Development of Technology for Processing Off-Balance Waste Ores with a Pilot Test for the Integrated Extraction of Precious Metals

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DOI: 10.47750/pnr.2022.13.S08.287

Abstract

The article deals with the issues and possibilities of processing off-balance waste ores with a pilot test for the integrated extraction of precious metals. The data on the dumps of the industrial region for the production of non-ferrous metals are given, the composition of the dumps is analyzed. Information about the methodology for conducting laboratory and semi-industrial experiments, as well as the result of the analysis to determine the form of finding precious components.

Keywords: Dumps, Sulfides, Oxides, Extraction, Flotation, Concentrate, Copper, Enrichment, Energy Dispersive Spectroscopy, Gold, Waste, Off-balance Ore, Palladium.

INTRODUCTION

According to the technology of AGMK JSC, the enrichment of ores from the Kalmakyr and Yoshlik -I deposits is carried out by flotation, and the resulting flotation concentrates are aimed at extracting copper and associated precious metals. In this work, the reserves and compositions of tailings of the Kalmakyr and Yoshlik -I deposits, in particular, off-balance sulfide and oxidized copper ores, were studied. The analysis of the obtained results of off-balance dump ores and technogenic wastes shows that they should initially be enriched in precious metals and copper should be extracted along with this, since the copper content in them is manifested in lower concentrations. Processing of technogenic wastes and tailings is profitable in cases where all precious metals are extracted from them in a complex [1,2].

MATERIALS AND RESEARCH METHODS

Let us consider the composition, properties, technologies for enrichment of off-balance ores and methods for processing concentrates with the extraction of precious metals. A laboratory technological study was carried out, the oxidized and off-balance sulfide ore stores of the Kalmakyr and Yoshlik -I deposits of JSC AMMC completed the work of the following stage:

- Sample preparation of sample material from all 6 warehouses was carried out: crushing, division into partial samples.
- Private samples were prepared with an initial fineness of -10+0; -5+0 mm for heap leaching tests.
- Partial samples were prepared with an initial size of -2 + 0 mm for carrying out technological experiments on gravity, flotation, and other studies on the leaching of copper and precious metals (gold, silver, platinum and palladium) and a method for processing concentrates.
- A screening of the crushed material of all 6 samples was carried out to prepare the material for mineralogical studies at the Central Research Laboratory of NMMC JSC.
- 3 samples were examined to study the material composition in Tashkent on the SEM-EDX Scanning Electron Microscope [4].
    1. Technogenic dumps A4, 8A and 9 belong to the oxidized types.
    2. Dumps A7 and 10 are mixed types.
    3. Dump A8 to sulfide types of off-balance copper ores.

A general chemical analysis of samples was carried out for all objects. The results of chemical analyzes are given in Table 5.1.

preparation of the material was carried out, the chemical composition of samples A8 in the Central Scientific Research Laboratory was studied, the results of the analysis show an average gold content of 0.44 g/t; average silver content 1.1 g/t; copper content 0.13%. The mineralogical composition of sulfide ores was also studied, A8 shows 50.7% SiO_2, 12.7% Al_2O_3. In addition, A8 samples were studied by the material composition of energy dispersive EMF spectroscopy (EDS), which are shown below in figures (Fig.1-6) [5,6].

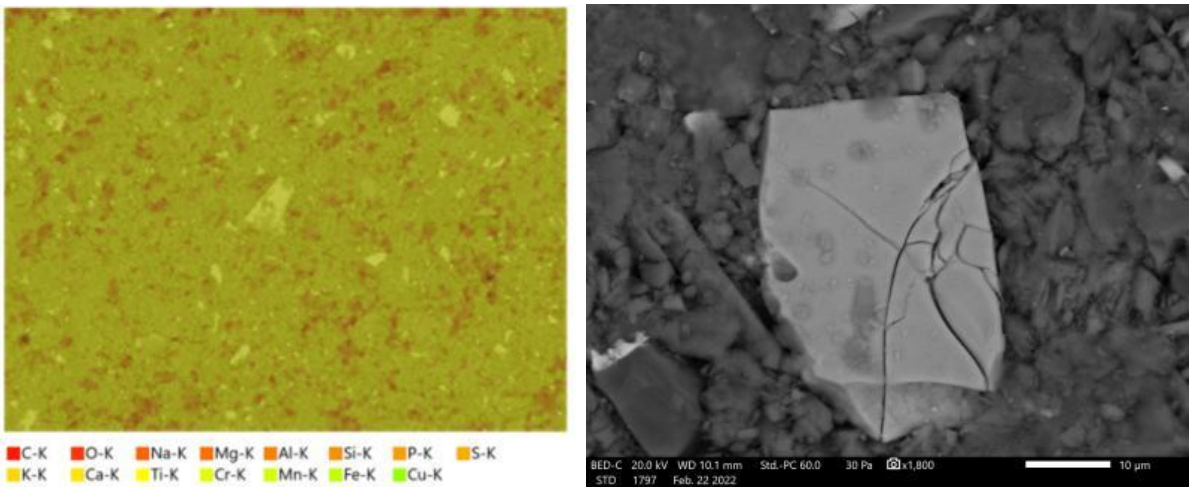


Fig.1. General elemental analysis of the entire surface of the sample A8

Conducted a general chemical analysis of the samples over the entire surface of each sample to determine the possible components of the studied objects. The photographs determined the size of copper particles, which is 10 microns, and it is mainly associated with sulfides. [9,10].

