Studies on heap leaching of gold with the addition of sodium acetate as an intensifying reagent

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One of the cheapest methods of extracting gold is heap leaching. However, the recovery of gold by this method is relatively low, compared with cyanidation of the crushed material, so the search for the ways to intensify leaching and increase gold recovery is an urgent task. Investigations on heap leaching of gold from the gold-bearing ore of the Sari Gunay deposit were conducted using a promising reagent sodium acetate to intensify the heap leaching process. The results of assay-gravimetric, chemical, mineralogical and granulometric analyses of oxidized ore are presented. The average gold content in the ore was 2.90 g/t. According to the electron probe analysis, gold in the ore is present in the form of fine (micron) inclusions in minerals and ore rocks. Comparative studies on heap leaching of gold from the crushed ore with a grain size of –20 + 0 mm with the addition of sodium acetate and without that were carried out. The degree of gold recovery with sodium acetate at a flow rate of 0.5 kg/t was 58.74%, that without sodium acetate was 54.69%, i.e. the addition of the reagent provides an increase in recovery of more than 4%. Leaching with the addition of the reagent also reduces sodium cyanide consumption from 0.65 to 0.59 kg/t. The research results have shown that sodium acetate can be used to intensify the process of heap leaching of gold when the ore size is –20+0 mm.

Key words: gold ore, heap leaching, cyanide, sodium acetate, intensifying reagent, technology of heap leaching, thermodynamic calculations.

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Introduction

Process of heap leaching, which allows involving large deposits with base ores into mining, has become the main factor in the development of gold mining around the world, and has made it possible to increase gold production by 2–4 times [1–6].

Leaching of gold with alkaline cyanide solutions in the presence of oxygen or air is a widely used process for extracting gold from mineral raw materials [6–10]. At that, gold is oxidized and dissolves with cyanide present giving an $[Au(CN)_2]^-$ complex ion. According to the equations of Bodlander (1) and (2) and Elsner (3), the latter is the sum of equations (1) and (2) [1–3, 6–7]:

$$2Au + 4CN^- + O_2 + 2H_2O \rightarrow \\ \rightarrow 2Au(CN)_2^- + 2OH^- + H_2O_2 \qquad (1)$$

$$2Au + 4CN^- + H_2O_2 \rightarrow 2Au(CN)_2^- + 2OH^- \qquad (2)$$

$$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4Au(CN)_2^- + 4OH^- \qquad (3)$$

However, due to the chemical, mineralogical, structural and physical characteristics of the rock as well as granulometric composition of the ores, the indicators of gold extraction by heap leaching are low [1–3, 11–13], and the working up of new methods for its intensification is a promising and topical problem.

At present, it is widely known from the literature and experience of gold mining factories that various chemical additions are used to intensify cyanidation processes, for example, oxygen [8–10], hydrogen peroxide [6, 14–16], potassium permanganate [14–17], ammonium peroxysulphate and potassium peroxysulphate [3, 14–17], sodium hypochlorite [3, 18–19] and others [15, 19–24]. In [25–28], acetic acid was used to intensify the process of leaching the rich gold-bearing gravity concentrates.

No examples of the use of sodium acetate were found, but thermodynamic analysis has showed that sodium acetate can react with sulphides, aide the opening of particles, and intensify the gold leaching process. In this paper, studied were the indicators of cyanide heap leaching of gold from the ore with addition of sodium acetate in order to increase the recovery and intensification of the process.

Experimental part

Gold ore from the Sari Gunay deposit (Iran) was used for research (Fig. 1). According to the results of assay analysis, the average gold content in the ore is 2.90 g/t [29–30]. The chemical composition [29–30] is represented in Table 1.

