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PROCESS of GOLD-COLLECTING SULPHIDE SYSTEMS ROASTING with COMPLETE BURNING OFF SULFUR, ELIMINATION of ARSENIUM and CARBON

Abstract: The object of the research was gold collector mattes, roasted products and volatile components as sulfur, arsenic, carbon, gold- and silver-containing mattes, slags, new collectors melted materials for gold, pyrometallurgical matte melts enriched with precious metals. Laboratory experiments were conducted to study the effect of temperature on the roasting process for the collector mattes for gold and other metals within 600-900 °C. At the same time, the results of these studies will be used for development and creation of new methods for extracting gold and other metals from the collector sulphide mattes. These mattes were obtained by smelting ledge ores resistant and double resistant to opening and gold concentrates by contractile pyrometallurgical selection (CPS-process) method.

Keywords: matte, slag, gold, contractile pyrometallurgical selection, CPS-process.

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Introduction. As you know, under the CPS-process of melting of refractory gold raw materials, the extracting phase for a number of precious and non-ferrous metal is sulfide collector matte, the main component of which is iron sulfide containing a quantity of metallic iron and copper sulfide [1].

Actually, various options of pyro- and hydrometallurgical systems can be used for extracting gold and other metals from these mattes, [1]. For example, in the work [2] within the course of industrial tests for the process of regenerative electric smelting of gold arsenic concentrates, the collector mattes obtained were subject to oxidative roasting and then the resulting roasted product was cyanidated and recovered using electrolysis.

In this work, the results of one of the most promising methods for processing of collector gold mattes with their roasting and with the removal of sulfur, arsenic and carbon from them. Actually, for existing large extra-refractory gold deposits in the remote and waterless areas of some countries (South Africa, Russia, China, the United States, Kyrgyzstan, etc.), their full pyrometallurgical melting with CPS-process, and extraction of gold and other metals from collector mattes, may be promising. This provision, being the main justification of the research, requires a significant amount of work to check new ways of extracting metals from collector products, in particular, with sulfide matte pre-roasting.

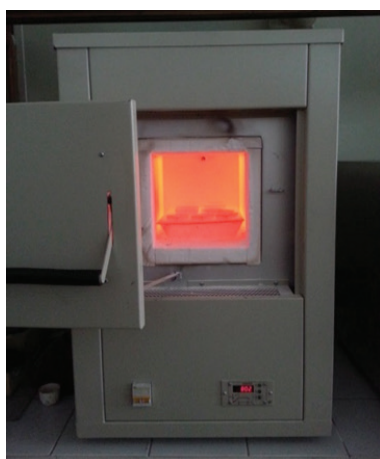
Experimental Part. At the first stage of our research the preparation of primary gold-iron mattes was necessary, and in some cases with performance of its additional chemical

analysis specifying the conditions for obtaining this sulfide collectors of gold. It was considered that use of collector mattes for gold and other metals with different content of gold and silver obtained by us during the CPS-process of melting of specific refractory ore and gold concentrates under laboratory conditions was the most appropriate.

Table 1 shows the compositions and weight of matte obtained from experimental CPS-melting under the conditions specified in our reports on study of technological parameters of the CPS-process for direct melting of number of the refractory gold ores and concentrates.

Table 1 - Chemical compositions of collector primary mattes for gold and other metals

Primary materials name	Sample No.	Chemical composition, %							Matte Sample Weight, g
		Fe	S	Cu	As	C	Au, g/t	Ag, g/t	
Mattes of Bakyrchik auriferous ores	93	48.84	32.87	6.33	0.33	2.05	49.60	55.8	145.0
	94	45.15	32.77	12.90	0.32	2.10	48.80	184.9	145.0
	95	51.07	33.70	4.14	0.32	1.90	57.20	43.0	108.0
	82	45.90	32.50	7.40	0.54	2.00	60.50	5.1	81.0
	84	48.90	33.10	7.50	0.54	2.10	59.70	5.4	140.0
	86	45.90	32.20	8.50	0.48	2.30	52.20	5.6	132.0
Mattes of Bestyube gold concentrates	54	48.50	29.80	9.0	0.012	-	-	-	250.0
	55	56.25	32.50	0.22	0.006	4.50	307.0	51.90	238.0
	50'	56.20	30.20	0.28	0.001	4.00	303.0	60.85	260.0
	50»	60.70	36.05	0.032	0.001	-	344.0	65.40	266.0
	50'»	62.20	35.01	0.25	0.001	-	336.0	63.20	257.0
Mattes of gold ledge ore of Kazakhaltyn JSC:									
Aksu	61	51.10	-	0.92	0.15	-	22.70	71.95	149.0
Zholymbet	63	52.55	-	0.60	0.22	-	15.50	62.1	201.0
Aksu	79	45.90	31.60	14.39	0.17	-	14.70	112.7	88.0
Bestyube	80	50.30	32.10	15.56	0.35	-	12.80	122.0	75.0



