

Development of a method for processing mixed copper ores with the extraction of gold and copper

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Abstract. Development of scientifically based technologies for processing waste and the industry as a whole, ensuring the extraction of valuable components of non-ferrous and noble metals, is an important direction for increasing the economic efficiency of mining and metallurgical production. In this article, a technological scheme for the complex extraction of copper and noble metals from off-balance mixed copper ores of the Yoshlik-I deposit was developed, and as a result of the experiments, the developed technology was implemented in practice at copper-enrichment plant-1 (CEP-1) of AMMC JSC. At the same time, the optimal parameters of two-stage beneficiation of mixed copper ores at the Knelson concentrator were established, resulting in a gold recovery rate of up to 78% and a comprehensive copper recovery of over 85.4% with additional operations for copper.

1 Introduction

One of the main tasks of metallurgy is to increase the degree of extraction of components from ore and technogenic raw materials into finished products. The Republic of Uzbekistan has vast reserves of off-balance copper ores with mixed origin and low copper and noble metals, particularly gold and silver. Scientific research on the creation of a comprehensive technology for extracting non-ferrous metals and non-ferrous metals from mixed ores is a pressing task in metallurgical production, with the development of new approaches to extracting noble metals from low-grade mixed ores. Excavated rocks, stacked off-balance ores, mineralized masses, and intermediate waste from the ore preparation process can serve as a promising raw material base for the development of Uzbekistan's metallurgy. At AGMK JSC, the reserves of non-ferrous metals concentrated in dumps and tailings can serve as an additional source [1].

Analysis of data on off-balance dump ores and technogenic waste indicates the need for initial enrichment of these materials to extract precious metals. In this case, copper is planned to be extracted indirectly, the concentration of which in the indicated materials is characterized by low values.

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2 Materials and methods

The research object of this work is the mixed oxidized and sulfide copper ores of the "Yoshlik-I" deposit of "AMMC" JSC. The work widely used modern comprehensive research methods, laboratory technological experiments, and pilot-industrial tests. The work used modern physicochemical research methods (IR spectroscopy, SEM scanning electron microscopy, EDS (energy-dispersive spectroscopy), energy-dispersive X-ray fluorescence spectroscopy, atomic emission analysis, and test analysis methods for determining gold and silver). Chemical and mineralogical analysis of samples selected from mixed copper ores was carried out at the Central Analytical Laboratory of AMMC JSC and the Central Research Laboratory of NMMC JSC, phase analysis of samples with determination of particle sizes was carried out at the Uzbek-Japanese Youth Innovation Center and by employees of the Institute of Mineral Resources (IMR) [2].

To determine the content of noble and rare metals, a spectrometric analysis was carried out using the high-performance NEX CG RIGAKU energy-dispersive X-ray fluorescence spectrometer — a specialized spectral technique employed to examine the material composition of mixed waste ores from the Yoshlik deposit.

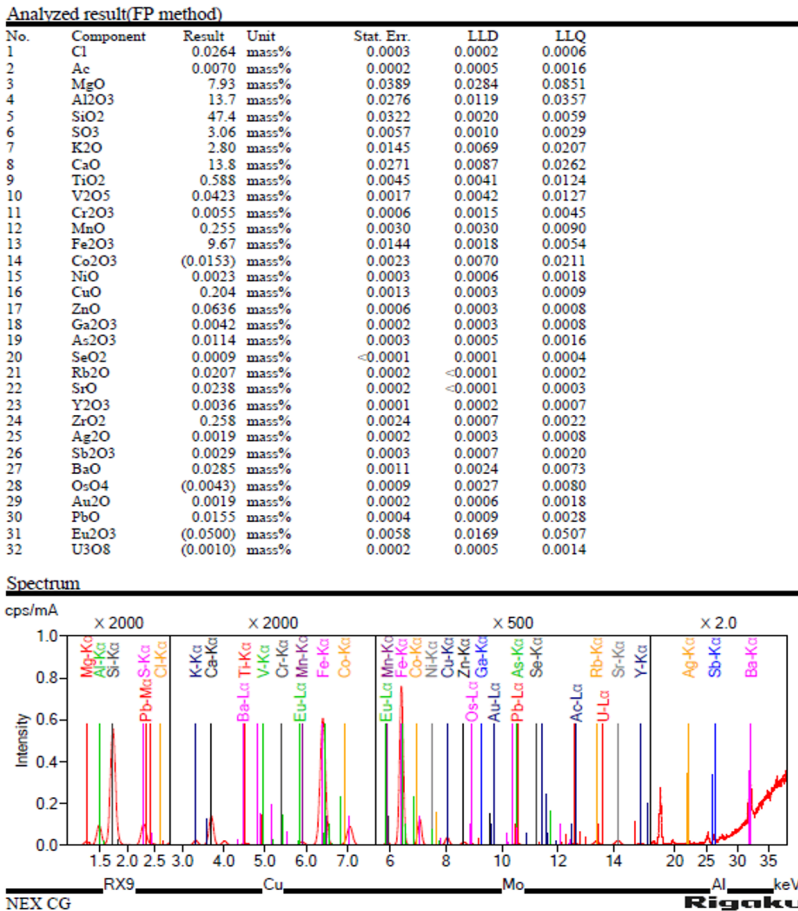


Fig. 1. Mineralogical composition of mixed copper ores of the Yoshlik-I deposits.