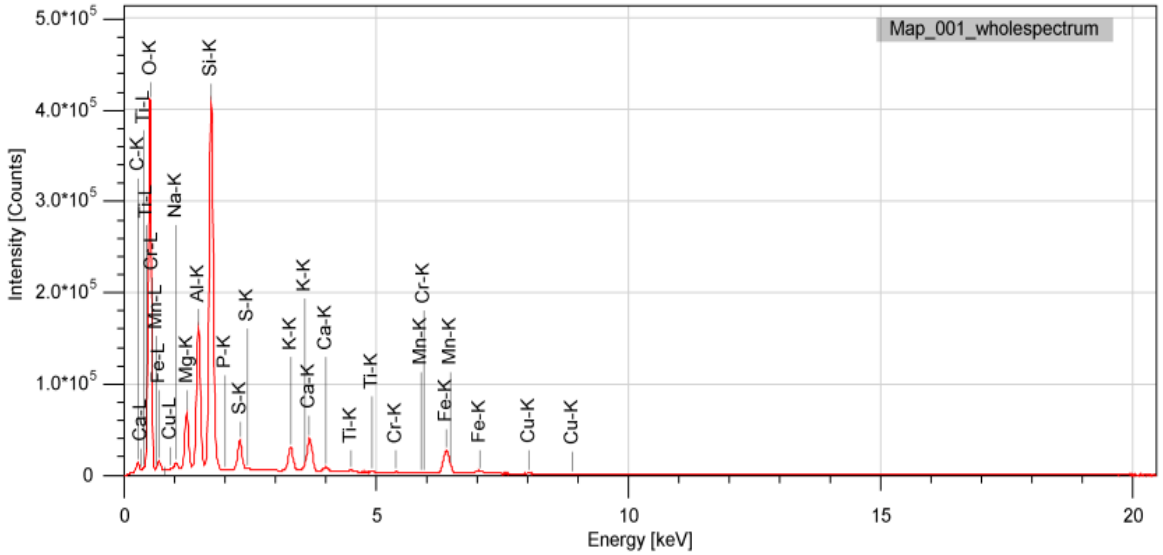


Fig.2. Sample analysis results A8

The studied surface is described mainly by copper, as an impurity, iron minerals at the peak meet with sulfur, which in turn forms iron sulfide minerals, and a noticeable amount of quartz at a high peak intensity of $4.0 * 10^5$ (Fig. 1).

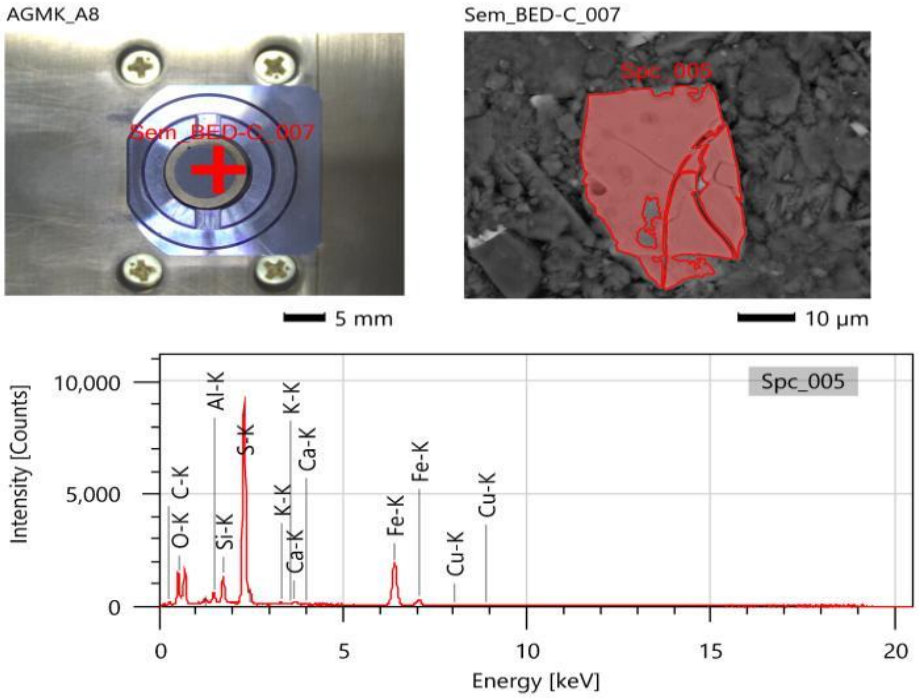


Fig.3. Sample analysis results A8

In the spectrum 005, the copper surface of the sample is indicated, which has a copper content of 0.15% in the studied sample, associated with oxygen (see Fig. 3. and Table 1. elemental composition of sample A8), iron sulfide and minerals of quartz, alumina and calcite are found as an impurity [7].