In the ore, gold is a commercially valuable component. Other metals are not of industrial significance due to their low content. Mass fraction of total sulfur is 1.48%; that of

Fig. 1. General view of the ore form the Sari Gunay deposit

Table 1.
Chemical composition of the gold ore from the Sari Gunay deposit

Component	Content, %	Component	Content, %
Cu	0.009	SiO_2	61.4
Zn	0.0082	Al_2O_3	19.7
Ni	0.0003	TiO_2	0.49
Pb	0.108	MgO	0.80
Mn	0.0005	CaO	0.31
Co	0.0003	P_2O_5	0.21
Cr	0.0013	$Fe_{tot.}$	2.67
Mo	0.0001	$Fe_{ox.}$	0.44
Hg	0.0025	$Fe_{S.}$	2.23
As	0.11	S_{tot}	1.48
Sb	0.0563	$S_{sulfide}$	0.73
K_2O	7.30	$S_{sulfate}$	0.75
Na_2O	1.34	Sulfur oxidation level	50.7

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.

Table 2.
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

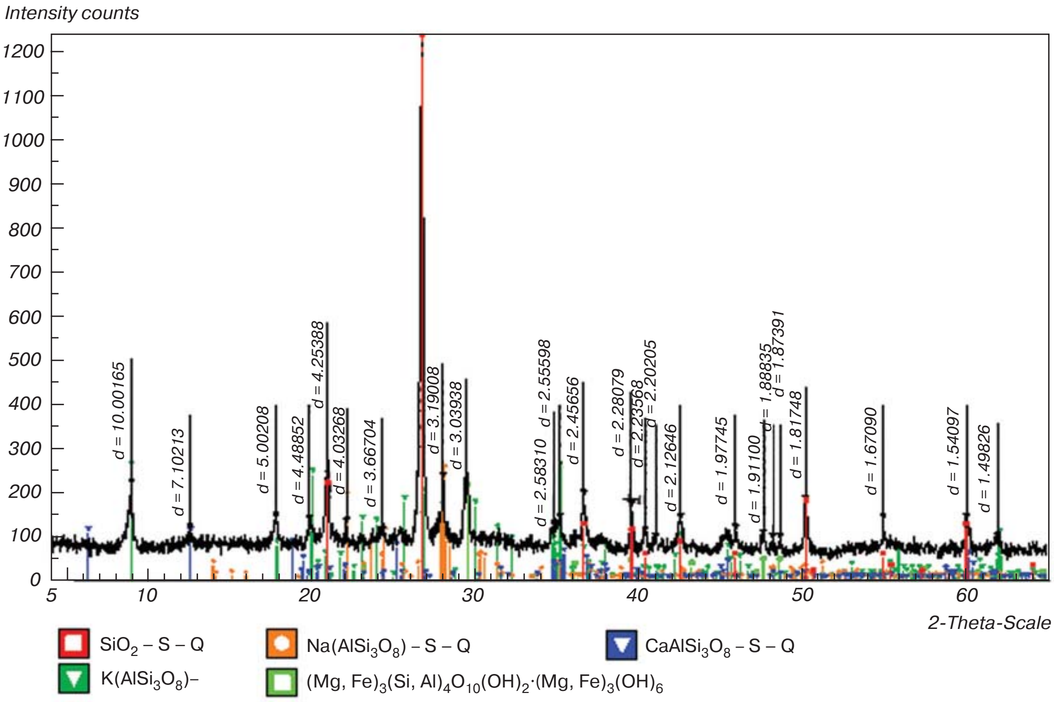

Fig. 2. Sample difractogram of the ore from the Sari Gunay deposit

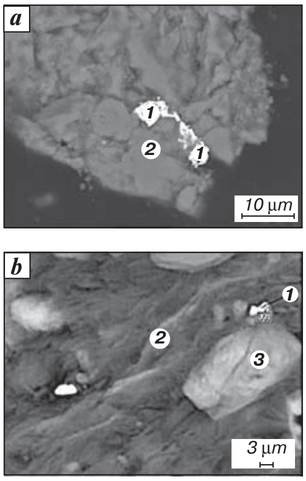

Fig. 3. Results of the ore electron probe analysis:
a — Gold (*1*) in scorodite (*2*), size of gold grains os 15×5 µm. COMPO mode, magn. 2200; *b* — Gold (*1*) in iron hydroxides (*2*) and quartz (*3*); nearby is scorodite, size of gold grains is 1–1.5 µm. EDS mode, magn. 4000

