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M. B. BARMENSHINOVA[1], Head of Department, Candidate of Engineering Sciences, Associate Professor
I. Yu. MOTOVILOV[1], Associate Professor, PhD in Metallurgy, i.motovilov@satbayev.university
Zh. ADILZHAN[1], Candidate for a Doctor's Degree
A. A. LAVRINENKO[2], Chief Researcher, Head of Laboratory, Doctor of Engineering Sciences

[1]Satbayev University, Almaty, Kazakhstan
[2]Academician Melnikov Institute of Comprehensive Exploitation of Mineral Resources–IPKON, Russian Academy of Sciences, Moscow, Russia

ANALYSIS OF PROCESSING FLOWSHEETS OF REFRACTORY GOLD ORE FROM THE AKTOBE DEPOSIT, CYANIDATION OF INITIAL ORE AND CONCENTRATES

The article presents the results of enrichment of gold-bearing ore from the Aktobe deposit, containing 1.57 g/t of gold, using flotation and gravity–flotation flowsheets with a closed flotation circuit. The expediency of obtaining gold-bearing concentrate by flotation with one cleaner operation is established. The following process indicators are obtained: the yield of the flotation concentrate is 6.13%; the gold content is 23.01 g/t at the recovery of 89.84%.

The comparative analysis of the closed-loop flotation circuit results shows that the obtained indicators in both flotation and gravity–flotation flowsheets are approximately at the same level. The highest process indicators in terms of recovery are obtained using the integrated grinding–centrifugal concentration–flotation flowsheet with one cleaner operation. In this case, gold recovery is 90.56%, which is 0.72% higher than the recovery in flotation flowsheet.

The studies on gold cyanidation and adsorption at activated carbon grade Gold Curb 207 C demonstrate low gold recovery, both during cyanidation of the original ore (recovery 62.42%) and during cyanidation of the flotation concentrate (recovery 48.53%). To increase the cyanidation efficiency, the methods of concentrate preparation for cyanidation such as pyrometallurgical treatment (roasting) and mechanical activation (ultrafine grinding) are recommended.

Keywords: *gold, gravity concentration, flotation, cyanidation, grinding, concentrate, recovery*
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Introduction

In view of depletion of rich ore, the gold industry is forced to develop processing technologies for refractory gold ore, with fine dispersion of gold in sulfide minerals, which impedes direct cyanidation of concentrates later on. There are many various process flowsheets for the refractory gold ore processing, and their choice depends on many factors. The main influences are: the chemical composition of initial ore; the occurrence form and distribution pattern of gold in ore; the properties of associate minerals; the presence of impurities which complicate processing [1].

The present-day experience of refractory gold ore processing uses technologies of flotation and integrated gravity–flotation with cyanidation of gold-bearing concentrates [2–8].

The current process flowsheets of gold ore enrichment range widely, from simple few operations to complex multi-operational circuits of dressing and pyro- and hydrometallurgy processes [9–11].

This article reviews the process flowsheets available for enrichment of gold ore of the Aktobe deposit with a view to selecting the most efficient and balanced technology.

The study has the following objectives:

- to implement gravity–flotation separation of refractory gold ore;
- to compare results of flotation and gravity–flotation process flowsheets;
- to analyze test data of cyanidation of the initial ore and gold-bearing flotation concentration.

Subjects of research

The subjects of research are the Aktobe gold ore, the processing technologies and the produced concentrates. The preliminary works included the analysis of the mineral composition of ore and its dressability by gravity, and the development of a flotation flowsheet for the initial ore. The results [12–14] show that:

—the ore minerals are pyrite to 6%, limonite to 0.5%, galena of 0.15–0.2% and sphalerite of 0.17–0.2%;

—the main enclosing minerals are quartz, potassic feldspar, calcite and mica;

—the toxic impurities of arsenic and antimony are almost absent, and the copper content is minimal;

—the ore represents impregnated nests of galena–sphalerite–pyrite aggregates according to microscopic investigations of the test samples. The main ore mineral is pyrite; it is observed in the form of anhedral aggregations and impregnations, individual isomorphic grains 0.02 to 1.5 mm in size, in concretion with sphalerite and galena, building up mostly along fissures. The Aktobe gold mostly has a coarseness less than 0.1 mm. Native gold occurs in blebs in the breccia heavily leached rock represented by limonite and iron hydroxides. The elongated grains 0.035×0.01 mm in size are yellow color with high reflection response;

—free gold and gold in aggregates (suitable for cyanidation) totals 46.47%; the rest gold occurs in sulfides (37.61%) and is finely disseminated in barren rock (15.92%), which is revealed by the phase analysis;

—the gold content of ore is 1.57 g/t.