Based on the results of chemical analysis, the average sulfide ore sample contains the following percentages: SiO₂ - 47.45; MgO - 7.95; Al₂O₃ -13.73; CaO - 13.82; CuO - 0.21; Ga₂O₃ - 0.0043; SO₃ -3.09; K₂O - 2.85; Fe₂O₃ - 9.68; ZnO - 0.065; As₂O₃ - 0.0115; SrO - 0.0239; SeO₂- 0.00091; Rb₂O - 0.02071; Au - 0.0019; Ag - 0.0019; NiO - 0.0024; PbO - 0.0154; MnO - 0.256; Co₂O₃-0.0154; Cr₂O₃-0.0057; Ac - 0.0071; Cl - 0.0265; BaO - 0.0286; OsO₄ - 0.00044; V₂O₅- 0.0424; TiO₂ - 0.589; U₃O₈ - 0.0011 Sb₂O₃ - 0.0029; Eu₂O₃ -0.051. The mineralogical composition of the ores is shown in Figures 1 and 2.

Analyzed result(FP method)

No.	Component	Result	Unit	Stat. Err.	LLD	LLQ
1	Cl	0.0561	mass%	0.0005	0.0004	0.0012
2	Na	2.52	mass%	0.0977	0.216	0.648
3	Mg	2.17	mass%	0.0208	0.0266	0.0798
4	Al	13.4	mass%	0.0237	0.0097	0.0292
5	Si	43.2	mass%	0.0270	0.0013	0.0038
6	P	(0.0140)	mass%	0.0025	0.0066	0.0199
7	S	1.18	mass%	0.0033	0.0006	0.0018
8	K	9.72	mass%	0.0339	0.0112	0.0335
9	Ca	11.4	mass%	0.0314	0.0191	0.0573
10	Ti	0.799	mass%	0.0062	0.0064	0.0193
11	V	0.0467	mass%	0.0022	0.0055	0.0164
12	Cr	0.0069	mass%	0.0008	0.0022	0.0067
13	Mn	0.582	mass%	0.0059	0.0053	0.0159
14	Fe	13.5	mass%	0.0210	0.0030	0.0089
15	Co	(0.0256)	mass%	0.0036	0.0108	0.0325
16	Ni	0.0050	mass%	0.0005	0.0012	0.0035
17	Cu	0.255	mass%	0.0021	0.0006	0.0019
18	Zn	0.0461	mass%	0.0008	0.0005	0.0016
19	Ga	0.0085	mass%	0.0003	0.0005	0.0015
20	As	0.0118	mass%	0.0003	0.0005	0.0014
21	Rb	0.0737	mass%	0.0005	0.0002	0.0006
22	Sr	0.131	mass%	0.0006	0.0002	0.0006
23	Y	0.0091	mass%	0.0002	0.0005	0.0016
24	Zr	0.541	mass%	0.0048	0.0014	0.0042
25	Mo	(0.0055)	mass%	0.0016	0.0027	0.0082
26	Sn	0.0077	mass%	0.0006	0.0010	0.0031
27	Sb	(0.0038)	mass%	0.0006	0.0014	0.0041
28	Ba	0.175	mass%	0.0032	0.0052	0.0155
29	Os	(0.0074)	mass%	0.0013	0.0040	0.0119
30	Ir	(0.0038)	mass%	0.0008	0.0022	0.0065
31	Pb	(0.0045)	mass%	0.0006	0.0017	0.0050
32	Eu	(0.105)	mass%	0.0129	0.0377	0.113
33	Ac	0.0101	mass%	0.0004	0.0007	0.0021
34	U	(0.0032)	mass%	0.0004	0.0012	0.0036

Spectrum

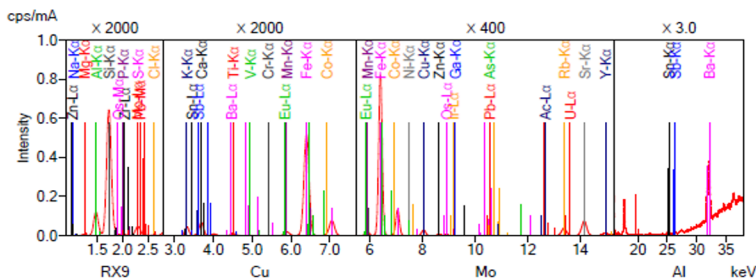


Fig. 2. Mineralogical composition of mixed copper ores of the Yoshlik-I deposits.

Based on chemical analysis, the average composition of the mixed ore sample is as follows (%): Au - 0.0019; Ag - 0.0017; PbO - 0.0018; NiO - 0.0022; MnO - 0.312; TiO₂ - 0.571; Ac - 0.0037; SiO₂ - 54.3; MgO - 2.49; K₂O - 5.72; Fe₂O₃ - 7.96; V₂O₅- 0.0352; Cr₂O₃- 0.0042; BaO - 0.0761; SrO - 0.0566; Rb₂O- 0.00295; Al₂O₃ - 16.5; SO₃ - 1.49; U₃O₈ - 0.0014; MoO₃ - 0.003; ZnO - 0.0214; CuO - 0.119; Co₂O₃- 0.0132; Na₂O - 2.52; Ga₂O₃-0.0042; CaO - 7.26; As₂O₃- 0.0057; SnO₂ - 0.0037; Cl - 0.028; Sb₂O₃- 0.0017. In order to investigate the distribution of noble and rare metals, monominerals such as pyrite, chalcopyrite,

molybdenite, and others were selected from off-balance ore dumps. The study revealed the following concentrations of noble metals in the mixed ores (g/t): Au – 12.2; Ag – 41.2; Pd – 0.25; Pt – 0.20; Rh – 0.02; Ru – 0.93; Os – 0.015.

