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Ore treatment hydrogen peroxide during heap leaching of gold

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ABSTRACT

Over the past century, many problems have been focused on the problems of low leaching rate of gold and methods have been developed to intensify the leaching of gold. Among these methods, the use of hydrogen peroxide to accelerate the leaching of gold is known. In order to intensify the leaching process, the indicators of cyanide leaching of gold from ore using hydrogen peroxide were studied. This article presents the results of assay-gravimetric, chemical, and mineralogical analyses of gold-bearing ore from the Sari Gunay Deposit (Iran). The content of sulfide sulfur ore belongs to the category of low-sulphide, by oxidation of sulphur (50.70%) to the category of oxidized ores. Thermodynamic analysis of possible reactions of ore components with hydrogen peroxide is carried out. Laboratory studies on cyanide leaching of gold have shown that the maximum recovery of gold is 52.92% at a concentration of hydrogen peroxide of 0.5%, the recovery of gold without ore treatment is 52.03%. The results of laboratory and column tests with and without treatment with hydrogen peroxide (H_2O_2–0.5%) were compared. Treatment of gold-bearing ore with hydrogen peroxide during heap leaching of gold increases gold recovery by 1.2% and amounts to 55.89%, without treatment - 54.69%. This increases the consumption of sodium cyanide by 0.04 kg/t.

Keywords: heap leaching gold, heap leaching intensification, gold leaching, hydrogen peroxide, oxidizer, gold.

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Introduction

The technology of heap leaching of gold-bearing ores has been known for about a hundred years and undoubtedly has positive aspects, namely [1]:

- low investment;
- reduced terms of preparation of production;
- low cost of extracting a valuable component;
- the possibility of developing small ore deposits that are economically inexpedient to develop using the traditional factory method;
- fast payback of projects;

- high labor productivity with a minimum number of workers;

- lack of energy-intensive and material-intensive operations.

Over the past century, many problems have been directed towards the low rate of gold leaching and methods have been developed to intensify gold leaching [2-4].

Among these methods, the use of hydrogen peroxide to accelerate the leaching of gold is known [5-9]. Hydrogen peroxide was mainly used for detoxification of waste water and neutralization of waste heaps [10-12] and for oxidation during intensive cyanidation of gold [13-15].

The reaction of dissolution of gold in the presence of hydrogen peroxide can be represented as follows [5-9]:

$$2Au + 4NaCN + H_2O_2 = 2NaAu(CN)_2 + NaOH \quad (1)$$

The more active the oxidizing agent, the higher its oxidizing capacity and concentration in the leach solution, a high degree of oxidation rate should be expected. At the same time, with a sufficient oxidation potential, for example, in the presence of hydrogen peroxide, in addition to gold, cyanide can also be oxidized [16]:

$$NaCN + H_2O_2 = NaCNO + H_2O \quad (2)$$

The above reaction is the chemical basis of a widely used method for neutralizing waste cyanide solutions. Thus, the introduction of an oxidizing agent, stronger than oxygen, which is the basis for the acceleration of cyanide leaching, itself has a limitation. It is quite obvious that the limiting factor is the redox potential of the leaching system. This parameter should ensure the intensification of gold oxidation (reaction (1), in which oxidative decomposition of cyanide becomes possible (reaction (2) [17].

In this research paper, in order to intensify the leaching process, the indicators of cyanide leaching of gold from ore using hydrogen peroxide were studied for the first time.

Experimental part and discussion of results

Gold ore from the Sari Gunay deposit (Iran) was used for research. According to the results of assay analysis, the average gold content in the ore is 2.90 g/t [18-20]. The chemical composition of the ore is represented by the following components in, %: Cu 0.009, Zn 0.0082, Ni 0.0003, Pb 0.108, Mn 0.0005, Co 0.0003, Cr 0.0013, Mo 0.0001, Hg 0.0025, As 0.11, Sb 0.0563, K_2O 7.30, Na_2O 1.34, SiO_2 61.4, Al_2O_3 19.7, TiO_2 0.49, MgO 0.80, CaO 0.31, P_2O_5 0.21, Fe total 2.67, Fe oxidized 0.44, Fe sulfide 2.23, S total 1.48, S sulfide 0.73, S sulfate 0.75. Mass fraction of total sulfur is 1.48%; that of sulfide sulfur is 0.73. The ore belongs to the low-sulfide category by the sulfide sulfur content and to the category of oxidized ores by the sulfur oxidation level (50.7%). A special feature of the rock is a negligible content of total iron (2.67%), while iron sulfide (2.23%) is mainly bound up with pyrite [20].

Mineralogical analysis has established that the gold in the sample is, in the main mass, in the form of dispersed grains (no more than 2 microns) and inclusions in hydroxides, iron oxides and skorodite. The mineralogical composition of the ore of the Sari Gunay deposit is presented in Table 1.

