SATBAYEV UNIVERSITY

Engineering Journal of Satbayev University

Volume 147 (2025), Issue 5, 1-9

https://doi.org/10.51301/ejsu.2025.i5.01

Determination of the optimal technological regime and parameters of the cyanidation process of the flotation concentrate obtained after the enrichment of resistant gold-bearing ores

Zh.A. Yussupova[1], N.K. Dosmukhamedov[1], V.A. Kaplan[2], E.E. Zholdasbay[3*], A.A. Argyn[3]

[1]*Satbayev University, Almaty, Kazakhstan*

[2]*Weizmann Institute of Science, Rehovot, Israel*

[3]*Zhezkazgan University named after O.A. Baikonurov, Zhezkazgan, Kazakhstan*

**Corresponding author: zhte@mail.ru*

Abstract. As a result of comprehensive studies of the material composition of the flotation concentrate and the forms of gold presence, it was established that the chemical composition of the concentrate is 55.17% represented by lithophile components with the mass fraction of 55.17%. The main ones are silica and alumina with mass fractions of 36.4% and 8.26%, respectively. Ore mineralization of the flotation concentrate is represented by pyrite with the mass fraction of 40.7%. It has been established that gold in the flotation concentrate sample is present in native form. The bulk of gold grains is represented by particles with a size of 10-38 microns - 82.89%. About 63% of gold is in free form. The proportion of closed grains is 9.23%. The main mineral in the flotation concentrate sample, associated with gold, is pyrite – 25%. The portion of gold associated with quartz is 3.07%. For industrial operation, sorption type of cyanidation of flotation concentrates with a consumption of Norit RO 3520 activated carbon in an amount of 10% of the volume of the liquid phase is recommended as the optimal mode. The parameters for sorption cyanidation of flotation concentrate have been established: flotation concentrate size – P80 10 microns; sodium cyanide concentration – 0.1% (sodium cyanide consumption – 2.3 kg/t); pH – 10.5; pulp density – 40% (solid); duration of the process is 24 hours. With the established parameters, relatively high, at least 86%, extraction of gold into the solution was achieved.

Keywords: *gold, flotation concentrate, cyanidation, sodium cyanide, concentration, activated carbon.*

Received: 25 July 2025
Accepted: 16 October 2025
Available online: 31 October 2025

1. Introduction

All over the world, the gold content in ore deposits is decreasing, and their mineralogy is becoming more complex and complex. Despite this, the process of producing gold by cyanidation remains dominant for many years due to the selectivity of cyanide to gold, the simplicity and efficiency of the process [1-4]. Today, the industry is adjusting its methods for extracting gold from ores and its enrichment products (concentrates, tailings), using more efficient processes and technologies.

For effective cyanidation leaching of refractory and/or complex ores, pre-treatment prior to leaching is necessary. When sulfides are present, they often prevent the cyanide from making physical contact with the gold particles, thereby preventing the gold from dissolving. Conversely, for ores containing carbonaceous matter, dissolved gold in the leach solution can be re-adsorbed to carbonaceous species, a process known as preg-robbing, which also interferes with gold recovery. To solve these problems, pre-treatments are used, which increase costs and technical requirements for the process flow [3, 4].

The characteristics of the ore dictate the choice of the correct cyanidation process design. Gold ores within a geological province/region (even the same deposit) may have different mineral components, different mineral concentrations and degrees of alteration or oxidation.

Gold in ores and concentrates is often found in combination with non-ferrous metals (Cu, Pb, Ag). Applying cyanide to these types of ores can present some difficulty as the variety of minerals present in these ores can make the application of cyanide unfavorable. This type of ore includes gold deposits in Central Kazakhstan with a content of 1-1.5 g/t gold. The complex nature of these ores necessitated pre-treatment operations using gravity and cyanidation flotation. Production is characterized by low gold recovery. In addition, the choice of the optimal concentration of sodium cyanide, which is used as a leaching reagent, requires clarification.

The reserves of rich and easy-to-process gold ores in Kazakhstan are being depleted, and ores belonging to the category of refractory ores are being involved in processing. The persistence of ores may be due to the fine dissemination of gold in carrier minerals, chemical depression of gold at the stage of metallurgical processing, or the presence of organic compounds that are active towards dissolved gold.