Due to the diversity of the mineralization of mixed ores, we considered it expedient to study the compositions, forms of occurrence of minerals, investigated by various methods, applying experimental methods for accurate determination of mineral composition and subsequent selection of enrichment methods. Studying samples using the JSM-IT200 scanning electron microscope (SEM) is an important step in the complex of research aimed at determining the elemental, mineralogical composition, and structure of the studied objects.

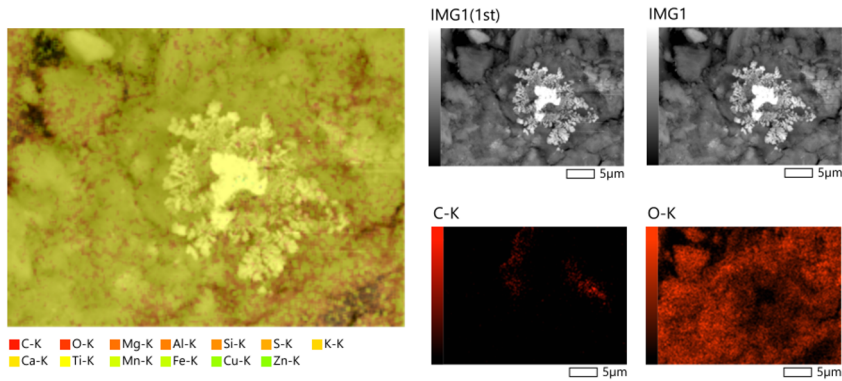


Fig. 3. General elemental analysis of the entire sample surface.

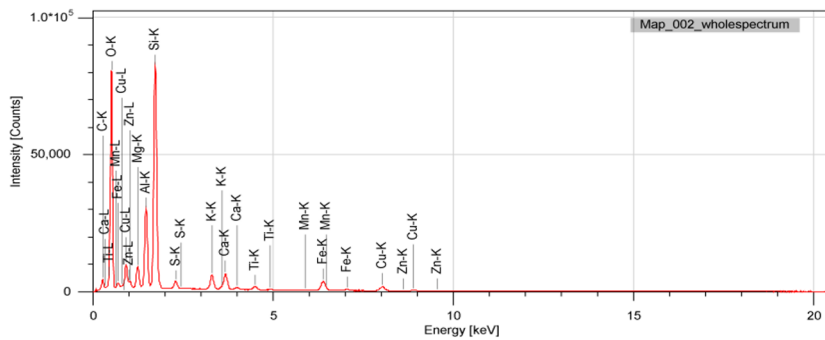


Fig. 4. A7 sample analysis results.

The analyzed surface is predominantly composed of copper, observed as a mixture of iron minerals located at the peak, where they interact with sulfur to form iron sulfide minerals. A significant amount of calcite is also present, with a peak intensity of $4.0 \cdot 10^5$ (refer to Figure 4). The analysis revealed that the copper content in the sample is 0.17%. The structure of copper sulfide appears denser, resulting in partial light reflection on areas of the sample, producing a shiny, slightly turbid green hue, indicating a closer association with sulfur. Additionally, A7 samples were examined for their material composition using energy-dispersive spectroscopy (EDS), with the results presented in Figure 5.

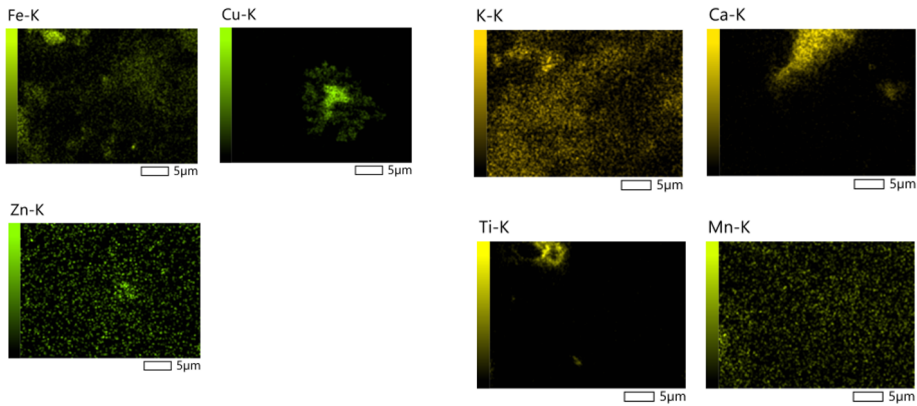


Fig. 5. Results of the analysis of A7 energy-dispersive EDS spectroscopy samples.

In the 005 spectrum, the copper surface of the sample is identified, containing 0.17% copper, which is associated with sulfide compounds. The peaks align with those of iron sulfide minerals (refer to Figure 5 for the elemental composition of sample A7). Copper depletion is observed in the chalcocopyrite phase, while titanium, alumina, quartz, and calcite appear as impurity minerals.

The method of phase analysis using X-ray diffraction was used to determine the main minerals contained in the mixed mis off-balance ores of the Yoshlik-I deposit. The study was conducted on an Empryean (Panalytic) X-ray diffractometer. The study of sulfide copper off-balance ores revealed various types of copper mineralization. In Figure 6, the mineral chalcocanthite $\text{CuSO}\cdot 5\text{H}_2\text{O}$ was identified.