Table 1 - Mineralogical composition of the ore from the Sari Gunay deposit

Minerals	Mass fraction, %
Rock-forming minerals	
Quartz	23.0
Orthoclase	30.0
Plagioclase	6.0
Hydromica	28.0
Biotite	2.0
Chlorite	1.0
Kaolin	1.0
Gypsum	<1.0
Ore minerals	
Jarosite	2.0
Magnetite, Haematite	1.0
Iron hydroxide	<2.0
Scorodite	2.0
Cinnabar	Isolated grains
Metacinnabar	Isolated grains
Sulphides	
Pyrite	1.0
Arsenopyrite	Isolated grains
Galena	Isolated grains
Total	100.0

In the research paper of a number of authors [21-24], it is proposed to use oxidizing agents such as hydrogen peroxide and others to open gold particles associated with metal sulfides. In this case, peroxide solutions are added directly to the cyanide leaching solution. The thermodynamic analysis of the reactions (Table 2) shows that the addition of such a strong oxidizer as hydrogen peroxide directly to the cyanide solutions used. In the heap leaching

Table 2 - Possible thermodynamic reactions of the ore components with hydrogen peroxide

№	Reaction	ΔG, kJ /mol			
		298 K	323 K	353 K	373 K
1	$2NaCN + H_2O_2 + 2O_2(g) = 2NaOH + 2CO_2(g) + N_2(g)$	-1261,41	-1260,52	-1259,34	-1258,54
2	$2NaCN + H_2O_2 = 2NaOH + 2C + N_2(g)$	-472,67	-471,65	-470,31	-469,39
3	$FeS_2 + 2.5O_2(g) + 2H_2O_2 = FeO + 2H_2SO_4$	-1195,93	-1184,04	-1170,04	-1160,86
4	$FeS_2 + 7.5H_2O_2 = Fe(OH)_3 + 2H_2SO_4 + 4H_2O$	-1866,88	-1856,34	-1844,47	-1836,96
5	$FeS_2 + 7H_2O_2 = FeO + 2H_2SO_4 + 5H_2O$	-1711,89	-1703,79	-1694,92	-1689,44
6	$2FeAsS + 9H_2O_2 = 2FeO + As_2O_3 + 9H_2O + 2SO_2(g)$	-2386,97	-2383,55	-2380,89	-2378,89
7	$2FeAsS + 10H_2O_2 = Fe_2O_3 + As_2O_3 + 10H_2O + 2SO_2(g)$	-2733,24	-2727,32	-2722,22	-2717,85
8	$FeAsS + 2.5H_2O_2 + 1.5O_2(g) = FeO + H_2SO_4 + H_3AsO_3$	-1135,35	-1126,16	-1116,88	-1107,51
9	$2FeAsS + 5H_2O_2 + 3.5O_2(g) = Fe_2O_3 + 2H_2SO_4 + 2H_3AsO_3$	-2513,77	-2492,12	-2470,29	-2448,27
10	$FeAsS + 2.5\ H_2O_2 + 2O_2(g) = FeO + H_2SO_4 + H_3AsO_4$	-1263,81	-1251,87	-1240,02	-1228,23
11	$2FeAsS + 5H_2O_2 + 4.5O_2(g) = Fe_2O_3 + 2H_2SO_4 + 2H_3AsO_4$	-2770,69	-2743,55	-2716,56	-2689,7
12	$FeAsS + H_2O_2 + 3O_2(g) = FeAsO4 + H_2SO_4$	-1218,49	-1204,82	-1191,24	-1177,75
13	$FeAsS + H_2O_2 + 2.5O_2(g) = FeAsO4 + H_2O + SO_2(g)$	-1065,81	-1058,72	-1051,71	-1044,75
14	$FeAsS + 2.5H_2O_2 = FeSO_4 + AsH_3(g) + H_2O$	-548,23	-546,91	-545,65	-544,43
15	$CuS + 4H_2O_2 = CuSO_4 + 4H_2O$	-1021,20	-1015,04	-1009,20	-1003,66

of gold will lead to the destruction of sodium cyanide to form an alkali (Reaction (1) and (2), Table 2). The decrease in the concentration of cyanide, respectively, reduces the extraction of gold. Based on the technology of heap leaching of gold, in which one of the stages of the process is paused between irrigations [25]. This technological method is used in the presence of sulfide minerals in the ore, in which there is finely disseminated gold.

If hydrogen peroxide is used when irrigating a heap without supplying alkaline cyanide solutions, then the oxidizing agent will react with the sulfide part of the ore. Thermodynamic calculations show that pyrite, arsenopyrite and galena present in ores can be oxidized in the presence of hydrogen peroxide with the formation of various compounds, oxides, sulfates, etc. Oxidation and dissolution of iron and copper sulfates will lead to the opening of finely disseminated gold, which can then be extracted at supply of cyanide solution.

Laboratory tests of ore leaching

Laboratory tests on cyanide leaching were carried out in an agitator with a rotation speed of 30 rpm. The modes of leaching were as follows: ore size -12 mm, ore sample weight for each experiment 500 g, ratio Solid:Liquid =1:2, pH 10-11, concentration of sodium cyanide 0.1 %, leaching duration 24 hours. During the leaching process, the concentration of sodium cyanide and the pH of the medium were monitored, and, if necessary, reagents were added.

Based on the data of thermodynamic analysis, the ore was treated with hydrogen peroxide for 30 min before cyanide leaching. The hydrogen peroxide concentration for treatment ranges from 0.2% to 1%. After the completion of leaching, the filtered solution and the solid phase of the tailings were analyzed for gold content.

The results of gold leaching are shown in Figures 1-2.

The results show that the maximum gold recovery is 52.92% at a hydrogen peroxide concentration of 0.5%, the gold recovery without ore treatment is 52.03%. For further research on heap leaching of gold, this concentration of hydrogen peroxide (0.5%) was chosen as the optimal one.

Research on the technology of heap leaching of gold

Heap leaching of gold in columns was fulfilled in a closed cycle: leaching of gold from the ore with alkaline cyanide solutions; sorption of dissolved gold with activated carbons; return of the solution into circulation for leaching after correcting the concentration of sodium cyanide and pH.