Table 3.
Possible thermodynamic reactions of the ore components with sodium acetate

Reaction	ΔG, kJ
$2FeS_2 + 8NaCH_3COO + 23.5O_2(g) = Fe_2O_3 + 4Na_2SO_4 + 16CO_2(g) + 12H_2O$	–9608.4
$2FeAsS + 4NaCH_3COO + 14O_2(g) = Fe_2O_3 + As_2O_3 + 2Na_2SO_4 + 8CO_2(g) + 6H_2O$	–5702.3
$PbS + 2NaCH_3COO + 6O_2(g) = PbO + Na_2SO_4 + 4CO_2(g) + 3H_2O$	–2389.6
$FeAsO_4 + 3NaCH_3COO + 5.75O_2(g) = FeO + Na_3AsO_4 + 6CO_2(g) + 4.5H_2O$	–2445.8
$Fe(OH)_2 + 3NaCH_3COO + 2O2(g) = Fe(CH_3COO)_2 + 3NaOH + 2CO_2(g) + H_2O$	–631.8
$Fe(OH)_3 + 2.667NaCH_3COO + 1.083O_2(g) = Fe(CH_3COO)_2 + 1.333Na_2CO_3 + 2.5H_2O$	–449.6
$Fe(OH)_2 + 2.667NaCH_3COO + 1.333O_2(g) = Fe(CH_3COO)_2 + 1.333Na_2CO_3 + 2H_2O$	–547.7

The *X*-ray diffractometric analysis of the average samples [29–30] was performed on a DRON-4 diffractometer with a Cu cathode and a graphite monochromator. Conditions for shooting diffractograms was the following: $U = 35$ kV; $I = 20$ mA; scale: 2000 imp.; time constant was 2 s; shooting theta-2theta; detector 2 deg/min.

Identification of mineral phases according to the *X*-ray diffractometric analysis is shown in Fig. 2, and the results of calculating quantitative ratio of the ore and rock minerals are shown in Table 2.

It is seen from the results in Table 2 that the ore is 91% composed of rock-forming minerals. Orthoclase prevails among them by mass fraction, a significant part form hydromica (28%) and quartz (23%). Associated ore minerals – iron hydroxides, haematite and scorodite form in an average sample an amount in the order of 7.0%. The proportion of sulfide minerals is in the range of 1% or less. Almost 99% of them are pyrite. Such minerals as pyrite, arsenopyrite, and galena are fixed in heavy fractions in rare and isolated grains. Gold can also be associated with sulfides.

According to the electron probe analysis performed on a JEOL JXA–8230 Electron Probe Microanalyzer, gold in the ore is present in the form of fine (micron) inclusions in scorodite (Fig. 3, *a*), iron hydroxides and quartz (Fig. 3, *b*).

Based on thermodynamic analysis, one can assume an active interaction of sulfides, scorodite and iron hydroxides with sodium acetate in the presence of oxygen, which contributes to the opening of gold particles and, as a consequence, their interaction with a leaching-out cyanide solution. At the same time, sodium acetate has no detrimental effect upon the alkaline cyanide solution.

The reactions that can occur under heap leaching conditions at a temperature of 20 °C are shown in Table 3.

The granulometric composition of the test sample is shown In Table 4.

Table 4
Granulometric composition of the ore at a size of –20+0 mm

Size grade, mm	Size yield, %	Gold content, g/t	Gold distribution, %
–20+12	14.53	3.41	16.23
–12+5	28.03	3.25	29.83
–5+2.5	25.87	2.98	25.24
–2.5+1	10.03	2.83	9.30
–1+0	21.54	2.75	19.40
Total	100.00	3.04	100.00

Table 3 makes it clear that gold is uniformly distributed in the test sample, but it is mostly found in larger classes (–20+12 mm and –12+5 mm).