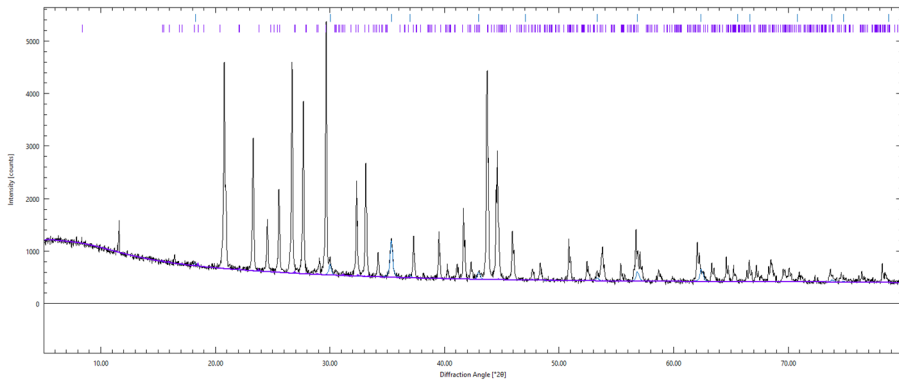


Fig. 6. Diffractogram of mixed copper ores of the Yoshlik-I deposit (chalcocanthite mineral).

The main approach involves obtaining the best possible data, determining all available settings, and entering basic systematic data for all stages, and then allowing the computer to model the data until it meets the experimental standard.

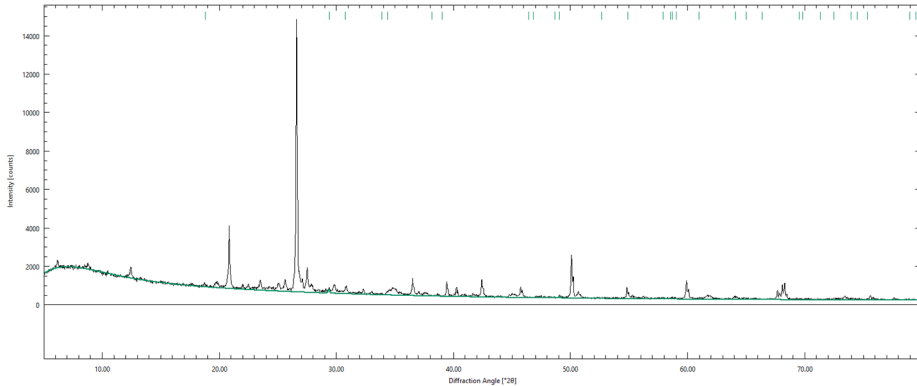


Fig. 7. Diffractogram of mixed copper ores of the Yoshlik-I deposit (chalcopyrite mineral).

When studying the diffractogram of Figure 7, the chalcopyrite mineral was determined, and the content of all minerals in the initial ore is presented in Table 1, calculated by the Rietveld method. As a useful accompanying component in the ore, the mineral sphalerite was identified (Figure 8), in which the height of the sphalerite peaks in this region is $14.411 \text{ } ^\circ 2\theta$, the depth of the peak is 1,790 thousand tons, the width is 3,128 a, followed by $27,297 \text{ } ^\circ 2\theta$ per year with a depth of 1,112 thousand tons and a width of 2,715 a.

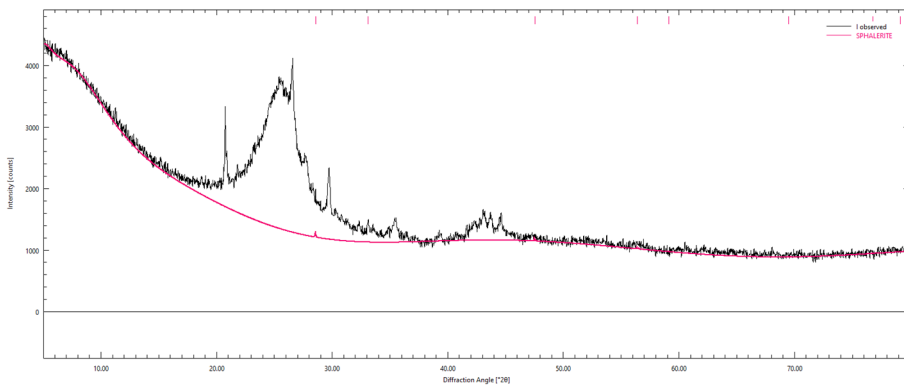


Fig. 8. Diffractogram of mixed copper ores of the deposit Yoshlik - I (sphalerite mineral).

From the obtained mineralogical analyses of mixed ores, 43-45% of quartz is found, which is characterized by occurrence together with feldspar base with its content of 15-20%. Ore mineralization in mixed ore samples is represented by iron and copper sulfides and oxides [3].

Table 1. Mineral composition of mixed ore samples.

Mineral	Mass fraction in sample, %			
	10	8A	A4	mixed sample
Rock-forming minerals				
Quartz	59.12	60.38	57.02	60.25
Feldspars	11.01	12.04	19.04	14.25
mica (muscovite, sericite)	6.03	12.05	8.05	8.75
Clay (hydromica, kaolinite)				6.0
Chlorite	14.05	5.52	6.04	7.87
Carbonates (calcite, dolomite)	1.55	1.134	0.852	1.12
Gypsum	1.34	0.75	0.78	0.68

Ore-forming minerals				
Pyrite	3.14.	2.69	2.22	2.05
Copper sulfides, including: Chalcopyrite Bornite, Covellite-chalcosine	0.25	0.188	0.358	0.35 0.1
Copper oxides, including: Copper carbonates Copper sulfates Chrysocolla Turquoise Pseudomalachite	0.27	0.095	0.48	0.35 0.1 0.2 0.4
Pale ore	-	-	-	Unit Signs
Molybdenite	Unit Signs	Unit Signs	Unit Signs	Unit Signs
Other sulfides (galena, arsenopyrite, sphalerite)	Unit Signs	Unit Signs	Unit Signs	Unit Signs
Iron hydroxides, yarocite	2.55	4.94	4.58	3.72
Accessory	1.16	0.66	1.08	0.7
Total	100	100	100	100

The amount of pyrite in different samples varies from 0.2 to 3%. Copper sulfides account for 0.1 to 0.4%. Copper carbonates, copper sulfates, chrysokol, turquoise, and pseudomalachite are present in sample 10 in amounts of 0.9-1.0%. In the remaining samples, including mixed-sheeted samples, their proportion is 0.1-0.2%.