a



b

a – general view of the furnace SNOL 12/16 (RF);
b – high-temperature chamber furnace HTC 08/16 made by Nabertherm GmbH (Germany).

Figure 1 - High-temperature furnace for experiments

Since the gold-iron mattes of CPS-process experimental melting of specific materials were used during each experiment, Table 1 shows the chemical compositions of mattes indicating numbers of samples.

Study of influence of gold-iron matte roasting temperature within 600-900 °C on a removal rate of sulfur, arsenic and carbon into the gas phase. Methods of the first exploratory series of experiments for roasting the matte involved placing a 50 g test matte sample into the chamber of SNOL 12/16 furnace (Russia) (Figure 1 a) or into high-temperature chamber furnace HTC 08/16 made by Nabertherm GmbH (Figure 1 b) with programmable automatic temperature rise. Upon reaching the programmable temperature the sample was left in the chamber for 30 minutes in an air. In addition, for the first exploratory set we used the auriferous matte obtained under experimental melting for refractory gold ores of Teriskei LLP, an Ore Mining Company, from two-electrode furnaces of the Chemical and Metallurgical Institute in the city of Karaganda. Composition of source raw materials and roasted products obtained are listed in Table 2.

The data in Table 2 show that roasted product obtained within 600-800 °C differs little from the primary matte, except for arsenic which content decreases from 0.47-0.64 % in the primary matte almost by single-order, making 0.048-0.088 % of roasted products. Apparently, this resulted in the composition of mattes with low content of iron and sulfur. As this matte was obtained in conditions of preliminary experimental melting in electric furnaces with a capacity of 100 kW, the primary matte test sample contained apparently substantial amounts of

slag inclusions. But the most important omission in this series of experiments was insufficient exposure time (30 min) for the test sample in a furnace.

Table 2 - Chemical compositions of primary gold-matte and roasted products

Product name	Content, %							Weight, g
	Au, g/t	Ag, g/t	Cu	Fe	S	C	As	
Primary Matte	134.4	78.6	7.4	42.0	20.7	2.05	0.47-0.64	50.0
Matte as-fired at temperature, °C								
600	136.8	79.3	6.45	41.45	16.21	2.05	0.088	56.17
650	128.8	75.6	6.81	39.97	16.10	2.05	0.048	56.35
700	122.4	78.0	6.45	41.45	15.27	2.01	0.052	56.80
750	123.4	81.6	6.69	42.19	14.48	2.00	0.048	56.92
800	127.8	73.6	6.21	39.97	14.34	2.00	0.056	56.66

Based on this, the second series of experiments on roasting of matte samples obtained during laboratory melting of gold-rich Bakyrchik gold ledge ores (Table 1, Sample No. 93) within 600-900 °C. However, the experimental procedure has significantly changed. Experiment was carried out in three stages. Matte was inserted in a alundum crucible placed into a high-temperature chamber furnace HTC 08/16 made by Nabertherm GmbH. Upon reaching the desired temperature in the furnace, the matte sample was subject to roasting for one hour with stirring during exposure, to prevent baking of the material, since baking may hinder removal of sulfur from the matte. After cooling, the crucible was removed from the furnace, the sample was mixed thoroughly for re-roasting at the same temperature. After such three-time roasting, samples of the roasted products obtained were transferred for sulfur, arsenic and carbon analysis.

Tables 3 and 4 below show the compositions of primary mattes obtained during melting of the ore from the Bakyrchik deposits together with the copper sulfide concentrate and calcium flux, and the second series results of experiments on roasting of gold-iron mattes.