Research on the technology of heap leaching of gold

Investigations on the technology of heap leaching of gold were carried out in laboratory columns. 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+0 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.

The schematic diagram of the process is given in Fig. 4.

For comparison purposes, two series of research were conducted on heap leaching of gold from the crushed ore with a size of –20+0 mm with the addition of sodium acetate and without that. In the first three leaching cycles, sodium acetate was added to the cyanide-alkaline solution. In subsequent leaching cycles, the addition of this reagent has been stopped. According to the results of previous laboratory studies [30], the optimal consumption of sodium acetate was 0.5 kg/t.

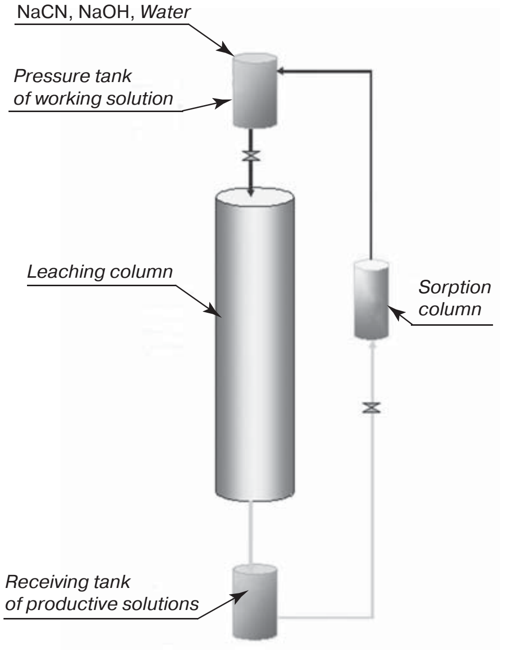

Fig. 4. Schematic diagram of the heap leaching unit

Discussion of results

The results of the investigations on leaching gold from the ore crushed to a size of –20+0 mm are shown in Fig. 5–7.

It took 15 leaching cycles to dissolve the gold. The total amount of the resulting productive solution without the reagent addition was 2.95 m^3/t of the ore. That with the addition of sodium acetate was 2.94 m^3/t.

The change in the gold concentration in productive solutions during leaching is shown in Fig. 5. It is noted that the addition of sodium acetate at the beginning of three leaching cycles increases the gold content in productive solutions.

Fig. 6 illustrates the dependences of gold extraction from the ore on the leaching duration; the degree of gold extraction with the addition of sodium acetate (58.74%) is 4% higher than it is in the experiments without the addition of this reagent (54.69%).

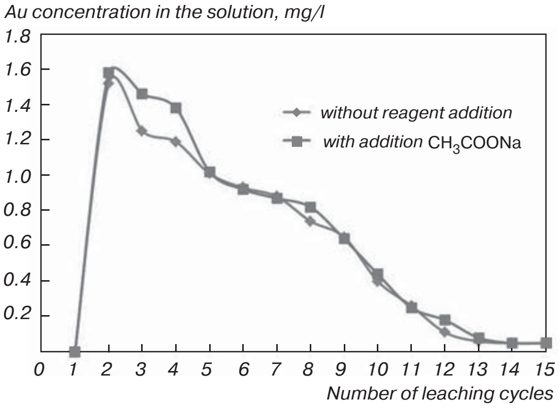

Fig. 5. A change in the content of gold in productive solutions in the leaching process

