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 ^{0}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 получаются 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 due to complete removal of the gangue material, iron, and sulfur (to the extent of treatment of sulfide raw material).

In the course of treatment of gold-bearing rocks by cyanidation, the loss of sodium cyanide is mainly associated with detrimental impurities, usually existing in the ore in kind of different minerals. One of the factors, reducing extraction of gold is the existence of iron and copper bearing minerals, binding the alkaline cyanide and transferring it to complex cyanic compounds of non-ferrous metals (Cu, Zn, Ni, Co) and iron compounds.

Experimental Part and Results Discussion. To perform research work, preparation of samples of oxidized Sayak field copper dumps, represented by three types of samples: Moldybay, Sayak oxidized, and Tastau. After averaging and quartering, the selected samples underwent chemical (to determine the content of total and oxidized copper and precious metals), x-ray diffraction and x-ray fluorescence analyses.

During studying the material composition, a chemical analysis of samples of oxidized Sayak field copper dumps was performed, the results of the analysis are given in Table 1.

Table 1 – Results of detailed chemical analysis of the sample of Sayak field copper dumps

Sample from dump	Cu, %		Au, g/ton	Ag, g/ton
	Total	Oxidized		
Moldybay	0,24	0,045	0,14	5,48
Sayak oxidized	1,02	0,51	0,16	7,32
Tastau	1,37	0,033	0,69	1,12

In order to study the opportunity of gold extraction from depleted copper-bearing dumps, the object of the research was selected the sample of Moldabay site, the most complicated by composition, of Sayak field, with the content of total copper - 0,24 %, in the oxidized form - 0,045 %. The content of precious metals was: Au – 0,14 g/ton, Ag – 5,48 g/ton. Studying the phase and elementary composition of the sample was conducted using methods of x-ray diffraction and x-ray fluorescence analyses. The results are given in tables 2-3. The X- ray fluorescence semi-quantitative analysis was performed on the wavelength dispersive X-ray fluorescence spectrometer Axios 1 kW of "PANalytical" Company (the Netherlands). Processing of derived data was performed within Super Q software using the software package Omnian 37 (by FP model). According to results of the analysis, the quality semi-quantitative elementary composition of sample was determined.

Table 2 – Phase composition of the original sample Moldybay of Sayak field

Name	Formula	S-Q, %
Quartz, syn	SiO_2	20
Andradite, aluminian	$Ca_3Al_{84}Fe_{1.16}Si_3O_{12}$	13.5
Wollastonite	$CaSiO_3$	11.6
Cronstedite-6	$Fe_3FeSiO_4(OH)_5$	9.6
Cordierite, ferroan, sodian	$Na_{25}(Mg_{1.4}Fe_6)(Al_{3.84}Be_{16})Si_5O_{18}(H_2O)_6$	9.6
Donbassite-2Mla	$Al_{4.33}(Si_3Al)O_{10}(OH)_8$	8.5
Albite, calcian, ordered	$(Na,Ca)Al(Si,Al)_3O_8$	6.6
Calcite	$Ca(CO_3)$	5.6
Dolomite	$CaMg(CO_3)_2$	3.3
Microcline	$(K_{95}Na)AlSi_3O_8$	2.8
Magnetite syn	Fe_3O_4	2.6
Muscovite-2M1	$K_{0.932}Al_2(Al_{0.932}Si_{3.068}O_{10})((OH)_{1.744}F_{0.256})$	2.4
Iron Oxide	$Fe_{2.932}O_4$	2.1
Clinochlore	$Mg_{2.5}Fe_{1.65}Al_{1.5}Si_{2.2}Al_{1.8}O_{10}(OH)_8$	1.7

Table 3 - The X- ray fluorescence analysis of the original sample

Name of elements	Content in the samples, %
O	53.542
Na	1.755
Mg	0.761
Al	5.062
Si	20.044
P	0.053
S	0.413
Cl	0.026
K	1.001
Ca	9.432
Ti	0.135
Mn	0.194
Fe	7.329
Cu	0.239
Zn	0.007
Rb	0.003
Sr	0.030
Zr	0.006
Mo	0.006
Pb	0.012