Attributes of the unit for conducting column studies are as follows: ore size is –20 mm; diameter of columns for leaching is 100 mm; height of leaching columns is 800 mm; height of the ore layer in the column is 750 mm. The ore mass in the columns by dry weight is 9 kg. Solutions of 0.05% (0.5 g/L) sodium cyanide were used as a leaching solution; the pH value was maintained within 10.5–11.0 by adding sodium hydroxide.

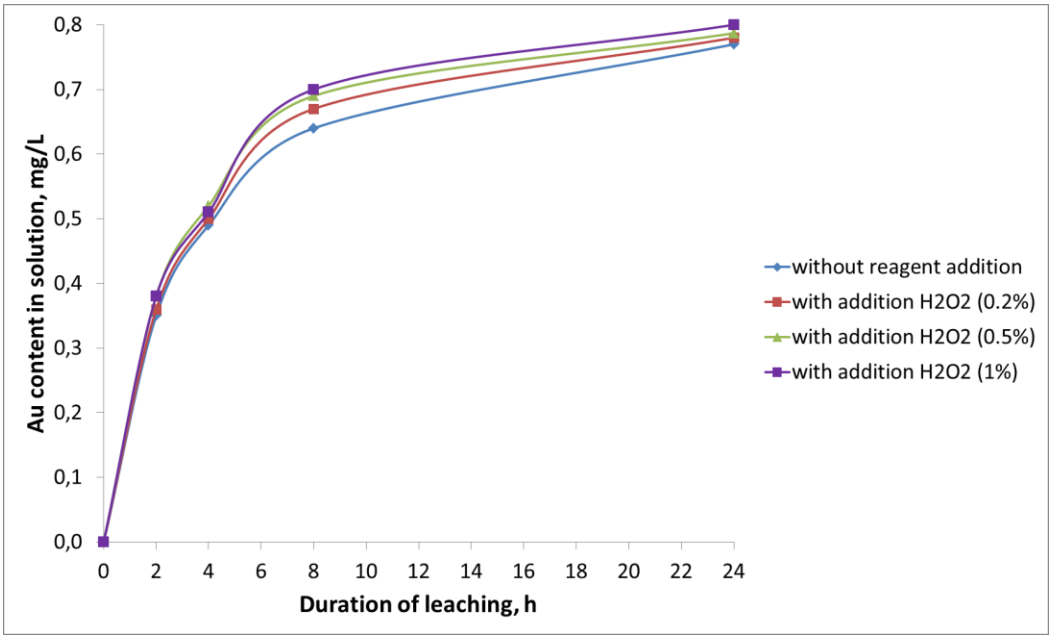

Figure 1 - Gold dissolution kinetics of crushed ore to a particle size of-12+0 mm

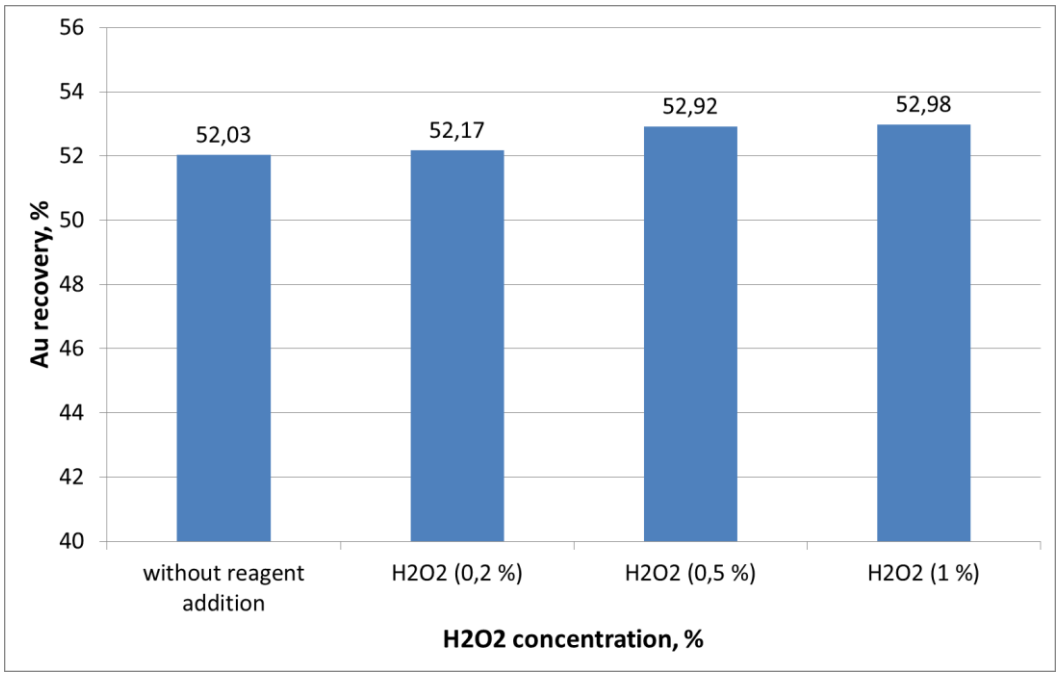

Figure 2 - Gold recovery degree of crushed ore to a particle size of -12+0 mm

For comparison purposes, two series of research were conducted on heap leaching of gold with the addition of hydrogen peroxide and without that.