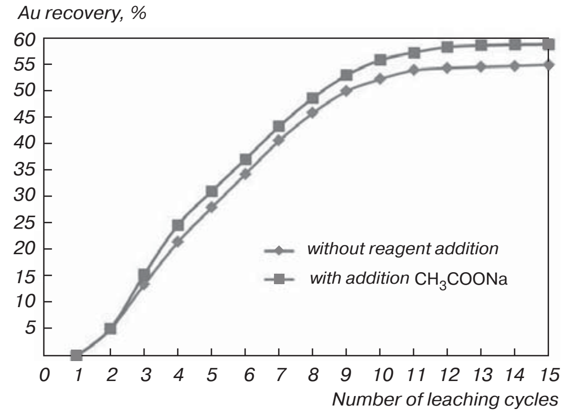

Fig. 6. Dependence of gold recovery on the duration of leaching

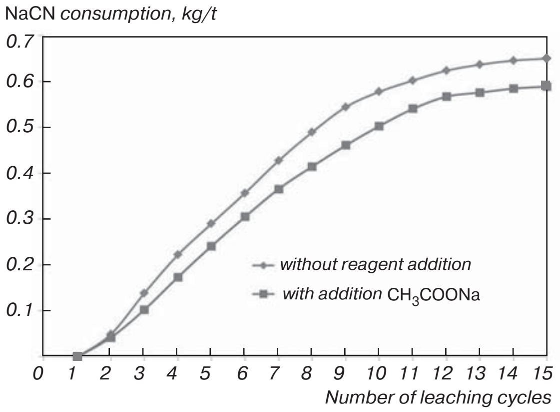

Fig. 7. Consumption of sodium cyanide in the leaching process

Table 5.
Gold balance on implementing column tests on heap leaching of gold

Indicator	Value	
	without reagent	with sodium acetate
Ore size, mm	–20+0	–20+0
Gold extracted by activated carbon: g/t of ore %	 1.57 54.13	 1.69 58.27
Gold extracted at the water washing operations, g/t of ore	0.05	0.06
Gold brought with the analyzed solutions, g/t of ore	0.04	0.04
Gold content in the column leaching tailings, g/t	1.36	1.24
Calculated gold content in the source ore, g/t	3.02	3.03
Degree of gold dissolution from ore by balance, %	54.69	58.74
Expected gold extraction into commercial product – Doré bars, %	48.95	52.57

The sodium cyanide consumption for leaching without adding the reagent was 0.65 kg/t; it decreases by 0.06 kg/t when adding sodium acetate and amounts to 0.59 kg/t. The change in the sodium cyanide concentration and its consumption during leaching is shown in Fig. 7.

Based on the data obtained, the gold balance was calculated for heap leaching of gold from the Sari Gunay ore deposit (Table 5).

To calculate the expected gold recovery in industrial conditions, the conversion factor equal to 0.9 was used to replace column tests with industrial operation.

The average calculated gold content in the ore according to the results of the study is 3.02 g/t without reagent and 3.03 g/t with sodium acetate, which is in good agreement with the results of the assay and sieve analyses of the ore. The expected recovery of gold into commercial products – Doré bars was 48.95% without a reagent and 52.57 % with reacting sodium acetate.

Conclusions

The thermodynamic calculations revealed the possibility of sodium acetate interaction reactions with components of gold ore, such as sulfides, iron hydroxides and scorodite, which leads to the opening of gold and its dissolution in a cyanide solution.

Studies on a column unit that simulates heap leaching conditions have established that the use of sodium acetate additives at a consumption rate of 0.5 kg/t intensifies the leaching process of gold ore. Gold recovery from the ore is increased by 4% up to 58.74%; sodium cyanide consumption is reduced by 0.06 kg/t. The expected recovery of gold into commercial products (Doré bars) was 48.95% without a reagent and 52.57% with reacting sodium acetate.

References

1. Manning T. J., Kappes D. W. Heap Leaching of Gold and Silver Ores. *Gold Ore Processing*. 2016. pp. 413–428. DOI: 10.1016/B978-0-444-63658-4.00025-6

2. Karaganov V. V., Uzhkenov B. S. Heap Leaching of Gold - Foreign Experience and Development Prospects. Reference Book. Moscow – Almaty: TOO Geointcentr, 2002. 288 p.