The data in Table 4 and Figure 2 show that the reduction of sulfur and carbon in the roasted products to 1.50 and 4.89 %, respectively, is observed with increasing roasting temperature. However, the arsenic content is remained mostly at the level of the primary matte. The observed increase in sample weight is apparently connected with the formation of Fe_2O_3 , Fe_3O_4 iron oxides. Moreover, repeatedly during experimental procedures it was found that during sulfur burning the ratio of percentages content of Fe_2O_3 and Fe_3O_4 in the roasted products increases.

Table 3 – Chemical compositions of primary gold-iron mattes

Product name	Sample No.	Chemical composition, %							Weight, g
		Fe	S	Cu	As	C	Au, g/t	Ag, g/t	
Matte	93	48.84	32.87	6.33	0.33	2.05	49.60	55.8	50
	94	45.15	32.77	12.90	0.32	2.10	48.80	184.9	50
	95	51.07	33.70	4.14	0.32	1.90	57.20	43.0	50

Table 4 – Chemical compositions of roasted products obtained from residual contents of sulfur, arsenic and carbon during the roasting of primary mattes within the temperature range 600-900 °C

T, °C	Primary Matte, sample No.	Material name	Sample No.	Content, %						Weight, g
				Au, g/t	Cu	Fe	S	As	C	
600	93	Roasted product	110	49.60	6.33	48.84	8.02	0.24	2.52	54.34
700	93		104	49.60	6.33	48.84	7.17	0.30	2.03	55.36
800	94		111	48.80	12.90	45.15	5.76	0.26	1.64	51.13
900	95		115	56.60	3.77	49.59	4.89	0.21	1.50	49.07

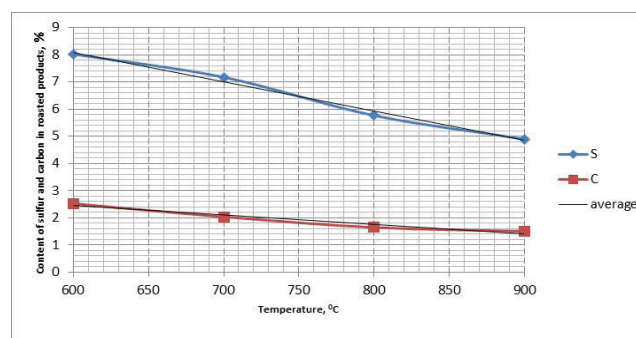


Figure 2 – Dependence of the residual contents of sulfur and carbon on the temperature during the roasting of mattes in an air

Results Discussion. In general, even at 900 °C full burning out of volatile components is not achieved in this series of experiments on roasting the mattes. One reason for such behavior of the sulfur, arsenic and

carbon in the test collector matte for gold, apparently, is lack of oxidation potential for gas-phase falling into the furnace only by air leaks which volumes during the experiments were not controlled. In addition, part of the residual sulfur content in roasted products can be associated with copper in a copper sulphide (Cu_2S), oxidation of which is possible only under conditions of full oxidation of ferrous sulfide and metallic iron.

Roasted products of gold-iron collector mattes samples have also been studied with physical methods of analysis. Thus, the results below are shown for mineralogical analysis of roasted product sample No. 115.

The composition of all samples and components of their natural and man-made structures was studied with the help of an JEOL JXA 8230 Electron Probe Microanalyzer. Electron probe studies were performed in the following modes: COMPO – minerals images in backscattered electrons; SEI – minerals images in secondary electrons; EDS – energy dispersive spectrometry, mapping by the elements; WDS – wave-length dispersive spectrometry with more sharp and sensitive images in comparison with EDS.

The color of roasted product sample is dark-brown. It has medium magnetization. Photomicrographs of the roasted products were obtained in COMPO mode (Figures 3, 4, 5, 6). The gold content in such roasted product is 56.6 g/t. Main mass of the sample material was represented by newly-formed compounds FeO_2 . Its content was about 75-77 %. They are represented in the form of grains without clear cut with size from thousandths to hundredths mm in cross-section. Often it formed aggregate accumulations of small grains. The mineral was light gray, anisotropic. About 10 % is newly formed mineral oldhamite with CaS , i.e. a mineral of cubic system. It is very rare and occurs naturally in meteorites. As a manufactured mineral, it is present in alloy material, i.e. in mattes.