The data of x-ray diffraction and x-ray fluorescence analyses showed in the sample the existence of significant amount of iron-bearing minerals. Thus, the x-ray diffraction analysis established, that the most part of iron was represented by comprehensive complexes and approximately 4,7 % are represented in kind of oxides: magnetite Fe_3O_4- 2,6 %, iron oxide $Fe_{2.932}O_4$- 2,1 %. The x-ray fluorescence analysis showed the total content of iron of approximately 7,3 %. In addition, existence of a large amount of calcium 9,4 was established in the sample. The content of silicon amounted to approximately 20 %, aluminum – 5 %, the x-ray diffraction analysis also detected the content of calcite ($Ca(CO_3)$) на уровне -5,6 % and dolomite ($CaMg(CO_3)_2$) – 3,3 %, which allows also refer Sayak field to carbonate-argillaceous rocks, enriched by silicon earth. This type is typical for such large fields as Gold Strike and Gold Quarry in the USA, Nezhdaninskoe, Natalkinskoe, Sovetskoe, Olimpiadninskoe and Sukhoy Log (Russia). Gold-sulfide pyrite-(pyrrhotine) arsenic-pyrite ore association with fine-dispersed gold is prevalent in them. The amount of sulfides and carbon in these ores do not usually exceed 3-5 %

During the process of studying the Moldybay sample, two experimental directions were worked out:

1) results of simultaneously conducted study on extraction of copper from dumps with grain size of up to 250 mm of Moldybay sample of Sayak field using percolation method were analyzed;

2) 3 variations of agitation leaching, with preliminary crushed material, were performed.

During percolation leaching of non-crushed dumps, after introduction of the process of extraction and further spraying by bypass solutions 78,6 % of copper was extracted within the period of 90 days. Moreover, significant amount of iron 13,5 13,5 g/dm^3, calcium– 0,6 g/dm^3, manganese – 0,46 g/dm^3, aluminum – 1,8 g/dm^3 were observed in the productive solution. As for precious metals, an insignificant content of silver amounted to 14 mg/dm^3 was detected, which was only 0,6 % of extraction from the original, no gold was detected. Results are provided in Table 4.

Table 4 - Analysis of solution for the content of precious and other extracted metals under acid spraying

Content						
Au, mg/l	Ag, mg/l	Al, g/l	Ti, g/l	Mn, g/l	Fe, g/l	Ca, g/l
not detected	0,14	1,85	0,0021	0,46	13,5	0,6

Results of the analysis showed, that in the process of leaching with sulfur acid, there is no gold extraction in the solution, silver is extracted in small amounts 0,3-0,6 %. The original content of gold in Moldybay dumps amounts to 0,14 g/ton, silver – 5,48 g/ton. Upon completion of leaching the copper by sulfur acid, the mass fracture of gold and silver in the depleted ore increases (Table No.5). In addition, in the process of sulfur acid treatment, there is reduction in the content of iron compounds, which like copper, inhibits the process of cyanidation in gold leaching.

Table. 5 – Change in the content of precious metals in dumps after sulfuric-acid leaching of copper

Original content, g/ton		The content after sulfuric-acid leaching of copper, g/ton	
Au	Ag	Au	Ag
0,14	5,48	0,57	6,3

Taking into account the derived results, experiments on agitation leaching of gold and silver from the depleted Moldybay dump of Sayak field were performed.

An ore charge of 400 g weight, preliminary crushed to grain size of 1,0 mm, with original content of copper - 0,24 %, gold – 0,14 g/ton, silver – 5,48 g/ton was taken for the purposes of study. At the first stage, leaching was performed using sulfur acid with the concentration of 20 g/dm^3, the solid to liquid ratio = 1:4, within 8 hours. Results are provided in table.6.

