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EXPERIENCE OF INTEGRATED USE OF GOLD-BEARING RAW MATERIAL IN THE PRODUCTION OF PRECIOUS METALS

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With the depletion of rich gold-bearing ores, the processing started to use polymetallic ores, which, in addition to precious metals, contain other elements that could be valuable after recovery. The problem of using such ores is extremely difficult because of the high cost of recovery of associated valuable components. The paper presents the results of studies on the integrated use of extracted gold-bearing raw materials based on the example of the Berezitovoye deposit (Amurskaya oblast), they have low content of precious metals and many heavy non-ferrous metals (copper, lead). Experimental work was carried out to obtain copper by the method of cementation from solutions formed after the leaching of the impurities of gold-containing cathode deposits with hydrochloric acid. The cementing metal was iron turnings (waste products of the turning shop of the enterprise). Next, it was proposed to use cemented copper as a collector during re-melting of slags – wastes of processing of low-grade polymetallic ores containing precious metals. The authors obtained ingots of alloyed gold with gold weight fraction of 16 %, which meets the requirements of TU 117-2-7-75 on the content of non-ferrous metals. During hydrochloric acid treatment of cathodic deposits silver partially passed into the solution, it was recovered together with cemented copper and, in subsequent melting, passed into alloyed gold. Thus, the method proposed by the authors helps to reduce the content of precious metals in the «incomplete production cycle» of the gold recovery factory. The opportunity of selling the cementation copper at the enterprises specializing on manufacturing of jewels is shown; the expected economic effect at the same time amounted to more than 1.8 million rubles.

Key words: metallurgy; precious metals; cathodic precipitation; impurities; cemented copper; recovery

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Introduction. Sustainable use of natural resources is one of the priority areas in the field of subsoil use. The development of gold-bearing deposits is associated not only with the fullest possible extraction of precious metals and environment protection, but with the complex use of processed raw materials. At present, this problem is extremely difficult to solve because of the high cost of associated valuable elements mining and the non-profitability of their subsequent processing [12, 13]. Most often, the solution of this problem is limited to paying fines for non-compliance with the requirements for the sustainable use of mineral resources or revising the terms of the license for mined minerals (Law of the Russian Federation «On Subsoil» No. 2395-1 of 21.02.1992).

The share of processed gold polymetallic ores accounts for about 10 % of all ores containing precious metals, but this value is steadily increasing due to the depletion of deposits rich in gold and silver. These include ores containing precious metals, two or more industrial components: Cu, Pb, Zn, etc. Thus, ores containing less than 60 % of quartz and not more than 12 % of aluminum oxide (silica gold) are often used as fluxes in pyrometallurgical processes. In this case, both gold and silica have industrial value. The processing of pyrite-arsenopyrite gold concentrates can produce sulfuric acid [14]. When processing gold-antimony ores, a rich antimony concentrate is simultaneously released. The gold-lead, gold-zinc, gold-tellurium, gold-bismuth, gold-tungsten, gold-barite, gold-tourmaline and other ores also have industrial value.

The main gold-polymetallic deposits in Russia – Gaiskoye (Orenburg oblast), Berezitovoye (Amurskaya oblast), Rubtsovskoye (Altai krai), Nikolaevskoe, Verkhnee, Partizanskoe (Far East), Dukat, Khatanga (Magadan oblast), Nezhdaninskoye (Yakutia), etc. – are characterized by the presence of other valuable components.

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Research objective. The Berezitovoe deposit is classified as having low-grade polymetallic ores with the following content, g/t: gold – 2.1, silver – 18.5. Besides precious metals, this ore contains various minerals with an average content, % by weight: lead – 0.5, zinc – 1.5, copper – 0.03. To extract valuable components, specialists of JSC «Irgiredmet» (Irkutsk) developed a combined ore processing technology to produce alloyed gold, lead and zinc concentrates, but due to the high cost of ore processing, they currently mine only gold and silver. A technological scheme for processing the ores of this field is shown in Fig.1.