The method of leaching with the addition of hydrogen peroxide was carried out as follows: The first 3 cycles of ore leaching were treated only with a solution of 0.5 % hydrogen peroxide. In subsequent leaching cycles, the addition of this reagent was stopped and the leaching was carried out with a cyanide-alkaline solution. It took 15 leaching cycles to dissolve the gold. The results of heap leaching of gold are shown in Figures 3-5.

Figures 3-4 show that pre-leaching ore treatment with hydrogen peroxide at the beginning of three leaching cycles increases the gold content in productive solutions. The degree of gold recovery with treatment with hydrogen peroxide (55.89%) is 1.2% higher than in the experiments without treatment of this reagent (54.69%).

The consumption of sodium cyanide for leaching without treatment was 0.65 kg/t.

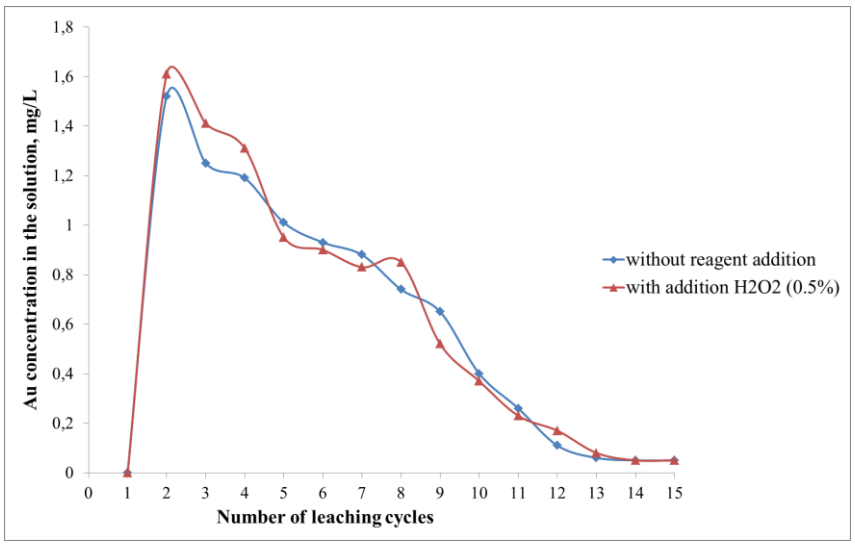

Figure 3 - A change in the content of gold in productive solutions in the leaching process

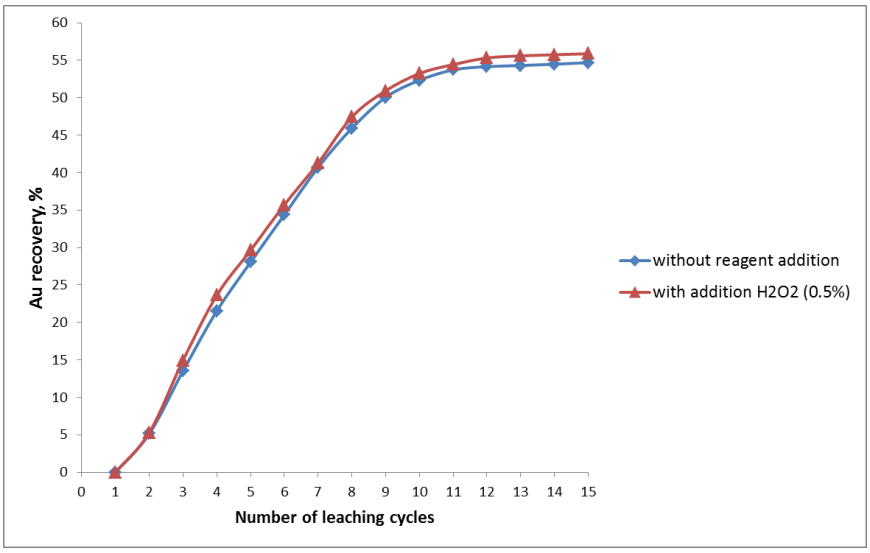

Figure 4 - Dependence of gold recovery on the duration of leaching

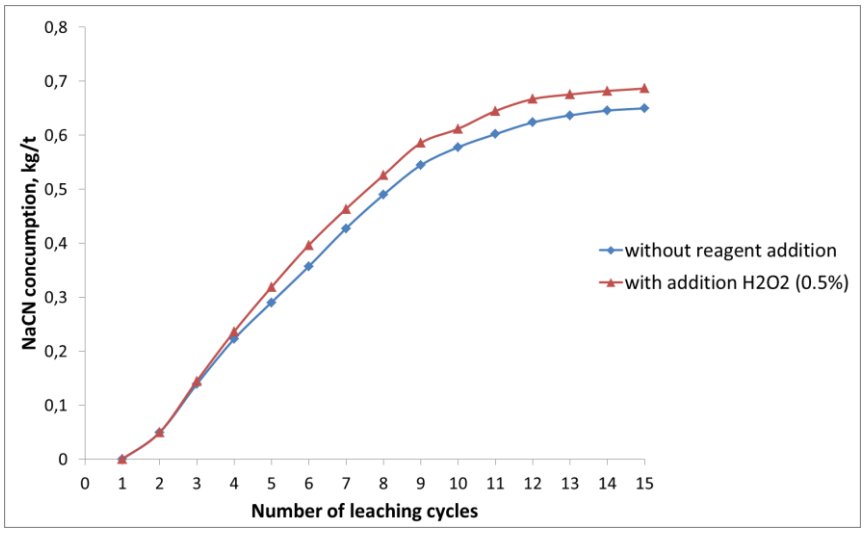

Figure 5 - Consumption of sodium cyanide in the leaching process

Treatment of ore with hydrogen peroxide increases the sodium cyanide consumption by 0.04 kg/t and is 0.69 kg/t (Figure 5).