3. Kappes D. W. Heap Leaching of Gold and Silver Ores. *Developments in Mineral Processing* (Ed. by Mike D. Adams, B. A. Wills). 2005. pp. 456–478. DOI: 10.1016/S0167-4528(05) 15019-4

4. Ilankoon I. M. S. K., Tang Yuan, Ghorbani Yousef, Northey Stephen, Yellishetty Mohan, Deng Xiangyi, McBride Diane. The Current State and Future Directions of Percolation Leaching in the Chinese Mining Industry: Challenges and Opportunities. *Minerals Engineering*. 2018. Vol. 125. pp. 206–222. DOI: 10.1016/j.mineng.2018.06.006

5. Aylmore M. G., Eksteen J. J., Jones M. G., Wells M. The Mineralogy and Processing Potential of the Commonwealth Project in the Molong Volcanic Belt, Central Eastern New South Wales, Australia. *Ore Geology Reviews*. 2019. Vol. 111. 102976. DOI: 10.1016/j.oregeorev.2019.102976

6. Marsden J., House I. The Chemistry of Gold Extraction. Littleton: Society for Mining, Metallurgy and Exploration, Inc. 2006. pp. 48–50

7. Zakharov B. A., Meretukov M. A. Gold: Refractory Ores. Moscow : "Ore and Metals" Publishing House, 2013. 452 p.

8. Bayat O., Vapur H., Akyol F., Poole C. Effects of Oxidizing Agents on Dissolution of Gumuskoy Silver Ore in Cyanide Solution. *Minerals Engineering*. 2003. Vol. 16, Iss. 4. pp. 395–398. DOI: 10.1016/S0892-6875(03)00050-5

9. Sampaio C. H., Petter C. O., Kautzmann R. M., Klein S. L. Technological Characterization of Riacho Dos Machados Gold Ore for Cyanide Leaching and Study of The Utilization of Oxidizing Agents. *Minerals Engineering*. 1997. Vol. 10, Iss. 5. pp. 547–550. DOI: 10.1016/S0892-6875(97)00032-0

10. Dai X., Jeffrey M. I. The Effect of Sulfide Minerals on the Leaching of Gold in Aerated Cyanide Solutions. *Hydrometallurgy*. 2006. Vol. 82, Iss. 3-4. pp. 118–125. DOI: 10.1016/j.hydromet.2006.03.005

11. Mineev G. G., Vasiliev A. A., Nikitenko A. G. Heap Leaching of Gold Ores. *Proceedings of Irkutsk State Technical University*. 2017. Vol. 21, Iss. 4, pp. 147–156. DOI: 10.21285/1814-3520-2017-4-147-156

12. Ghorbani Y., Becker M., Mainza A., Franzidis J.-P., Petersen J. Large Particle Effect Sin Chemical/Biochemical Heap Leach Processes – A Review. *Minerals Engineering*. 2011. Vol. 24, Iss. 11. pp. 1172–1184. DOI: 10.1016/j.mineng.2011.04.002

13. Rintala L., Leikola M., Sauer Ch., Aromaa J., Roth-Berghofer T., Forsén O., Lundström M. Designing Gold Extraction Processes: Performance Study of a Case-Based Reasoning System. *Minerals Engineering*. Vol. 109. 2017. pp. 42–53. DOI: 10.1016/j.mineng.2017.02.013

14. Nunan T. O., Viana I. L., Peixoto G. C., Ernesto H., Verster D. M., Pereira J. H., Bonfatti J. M., Teixeira L. A. C. Improvements in Gold Ore Cyanidation by Pre-Oxidation with Hydrogen Peroxide. *Minerals Engineering*. 2017. Vol. 108. pp. 67–70. DOI: 10.1016/j.mineng.2017.01.006

15. Evdokimov A. V. Search for New Reagent-Accelerators Intensifying the Process of Cyanidation. *Proceedings of Irkutsk State Technical University*. 2010. Vol. 44, Iss. 4. pp. 139–143.

16. Evdokimov A. V. The Effect of Reagents-Boosters on Indices of Gold Extraction from Gravitational Concentrate on Example of Some Deposit. *Proceedings of Irkutsk State Technical University*. 2011. Vol. 49, Iss. 2. pp. 132–136.

17. Sorokin I. P. An Investigation of Gold and Silver Dissolution in Cyanic Solutions at Low Temperatures. *Trudy VNII-1*. Magadan, 1958. No. 33. pp. 13–79.