Table 1. Elemental composition of the total sample area area A8

Element	Line	Mass, %	Atom, %
Spc_005	line	Mass %	atom %
C	K	9.37 ± 0.19	20.52±0.42
O	K	17.53 ± 0.18	28.81 ± 0.30
Mg	K	0.68 ± 0.03	0.73±0.04
Al	K	1.73 ± 0.04	1.69 ± 0.04
Si	K	3.69 ± 0.06	3.45±0.06
S	K	32.27 ± 0.16	30.57 ± 0.13
K	K	0.46 ± 0.03	0.31 ± 0.02
Ca	K	0.72 ± 0.03	0.47 ± 0.02
Fe	K	28.41 ± 0.22	13.38 ± 0.10
Cu	K	0.15 ± 0.04	0.06 ± 0.02
Total		100.00	100.00
Spc_005 Fitting ratio 0.0149			

Figures 1-4 show the best results obtained by a scanning electron microscope, and in the appendix section all SEM images are attached to determine the elemental composition of sections A7, A8, 10 [8].

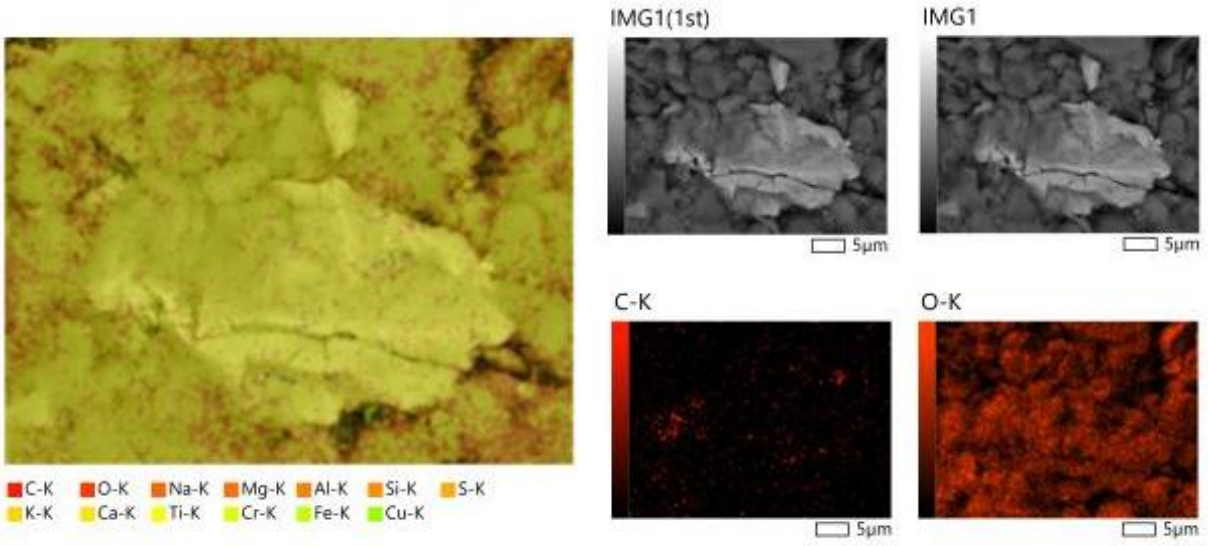


Fig.4. Sample analysis results A8.

In Table 2, the average content of Au, Ag, Pt, Pd and Cu is determined to select the optimal processing technology, in addition, we analyzed the silicate and mineral composition of 6 samples, the detail for determining the content, composition and particle size of metals related to the enrichment method. Analysis of the composition of site 10 is given below [11].

Sample area 10 refers to oxidized beyond balance copper ores; the material composition of energy dispersive EMF spectroscopy (EDS) was studied. The drawings are shown below (Fig.5-8).