3 Results and discussion

Initially, a whole series of concentrators based on the principle of separating a mixture of minerals with different density characteristics in a gravitational field was tested in the development of a technology for enriching poor technogenic waste at gold processing plants. At the research stage of the work, it was determined that there is no native gold with a size of 100-400 μm in the composition of the mixed off-balance copper ores of AMMC JSC. Gold was also not detected in the obtained concentrates with a particle size of $>70 \mu\text{m}$. This is explained by the fact that large crystalline nuggets are present in the technological unit of the plants in very small quantities and only small gold is present. This conclusion reduced the research time for gravitational enrichment using the following equipment, such as a screw separator, sedimentation machines, and gates, which are designed to extract large metal particles. For industrial use selection, the types of the listed devices did not show sufficient effectiveness. It has been determined that during the storage of technogenic waste in dumps over many years, the strength of the tailing changes [4]. In the conditions of the Central scientific research laboratory of "NMMC" JSC, research was conducted on the gravitational enrichment of technogenic waste of "NMMC" JSC using the Knelson MD3 centrifugal concentrator and changing its parameters. For the enrichment of noble other technogenic wastes, enlarged laboratory studies were conducted at the Knelson GX9 centrifugal concentrator under the conditions of the Research Laboratory of the Navoi State University of Mining and Technologies. At the same time, the main focus was on noble and rare metals that are part of technogenic waste and have higher densities, which are well separated by the centrifugal concentration field.

Experiments on the enrichment of the mixed sample were conducted on 10 kg of the initial material, with a centrifugal force of 90G and 120G, water consumption of 2 l/min and 5 l/min, respectively, for the 1st and 2nd stages of gravitational concentration. The research results are presented in Table 2.

Table 2. Results of centrifugal enrichment of mixed off-balance ores.

Naim.	Weight, gr	Output, %	Content, %				Extraction, %			
			Au, g/t	Ag, g/t	Cu	Ss	Au	Ag	Cu	Ss
Gravity concentration results, sample No1										
Concentrate 1	200	2	14.3 2	24.0 0	1.07	1.92	58.4 4	28.2 4	7.74	3.37.
Concentrate 2	191	1.91	3.73	35.8 0	2.30	4.45 .	14.5 4	40.2 2	15.8 8	7.45
Total concentrate	391	3.91	9.15	29.7 7	1.67	3.15 .	72.9 8	68.4 6	23.6 2	10.8 2
Tails	9609	96.09	0.14	0.56	0.22	1.06	27.0 2	31.5 4	76.3 8	89.1 8
Ore recovery	10000	100	0.49	1.7	0.27 7	1.14	100	100	100	100
Gravity concentration results, sample No2										
Concentrate 1	210	2.1	12.8 1	22.3 1	1.37	2.84	54.8 9	27.5 6	10.4	5.24
Concentrate 2	202	2.02	4.49	35.0 4	3.03	5.10	18.5 3	41.6 3	22.0 6	9.04
Total concentrate	412	4.12	8.73	28.5 5	2.18	3.95	73.4 2	69.1 9	32.4 6	14.2 8
Tails	9588	95.88	0.14	0.55	0.20	1.02	26.5 8	30.8 1	67.5 4	85.7 2
Ore recovery	10000	100	0.49	1.7	0.27 7	1.14	100	100	100	100
Gravity concentration results, sample No3										
Concentrate 1	224	2.24	11.4 6	6.66	1.09	3.62	52.4	19.8 9	8.78	7.12
Concentrate 2	210	2.1	5.96	37.0 6	2.58	7.85	25.5 5	45.7 8	19.5 5	14.4 6
Volume concentrate	434	4.34	8.80	25.7 2	1.81	5.67	77.9 5	65.6 7	28.3 3	21.5 8
Tails	956.6	95.66	0.11	0.61	0.21	0.93	22.0 5	34.3 3	71.6 7	78.4 2
Ore recovery	10000	100	0.49	1.7	0.27 7	1.14	100	100	100	100
Gravity concentration results, sample No4										
Concentrate 1	216	2.16	12.8 7	19.9 4	1.18	4.69	56.7 4	25.3 3	9.17	8.89
Concentrate 2	211	2.11	4.66	34.3 1	2.12	9.46	20.0 6	42.5 8	16.1 3	17.5 1
Volume concentrate	427	4.27	8.81	27.0 4	1.64	7.05	76.8	67.9 1	25.3	26.4
Tails	9,573	95.73	0.12	0.57	0.22	0.88	23.2	32.0 9	74.7	73.6
Ore recovery	10000	100	0.49	1.7	0.27 7	1.14	100	100	100	100
Gravity concentration results, sample No5										
Concentrate 1	212	2.12	12.4 6	18.2 1	1.16	5.14	53.9 2	22.7 1	8.89	9.56
Concentrate 2	195	1.95	5.49	41.1 8	2.24	9.75	21.8 3	47.2 4	15.7 8	16.6 7