Conclusions

The treatment of gold-bearing ore of the Sari Gunay deposit with hydrogen peroxide in heap leaching of gold increases gold recovery by 1.2% and is 55.89%, without treatment - 54.69%. This increases the consumption of sodium cyanide by 0.04 kg / t.

In the future, studies will be carried out on the intensification of gold-bearing ores using alternative oxidizers and experiments for gold-bearing ores of Kazakhstan.

Conflicts of interest. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Алтынды үйінді шаймалау кезінде кенді сутегінің асқын тотығымен өңдеу

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ТҮЙІНДЕМЕ

Өткен ғасырда көптеген проблемалар алтынды шаймалаудың жылдамдығының төмен болуымен байланысты болды, ал кейіннен алтынды ерітінділеуді қарқындату әдістері жасалды. Осы әдістердің ішінде алтынды шаймалауды тездету үшін сутегі асқын тотығын қолданатын әдіс бар. Шаймалау процесін қарқындату мақсатында, сутегінің асқын тотығын қолдана отырып, кеннен алтынды цианидтік шаймалау арқылы алу көрсеткіштері зерттелді. Бұл жұмыста Сары-Гүнай (Иран) кенорынның алтынқұрамды кендерін сынама-гравиметриялық, химиялық, минералогиялық талдауларының нәтижелері ұсынылған. Сульфидтегі күкірттің мөлшері бойынша кен аз сульфидті санатқа, ал күкірттің тотығу дәрежесі бойынша (50,70%) – тотыққан кендер санатына жатады. Кен компоненттерінің сутегі асқын тотығымен мүмкін болатын реакцияларына термодинамикалық талдау жүргізілді. Алтынды цианидтік шаймалау арқылы алу бойынша жүргізілген зертханалық зерттеулер көрсеткендей, сутегі асқын тотығының концентрациясы 0,5% болған кезде алтынның ең жоғары бөлінуі 52,92%-ды құрайды, реагентті қолданбаған кезде алтынның бөлінуі 52,03% болады. Сутегі асқын тотығымен (H_2O_2–0,5%) өңдеген және өңдемеген кездегі зертханалық және бағаналық сынақ көрсеткіштеріне салыстыру жүргізілді. Алтынды үйінді шаймалау кезінде кенді сутегі асқын тотығымен өңдесе алтынның алынуы 1,2%-ға артады, яғни 55,89%-ды құрайды, ал өңдемеген жағдайда 54,69%-ды құрайды. Бұл кезде натрий цианидінің шығыны 0,04 кг/т-ға артады.

Түйін сөздер: алтынды үйінді шаймалау, үйінді шаймалау процесін қарқындату, алтынды шаймалау, сутегінің асқын тотығы, тотықтырғыш, алтын.

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Обработка руды пероксидом водорода при кучном выщелачивании золота

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АННОТАЦИЯ

На протяжении последнего столетия многие проблемы были направлены на решение задачи низкой скорости выщелачивания золота и, в дальнейшем были разработаны методы интенсификации выщелачивания золота. Среди этих методов, известно использование пероксида водорода для ускорения выщелачивания золота. С целью интенсификации процесса выщелачивания были изучены показатели цианидного выщелачивания золота из руды с использованием пероксида водорода. В данной работе представлены результаты пробирно-гравиметрического, химического, минералогического анализов золотосодержащей руды месторождения Сари-Гунай (Иран). По содержанию сульфидной серы руда относится к категории малосульфидной, по степени окисления серы (50,70%) – к категории окисленных руд. Проведен термодинамический анализ возможных реакции компонентов руды с пероксидом водорода. Лабораторные исследования по цианидному выщелачиванию золота показали, что максимальное извлечение золота составляет 52,92% при концентрации пероксида водорода 0,5%, извлечение золота без обработки руды составляет 52,03%. Проведено сравнение показателей лабораторного и колонного испытания с обработкой и без обработки пероксидом водорода (H_2O_2–0.5%). Обработка золотосодержащей руды пероксидом водорода при кучном выщелачивании золота увеличивает извлечение золота на 1,2% и составляет 55,89%, без обработки – 54,69%. При этом увеличивается расход цианида натрия на 0,04 кг/т.

Ключевые слова: Кучное выщелачивание золота, интенсификация кучного выщелачивания, выщелачивание золота, пероксид водорода, окислитель, золото.

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Литература

[1] Van Zyl, D. J., Hutchison, I. P., & Kiel, J. E. (1988). Introduction to evaluation, design, and operation of precious metal heap leaching projects. *Society of Mining Engineers*, Littleton. Colorado. VII. 372.

[2] Surimbayev B.N., Baikonurova A.O., Bolotova L.S. (2017) Prospects for the development of the process of intensive cyanidation of gold-containing products in the Republic of Kazakhstan. *News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences*. Almaty, Kazakhstan, 4(424): 133–141. ISSN 2224-5278.

[3] Abubakriev, A. T., Koizhanova, A. K., Magomedov, D. R., Erdenova, M. B., Abdyldaev, N. N. (2019). Leaching of gold-containing ores with application of oxidation activators. *Kompleksnoe Ispol'zovanie Mineral'nogo syr'â/Complex Use of Mineral Resources/Mineraldik Shikisattardy Keshendi Paidalanu*, 3(310), 10–15. https://doi.org/10.31643/2019/6445.23

[4] Kenzhaliyev B.K., Koizhanova A.K., Magomedov D.R., Kamalov E.M., Erdenova M.B., Abdyldaev N.N. (2020). A study of the biohydrometallurgical method for extracting gold from flotation tailings. *Metalurgija*. 59, 4, 477 - 480.