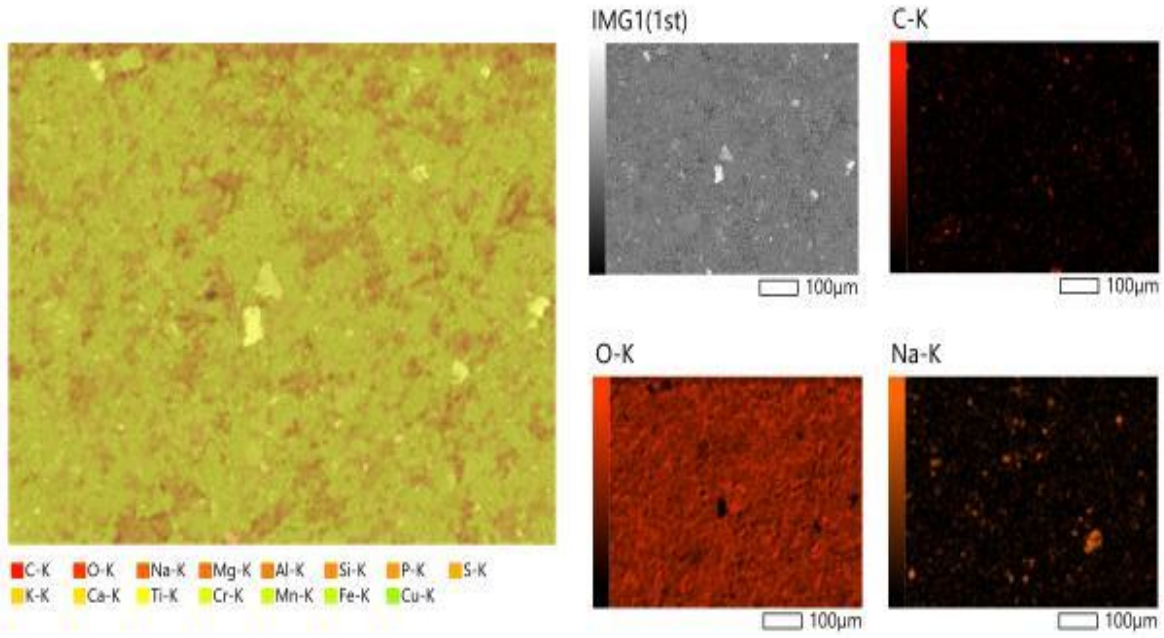


Fig.5. General elemental analysis of the sample surface of area 10.

Table 2. The chemical composition of the initial samples of the warehouses of JSC «AMMC»

Stock	The content of the elements, g/t				Content of elements, %													
	Au	Ag	Pt	Pd	S_{about}	S_{s}	$SO_{3\ calc.}$	Fe_{about}	Fe^{2+}	$Fe^{3+}_{calc.}$	C_{total}	C_{org}	$CO_{2\ calc.}$	As	Sb	Cu	Pb	Zn	Mo
A8	0.44	1.1	2.25	3.1	3.1	2.2	2.3	4.7	3.2	1.5	0.79	<0.1	2.7	<0.09	<0.005	0.13	0.007	0.01	<0.005
A7	0.38	4.4	1.46	1.8	1.8	1.1	1.8	3.7	1.9	1.8	0.4	<0.1	1.3	<0.09	<0.005	0.11	0.018	0.038	<0.005
ten	0.39	1.1	1.15	2.2	1.6	0.74	2.2	3.6	1.8	1.8	0.4	0.1	1.1	<0.09	<0.005	0.13	0.006	0.016	<0.005
9	1.77	2.3	2.1	2.7	<0.2	<0.2	<0.3	4.7	0.9	3.8	0.16	<0.1	0.4	<0.09	<0.005	0.42	0.006	0.01	<0.005
A4	0.7	6.5	2.5	4.4	<0.2	<0.2	<0.3	3.5	1.7	1.8	0.38	<0.1	1.2	<0.09	<0.005	0.73	0.008	0.016	<0.005
8A	0.4	1.3	0.7	1.9	0.89	0.35	1.4	3.55	1.0	2.55	0.22	<0.1	0.5	<0.09	<0.005	0.08	0.016	0.018	<0.005

Table 3: The silicate mineralogical composition of the initial samples of the warehouses of JSC «AMMC»

Stock	Content of elements, %											
	SiO_2 _	Al_2O_3 _ _ _	TiO_2 _	FeO	Fe_2O_3. _ _	CaO	MgO	Na_2O _ _	K_2O _ _	P_2O_5 _ _ _	MNO	p.p.p. _
A8	50.7	12.7	0.36	4.1	2.1	5.9	4.3	2.8	2.2	1.3	0.1	1.3
A7	53.5	13.5	0.5	2.4	2.6	2.7	3.8	1.7	2.1	0.1	0.09	5.3
ten	59.1	14.3	0.5	2.3	2.6	3.0	3.3	0.9	3.2	0.08	<0.01	5.0
9	64.6	13.6	0.5	1.2	5.4	1.5	2.0	0.6	3.5	0.1	0.04	3.7
A4	57.0	15.4	0.5	2.2	2.6	3.7	3.5	1.8	2.9	<0.01	0.1	4.6
8A	62.4	14.2	0.5	1.3	3.6	2.3	2.3	1.0	3.4	<0.01	0.04	3.9

The material composition of the studied sample points to chalcopyrite minerals.