18. Fedotov G. P., Blokhin N. N., Khmelevskaja G. A., Zabelskij V. K., Avargin V. A. Compound and Method of Gold Leaching. Patent RF, No. 2093672. Applied: 05.04.1991. Published: 20.10.1997.

19. Samusev A. L. The Modern Ways of Intensifying the Process of Heap Leaching. *GIAB*. 2011. No. 6. pp. 157–162.

20. Astuti W., Hirajima T., Sasaki K., Okibe N. Comparison of Effectiveness of Citric Acid and Other Acids in Leaching of Low-Grade Indonesian Saprolitic Ores. *Minerals Engineering*. 2016. Vol. 85, pp. 1–16. DOI: 10.1016/j.mineng.2015.10.001

21. Strizhko L. S., Boboev I. R., Vasiliev R. A., Bobozoda S., Gorbunov E. P. A Proposal on Intensifying Heap Leaching of Gold-Bearing Raw Materials. *Yestesstvennye i Tekhnicheskie Nauki: Opyt, Problemy, Perspektivy*. 2015. No. 1. pp. 52–55.

22. Alekhin A. I., Ivanov M. A. Proposal on Intensifying The Process of Heap Leaching of Gold in a Northern Region

of Russia. *The Potential of Modern Science*. 2015. Vol. 11, Iss. 3. pp. 73–77.

23. Ivanov M. A., Alekhin A. I. Intensification the Process of Heap Leaching of Gold in Northern Russia. *Sovremennaya Nauka: Aktualnye Problemy i Puti ikh Resheniya*. 2015. No. 4. pp. 94–97.

24. Strizhko L. S., Boboev I. R., Gurin K. K., Rabiev F. B. Development of Hydrometallurgical Processing Technology for the Oxidized Gold-Containing Ore from Taror Deposit. *Tsvetnye Metally*. 2013. No. 4. pp. 46–49.

25. Surimbayev B., Bolotova L., Baikonurova A., Mishra B. Intensive Cyanidation of Gold Using an Organic Reagent-Activator. *Journal of Chemical Technology and Metallurgy*. 2019. Vol. 54, Iss. 2. pp. 387–390.

26. Surimbayev B., Bolotova L., Baikonurova A., Shalgymbayev S. Application of Acetic Acid as a Reagent-Activator in Intensive Cyanidation of Gravity Concentrates. *Complex Use of Mineral Resources*. 2019. Iss. 1. pp. 83–88. DOI: 10.31643/2019/6445.10

27. Surimbayev B., Bolotova L., Mishra B., Baikonurova A. Intensive Cyanidation of Gold From Gravity Concentrates in a Drum-Type Apparatus. *News of the National Academy of Science of the Republic of Kazakhstan. Series of Geology and Technical Sciences*. 2018. Vol. 431, Iss. 5. pp. 32–37. DOI: 10.32014/2018.2518-170X.7

28. Surimbayev B., Baikonurova A., Bolotova L., Mishra B. Intensive Leaching of Gold from Gravity Concentrate at Low Concentration of Sodium Cyanide. *Complex Use of Mineral Resources*. 2018. Vol. 07, Iss. 4. pp. 65–70. DOI: 10.31643/ 2018/6445.31

29. Yessengarayev Ye. K., Baimbetov B. S., Mamyachenkov S. V., Surimbayev B. N. Study of the Material Composition of Gold-Containing Ore from the Sari Gunay Deposit. *Gornyi Zhurnal Kazakhstana*. 2020. No. 2. pp. 6–11.

30. Yessengarayev Ye. K., Baimbetov B. S., Mamyachenkov S. V., Surimbayev B. N., Prozor N. G. Study of the Process of Cyanide Leaching of Gold Using Sodium Acetate at Different Ore Sizes. *Complex Use of Mineral Resources*. 2020. Vol. 321, Iss. 1. pp. 59–68. DOI: 10.31643/2020/6445.08 NFM