L. Leaching was carried out at T = 25 °C, S: L = 1:4.

The microorganisms used are adapted to this sample for effective bio-oxidation. With the temperature of 25 °C using mesophilic bacteria (Figure 3).

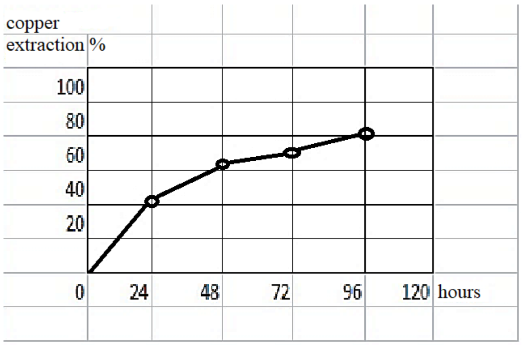

Figure 3. The dependence of the extraction on bio-leaching time

As can be seen from Figure 3, the bio-leaching of copper in laboratory studies for 4 days approached 80%. These data show the applicability of the use of bacterial oxidation for Borghessay tail dump. The results of the chemical analysis of the samples are shown in the Table 2.

Table 2. Chemical analysis results of the processed samples

No. of sample	Composition	Content, %
1	Cu	0.08
4	Zn	0.01
6	Fe_{total}	0.5
7	S	0.08

The analysis of the initial tailings sample showed that copper is of industrial importance, its content is 0.22%. In the samples during chemical analysis, the presence of a large number of rare earth metals was noted. The possibility of isolating them during leaching requires additional research [126].

Indicators of agitation bacterial-chemical leaching are given below. The results of one of the samples should be noted (No. B6 (2) + 0.15 m. The initial sample weighing m=1 g contains 0.22% copper. After leaching, the copper content was 0.08% (Table 2). This data show that the degree of copper recovery reached 63.6%. Sulfuric acid bacterial leaching of the sample was carried out for 120 hours. These data show the effectiveness of sulfuric acid bio-leaching in the agitator. The technological scheme for bioleaching copper from tailings to obtain copper concentrate is shown in Figure 4.

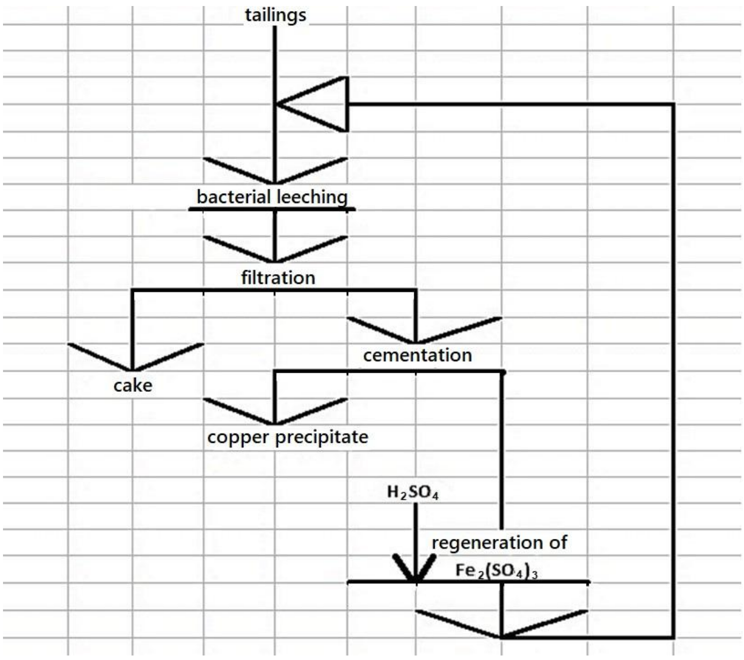

Figure 4. Technological scheme of bio-leaching copper from tailings

4. Conclusions

The amount of copper minerals within view of polished sections is approximately 5-7%. Copper minerals (chalcopyrite, bornite, chalcocite, covellite) are found in the tails in approximately equal amounts. Tailings have the form of finely divided material and its fractions vary from +0.15 to -0.074 mm. Mineralogical analysis shows that grains of copper minerals are finely disseminated in quartz and fragments of siliceous rocks. The grain size is less than 20 microns. Such finely disseminated copper minerals explains the presence of a high copper content, which was not extracted during processing at the enrichment plant. For the full disclosure of minerals, their destruction is required in order to release copper sulfides.

For optimal extraction of copper from the tailings, it is expected to leach with regrinding at the next stages of the study. Ultrafine grinding for the destruction of minerals is an expensive procedure. An alternative to this process is the biodegradation of quartz and siliceous grains in order to release copper minerals and access leaching reagents to them. Percolation leaching (an analogue of heap leaching) did not achieve a satisfactory technological effect. Agitation chemical digestion of samples showed a low efficiency of the process. In 96 hours, copper recovery was about 30%. The use of bacterial-chemical leaching can achieve copper recovery of more than 63% in 120 hours and can be recommended for leaching tailings to intensify the copper recovery process. For effective extraction by leaching of other valuable metals, including rare earth, further scientific research is required to determine the optimal process parameters and optimize process conditions.

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