[5] Сорокин И.П. (1958). Изучение условий растворения золота и серебра в цианистых растворах при низких температурах /*Труды ВНИИ-1.* Магадан. № 33, 13-69.

[6] Есенгараев Е.К. Баимбетов Б.С. Болотова Л.С. Каналы Е.С. Акжаркенов М.Д. (2018). Влияние перекиси водорода на выщелачивание золота. *Mezhdunarodnaya nauchno-prakticheskaya konferentsiya «Innovatsii v kompleksnoy pererabotke mineral'nogo syr'ya»/International scientific-practical conference «Innovations in the complex processing of mineral raw materials»/Halyqaralyq ǵylymı-praktıkalyq konferentsıa «Mıneraldy shıkizatty keshendi óńdeýdegi ınnovatsıalar».* Алматы, 90-91. ISBN 978-601-06-5370-2

[7] Huang Kong-xuan. (1996). New advantages on gold extraction in foreign countries. *Hydrometallurgy*, 9-18 (in Chinese.)

[8] Guzman L, Sgarra M, Chimenos J M, Fernandez M A, Espiell F. (1999). Gold cyanidation using hydrogen peroxide. *Hydrometallurgy*. 52, 21-35. https://doi.org/10.1016/S0304-386X(99)00006-7

[9] Турысбекова Г.С., Меретуков М.А., Бектай Е.К. (2015). *Золото: инновации в химии и металлургии.* Алматы, 117. ISBN: 978-601-228-838-4, 117-223-228.

[10] Botz, M.M., Mudder, T.I., & Akcil, A.U. (2016). Cyanide treatment: physical, chemical, and biological processes. In Gold ore processing, Elsevier. 619-645. https://doi.org/10.1016/B978-0-444-63658-4.00035-9

[11] Breuer, P., Sutcliffe, C., Meakin, R. (2010). Comparison of industrial cyanide destruction processes. *25th International Mineral Processing Congress - IMPC2010, 7*, 1483–1493. http://hdl.handle.net/102.100.100/109330?index=1

[12] Kitis, M., Akcil, A., Karakaya, E., Yigit, N.O. (2005). Destruction of cyanide by hydrogen peroxide in tailings slurries from low bearing sulphidic gold ores. *Miner. Eng. 18*, 353–362. https://doi.org/10.1016/j.mineng.2004.06.003

[13] Longley, R.J., McCallum, A., Katsikaros, N. (2003). Intensive cyanidation: onsite application of the InLine Leach Reactor to gravity gold concentrates. *Miner. Eng. 16*, 411–419. https://doi.org/10.1016/S0892-6875(03)00054-2

[14] Surimbayev B., Bolotova L., Mishra B., Baikonurova A. (2018). Intensive cyanidation of gold from gravity concentrates ina drum-type apparatus, *News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technical sciences.* 5, 431, 32–37. https://doi.org/10.32014/2018.2518-170X.7

[15] Surimbayev B., Bolotova L., Baikonurova A., Shalgymbayev S. (2019). Acetic acid application as an activating reagent in the intensive cyanidation of gravity concentrates. *Kompleks. ispol'zovanie Miner. syr'â/Complex Use Miner. Resour. shikisattardy Keshendi Paid*. 1, 308, 83–88. https://doi.org/10.31643/2019/6445.10

[16] Lawes, B.C., Mathre, O.B. (1971). Process for detoxifying cyanide waste waters. *U.S. Patent No. 3,617,582.* Washington, DC: U.S. Patent and Trademark Office, application 15.05.1969, publication 02.11.1971.

[17] Лобанов В.Г., Тимофеев Е.И., Набиуллин Ф.М., Начаров В.Б., Третьяков А.В., Филонов Н. А., Миков С. В., Горбут В.Н., Маковская О.Ю., Старков А.М. (2017). Способ цианистого выщелачивания золота и серебра. *Патент RU № 2624751C1,* заяв. 11.04.2016, опубл. 06.07.2017, бюл. № 19.

[18] Есенгараев Е. К., Баимбетов Б. С., Мамяченков С. В., Суримбаев Б. Н., Прозор Н.Г. (2020). Изучение процесса цианидного выщелачивания золота с применением ацетата натрия при различной крупности руды. *Kompleksnoe Ispol'zovanie Mineral'nogo syr'â/Complex Use of Mineral Resources/Mineraldik Shikisattardy Keshendi Paidalanu.* №1 (312), 59-68. https://doi.org/10.31643/2020/6445.08

[19] Есенгараев Е. К., Баимбетов Б. С., Мамяченков С. В., Суримбаев Б. Н. (2020). Изучение вещественного состава золотосодержащей руды месторождения Сари-Гунай. *Gornyy zhurnal Kazakhstana /* Mining Journal of Kazakhstan*/Qazaqstannyń taý-ken jýrnaly.* №2. 6-11.

[20] Yessengarayev Ye. K., Baimbetov B. S., Surimbayev B. N. (2020). Studies on heap leaching of gold with the addition of sodium acetate as an intensifying reagent. *Non-ferrous Metals*. 2, 25–30. https://doi.org/10.17580/nfm.2020.02.04

[21] Шумилова Л.В., Резник Ю.Н., Зыков Н.В., Добромыслов Ю.П, Конарева Т.Г. (2009). Способ кучного выщелачивания золота из окисленных и смешанных руд. (2009). Патент RU № 2361076C1, заяв. 06.12.2007, опубл. 10.07.2009, бюл. № 19.