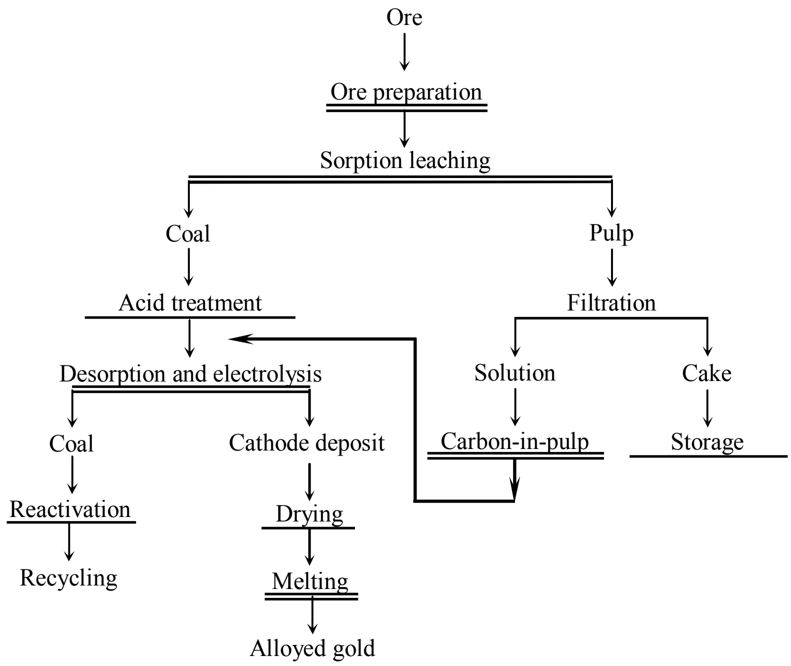

Fig.1. Technological flow chart of processing of gold polymetallic ores mined at Berezitovoe deposit (Amurskaya oblast) [2]

The content of metal-impurities in the ore increases and the content of precious metals falls along with the development activities, which causes the enterprise to take measures to eliminate the negative influence of the chemical composition of resulting gold and silver alloys of impurity metals on finished products [16].

One of the main accompanying metals in the ore is copper, which, in its chemical properties, is close to precious metals and during leaching it passes into solution, forming stable cyanide composites, which, when accumulated, can interfere with the dissolution of gold and silver [6, 10, 11]. Table 1 presents data on the chemical composition of gold-bearing cyanide solutions of OJSC Berezitovy Rudnik, obtained by the processing flow chart (Fig. 1), and atomic absorption analysis on the «Kvant-2AT» device (Russia).

Table 1

Chemical composition of gold-bearing cyanide solutions

Test №	Element content, g/m^3		
	Au	Ag	Cu
1	24	125	1081
2	36	0.1	334
3	125	118	780
4	80	140	575
5	110	13	158

From Table 1 it can be seen that the content of copper in solution is several times higher than the content of precious metals. Figure 2 shows the distribution map of characteristic X-ray radiation from a sample of the cathode deposit obtained by studying the chemical composition by X-ray spectral microanalysis performed on a JXA-8200 microanalyzer (Interactive Corporation, Japan).

On the map (Fig.2), the change in the intensity of the X-ray radiation of the target element is reflected in color changing from black to red. Black color corresponds to the minimum intensity of the element on a given surface area. If the content of the element in the map area changes from 1 to 100 %, the red color will correspond to the 100 % area and the blue to 1 %; in case of a change in the chemical composition from 0.1 to 1 %, the red on the map will be an area with a content of 1 %,