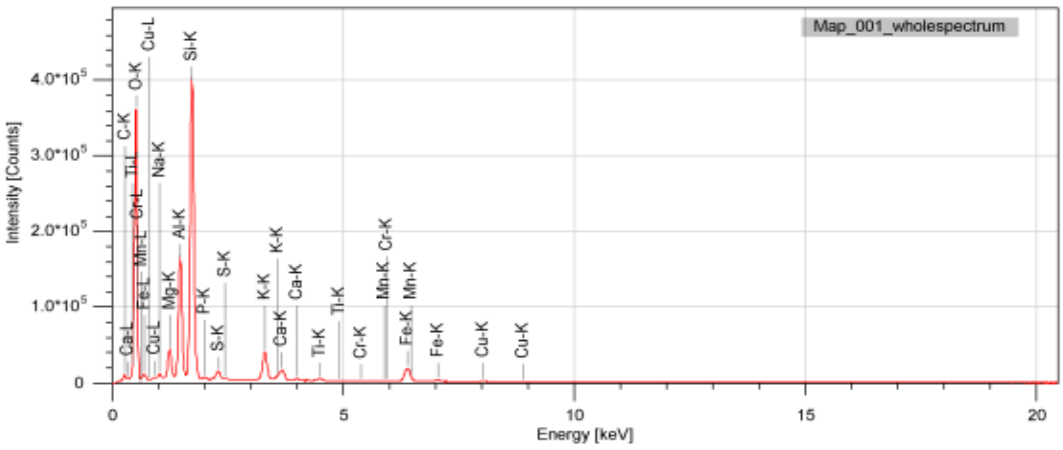
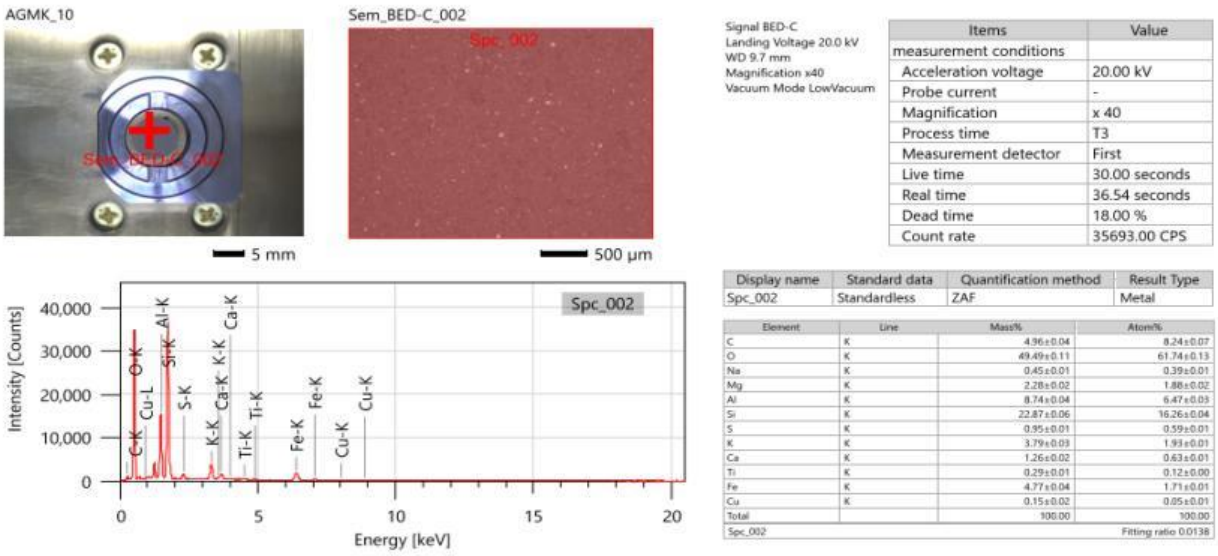


Fig.6. The results of the analysis of samples plot 10



Items	Value
measurement conditions	
Acceleration voltage	20.00 kV
Probe current	-
Magnification	x 40
Process time	T3
Measurement detector	First
Live time	30.00 seconds
Real time	36.54 seconds
Dead time	18.00 %
Count rate	35693.00 CPS

Display name	Standard data	Quantification method	Result Type
Spc_002	Standardless	ZAF	Metal

Element	Line	Mass%	Atom%
C	K	4.96±0.04	8.24±0.07
O	K	49.49±0.11	61.74±0.13
Na	K	0.45±0.01	0.39±0.01
Mg	K	2.28±0.02	1.88±0.02
Al	K	8.74±0.04	6.47±0.03
Si	K	22.87±0.06	16.26±0.04
S	K	0.95±0.01	0.59±0.01
K	K	3.79±0.03	1.93±0.01
Ca	K	1.26±0.02	0.63±0.01
Ti	K	0.29±0.01	0.12±0.00
Fe	K	4.77±0.04	1.71±0.01
Cu	K	0.15±0.02	0.05±0.01
Total		100.00	100.00
Spc_002			Fitting ratio 0.0138

Fig.7. The results of the analysis of samples from plot 10

The results of analyzes of samples from site 10 show an average copper content of 0.15%, and the size of copper minerals is 100 microns on average. (See fig.5 and 8.).