Experimental procedure

For finding measures of ore processing by gravity–flotation, the closed-loop flotation tests were carried out at natural pH of pulp using gravity separation tailings, with return of recycles (8 closed-loop cycles) in a mode developed at the preliminary stage of research for the initial ore: grinding coarseness was 80% of –0.071 mm; consumption of potassium butyl xanthate was 100 g/t in rougher flotation and 50 g/t in cleaner flotation; consumption of frother C-7 was 20 g/t in rougher flotation and 10 g/t in cleaner flotation; duration of treatment in a mechanical-air machine was 6 min for rougher flotation and 8 min for cleaner flotation; two flowsheets of cleaner flotation were tested in a mechanical flotation machine—with one cleaner operation and with two cleaner operations, and the time of the first and second cleaner operations was 4 min and 3 min, respectively.

The hydrometallurgical research involved the method of cyanide leaching in bottle-type agitators. Cyanidation of the initial ore and flotation concentrate was carried out as direct leaching (without a sorbent) and with adsorption from leach solution (with activated carbon Gold Curb 207 C).

Cyanidation of the initial ore and concentrate proceeded as follows:

—samples of the initial ore 200 g in weight and with 80% size of –0.071 mm were placed in bottles with a volume of 1 l;

—each bottle was added with reagents: CaO—lime to create protective alkali, 1. 5 kg/t; BaO_2—barium bioxide (oxidizer) to maintain concentration of oxygen in cyanidation, 2 g; activated carbon Gold Curb 207 C—sorbent, depending on the testing conditions, 1.5 g;

—the bottles with reagents were filled with the prepared solution of cyanide NaCN at concentration of 0.1% for the initial ore cyanidation and at concentration of 0.3% for the flotation concentrate cyanidation;

—the bottles were placed in the agitator for leaching for 18 h;

—every 3 h the aliquot was sampled from the bottles and used to determine the concentrations of cyanide and free alkali, and, if necessary, the leaching solutions were strengthened with concentrated cyanide;

—at the end of each test, the final concentration of cyanide was determined together with its consumption per ton of ore;

—the cyanidation tailings were neutralized with potassium permanganat, washed, thickened, dried and assayed to determine the content of gold.

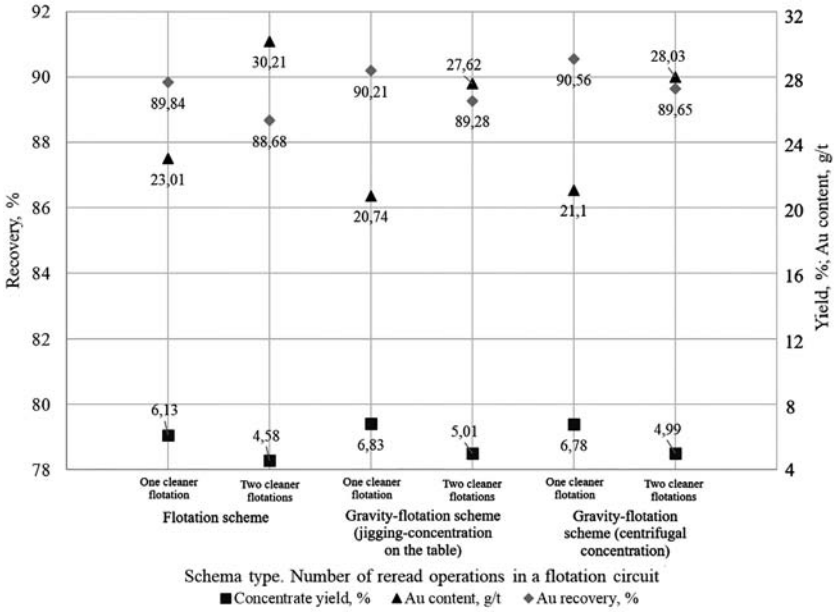

Fig. 1. Yield, content and recovery of gold in concentrate versus processing flowsheet and number of cleaner operations in closed-loop test

Table 1. Results of closed-loop experimental flotation of gravity separation tailings (milling–table concentration)

Product	Yield, %	Au content, %	Au recovery, %
Flotation with one cleaner operation			
Au flotoconcentrate	5.63	20.58	73.82
Gravity concentrate	1.20	21.45	16.39
Total gravity+flotation concentrate	6.83	20.74	90.21
Flotation tailings	93.17	0.165	9.79
Ore	100.00	1.57	100.00
Flotation with two cleaner operations			
Au flotoconcentrate	3.81	29.56	72.67
Gravity concentrate	1.20	21.45	16.61
Total gravity+flotation concentrate	5.01	27.62	89.28
Flotation tailings	94.99	0.175	10.72
Ore	100.00	1.55	100.00