Volume concentrate	407	4.07	9.12	29.2 2	1.68	7.35	75.7 5	69.9 5	24.6 7	26.2 3
Tails	9,593	95.93	0.12	0.53	0.22	0.88	24.2 5	30.0 5	75.3 3	73.7 7
Ore recovery	10000	100	0.49	1.7	0.27 7	1.14	100	100	100	100

Gravitational concentrate is formed after gravitational enrichment of mixed (shifted) ores rich in precious metals of the following composition: gold averages 14.31-20.12 g/t, silver 59.42-67.3 g/t. The resulting precious metal concentrate, based on its precious metal content, can subsequently be sent for conversion smelting, where gold, silver, and copper transition to the crude copper phase. However, high losses of gold and silver are observed due to the low sulfidization of noble metals. In this regard, experiments on intensive cyanidation and sorption of noble metals using activated carbon were conducted as research work. A rational analysis of noble metals was conducted to determine the sorption activity of metals (see Table 3) [5].

The ore contains only 5.88% of free gold. The amalgamation results of a material with a size of -2 mm show 88.24% of the precious metal present in available direct cyanidation [6]. The gold resistant to the 93-cyanide process in the ore is represented mainly by metal in acid-soluble films - 5.88%. The gold content in minerals insoluble in aqua regia and quartz is 3.92%. The proportion of finely dispersed gold in sulfides is 1.96%

The total proportion of persistent gold, not readily available for direct cyanidation, is 11.76%, which is equivalent to 0.06 g/t of gold. The obtained data allow us to conclude that the composite sample of the oxidized ore of the "Almalyk MMC" plant is a favorable raw material for the cyanidation process. A complicating factor for the application of the cyanidation process will be the presence of a high copper content, which leads to increased NaCN consumption.

Table 3. Results of phase analysis of gold in the composite sample of oxidized ore.

Forms of gold occurrence and the nature of its connection with ore and rock-forming minerals	Distribution of gold	
	g/t	%
Free, extractable by amalgamation at a size of -2.0 mm	0.03	5.88
Free, extracted by amalgamation when finely ground to a size of 60% -0.071 mm	0.04	7.84
Free, extracted by amalgamation when finely ground to a size of 95% -0.071 mm	0.09	17.65
Total free gold with a clean surface	0.16	31.37
In the form of open inclusions with ore and rock-forming components	0.29	56.86
Total in cyanidated form	0.45	88.24
In acid-soluble films	0.03	5.88
Finely dispersed in sulfides	0.01	1.96
Finely dispersed in minerals insoluble in royal water and quartz	0.02	3.92
Total	0.51	100.00

The gold in the mixed sample of the oxidized ore is present mainly in native form. Single grains correspond to the compound of gold with silver - electrum, kyustelite, and tellurium - petsite. The average gold fineness is 890 conventional units. The size of gold grains does not exceed 20 μm . A significant mass of valuable component grains in the composite sample of oxidized ore is represented by fine particles with a size of 0-2 μm , constituting 51.6%.

Also, after sorption of the desalinated pulp, the copper-containing solution was separated, and a study was conducted on the regeneration of the cyanide solution and copper precipitation. To extract copper, it is planned to study the tailings of centrifugal enrichment

of mixed ores for agitation leaching with sulfuric acid solution with subsequent sedimentation. At the same time, the maximum degree of copper extraction is achieved, which ultimately solves the problem of complex extraction of metals from mixed off-balance copper ores [7].

As can be seen from Table 4, with an increase in the sorption time and concentration of sodium cyanide, the indicators of sorption cyanidation of the beneficiation products generally improve.

Table 4. Results of cyanidation of concentrate enrichment of mixed copper ores.

No	Position Name	Experiment number	Cyanidation parameters		Content, g/t				Extraction, %	
			C _{NaCN} , g/l	Search time, h	Source pr.		Cake		Au	Ag
					Au	Ag	Au	Ag		
1	Averaged Sample, k-t Knelson sample No1	1 experience	0.5	16	9.15	29.77	2.24	7.56	75.57	74.59
		2 experiments	1.	18	9.15	29.77	1.67	5.25	81.79	82.36
2	Averaged sample, k-t Knelson sample No2	1 experience	0.5	16	8.73	28.55	2.21	8.22	74.74	71.21
		2 experiments	1	18	8.73	28.55	1.72	3.89	80.30	86.37
3	Averaged sample, k-t Knelson sample No3	1 experience	1	16	8.80	25.72	1.41	5.16	83.98	79.94
		2 experiments	1.5	18	8.80	25.72	1.10	4.41	87.47	82.87
4	Averaged sample, k-t Knelson sample No4	1 experience	0.5	16	8.81	27.04	1.49	5.69	83.04	78.95
		2 experiments	1.	18	8.81	27.04	1.21	5.03	86.22	81.38
5	Averaged sample, k-t Knelson sample No5	1 experience	1.	16	9.12	29.22	1.39	5.67	84.80	80.59
		2 experiments	1.5.	18	9.12	29.22	1.07	4.13	88.27	85.87

Note: The following were adopted as constant parameters: weight - 100 g, S:L =1:2; protective alkali concentration - 0.02%; grinding size - 0.071+0 mm; pH = 11.0-11.5; the concentration of cyanide in the pulp's liquid phase - exceeded the value compared to the first experiment from 0.5 g/l to 1 g/l and up to 1.5 g/t; leaching duration - 16-18 hours.

The highest indicators of gold extraction from the resin were observed during the sorption cyanidation of sample No5. Thus, during sorption cyanidation of sample No. 5 at a sodium cyanide concentration of 1.5 g/l and a process duration of 18 hours, the extraction of gold on coal was 88.27%.