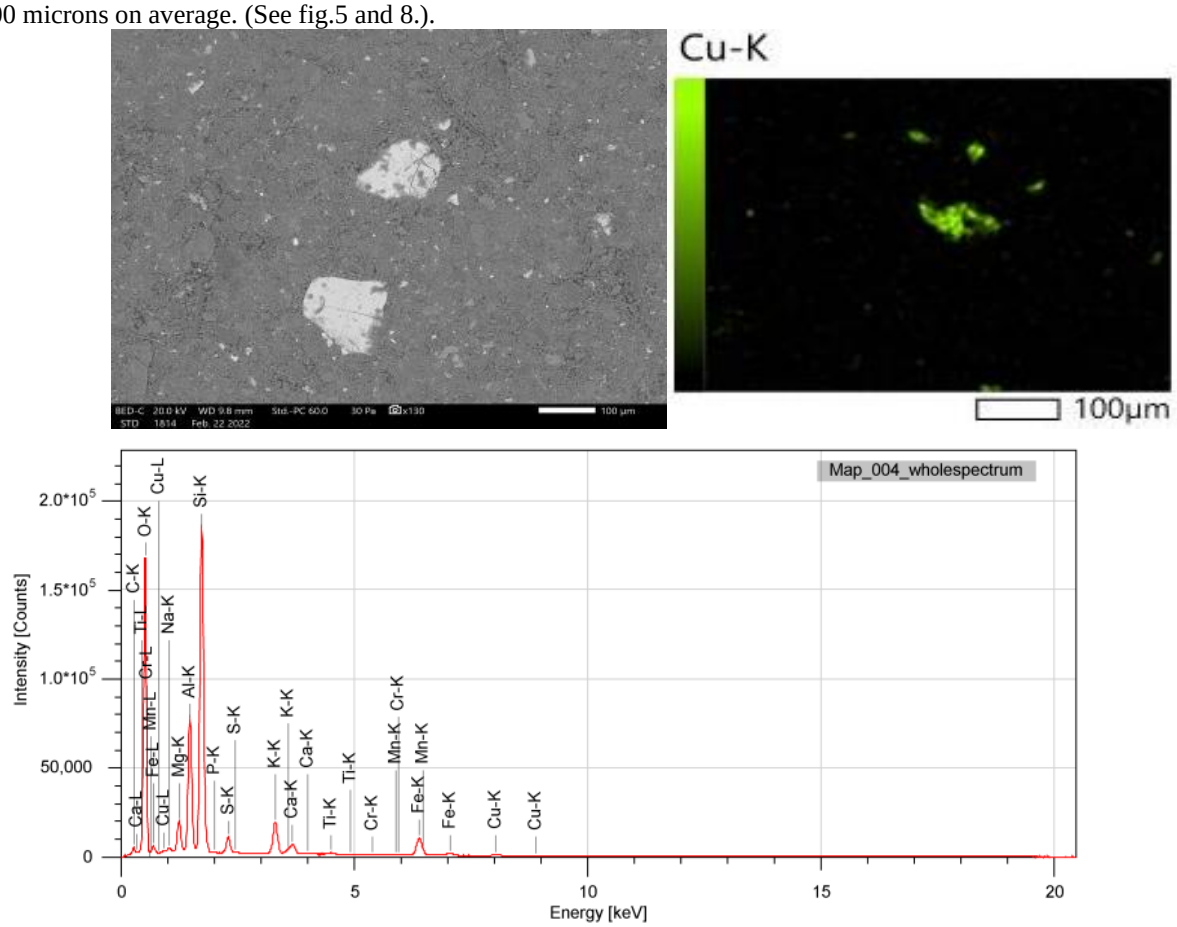


Fig.8. The results of the analysis of samples from plot 10

From figure 8, it can be determined that copper is also found in ores in an oxidized form, the Cu peak is equal to the O $_{2\ peak.}$ First, flotation enrichment was carried out in the ores of all x 6 dumps.

RESULTS AND DISCUSSION

Based on the average contents of copper and gold in the sample, experiments on flotation enrichment were carried out. The results of preliminary experiments on flotation enrichment of all samples are shown in Table 4.

The mineralogical composition and the results of the experiments show that the off-balance ores of the A 8 site are sulfide, but the results of the analysis of flotation concentrates showed a low concentration of copper and precious metals (gold, silver, platinum and palladium) that such flotation concentrate does not meet the requirements of the CMP JSC «AMMC». Of the results, only silver has good concentration and recovery in the concentrate phase. Copper particles in a very finely dispersed state, this indicates that the gravity of the sample does not give us the expected results.

For these reasons, it is necessary to test the sulfide ores of sample A8 by direct thio-sulfate leaching with agitation. The purpose of this method is the simultaneous leaching of sulfide copper minerals and the transfer of free gold and silver into the solution. With good leaching results, selective precipitation of copper and precious metals is used.