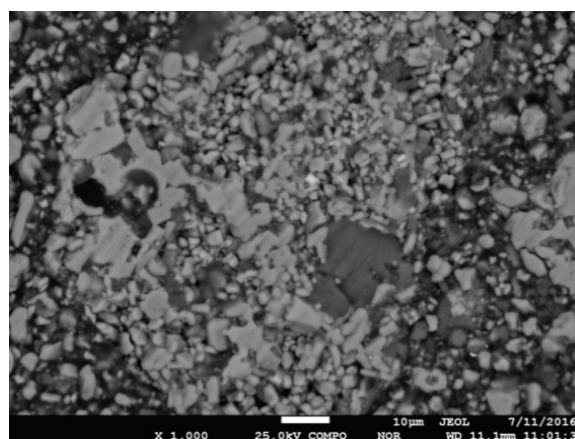
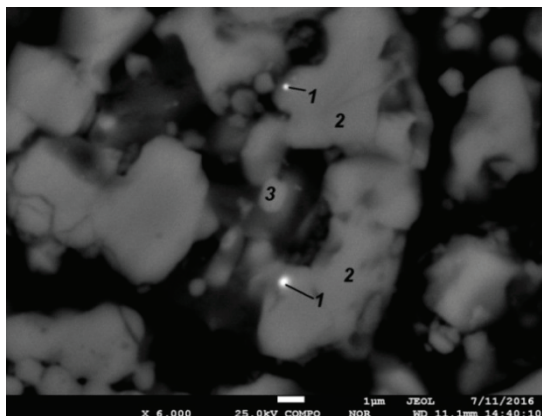
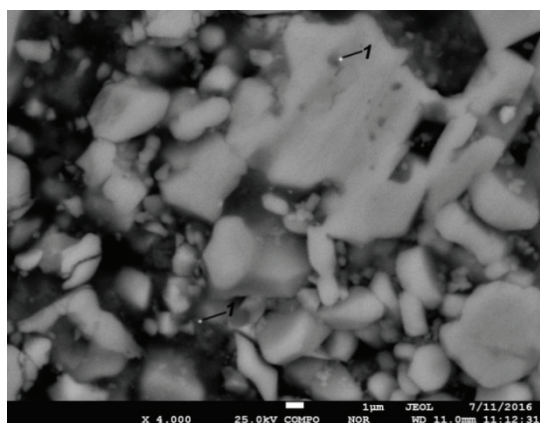


Figure 3 – Photomicrograph of a roasted product sample (COMPO, x 1000)



1 - finely dispersed gold; 2 - artificial mineral matrix consisting of iron, copper and zinc oxides

Figure 4 – Roasted product sample (COMPO, x 6000)



1 - finely dispersed gold in artificial mineral matrix consisting of iron and oldhamite oxides

Figure 5 – Roasted product sample (COMPO, x 4000)

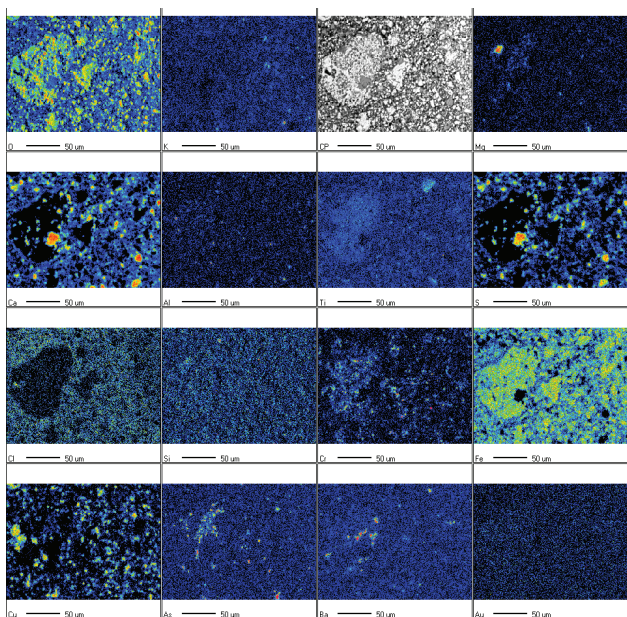


Figure 6 – Element concentration in artificial mineral matrix of roasted product sample No. 115 (WDS, x500)

Figures 7, 8 show thermograms of roasted product heating and cooling obtained at 900 °C. As a result, these data show that intensive weight reduction for roasted product starts at 900 °C, and the melting temperature for roasted products with the occurrence of a liquid phase has been determined at the level of 1241 °C. The following describes the thermograms obtained from research of the roasted products.