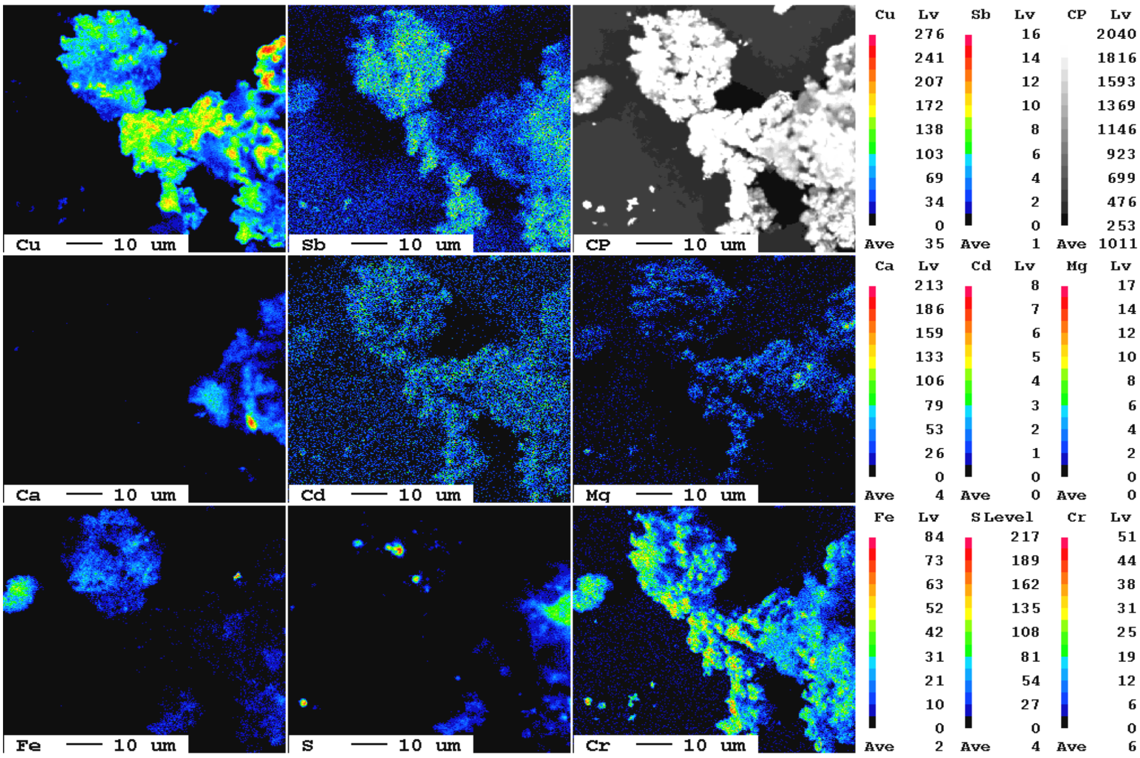

Fig.2. The distribution map of characteristic X-ray radiation of elements of cathode deposit sample (for Cu, Sb, Ca, Cd, Mg, Fe, S, Cr)

and the black color will correspond to zero content (shooting mode: CP is the surface in back scattered electrons). The copper content in the sample of the cathode deposit predominates in comparison with other elements.

Copper present in the cathode deposits during subsequent processing goes into the finished product, the alloyed gold. Table 2 shows the chemical composition of the alloyed gold obtained at the enterprise (the mass fraction of precious metals was determined by the assay method of analysis).

Table 2

Chemical composition of alloyed gold

Alloy №	Weight fraction, %			
	Au	Ag	Cu	Other
1	16	17	32	35
2	14	13	28	45
3	22	32	43	3
4	18	28	49	5
5	24	27	39	10
6	19	18	62	1
7	20	27	41	12
Average	19	23	42	16

As it can be seen from the data in Table 2, the weight fraction of copper in the alloy varies within the range of 28-62 %, which significantly increases the costs for subsequent refining of products. The presence of a large amount of copper and other impurities in the alloy also causes unreliable data on total gold content of the sample [5, 6]. In alloys with an increased copper content, a very uneven distribution of gold and silver is observed; the latter are accumulated mainly in the lower part of the ingot [1, 9].

One of the ways to remove copper from the alloy is preliminary saline-acid treatment of cathode deposits before melting, which was the object of our research [7]. This operation made it possible to

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convert up to 80 % of copper in the form of dichloro-cuprates of alkali and alkaline earth metals. After leaching of impurities of cathode deposits the solutions were neutralized and dumped into the drainage.

For recovery of copper from solutions, one can use the cementation process with iron scrap. As is known, this method is efficient and low-cost [4] one.

The technology is based on the reaction of copper displacement from the solution by more electronegative metal – iron [8]:

$$Na_2CuCl_4 + Fe = Cu + FeCl_2 + 2NaCl, \quad \Delta G^0_{298} = -140{,}61 \text{ kJ/mol.}$$

The calculation of the magnitude of the change in Gibbs energy showed that this reaction is thermodynamically possible.

Based on the results of our experiments, a technology was proposed that makes it possible to isolate copper ions from solutions in the form of a metal and use it further as a collector during recovery of precious metals for re-melting of slags [1, 15].

Results and discussion. Cementation of copper ions from solutions formed after the treatment of cathode deposits with hydrochloric acid was performed using iron turnings, which are waste products of the turning shop of the enterprise. The cementation time lasted for 1 hour. Then the cementation precipitate was filtered and dried for 1-2 hours. The results of the cementation copper chemical composition analysis (atomic absorption analysis performed on the “Kvant-2AT” device (Russia)) are shown in Table 3.