Table 2. Results of closed-loop experimental flotation of gravity separation tailings (milling–centrifugal concentration)

Product	Yield, %	Au content, %	Au recovery, %
Flotation with one cleaner operation			
Au flotoconcentrate	5.54	17.70	62.06
Gravity concentrate	1.24	36.32	28.50
Total gravity+flotation concentrate	6.78	21.10	90.56
Flotation tailings	93.22	0.16	9.44
Ore	100.00	1.58	100.00
Flotation with two cleaner operations			
Au flotoconcentrate	3.75	25.28	60.78
Gravity concentrate	1.24	36.32	28.87
Total gravity+flotation concentrate	4.99	28.03	89.65
Flotation tailings	95.01	0.17	10.35
Ore	100.00	1.56	100.00

Results and discussion

The tests of the initial ore flotation defined the expediency of production of a gold concentrate through flotation with one cleaner operation. The flotation of ore with the gold content of 1.57 g/t produced: the concentrate yield of 6.13%; the gold content of 23.01 g/t at the recovery of 89.84%.

Tables 1 and **2** give the results of flotation tests of gravity separation tailings.

Figure 1 compares the results obtained in the closed-loop tests of flotation and gravity–flotation concentration of the Aktobe refractory ore.

The comparative analysis of the closed-loop processing results shows that both in flotation and in gravity–flotation tests, the production data are approximately on the same level. The highest data of recovery are obtained in the integrated milling–centrifugal concentration–flotation flowsheet with one cleaner operation. The gold recovery is 90.56%, which is 0.72% higher than the recovery in the flotation flowsheet (89.84%).

It follows from the aforesaid that processing of gold ore from the Aktobe deposit can use both the simple flotation flowsheet and the integrated gravity–flotation flowsheet with centrifugal concentration in the gravity circuit. The economic component of the technology should also be taken into account.

The chemical composition of the initial ore and flotation concentrate for cyanidation is described in **Table 3**.

Table 3. Chemical composition of initial ore and flotation concentrate

Element	Mass fraction	
	Initial ore	Flotation concentrate
Gold, g/t	1.57	23.01
Silver, g/t	42.50	605.00
Quartz, %	64.50	25.26
Aluminum oxide, %	18.11	5.49
Iron, %	2.14	25.95
Sulfur (total), %	1.06	31.01
Copper, %	0.01	0.128
Lead, %	0.15	2.415
Zinc, %	0.17	3.876
Arsenic, %	0.05	0.608

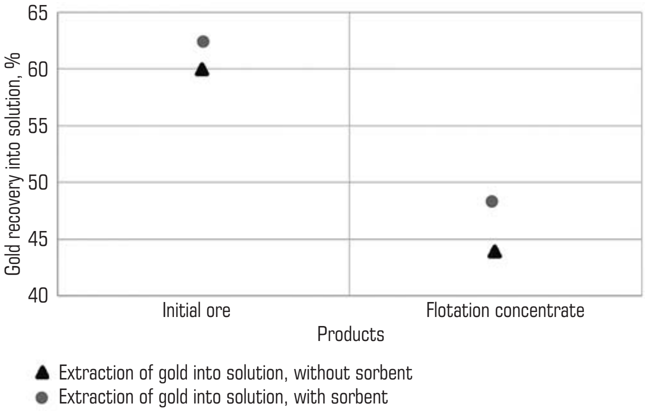

Fig. 2. Cyanidation results for initial ore and flotation concentrate

The initial ore and the produced flotation concentrate feature a high content of silver at its ratio to gold within a range of 27–28. The flotation concentrate has the contents of arsenic and copper higher more than by an order of magnitude as compared with the initial ore.

The cyanidation tests are illustrated in **Fig. 2**.

The analysis of Fig. 2 shows that after 18 h of agitation leaching of the initial ore at the concentration of NaCN 0.1%, the higher recovery of gold is achieved in adsorption from cyanide leach solution and is 62.42%. The consumption of NaCN in the initial ore cyanidation was 0.508 kg/t/.

In cyanidation of the flotation concentrate for 18 h at the concentration of NaCH 0.3%, the higher gold recovery reaches 48.53%, which is lower than the result achieved in case of the initial ore by 13.89%. The consumption of NaCN in cyanidation of the flotation concentrate was 3.391 kg/t.

Thus, the cyanidation results are reflective of the low efficiency of the process. The study of cyanidation of flotation concentrates will be continued to attain higher gold recovery. To that end, it is planned to examine the method of the preparation of concentrates for cyanidation, such as pyrometallurgical treatment (roasting) and mechanical activation (ultrafine milling) [15, 16]. It is expected that eventually the integrated approach to ore processing will find the most efficient processing technology for the Aktobe ore.