Table 6 – The content of elements in the productive solution in agitation leaching.

The content of elements, g/dm^3			
Cu	Ca	Fe^{3+}	Fe^{2+}
0,54	0,77	0,29	1,48

The volume of productive solution amounted to 1,3 l, which under concentration of Cu – 0,54 g/l provides the index of copper extraction of 73,13 %. The yield of precious metals to the solution was not observed, their mass fraction in cake increased up to: Au – 0,6 g/ton, Ag – 6,4 g/ton. The cake mass after leaching amounted to 392 g. Two charges of 100 g were taken from the remaining part of cake for experiments with cyanidation. After measuring the pH index, neutralization of acid medium in cake was performed. In addition, a charge of 100 g of the original sample was selected without preliminary leaching by sulfur acid, also crushed up to grain size of 1 mm. the experimentation on agitation leaching was performed in three variations:

1) Cyanidation of the original sample without preliminary leaching using sulfur acid;

2) Cyanidation of the sample after copper leaching using sulfur acid.

Leaching was conducted within 12 hours using cyanide solution with concentration of 1 g/dm^3, with solid to liquid ratio = 1:4. In addition to agitation leaching, an experiment on dump cyanidation was also performed. The remained sample of non-crushed dump after neutralization of acid medium and attaining the pH of 10,5-11,0, underwent the spraying with solution of sodium cyanide with concentration of 1 g/dm^3, within 50 days. Cakes and the dump derived from the agitation leaching after cyanidation were analyzed for the content of gold and silver. Results of analyses were provided in table 7.

Table 7 – Results of cyanidation of Moldybay sample of Sayak field

Sample	Leaching method	Size class, mm	Content original, g/ton		Content in cake, g/ton		Extraction, %	
			Au	Ag	Au	Ag	Au	Ag
Original	Agitation, CN 1g/l	-1,0	0,14	5,48	0,28	2,58	-	52,92
After acid leaching of copper	Agitation, H_2SO_4, → neutral. → CN 1g/l	-1,0	0,6	6,4	0,2	2,1	66,7	67,2
Dump after acid leaching of copper	Percolation, H_2SO_4, → neutral. → CN 1g/l	-250	0,57	6,3	0,35	2,28	44,5	60,3

According to results of analyses, it was determined that preliminary leaching of non-ferrous metals using sulfur acid with subsequent neutralization allows further extraction through cyanidation. Thus, in cyanidation of the original sample, increase in mass fraction of gold from 0,14 to 0,28 g/ton was observed in cake. This is the evidence that no extraction of gold take place, but cyanide addition is spent for formation of cyanic complexes of iron and copper. However, silver is extracted of up to 52,92 %. Preliminary extraction of copper and the concurrent transformation to sulfur acidic solution of iron compounds allows extracting gold of up to -66,7 %, silver – 67,2 %. Spraying of the depleted copper dump with cyanide provides indexes of extraction lower than in agitation leaching, in terms of gold it amounts to – 44,5 %, in terms of silver – 60,3 %.

Conclusion: Low production costs of dump leaching allow excluding performance of tank leaching at a factory, which include preliminary crushing, transportation and other preparation processes. Leaching in heaps under insignificant capital and operational costs allows processing large masses of unpayable raw materials, and deriving significant amount of copper. In subsequent extraction of precious metals from already decoppered dump, using the method of dump leaching, preparation processes, associated with dump transportation, heap formation, installation of spraying and drainage system. The unpayable raw materials with the content of gold within 0,5-0,7 g/ton is referred today as an unprofitable in terms of gold mining. However, considering the tendency of increasing the share of ores with increasingly low content of gold, as well as the fact that in case with Sayak field an opportunity of further cyanidation of dumps, avoiding the stage of ore preparation - leaching of precious metals under dump technology may be considered as further perspective for the group of these fields.