An important problem in the processing of refractory gold ores is the extraction of ultrafine gold, which is encapsulated in sulfide minerals and is difficult to extract by traditional methods. Minor concentrations of «invisible» gold, as established in [5], usually contain pyrrhotite, chalcopyrite, bornite and galena. Work [6] shows that finely dispersed gold can be associated not only with sulfide, but also with rock-forming minerals. The most common carrier minerals of «invisible» gold are arsenopyrite and arsenic pyrite. The gold content of arsenopyrite depends on its morphological variety [7].

In work [8], based on studies of the gold content of arsenopyrite in gold-sulfide deposits in Kazakhstan, it is shown that due to the high sorption activity of the carbonaceous substance, metallurgical processing of flotation sulfide concentrate is impossible when the Au/Corg ratio is <8 g/kg. If the ratio is not met, additional gravitational enrichment of concentrates is required.

Due to the unique structure of the carbonaceous substance, the question related to the particular component and which one has increased sorption activity towards dissolved gold remains poorly understood. The high sorption activity of carbonaceous matter has a significant impact on the technology of processing ores and concentrates using flotation, pyro- and hydrometallurgical methods [9, 10].

A promising method for extracting ultrafine gold from refractory ores due to its enlargement may be the processing of feedstock and enrichment products using various physical and energetic methods of influence [11-14]. However, these methods have not been widely used in practice.

For gold ores of Central Kazakhstan, cyanidation of current flotation concentrates containing refractory minerals and carbonaceous substances, the presence of which causes a «slowdown» of the kinetic patterns of leaching and a decrease in gold recovery, has a particular relevance from a technological and environmental point of view. Processing of these materials by cyanidation entails high consumption of cyanide and increased costs [15, 16].

The importance of studying this issue is enhanced by the fact that in the scientific literature there is only a limited number of information devoted to the study of gold extraction based on the specific properties of the ore. In addition, in publically known works it was not possible to achieve high gold extraction from such ores.

In this article, based on a comprehensive study of the material composition of flotation concentrate obtained from the beneficiation of ore in Central Kazakhstan, the influence of the concentrate size, sodium cyanide concentration and leaching duration on gold recovery in the cyanidation process is investigated.

2. Materials and methods

For laboratory hydrometallurgical studies, a flotation concentrate with a gold content of 17.9 g/t was used, obtained after gravity-flotation enrichment of ore from a deposit in Central Kazakhstan.

The material composition of flotation concentrate was studied using optical and electron microscopic mineralogical studies. Chemical, assay, X-ray spectral and sieve analyzes were performed.

The chemical composition of the flotation concentrate was determined using optical emission (ICP90, ICP40 analyses) and atomic absorption methods of analysis. To increase the reliability of the gold content results, direct assay analysis was carried out on four parallel samples.

Determination of the mineral composition of flotation concentrate samples was carried out using a complex of various studies, including: diffractometric, quantitative mineralogical analyses, optical study of heavy fractions and mapping of products on a Quanta FEG-650 F electron microscope as part of the automated mineralogical complex Qemscan.

The study of gold forms for the presence of large gold particles in the flotation concentrate was carried out using an Olympus SZX-7 stereomicroscope. To conduct research, a sample of flotation concentrate was divided into size classes using the sieve analysis method. From each size class, ½ part was submitted for assay analysis; briquette sections were made from the second part. The study of briquette sections was carried out using an automated mineralogical complex Qemscan based on an electron scanning microscope. The parameters of the complex were configured to search for valuable minerals (SMS – Specific Mineral Search), mapping was performed in automatic mode.

Laboratory hydrometallurgical studies were carried out using cyanide leaching in bottle-type agitators. External view of laboratory stands with agitators shown on Figure 1.

Figure 1. Laboratory stand for conducting study on agitated leaching

To assess the level of sorption activity of the flotation concentrate sample, tests were performed to determine the PRI index (preg-robbing index) analytical method. Agitated cyanidation of the flotation concentrate was carried out on material subjected to fine grinding in a ball mill to a particle size of P80 71 and 45 microns, as well as ultrafine grinding to a particle size of P80 30, 20, 10 and 7 microns.