Table 4: Results of flotation enrichment of off-balance copper ores

Name.	Weight, gr	Exit, %	Content, %				Recovery, %			
			Au, g/t	Ag, g/t	Cu	Ss	Au	Ag	Cu	Ss
	Results of flotation enrichment of A8 samples									
Concentrate	**144.00**	**14.40**	**1.68**	**40.27**	**0.95**	**16.64**	**62.43**	**93.13**	**76.14**	**93.33**
Tails	856.00	85.60	0.17	0.50	0.05	0.20	37.57	6.87	23.86	6.67
Ore	1000.0	100.0	0.39	6.23	0.18	2.57	100.0	100.0	100.0	100.0
	Results of flotation enrichment of samples 8A									
Concentrate	**122.00**	**12.2**	**1.98**	**5.45**	**0.33**	**4.09**	**50.49**	**48.65**	**48.02**	**73.98**
Tails	878.0	87.8	0.27	0.8	0.05	0.2	49.51	51.35	51.98	26.02
Ore	1000.00	100	0.48	1.37	0.08	0.67	100	100	100	100
	Results of flotation enrichment of samples 10									
Concentrate	**156.00**	**15.60**	**1.63**	**3.36**	**0.64**	**7.79**	**63.90**	**60.80**	**56.93**	**87.80**
Tails	844.00	84.40	0.17	0.40	0.09	0.2	36.10	39.20	43.07	12.20
Ore	1000.00	100.00	0.40	0.86	0.18	1.38	100.00	100.00	100.00	100.00
	Results of flotation enrichment of A4 samples									
Concentrate	**119.0**	**11.9**	**2.03**	**4.41**	**1.76**	**0.72**	**60.70**	**64.60**	**17.81**	**32.75**
Table 4 continued										
Tails	881.0	88.1	0.44	0.40	1.1	0.2	39.30	25.40	82.19	67.25
Ore	1000.00	100.00	0.70	6.5	1.8	0.26	100.00	100.00	100.00	100.00
	Results of flotation enrichment of A7 samples									
Concentrate	**152.0**	**15.2**	**1.59**	**32.09**	**0.21**	**7.18**	**61.72**	**90.27**	**29.72**	**86.54**
Tails	848.0	84.8	0.17	0.45	0.09	0.2	3828	9.73	70.28	13.46
Ore	1000.00	100.00	0.38	4.4	0.11	1.26	100.0	100.0	100.00	100.00
	Results of flotation enrichment of samples 9									
Concentrate	**145.0**	**14.5**	**4.26**	**5.41**	**1.17**	**0.72**	**64.30**	**66.90**	**24.8**	**37.75**
Tails	855.0	85.5	0.56	0.50	0.6	0.2	35.70	33.10	75.16	62.25
Ore	1000.00	100.00	1.77	2.3	0.68	0.27	100.00	100.00	100.00	100.00
	Change 19 min. I Main. Kst =50 g/t, T-92=60 g/t, tf =10 min. I Contr. Kst \u003d 2 g / t, T-92 \u003d 30 g / t, tf \ u003d 15 min. pH=10, Size -0.074 mm -80%.									

Based on the average contents of copper and precious metals in the sample, experiments were carried out on the gravitational enrichment of ore from warehouses A4, A7, 9 according to the developed technological scheme shown in Figure 9.

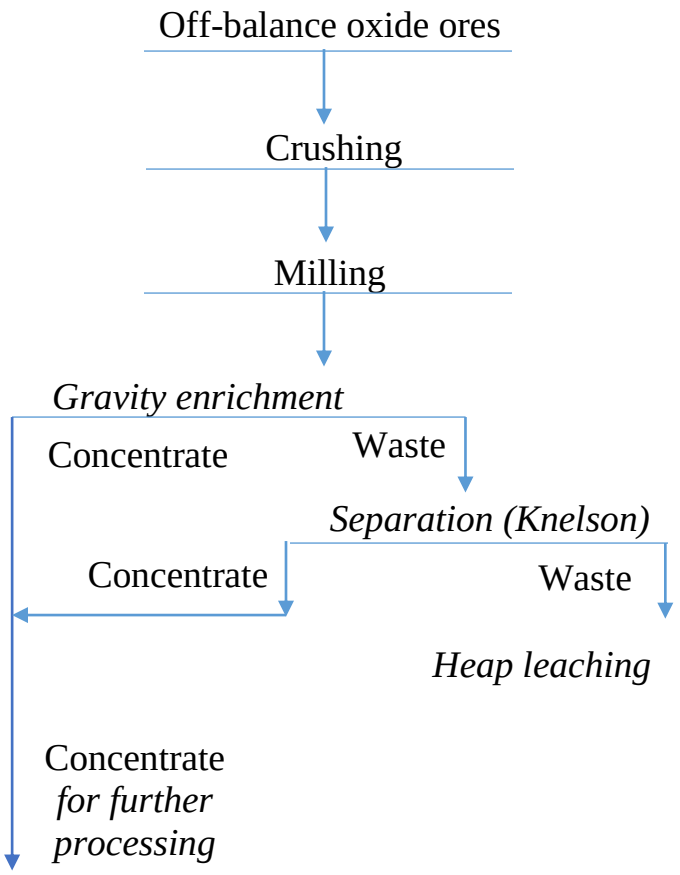


Fig.9. The proposed technological scheme for the enrichment of oxidized off-balance ores