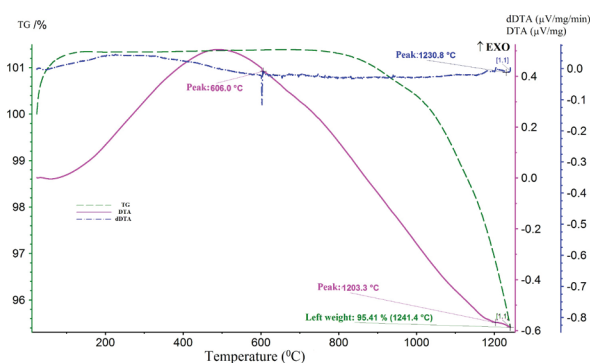


Figure 7 – Thermogram of roasted product matte heating (at 900 °C) within 100-1200 °C

There are two extremely weak endothermic effects appeared in the DTA curve of the sample No. 115 (Table 4). Their extremums were in 606 and 1203 °C. The first temperature effect is suitable for development of the polymorphic transformation of SnS (602 °C), for which there are no RFSA data, so we can only suppose. After 900 °C melting the weight of the sample reduces intensively. The latter effect is associated with occurrence of a liquid phase, but during heating to 1241 °C the sample was completely melted. On the DTA curve obtained during sample cooling, there were two exothermic effects with peaks at 927 and 1189 °C. The first temperature peak is suitable to occurrence of AgO_2 or Ag.

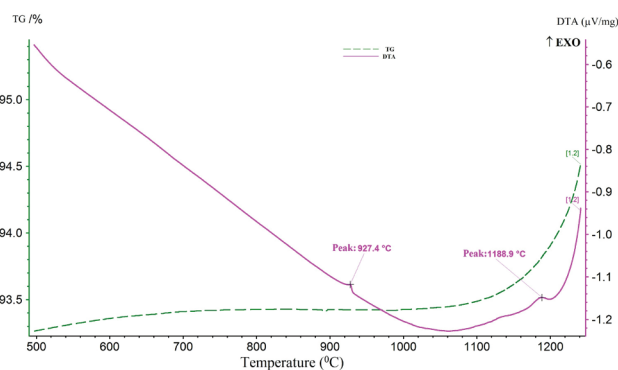


Figure 8 – Thermogram of roasted product matte cooling (at 900 °C) within 1200-500 °C

In general, in this section on temperature effect on oxidation of ferrous collector matte for gold, silver

and copper, the findings according to general view are similar to the same results for the solid-phase oxidation of pure iron sulfide [4-6].

Conclusions. In conclusion, it should be noted that in the process of study of solid-phase oxidation of gold-iron collector mattes, and during subsequent studies of oxidation products of tested matte samples, the following features of their composition should be considered. Firstly, in this case, metallized glandular mattes are studied objects which contain copper sulfides, metal iron and minor constituents of slag inclusion besides the main component, iron sulfide. Secondly, in the condition of lack of contact of the oxidative gas phase with analyzed collector matte weight, the partial oxidation of the main component, i.e. iron sulfide, has taken place in the roasted products received. Under these conditions noted above, a major amount of sulfur in the roasted products was apparently in the form of cuprous sulphide. Table 7 shows that the copper content in primary matte was within the limits of 3.77-12.9 %.

Thus, given the data on oxidation of collector mattes in air and the results of their thermographic studies it can be considered that the optimum temperature of such process should be within the limits of 700-800 °C.