[22] Karimi, P., Abdollahi, H., Amini, A., Noaparast, M., Shafaei, S.Z., Habashi, F. (2010). Cyanidation of gold ores containing copper, silver, lead, arsenic and antimony. *Int. J. Miner. Process. 95 (1–4),* 68–77 https://doi.org/10.1016/j.minpro.2010.03.002 , ISSN 0301-7516.

[23] Thiago Oliveira Nunan, Isabella Lima Viana, Guilherme C. Peixoto, Herbert Ernesto, Daniel Martin Verster, Jose Henrique Pereira, Jose M. Bonfatti, Luiz Alberto Cesar Teixeira. (2017). Improvements in gold ore cyanidation by pre-oxidation with hydrogen peroxide. *Minerals Engineering. Vol. 108.* 67-70. https://doi.org/10.1016/j.mineng.2017.01.006.

[24] Marsden J., House I. (2006). The Chemistry of Gold Extraction. *Society for Mining, Metallurgy and Exploration. 2nd edition. West Sussex, England: Ellis Horwood*. ISBN 10: 0873352408 / ISBN 13: 9780873352406.

[25] Бейсембаев Б.Б., Кенжалиев Б.К., Абсалямов Х.К., Говядовская О.Ю., Копенов М.К., Турсунбаева А.К. (2000). Способ кучного выщелачивания золотосодержащих руд. Патент KZ № 9446, заяв. 17.08.1999, опубл. 15.09.2000, бюл. № 9.

Reference

[1] Van Zyl, D. J., Hutchison, I. P., & Kiel, J. E. (1988). Introduction to evaluation, design, and operation of precious metal heap leaching projects. Society of Mining Engineers, Littleton. Colorado. VII. 372. (in Eng.)

[2] Surimbayev B.N., Baikonurova A.O., Bolotova L.S. (2017). Prospects for the development of the process of intensive cyanidation of gold-containing products in the Republic of Kazakhstan. *News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences*. Almaty, Kazakhstan, 4(424): 133–141. (in Eng.)

[3] Abubakriev, A. T., Koizhanova, A. K., Magomedov, D. R., Erdenova, M. B., Abdyldaev, N. N. (2019). Leaching of gold-containing ores with application of oxidation activators. *Kompleksnoe Ispol'zovanie Mineral'nogo syr'â/Complex Use of Mineral Resources/Mineraldik Shikisattardy Keshendi Paidalanu*, 3(310), 10–15. https://doi.org/10.31643/2019/6445.23 (in Eng.)

[4] Kenzhaliyev B.K., Koizhanova A.K., Magomedov D.R., Kamalov E.M., Erdenova M.B., Abdyldaev N.N. (2020). A study of the biohydrometallurgical method for extracting gold from flotation tailings. *Metalurgija*. 59, 4, 477 - 480. (in Eng.)

[5] Sorokin I.P. (1958). *Izucheniye usloviy rastvoreniya zolota i serebra v tsianistykh rastvorakh pri nizkikh temperaturakh* (Studying the conditions for the dissolution of gold and silver in cyanide solutions at low temperatures). *Trudy VNII-1.* (Transactions of VNII-1.) Magadan Russia. № 33, 13-69 (in Russ.)

[6] Yessengarayev Ye.K., Baimbetov B.S., Bolotova L.S., Kanaly Ye.S., Akjerkenov M.D. (2018). *Vliyaniye perekisi vodoroda na vyshchelachivaniye zolota* (Effect of hydrogen peroxide on gold leaching). *Mezhdunarodnaya nauchno-prakticheskaya konferentsiya «Innovatsii v kompleksnoy pererabotke mineral'nogo syr'ya»(International scientific-practical conference «Innovations in the complex processing of mineral raw materials).* Almaty, 90-91. ISBN 978-601-06-5370-2 (in Russ.)

[7] Huang Kong-xuan. (1996). New advantages on gold extraction in foreign countries. *Hydrometallurgy*, 9-18 (in Chinese.)

[8] Guzman L, Sgarra M, Chimenos J M, Fernandez M A, Espiell F. (1999). Gold cyanidation using hydrogen peroxide. *Hydrometallurgy*. 52, 21-35. https://doi.org/10.1016/S0304-386X(99)00006-7 (in Eng.)

[9] Turysbekova G.S., Meretukov M.A., Bektaj E.K. (2015). *Zoloto: innovacii v himii I metallurgii* (Gold: Innovations in Chemistry and Metallurgy). Almaty, 117. ISBN: 978-601-228-838-4, 117-223-228 (in Russ.)

[10] Botz, M.M., Mudder, T.I., Akcil, A.U. (2016). Cyanide treatment: physical, chemical, and biological processes. In Gold ore processing, Elsevier. 619-645. https://doi.org/10.1016/B978-0-444-63658-4.00035-9 (in Eng.)

[11] Breuer, P., Sutcliffe, C., Meakin, R. (2010). Comparison of industrial cyanide destruction processes. *25th International Mineral Processing Congress - IMPC2010, 7*, 1483–1493. http://hdl.handle.net/102.100.100/109330?index=1 (in Eng.)