For ore samples of dump A4 and 9, the results of gravity enrichment experiments gave good indicators for all precious metals, in particular gold, silver, platinum and palladium, but low for copper. For these reasons, it is necessary to further check the dressability of A7 ore by the gravity method, and additionally check the concentrate for the content of selenium and tellurium. The formed tailings of gravitational enrichment of oxidized ores (dumps A4, A7 and 9) are directed to heap leaching of copper together with sulfide out -of -balance ores in order to extract copper from them. The results of preliminary experiments on gravity enrichment of all 3 samples are shown in Table 5.

Table 5: Results of gravity enrichment of oxidized off-balance ores

Name.	Weight, gr	Exit, %	Content, %						Recovery, %					
			Au, g/t	Ag, g/t	Pt, g/t	Pd, g/t	Cu	Ss	Au	Ag	Pt	Pd	Cu	Ss
	Results of gravity enrichment of A4 samples													
Concentrate	**180.00**	**1.80**	**46.72**	**52.91**	**96, 12**	**170.13**	**1.46**	**1.46**	**72.18**	**13.72**	**83, 27**	**81, 62**	**11.78**	**2.82**
Tails	9820.00	98.20	0.33	6.10	0.41	0.82 _	0.20	0.92	27.82	86.28	16, 73 _	18, 38	88.22	97.18
Ore	10000.00	100.00	1.16	6.94	2.5 0	4.4 0	0.22	0.93	100.00	100.00	100.0	100.0	100.00	100.00
	Results of gravity enrichment of A7 samples													
Concentrate	**192.00**	**1.92**	**6.32**	**57.73**	**19, 22**	**27, 14**	**17.48**	**0.58**	**27.88**	**21.20**	**31, 98**	**33, 24**	**25.88**	**6.27**
Tails	9808.00	98.08	0.32	4.20	1, 01	1,20 _	0.98	0.17	72.12	78.80	68.02 _ _ _	66, 76	74.12	93.73
Ore	10000.0	100.0	0.44	5.23	1.46	1.8 0	1.30	0.1	100.0	100.0	100.	100.	100.0	100.0

	0	0						8	0	0	0	0	0	0
	Results of gravity enrichment of samples 9													
Concentrate	**185.00**	**1.85**	**28.70**	**54.12**	**80.70**	**102,85**	**2.20**	**0.81**	**32.97**	**41.18**	**66,37**	**70,38**	**17.17**	**3.23**
Tails	9815.00	98.15	1.10	1.08	0,70 _ _ _	0,80 _ _ _	0.20	0.46	67.03	58.82	33,63	29,62	82.83	96.77
Ore	10000.00	100.00	1.61	1.84	2.10	2.70	0.24	0.47	100.00	100.00	100.0	100.0	100.00	100.00
	Knelson: water l/min, g=90, Grinding -60 min, Fineness -0.074 mm-80%.													

After gravitational enrichment of oxide off-balance copper ores (sections A4, A7 and 9), a gravitational concentrate is formed, rich in precious metals according to the following composition: for gold on average 28-46 g/t, for silver 52-58 g/t, for platinum 80 -96 g/t, for palladium 100-170 g/t. The resulting concentrate of precious metals in terms of the content of precious metals is characterized by similarity in composition and content of the obtained concentrates from CRU and smelting slag, which is processed according to the new technological scheme we are developing (Fig. 9.). The idea of processing concentrates obtained after enrichment of oxidized off-balance ores is to direct the same technological cycle to the hydrometallurgical method of complex extraction of precious metals.

CONCLUSION

As a result, the study of the mineralogical composition and particle size of copper and precious metals in the composition of sulfide and oxidized off-balance ores of the Kalmakyr deposit determined the low flotation properties of copper minerals, evidence for these flotation enrichment of sulfide off-balance copper ores gave the worst results. Copper particles in a very finely dispersed state, this indicates that the normal gravity of the sample does not give us the expected results. An additional study was carried out for oxidized out -of -balance ores in order to concentrate the main precious metals in the composition of concentrates. A number of studies using Knelson centrifugal concentrators gave good results under the following conditions: Water flow g=90 (l/min), material grinding time τ=60 min, fineness of the crushed material $\beta_{-0.074\ mm}$ = 80%, with a crushed material turnover of 800 rpm /min As a result of centrifugal concentration of oxidized off-balance copper ores (sections A4, A7 and 9), a concentrate is formed containing the main precious metals of the following composition: gold on average 28-46 g/t, silver 52-58 g/t, platinum 80-96 g /t, palladium 100-170 g/t.

The resulting concentrate of precious metals from oxidized off-balance copper ores will be processed at a copper plant to obtain precious metals and the remaining tailings are subjected to heap leaching of copper with the extraction of non-ferrous metals.

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