Ultrafine grinding was carried out in a Netzsch IsaMill M4B laboratory mill, the general view of which is shown in Figure 2. In the test the feed charge with beads size 2.8 mm was used: 60% 2.5-2.8 mm; 30% 1.8-2.0 mm; 10% 1.4-1.6 mm; solid content of the feed was ~43%, quantity of grinding cycles – 8.

Grinding was carried out in the following mode: mass of crushed material – 200 g; loading of grinding medium – 72.5% of the mill volume; pulp density during grinding – 55.25% solid; impeller rotation speed – 1300 rpm.

Figure 2. General view of Netzsch IsaMill M4 bead mills

Estimated specific energy consumption when grinding flotation concentrate from an initial size of 80% 150 microns to a size of 80% 10.1 μm was 81.5 kWh/t.

To determine the optimal leaching parameters, tests were carried out with different sizes of grinded concentrate under cyanidation conditions without loading sorbent and sorption type leaching, with different concentrations of sodium cyanide, and process duration with the purpose of studying the dynamics of leaching.

During the tests, NaCN concentration was monitored as well as pulp pH. The cyanidation products were subjected to atomic absorption (solution) and assay (cake, coal) types of analysis.

3. Results and discussion

3.1. Study of the material composition of flotation concentrate

The chemical composition of the flotation concentrate, determined by optical emission (ICP90, ICP40 analyses) and atomic absorption analyzes is presented in Table 1.

Table 1. Chemical composition of flotation concentrate

Element	Mass fraction, %	Element	Mass fraction, %
SiO_2	36.40	S_{total}	22.90
Al_2O_3	8.26	S_{sulf}	<0.25
CaO	1.50	Pb	0.015
K_2O	1.12	Zn	0.048
Na_2O	3.00	Cu	0.059
MgO	1.28	As	0.087
MnO	0.06	Sb	0.0066
P_2O_5	0.07	Ba	0.022
TiO_2	0.18	Co	0.012
C_{org}	0.26	Cr	0.0017
C_{total}	0.83	Ni	0.021
CO_2	3.04	Sr	0.014
Fe_{total}	20.60	Ag, g/t	2.90
Fe_{sulf}	18.90	Au, g/t	17.30

To increase the reliability of the result on gold content, its determination was carried out on four parallel samples using direct assay analysis. The established average gold content (17.47 g/t) based on the gold content in four samples, g/t: 16.8; 17.2; 18.2 and 17.7 showed good correlation with the result given in Table 1.

The chemical composition of the flotation concentrate is represented mainly by lithophile components with the mass fraction of 55.17%. The main ones are silica and alumina with mass fractions of 36.4% and 8.26%, respectively.

The total proportion of oxides of alkali and alkaline earth metals, with a significant predominance of sodium oxide 3.0%, is ~6.90%.

3.2. Mineral composition of flotation concentrate

The mineral composition of the flotation concentrate is shown in Table 2.

Table 2. Mineral composition of flotation concentrate

Mineral, group of minerals	Mass fraction in sample, %
Rock-forming minerals	
Plagioclases	26.0
Quartz	18.0
Mica (sericite, chlorite)	9.0
Carbonates	5.0
Gypsum, anhydrite, jarosite	-
Ore-forming minerals	
Pyrite	40.7
Sphalerite, galena, altaite	0.1
Faded ore, chalcopyrite	0.3
Arsenopyrite	0.1
Iron hydroxides	0.5
Accessory minerals	
Titanium minerals, apatite	0.3
Total	100

From Table 2 it is clear that the mineral composition of the flotation concentrate samples consists of 58% rock-forming minerals. Ore minerals are represented mainly by pyrite 40.7%. Other sulfides are noted in the samples in amounts of tenths of a percent.

3.3. Forms of gold presence

The analysis of the forms of gold presence in the flotation concentrate sample was performed sequentially. First, using the Olympus SZX-7 stereomicroscope, an initial study was conducted to identify large, visible gold particles. Then, a more detailed study of the gold's forms was carried out using an electron microscope. The initial analysis did not reveal large visible gold particles. It was found that the bulk of the gold in the flotation concentrate, namely 99.96%, is represented as native gold. The remaining insignificant fraction (0.04%) of gold was found in the form of tellurides of various compositions. Due to the extremely small number of tellurides, the technological and mineralogical characteristics were studied only for native gold.

Figure 3 shows the granulometry of gold grains present in the flotation concentrate.