Table 3

Chemical composition of cementation copper

Test №	Element content, % by weight			
	Cu	Pb	Ag	Other*
1	96.5	–	3.5	–
2	95.3	0.1	2.2	2.4
3	94.8	0.5	1.9	2.8
4	97.8	0.2	1.8	0.2
Average	96.1	0.2	2.35	1.35

* Elements not considered in the experiments due to their insignificant amount.

From Table 3 it can be seen that the precipitated cemented copper contains a small amount of impurities; its chemical composition depends primarily on the chemical composition of the original cathode deposits. A small amount of silver, which passed into the solution with hydrochloric leaching, is also recovered with iron during cementation and passes into cementation copper, which is a favorable condition for preventing irreversible losses of this precious metal and increasing its subsequent total recovery during ore processing.

Application of cementation copper in production of precious metals. Cathode deposits serve as raw materials to produce alloyed gold using the pyrometallurgical method (melting) [1]; the less impurities of heavy non-ferrous metals are present in them, the more chemically pure are the alloys of precious metals.

The most negative effect on the melting process of cathode deposits in traditional technology is produced by Cu, Pb and S, as copper and lead are the collectors of precious metals during melting: they accumulate gold and silver [3]. The presence of sulfur in the cathode deposits causes formation of an intermediate matte phase during melting, which contains a large amount of gold in the form of metallic beads. During melting of cathode deposits, also rich in content of precious metals, slags are formed. All melting waste containing precious metals (slag, matte, crucibles and other industrial products) is returned to the initial stage of the process (in the ore grinding cycle). Various attempts

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to re-melt slag and matte for extracting Au and Ag did not yield positive results. In this regard, and with the need to maximize the recovery of precious metals, we carried out experiments on the re-melting of slags [1] using copper as a copper collector obtained by cementation from hydrochloric acid solutions from leaching.

Two slag lots containing a matte phase with a total mass of 20 kg were used to carry out the experimental melting. We used melting fluxes with the following composition, %: borax – 50, sodium carbonate – 10, cemented copper – 2-5.

The borax was placed into the heated induction furnace; after its melting, the remaining part of the fluxes was mixed with the slag and added to the melting mass. After full melting of slag, cemented copper was added and melted to obtain a uniform melt. As a result, two ingots of alloyed gold with the following weight fraction were obtained, %: Au – 16.1, Ag – 21.5. The output of ingots was 17.84 and 11.20 %.

Thus, because of smelting of slags for copper collector, ingots of alloyed gold were obtained, corresponding to TU117-2-7-75, they were sent for subsequent refining. This technology for the use of cementation copper as a collector of precious metals in the smelting of slags has been recommended for use in existing production.

The resulting cemented copper can also be sold to copper smelting plants or companies specializing in the production of jewelry.

Economic effect of selling the cementation copper. The content of copper in the cement slurry is ≈ 96 %, which allows, if it is separated from the solution, to be sold to the copper processing enterprises. Calculation of the expected economic effect from selling this cementation copper is based on the example of OJSC «Krasnoyarsky zavod tsvetnkh metalov n.a. V.N.Gulidov», where it is could be used for production of jewelry, it was shown that there is the possibility of having an economic effect of 1883700 rubles per year (based on the data on the amount of copper formed during cementation (2,691 tons/year) and the cost of metal receipt at the plant is 700 rubles/kg). The transportation costs for the delivery of copper were not considered in the calculation, since this type of industrial product can be transported together with the alloyed gold sent to the refinery, also located in Krasnoyarsk, and the capital expenditures for the equipment used (all necessary equipment – furnace, vacuum filter, etc. – is already available in the enterprise).

Thus, an enterprise can profit (without significant additional costs) from the sale of cemented copper.

Conclusion. The carried-out research has shown expediency of technology of copper cementation from hydrochloric solutions, resulting from leaching of impurities of cathodic deposits. The weight fraction of copper in the resulting cementation sediment was more than 95 %. Silver, which passed into solution during hydrochloric treatment of cathode deposits, is recovered with copper during cementation and slag re-melting, when it is used as a collector, it passes into alloyed gold. The proposed measures help to reduce the content of precious metals «in the incomplete production» of the gold recovery plant. The enterprise can also receive an additional profit of more than 1.8 million rubles per year from the sale of cemented copper to copper processing plants. Thus, the technology proposed by the authors promotes the integrated use of natural ore raw materials.

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