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ТҮЙІНДЕМЕ

Бұл жұмыста үйінді түріндегі мысқұрамды шикізатты кешенді өңдеу және сонымен бірге қосымша асыл металдарды алу мүмкіндіктері зерттелген. Саяқ кенорнының үйінділерінен мысты ерітінділеу бойынша жүргізілген тәжірибелер барысында агитациялық және перколяциялық әдістер арқылы ары қарай алтын мен күмісті қосымша алу мүмкіндіктері зерттелді. Негізгі металлургиялық өнім – мысты алдын ала қышқылдық ерітінділегенде, алтынның массалық үлесі 0,5-0,6 г/т деңгейге дейін артатыны анықталды. Бұл өңделіп біткен мыс үйінділерін есептен шығарылған алтынқұрамды шикізатқа жатқызуға мүмкіндік береді және олардағы қышқылдық ортаны бейтараптағаннан кейін асыл металдарды цианидті ерітінділеу арқылы алуға болады. Мысты алу үрдісінде үйінділерді ұзақ уақыт күкірт қышқылымен өңдегенде темір қосылыстары сыртқа шығарылады, ал темір мыс сияқты циандағанда алтынның бөлінуін қиындатады. Мысты 90 тәулік бойы ерітінділегенде ұсатылмаған үйіндідегі мыстың бөліну көрсеткіші 78,6 % құрады. Мыссыздандырылған үйінділерден асыл металдарды ерітінділеу бойынша тәжірибелер алтынның бөліну көрсеткіші – 44,5 %, күмістің – 60,3 % көрсетті, ал үйіндіні алдын ала – 1,0 мм ірілікке дейін ұсатқанда бұл көрсеткіштер алтын бойынша – 66,7 %, күміс бойынша – 67,2 % құрады. Есепке алынбаған кендерді алтын алу үрдісіне тартудағы әлемдік үрдісті және кендердегі алтынның мөлшері күннен күнге азайып бара жатқанын ескеріп, Саяқ кенорнының мыссыздандырылған үйінділері болашақта асыл металдарды алатын шикізат ретінде қарастырылуы мүмкін.

Түйін сөздер: үйіндіні ерітінділеу, есептен шығарылған кендер, мыс үйінділері, мысты ерітінділеу, асыл металдарды ерітінділеу

РЕЗЮМЕ

В данной работе исследована возможность комплексной переработки медьсодержащего сырья, представляющего собой отвалы, и перспективы доизвлечения из них благородных металлов. В ходе проведения экспериментов по выщелачиванию меди из отвалов месторождения Саяк, агитационным и перколяционным методами, изучена возможность последующего доизвлечения золота и серебра. Было установлено, что предварительное кислотное выщелачивание основного металлургического продукта – меди, повышает массовую долю золота, до уровня 0,5-0,6 г/т. Это позволяет впоследствии отнести отработанные медные отвалы к забалансовому золотосодержащему сырью и после нейтрализации кислой среды вести цианидное выщелачивание благородных металлов. Длительная обработка отвалов серной кислотой в процессе извлечения меди, способствует также удалению соединений железа, которое в свою очередь также как и медь затрудняет извлечение золота при цианировании. В ходе выщелачивание меди в течение 90 сут. из недробленого отвала показатель извлечения меди составил 78,6 %. Эксперименты по выщелачиванию благородных металлов из обезмеженных отвалов показали извлечение, %: золото – 44,5; серебро – 60,3. При предварительном измельчении отвала до класса крупности –1,0 мм эти показатели составили, %: золото – 66,7; серебро – 67,2. Учитывая мировую тенденцию вовлечения в процесс золотодобычи забалансовых руд с все более и более низкими показателями содержания золота, обезмеженные отвалы месторождения Саяк в дальнейшей перспективе могут также рассматриваться как сырье для получения благородных металлов.

Ключевые слова: выщелачивание отвалов, забалансовые руды, медные отвалы, благородные металлы, медь, золото, серебро, цианирование.

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