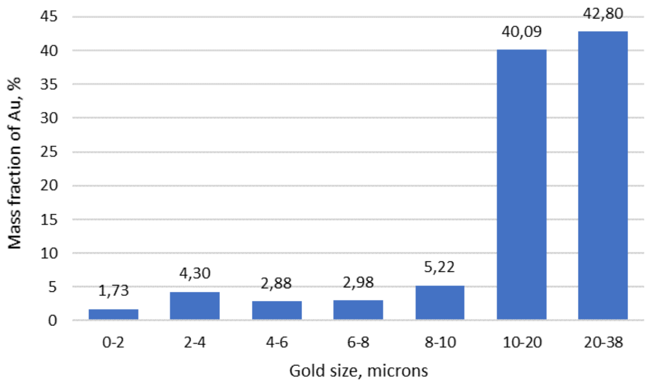

Figure 3. Granulometric characteristics of gold

The bulk of the valuable component consists of particles ranging in size from 10 to 38 microns, the total proportion of which reaches 82.89%. The number of small particles not exceeding 2 microns is insignificant and does not exceed 1.73%. In the size range from 2 to 10 microns, the gold content ranges from 2.88 to 5.22%. The results of the mineral associations of gold in the flotation concentrate sample, presented in Table 3, show that the background includes free gold and gold with a partially free surface. Thus, 69.15% of the grains of the valuable component have access of the solution and reagents to the grain surface.

Table 3. Mineral associations of gold

Mineral, group of minerals	Mass fraction of gold, %
Background	69.15
Quartz	3.07
Mica	0.11
Chlorite	0.60
Feldspars	0.05
Tellurides	0.86
Pyrite	25.03
Chalcopyrite	0.35
Galena	0.004
Sphalerite	0.11
Arsenopyrite	0.03
Faded ore	0.62
Accessory minerals	0.03
Total:	100

The main mineral associated with gold in the flotation concentrate sample is pyrite. The ratio of such intergrowth's accounts for 25.03% of the metal. In contact with quartz, the proportion of gold is 3.07%. In intergrowth with other minerals, the share of gold is tenths and hundredths of a percent. The established patterns are clearly illustrated by fragments of the map of gold mineral particles in the flotation concentrate sample and associations of gold with various minerals, shown in Figure 4.

Thus, the results of studies of the material composition of the flotation concentrate show that its chemical composition is represented by lithophilic components with a mass fraction of 55.17%. The mass fraction of silica and alumina in them is 36.4% and 8.26%, respectively. The total proportion of alkali and alkaline earth metal oxides, with a significant predominance of sodium oxide 3.0%, is ~6.90%. The ore-forming components are represented by iron and sulfur, where iron predominates in the sulfide form. The proportion of sulfur is 22.90%. The mineral composition of the flotation concentrate samples is 58% composed of rock–forming minerals in the following proportions: plagioclases – 26%; quartz – 18%; Mica – 9% and carbonates - 5%.

Ore mineralization of the flotation concentrate is represented mainly by pyrite with the mass fraction of 40.7%. Other sulfides are observed in tenths of a percent. Iron hydroxides make up 0.5% of the total sample mass.

It has been established that gold in the flotation concentrate sample is present in native form. The ratio of gold in the form of tellurides of various compositions accounts for no more than 0.04%. The bulk of gold grains is represented by particles with a size of 10-38 microns - 82.89%. About 63% of gold is in free form. The proportion of closed grains is 9.23%. The main mineral in the flotation concentrate sample, the gold is in association with, is pyrite – 25%. The ratio of gold associated with quartz is 3.07%. Tenths and hundredths of a percent of the total mass of native gold have been established in intergrowth with other minerals.