Conclusions

As a result of the implemented research into gravity–flotation processing of gold ore from the Aktobe deposit and from the comparative analysis of the used processing flowsheet, it is found that it is possible to use both the simple flotation flowsheet with the gold recovery of 89.84% and the integrated gravity–flotation flowsheet, with centrifugal concentrators in the gravity circuit, with the gold recovery of 90.56%.

The study of cyanidation with agitation shows that the recovery of gold is relatively low, both in cyanidation of the initial ore (gold recovery of 62.42%) and in cyanidation of the flotation concentrate (gold recovery of 48.53%). Aimed to enhance cyanidation efficiency, it is recommended to prepare the concentrate for cyanidation using the pyrometallurgical method (roasting) and mechanical activation (ultrafine milling).

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References

1. Komogortsev B. V., Varenichev A. A. The problems of processing of poor and refractory gold-bearing ores. *MIAB*. 2016. No. 2. pp. 204–218.
2. Lodeyshchikov V. V. Gold-extracting factories of the world: Analytical review. Irkutsk : Irgiredmet JSC, 2005. 447 p.
3. Tsarkov V.A. Experience of work of gold extraction enterprises of the world. Moscow : Ore and Metals Publishing House, 2004. 112 p.
4. Abdykirova G. J., Kenzhaliev B. K., Koyzhanova A. K., Magomedov D. R. Study of enrichment of low-sulfide gold–quartz ore. *Obogashchenie Rud*. 2020. No. 3. pp. 14–18.
5. Algebraistova N. K., Samorodsky G. N., Kolotushkin D. M., Prokopyev I. V. Technology of gold recovery from gold-bearing technogenic raw materials. *Obogashchenie Rud*. 2018. No. 1. pp. 33–37.
6. Surimbayev, B., Akcil A., Bolotova L., Shalgymbayev S., and Baikonurova A. Processing of refractory gold-bearing sulfide concentrates. A review. *Mineral Processing and Extractive Metallurgy Review*. 2024. Vol. 45, Iss. 6. pp. 573–591.
7. Surimbayev B., Bolotova L., Akcil A. et al. Gravity concentration of gold-bearing ores and processing of concentrates: A review. *Mineral Processing and Extractive Metallurgy Review*. 2024. DOI: 10.1080/08827508.2024.2395824
8. Evdokimov S. I., Golikov N. S., Zadkov D. A., et al. Studying the flotation of gold-bearing ores using carrier minerals. *Minerals*. 2024. Vol. 14, Iss. 1. ID 88.
9. Han S., Jung M., Lee W. et al. Diagnosis and optimization of gold ore flotation circuit via linear circuit analysis and mass balance simulation. *Minerals*. 2021. Vol. 11, Iss. 10. ID 1065.
10. Fedotov P. K., Senchenko A. E., Fedotov K. V., Burdonov A. E. Analysis of industrial studies of gold ores of the Chukotka deposit. *Obogashchenie Rud*. 2018. No. 2. pp. 23–29.
11. Fedotov P. K., Senchenko A. E., Fedotov K. V., Burdonov A. E., Vlasova V. V. Technology for processing low-sulfide gold–quartz ore. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*. 2022. Vol. 333, No. 6. pp. 178–189.
12. Barmenshinova M. B., Motovilov I. Y., Telkov Sh. A., Omar R. S. Study of the material composition of refractory gold-bearing ore from the Aktobe deposit. *Complex Use of Mineral Resources*. 2024. Vol. 331, No. 4. pp. 5–11.
13. Barmenshinova M. B., Motovilov I. Y., Omar R. S., Fedorov E. V. Study of gravity pretreatment of refractory gold-bearing ore from Aktobe deposit. *Eurasian Mining*. No. 1. 2024. pp. 11–14.
14. Barmenshinova M. B., Motovilov I. Yu., Omar R. S., Adilzhan Zh. Development of flotation technology for processing refractory gold-bearing ores from the Aktobe deposit. *Obogashchenie Rud*. No. 6. 2024. pp. 3-7.
15. Karimova L. M., Oleinikova T. O., Mansurov B. E., Saganbek S. Oxidizing roasting and cyanidation for the processing of refractory gold concentrates. *Obogashchenie Rud*. 2023. No. 3. pp. 10–15.
16. Gordeev D.V., Petrov G.V., Khasanov A.V., Severinova O.V. Review of modern technologies for processing refractory gold ores and concentrates using nitric acid. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*. 2022. Vol. 333, No. 1. pp. 214–223. EM