REFERENCES

- 1 Kozhakhmetov S.M. *Novyye effektivnyye protsessy v pirometallurgii medi, nikelya i zolota: izbrannyye trudy* (New effective process in igneous metallurgy of copper, nickel and gold: selected). Almaty: CNZMO, **2015**, 406 (in Russ.).
- 2 Lerman B.D., Omarova N.S. *Promyshlennyye ispytaniya vosstanovitel'noy elektroplovki zolotomyslyakovykh kontsentratorov Akbakayskogo GOKa* (Industrial tests for regenerative electric smelting of gold arsenic concentrates of Akbakay mining and refining plant). *Gornyy zhurnal Kazakhstana = Mining Journal of Kazakhstan*. **2008**. 3, 33-35 (in Russ.).

3 Pat. 13914 RK. *Sposob vyshchelachivaniya polimetallicheskogo syr'ya ustroystvo dlya yego osushchestvleniya* (Method of polymetallic raw materials leaching and device for its implementation) Kosmukhambetov A.R. Opubl. 15.01.2004, 1 (in Russ.).

4 Smirnov V.I. *Obzhig mednykh rud i kontsentratorov* (Roasting of copper ores and concentrates). Moscow: Metallurgiya, **1958**, 255 (in Russ.).

5 Margulis Ye.V. *Teoriya oksiditel'nogo obzhiga sulfidnykh materialov* (The theory of sulphide materials oxidizing roasting). *Metallurgiya tsvetnykh metallov i metody ikh analiza: sb. nauch. tr. Vsesoyuznogo nauchno-issledovatel'skogo gorno-metallurgicheskogo instituta tsvetnykh metallov* (Metallurgy of non-ferrous metals and methods of their analysis: collection of research papers of All-Union Scientific Research Institute of Mining and Metallurgy of non-ferrous metals). Moscow, **1962**, 7, 15-20 (in Russ.).

6 Grishankina N.S. *Issledovaniya povedeniya sernistogo zheleza primeritel'no k usloviyam plavki mednogo sulfidnogo syr'ya v rasplavlennom sostoyanii: avtoref.... k.t.n.* (The iron sulfide behavioral research relative to copper sulfide raw material smelting conditions in a molten state: abstract of thesis for PhD Tech. Sci.: 05-322). Alma-Ata: Institute of metallurgy and ore beneficiation, **1971**, 20 (in Russ.).

ЛИТЕРАТУРА

- 1 Кожакметов С.М. Новые эффективные процессы в пирометаллургии меди, никеля и золота: избранные труды. – Алматы: ЦНЗМО, 2015. – 406 с.
- 2 Лерман Б.Д., Омарова Н.С. Промышленные испытания восстановительной электроплавки золотомышьяковых концентратов Акбайского ГОКа // Горный журнал Казахстана. – 2008. – №3. – С. 33-35.
- 3 Пат. 13914 РК. Способ выщелачивания полиметаллического сырья устройство для его осуществления / Космукхамбетов А.Р.; опубл. 15.01.04, Бюл. №1.
- 4 Смирнов В.И. Обжиг медных руд и концентратов. – М.: Metallurgiya, 1958. – 255 с.
- 5 Маргулис Е.В. Теория окислительного обжига сульфидных материалов // Metallurgiya tsvetnykh metallov i metody ikh analiza: sb. nauch. tr. Vsesoyuznogo nauchno-issledovatel'skogo gorno-metallurgicheskogo instituta tsvetnykh metallov. – Москва, 1962. – №7. – С. 15-20.
- 6 Гришанкина Н.С. Исследования поведения сернистого железа применительно к условиям плавки медного сульфидного сырья в расплавленном состоянии: автореф.... к.т.н.: 05-322. – Алма-Ата: Институт металлургии и обогащения, 1971. – 20 с.

ТҮЙІНДЕМЕ

Зерттеу аумағы болып табылатын алтын үшін коллекторлы штейндер, күйінді және ұшқыш заттарды құрайтын – күкірт, мышьяк және көмітек, алтын және күміс құрайтын штейндер, қождар, жаңа коллекторлы алтын балқымалары, штейнді балқымаларды құнды металдармен пирометаллургиялық байыту. Лабораториялық жағдайда 600-900 °C температура интервалында алтын үшін коллекторлы және басқа да металдар штейнін күйдіру процесіне температураның әсерін зерттеу жұмыстары жүргізілді. Осы жағдайда алынған нәтижелер қысқартылған пирометаллургиялық селекция (ҚПС-процесс) әдісімен, берік және екі еселі берік түпкі алтын кенін және концентраттарын ашу барысында коллекторлы сульфидті штейн құрамынан жаңа әдіспен алтынды бөліп алу әдісін құру және өңдеу жолында қолданылатын болады.