Overall, the research was accompanied by achieving maximum copper extraction from mixed ores. For this task, the possibility of increasing the degree of copper extraction from

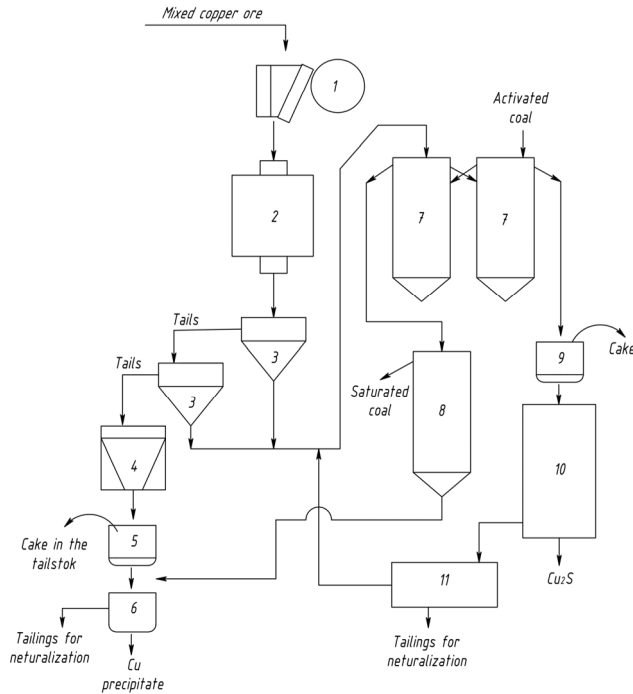


Fig. 10. Diagram of the chain of apparatuses for processing mixed ores with the extraction of noble metals: 1-check crusher, 2-mill, 3-centrifugal concentrator, 4-washing reactor, 5-filter, 6-precipitator, 7-cyanizing pachuck, 8-washing column, 9-filter, 10-precipitator, 11-regeneration column.

Thus, for low-concentration copper products, it is advisable to use a widely used method of agitation leaching with copper precipitation. Extraction and sorption methods are not economically viable [8]. The study of the phase analysis of copper tailings proved its high solubility in sulfuric acid solution. The resulting copper sulfate solution is contaminated with high impurity content, which is limited by the copper electrolysis process. As a result of laboratory studies, optimal parameters for copper leaching and a copper precipitation method using iron scrap were established.

To track all parameters of the beneficiation and metallurgical processes, the material balance of metals, particularly gold, silver, and copper, was calculated. The material balance of the metals presented in Table 5 shows the degree of through extraction: for gold 66.88%, for silver 60.46%, and for copper 85.40%.

Table 5. Material balance of metals of processing of mixed copper ores with extraction of noble metals and copper.

No	Product name	Product quantity, t	Product yield, %	Average Au content, g/t	Average Ag content, g/t	Average Cu content, %	Extraction of Au, %	Extraction of Ag, %	Extraction of Cu, %
Gravitational enrichment (Knelson) I and II									
Received									
1.	Mixed copper ore	100.00	100.00	0.49	1.70	0.277	100.00	100.00	100.00
	Total	100.00	100.00	0.49	1.70	0.277	100.00	100.00	100.00
It turns out									
1.	Concentrate I	2.24	2.24	11.46	6.66	1.09	52.40	19.89	8.78

2.	Concentrate II	2.10	2.10	5.96	37.06	2.58	25.55	45.78	19.55
3.	Combined concentrate	4.34	4.34	8.80	25.72	1.81	77.95	65.67	28.33
4.	Tails	95.66	95.66	0.11	0.61	0.21	22.05	34.33	71.67
	Total	100.00	100.00	0.49	1.70	0.277	100.00	100.00	100.00
Sorption cyanidation									
Received									
1.	Combined concentrate	4.34	4.34	8.80	25.72	1.81	77.95	65.67	28.33
2.	Activated carbon	0.87	0.87						
	Total	5.21	5.21	8.80	25.72	1.81	77.95	65.67	28.33
It turns out									
1.	Coal	0.87	0.87	73.33	73.73	0.32	68.81	63.00	7.65
2.	Gold-free pulp, m ³	4.34	4.34	0.59	1.21	1.49	9.14	2.67	20.68
	Total	5.21	5.21	8.80	25.72	1.81	77.95	65.67	28.33
Copper washing									
Received									
1.	Saturated coal	0.87	0.870	73.33	73.73	0.32	68.81	63.00	7.65
	Total	0.87	0.870	73.33	73.73	0.32	68.81	63.00	7.65
It turns out									
1.	Saturated coal	0.867	0.867	73.33	73.73	0.003	66.87	61.11	0.75
2.	Cu solution-2, m ³	0.003	0.003	1.41	4.328	0.317	1.93	5.87	6.90
	Total	0.870	0.870	73.33	73.73	0.32	68.81	63.00	7.65
Filtration									
Received									
1.	Gold-free pulp, m ³	4.34	4.34	0.59	1.21	1.49	9.14	2.67	20.68
	Total	4.34	4.34	0.59	1.21	1.49	9.14	2.67	20.68
It turns out									
1.	Cake	4.253	4.253	0.56	1.09	0.06	8.56	1.26	0.83
2.	Pulp volume solution	0.087	0.087	0.03	0.12	57.00	0.59	1.41	19.85
	Total	4.34	4.34	0.59	1.21	1.49	9.14	2.67	20.68
Copper precipitations									
Received									
1.	Recycling pulp solution, m ³	0.087	0.087	0.03	0.12	57.00	0.59	1.41	19.85
	Total	0.087	0.087	0.03	0.12	57.00	0.59	1.41	19.85
It turns out									
1.	Cyanide solution	0.010	0.010	0.08	0.09	0.08	0.17	10.00	1.99
2.	Cu ₂ S precipitate	0.077	0.077	0.180	8.53	64.50	0.42	90.00	17.87
	Total	0.087	0.087	0.03	0.12	57.00	0.59	1.41	19.85
Cyanide regeneration									
Received									
1.	Cyanide solution	0.0101	0.0101	0.08	0.09	0.08	0.17	10.00	1.99
	Total	0.0101	0.0101	0.08	0.09	0.08	0.17	10.00	1.99
It turns out									
1.	NaCN solution	0.00001	0.00001	0.08	0.09	0.00	0.17	10.00	0.00