[12] Kitis, M., Akcil, A., Karakaya, E., Yigit, N.O. (2005). Destruction of cyanide by hydrogen peroxide in tailings slurries from low bearing sulphidic gold ores. *Miner. Eng. 18*, 353–362. https://doi.org/10.1016/j.mineng.2004.06.003 (in Eng.)

[13] Longley, R.J., McCallum, A., Katsikaros, N. (2003). Intensive cyanidation: onsite application of the InLine Leach Reactor to gravity gold concentrates. *Miner. Eng. 16*, 411–419. https://doi.org/10.1016/S0892-6875(03)00054-2 (in Eng.)

[14] Surimbayev B., Bolotova L., Mishra B., Baikonurova A. (2018). Intensive cyanidation of gold from gravity concentrates ina drum-type apparatus, *News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technical sciences.* 5, 431, 32–37. https://doi.org/10.32014/2018.2518-170X.7 (in Eng.)

[15] Surimbayev B., Bolotova L., Baikonurova A., Shalgymbayev S. (2019). Acetic acid application as an activating reagent in the intensive cyanidation of gravity concentrates. *Kompleks. ispol'zovanie Miner. syr'â/Complex Use Miner. Resour. shikisattardy Keshendi Paid.* 1, 308, 83–88. https://doi.org/10.31643/2019/6445.10 (in Eng.)

[16] Lawes, B.C., Mathre, O.B. (1971). Process for detoxifying cyanide waste waters. *U.S. Patent No. 3,617,582.* Washington, DC: U.S. Patent and Trademark Office, application 15.05.1969, publication 02.11.1971. (in Eng.)

[17] Lobanov V.G., Timofeev E.I., Nabiullin F.M., Nacharov V.B., Tretyakov A.V., Filonov N.A., Mikov S.V., Gorbut V.N.,

Makovskaya O.Yu., Starkov A.M. (2017). *Sposob tsianistogo vyshchelachivaniya zolota i serebra* (Method of cyanic leaching of gold and silver). *Pat. RU No. 2624751C1,* application 11.04.2016, publication 06.07.2017, Bull. № 19 (in Russ.)

[18] Yessengarayev Ye.K., Baimbetov B.S., Mamyachenkov S.V., Surimbayev B.N., Prozor N.G. (2020). *Izucheniye protsessa tsianidnogo vyshchelachivaniya zolota s primeneniyem atsetata natriya pri razlichnoy krupnosti rudy*. [Study of the process of cyanide leaching of gold using sodium acetate at different ore sizes]. *Kompleksnoe Ispol'zovanie Mineral'nogo syr'â/Complex Use of Mineral Resources/Mineraldik Shikisattardy Keshendi Paidalanu,* №1 (312), 59-68. https://doi.org/10.31643/2020/6445.08 (in Russ.)

[19] Yessengarayev Ye.K., Baimbetov B.S., Mamyachenkov S.V., Surimbayev B.N. (2020). *Izucheniye veshchestvennogo sostava zolotosoderzhashchey rudy mestorozhdeniya Sari-Gunay*. [Study of the material composition of gold-containing ore from the Sari-Gunai deposit]. *Gornyy zhurnal Kazakhstana/*Mining Journal of Kazakhstan */ Qazaqstannyń taý-ken jýrnaly*, №2. 6-11 (in Russ.)

[20] Yessengarayev Ye. K., Baimbetov B. S., Surimbayev B. N. (2020). Studies on heap leaching of gold with the addition of sodium acetate as an intensifying reagent. Non-ferrous Metals. 2, 25–30. https://doi.org/10.17580/nfm.2020.02.04 (in Eng.)

[21] Shumilova L.V., Reznik J.N., Zykov N.V., Dobromyslov J.P., Konareva T.G. (2009). *Sposob kuchnogo vyshchelachivaniya zolota iz okislennykh i smeshannykh rud* (Method of heap leaching of gold out of oxidised and mixed ores). Pat. RU *No.* 2361076C1, application 06.12.2007, publication. 10.07.2009, Bull. № 19 (in Russ.)

[22] Karimi, P., Abdollahi, H., Amini, A., Noaparast, M., Shafaei, S.Z., Habashi, F. (2010). Cyanidation of gold ores containing copper, silver, lead, arsenic and antimony. *Int. J. Miner. Process. 95 (1–4),* 68–77. https://doi.org/10.1016/j.minpro.2010.03.002 , ISSN 0301-7516 (in Eng.)

[23] Thiago Oliveira Nunan, Isabella Lima Viana, Guilherme C. Peixoto, Herbert Ernesto, Daniel Martin Verster, Jose Henrique Pereira, Jose M. Bonfatti, Luiz Alberto Cesar Teixeira. (2017). Improvements in gold ore cyanidation by pre-oxidation with hydrogen peroxide. *Minerals Engineering. Vol. 108.* 67-70. https://doi.org/10.1016/j.mineng.2017.01.006 (in Eng.)

[24] Marsden J., House I. (2006). The Chemistry of Gold Extraction. *Society for Mining, Metallurgy and Exploration. 2nd edition. West Sussex, England: Ellis Horwood*. ISBN 10: 0873352408 / ISBN 13: 9780873352406 (in Eng.)

[25] Beisembaev B.B., Kenzhaliev B.K., Absalyamov H.K., Govyadovskaya O.Yu., Kopenov M.K., Tursynbayeva A.K. (2000). *Sposob kuchnogo vyshchelachivaniya zolotosoderzhashchikh rud* (Method for heap leaching of gold-bearing ores.). Pat. KZ № 9446, application 17.08.1999, publication 15.09.2000, Bull. № 9 (in Russ.).