Түйінді сөздер: штейн, қож, алтын, қысқартылған пирометаллургиялық селекция, ҚПС-процесс.

РЕЗЮМЕ

Объектом исследований явились коллекторные для золота штейны, огарки и летучие составляющие – сера, мышьяк и углерод, золото- и серебросодержащие штейны, шлаки, новые коллекторы – расплавы золота, пирометаллургически обогащенные

благородными металлами штейновые расплавы. Проведены лабораторные опыты по изучению влияния температуры на процесс обжига коллекторных для золота и других металлов штейнов в интервале температур 600-900 °С. При этом результаты проведенных исследований будут использованы в разработке и создании новых методов извлечения золота и других металлов из коллекторных сульфидных штейнов. Указанные штейны получают при плавке упорных и двойной упорности к вскрытию коренных руд и концентратов золота, методом сократительной пирометаллургической селекции (СПС-процесс).

Ключевые слова: штейн, шлак, золото, сократительная пирометаллургическая селекция, СПС-процесс.

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EXTRACTION of COPPER and PRECIOUS METALS from DEPLETED COPPER DUMPS of SAYAK DEPOSIT

Abstract: An opportunity of complex recycling of dumps of copper-bearing materials with perspective of additional extraction of precious metals from them was studied in this work. During experiments on leaching the copper from the dumps of Sayak field, by agitation and percolation methods, the opportunity of subsequent additional extraction of gold and silver was studied. It was established that preliminary acid leaching of the basic metallurgical product - copper increases the weight portion of gold up to the level of 0.5-0.6 g/t. Further that allows refer the depleted copper dumps to off-balance gold-bearing raw materials and after neutralization of acid medium to conduct cyanide leaching of precious metals. Long-term treatment of dumps with sulfuric acid in the course of copper extraction promotes also removal of iron compounds, which also as copper, inhibits extraction of gold during cyanidation. In the course of copper leaching during 90 days, from the uncrushed dumps, the index of copper extraction was 78.6 %. Experiments on leaching the precious metals from decoppered dumps showed the following extraction results, %: gold – 44.5, silver – 60.3. At preliminary crushing the dump material to grain size grade of –1.0 mm, these results was, %: gold – 66.7, silver – 67.2. Taking into account the global tendency of involving off-balance ores with decreasing content of gold to the process of gold extraction, the decoppered dumps of Sayak field in the longer term perspective, may also be considered as a raw material for extraction of precious metals.

Keywords: off-balance ores, copper dumps, copper leaching, precious metals, cyanidation, recovery, gold, silver, extraction.

Introduction: Modern tendency of reducing the quality of gold-bearing ores is associated with increasing the fraction of ores with low gold content, as well as inclusion to retreatment of depleted gold-bearing rock, accumulated dumps, low-grade and unpayable ores. If in the 1960s, a ton of extracted front metal ore contained up to 10-20 g, and sometimes up 100 g of gold, today, at average the content does not exceed 1,5-2 g/ton. By now, a great amount of unpayable ores with gold content of 0,4-0,7 g/t has been accumulated at ore stockpiles of many fields. For the purposes of re-extraction of these ores using method of dump leaching, studies on column and agitation leaching are conducted in laboratories.

Formation of metal production from ores, concentrates or other types of metal-bearing

rocks -is quite a difficult task, It is significantly complicated for copper and nickel ores, which are as a rule comparatively low-grade and comprehensive poly-metallic rock. In retreatment of such rock by hydrometallurgical methods, it is necessary to ensure complex precipitation of all other valuable components to independent commodity products at high degree of their extraction, along with formation of the basic metal. Finally, metallurgical production should provide full application of all components of the processed raw material without any exclusion and creation of waste-free (dump-free) technologies.

The basic mass of copper ores consists of the compounds of copper, iron and gangue materials, thus the final aim of hydrometallurgical retreatment of these ores amounts to formation of the product