2.	Solution for tailings disposal	0.01006	0.01006	0.00	0.00	15.79	0.00	0.00	1.99
	Total	0.01007	0.01007	0.08	0.09	0.08	0.17	10.00	1.99
Vat leaching of copper									
Received									
1.	Tails	95.66	95.66	0.11	0.61	0.21	22.05	34.33	71.67
	Total	95.66	95.66	0.11	0.61	0.21	22.05	34.33	71.67
It turns out									
1.	Pulp after leaching.	95.66	95.66	0.11	0.61	0.21	22.05	34.33	71.67
	Total	95.66	95.66	0.11	0.61	0.21	22.05	34.33	71.67
Filtration									
Received									
1.	Pulp after leaching	95.66	95.66	0.11	0.61	0.21	22.05	34.33	71.67
	Total	95.66	95.66	0.11	0.61	0.21	22.05	34.33	71.67
It turns out									
1.	Cu solution-1, m ³	0.957	0.96	0.00	0.03	14.25	0.00	6.87	64.93
2.	A kick in the tail.	94.70	94.70	0.11	0.49	0.01	22.05	27.46	6.74
	Total	95.66	95.66	0.11	0.61	0.21	22.05	34.33	71.67
Copper precipitations									
Received									
1.	Cu solution-1, m ³	0.96	0.96	0.00	0.03	14.25	0.00	6.87	64.93
2.	Cu solution-2, m ³	0.003	0.003	1.41	4.33.	0.32	1.93	5.87	6.90
	Total	0.96	0.96	0.9877	22.57	20.74	1.93	12.74	71.83
It turns out									
1.	Cu precipitate	0.361	0.361	0.00	34.09	51.87	0.00	11.59	67.60
2.	Neut. solution, m ³	0.598	0.598	0.00	3,257	1.96	0.00	1.15	4.24.
	Total	0.959	0.959	0.99	22.57	20.74	1.93	12.74	71.83

4 Conclusion

For the first time, a combined technology for centrifugal concentration of precious metals from mixed copper ores with the transition of precious metals to the concentrate phase has been developed, with further development of selective extraction of gold, silver, and copper by sorption leaching, and the optimal parameters for sulfuric acid extraction of copper from the beneficiation tailings have been determined.

Optimal parameters for concentrating the main amount of gold with a water flow rate of 2 l/min were established for the first stage of concentrating the mixed (shifted) copper ore at a centrifugal force of 90G, and a combined gravitational concentrate with an average gold content of 14.31-20.12 g/t and a gold recovery rate of 72.98-77.95% was obtained. Also, at the second stage of centrifugal concentration, the parameters of 120G were determined, at a gravitational concentration flow rate of 5 l/min, a concentrate with a silver content of 59.42-67.3 g/t was obtained, with an extraction rate of 68.46-69.95%.

As a result of a series of experiments, a technological scheme for the complex extraction of copper and noble metals from mixed copper ores was developed, and the optimal parameters of all processes were developed, with the selection of equipment design for the

production scale, and the apparatus circuit diagram was substantiated. The material balance of metals shows that the degree of through extraction for gold is 66.88%, for silver 60.46%, and for copper 85.40%.

References

1. K. Sanakulov, U.A. Ergashev, I.O. Khamroev, O.U. Fuzaylov, *Non-ferrous metals Journal* **9**, 22-30 (2023).
2. B. Vokhidov, A. Hasanov, M. Babayev, G. Mamaraimov, A. Yandashev, *Acta Innovations* **52**, 51-59 (2024).
3. S.S. Jena, S.K. Tripathy, N.R. Mandre, R. Venugopal, S. Farrokhpay, *Minerals* **12**, 545-596 (2022).
4. Shaker M.A. Qaidi, Bassam A. Tayeh, Abdullah M. Zeyad, Afonso R.G. G. de Azevedo, Hemn Unis Ahmed, Wael Emad, *Case Studies in Construction Materials* **16**, 1-22 (2022).
5. N.K. Dosmukhamedov, Zh.A. Yussupova, V.A. Kaplan, E.E. Zholdasbay, *Non-ferrous Metals* **2**, 39-44 (2024).
6. I.A. Tagaev, N.A. Doniyarov, L.S. Andriyko, I.N. Murodov, A.A. Asrorov, *Issues of Chemistry & Chemical Technology* **4**, 75 (2022).
7. O.E. Gorlova, N.L. Medyanik, O.A. Mishurina, E.R. Mullina, *Journal of Mining Science* **57**, 834-841 (2021).
8. Q. Feng, W. Yang, S. Wen, H. Wang, W. Zhao, G. Han, *International Journal of Mining Science and Technology* **32**, 1351-1364 (2022).