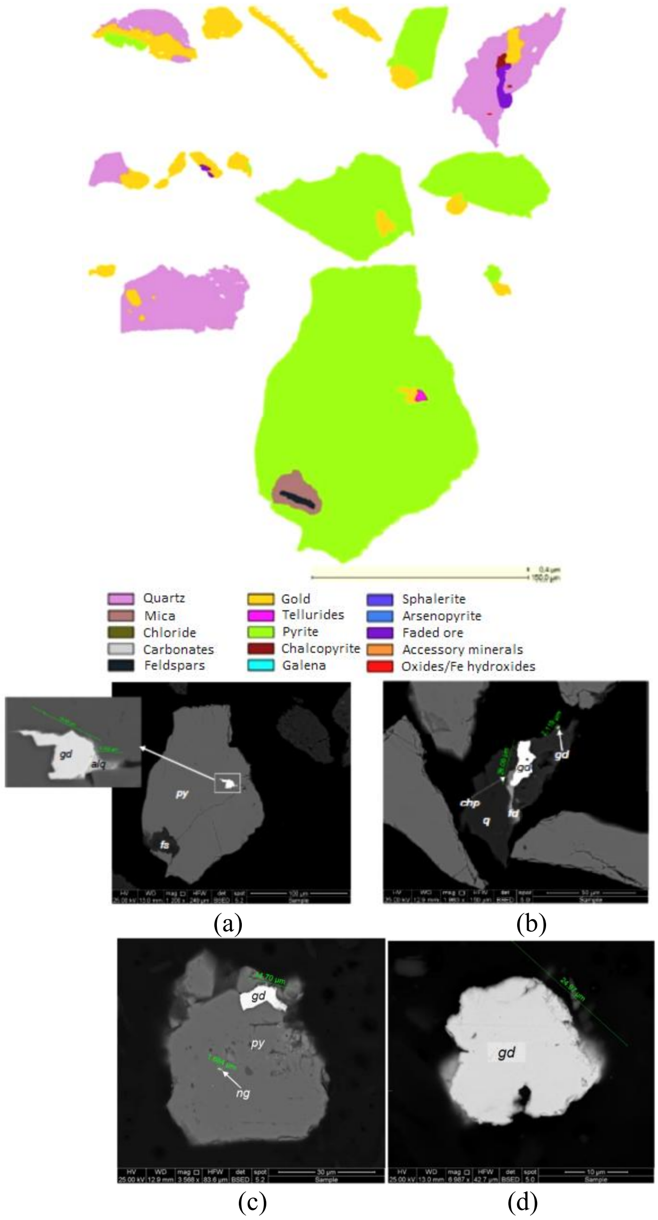

Figure 4. Map of gold mineral particles in a flotation concentrate sample and photographs of gold grains in association with various minerals: (a) – Pyrite (py) with inclusions of feldspar (fs) and native gold (gd) in association with lead mineral (altaite (alq)); (b) – Native gold (gd) in association with quartz (q), chalcopyrite (chp), faded ore (fd); (c) – Pyrite (py) with gold inclusions of variable composition (native gold (gd), nagiagite (ng)); (d) – Free grain of native gold (gd)

It should be expected that the resistance of gold to the cyanide process will be due to the presence of oxidized films on the surface of the metal and its association with carbonates and minerals insoluble in aqua regia.

3.4. Determination of sorption activity index (PRI test) of flotation concentrate

The level of sorption activity was assessed analytically by calculating the PRI (preg-robbing index). The method for determining the sorption activity index consists in analyzing the amount of gold extracted into the solution during cyanidation and the remaining amount in the solution after cyanidation, when a certain amount of gold in the form of a cyanide complex was previously added to the solution. Thus, each PRI test consists of two parts:

1. Cyanidation of a sample of the test material in a pure gold-free solution;

2. Cyanidation of a sample of the test material in a solution previously saturated with gold to a certain concentration.

For each part of the PRI tests, 100 g of pre-ground concentrate was used to a coarseness of P80 71, 30 and 10 microns. Cyanidation was performed in the mode without sorbent loading with the following parameters: test duration – 1 hour; pulp density – 33.3%; initial concentration of NaCN – 0.3%; concentration of NaOH – 0.1%.

A gold concentration of 1.71 mg/l was previously created in the solution for the second part of the PRI tests.

After a set cyanidation time, the solution was filtered out and the concentration of gold in it was determined by atomic absorption method. The sorption activity index was calculated using the formula:

$$PRI = 2 \times 1.71 + 2\cdot([Au]_{solution\ 1} - [Au]_{solution\ 2}), \quad (1)$$

where: PRI is sorption activity index; $[Au]_{solution\ 1}$ is concentration of gold in the solution of the first part of the test, mg/l; $[Au]_{solution\ 2}$ is concentration of gold in the solution of the second part of the test, mg/l.

Based on the calculated values of the PRI index sorption activity was assessed using the following criteria:

– PRI = 0 – the material does not have sorption activity;

– 0 < PRI < 1.0 – the material has low sorption activity;

– 1.0 ≤ PRI < 2.5 – the material has moderate sorption activity;

– 2.5 ≤ PRI ≤ 3.4 – the material has high sorption activity.

The results for determining the sorption activity index are shown in Table 4.

Table 4. Results of the sorption activity index (PRI)

Concentrate grinding size P_{80}, microns	$[Au]_{solution\ 1}$, mg/l	$[Au]_{solution\ 2}$, mg/l	Assessment of sorption activity
71	0.25	0.05	Very high
30	0.38	0.12	Very high
10	0.51	0.28	Very high

Analysis of the obtained data shows that the studied concentrate has a very high sorption activity at all degrees of grinding. The PRI index significantly exceeds 3.4 for all three fractions, which indicates a strong «preg-robbing» effect.

An increase in the degree of grinding leads to a slight decrease in the PRI index, although it remains in the range of «very high» sorption activity. This may be due to an increase in the surface area of the material with finer grinding, which contributes to a more intensive absorption of gold.

The high sorption activity of the concentrate can significantly reduce the efficiency of the cyanidation and gold extraction process. The material actively absorbs gold from the cyanide solution, preventing it from passing into solution and further extraction.

To increase the efficiency of gold extraction from this concentrate, it is necessary to apply methods aimed at reducing or blocking sorption activity. Such methods include pretreatment with activated carbon, the addition of special depressant reagents, or the use of higher concentrations of cyanide. The choice of the optimal method depends on the specific characteristics of the material and the process conditions.

In this work, Norit RO 3520 activated carbon was used as a sorbent.

3.5 Cyanidation of flotation concentrate of various sizes

The experiments were carried out in two modes – in the cyanidation mode without loading the sorbent and in the sorption cyanidation mode with the addition of activated carbon Norit RO 3520. The experimental conditions and parameters of agitation cyanidation of the flotation concentrate are presented in Table 5.

Table 5. Parameters of agitated cyanidation of flotation concentrate

Parameter	Unit	Measurement
Sodium cyanide concentration	%	0.2
pH	–	10.5
Pulp density during cyanidation	% solid	40
Coal loading (only for sorption type of cyanidation)	% of liquid phase volume	10
Type of sorbent	–	Activated carbon Norit RO 3520
Leaching duration	hour	24

Agitation cyanidation of the flotation concentrate was carried out on the material obtained after fine grinding in a ball mill to a size of P80 71 and 45 microns and ultrafine grinding in a bead mill to a size of P80 30, 20, 10 and 7 microns.

The results of cyanidation tests for flotation concentrate at different grinding sizes are shown in Table 6.

Table 6. Results of cyanidation of flotation concentrate at different grinding sizes

Material size P_{80}, microns	Reagent consumption, kg/t			Au content, g/t		Au recovery, %
	NaCN		CaO	in the feed	in a cake	
	total	considering the residue				
Cyanidation without sorbent loading						
71	3.3	0.7	1.5	17.9	7	60.89
45	3.8	1.1	1.5		8.4	53.07
30	3.9	2	1.4		5.2	70.95
20	3.8	1.8	1.4		4.2	76.54
10	3.9	2.1	1.4		3.4	81.01
7	3.9	2.2	1.5		3.4	81.01
Sorption type cyanidation						
71	3.5	1.2	2	17.9	5	72.07
45	3.9	1.3	2		4.7	73.74
30	3.9	1.8	1.9		3.3	81.56
20	3.8	2	1.9		3	83.24
10	3.9	2.1	2		2.4	86.59
7	4.4	3.1	1.9		2.4	86.59

The results presented in Table 6 show that the flotation concentrate is favorable in relation to the process of agitated cyanidation. The recovery of gold from a concentrate with a particle size of P80 71 microns during cyanidation without loading a sorbent was 60.89%, and with sorption type cyanidation – 72.07%. A comparative analysis of the results of direct and sorption type cyanidation in the studied range of changes in P80 size from 71 to 7 μm indicates the presence of sorption activity of the flotation concentrate. Figure 5 visualizes the dependence of gold recovery on the size of the material.

Grinding the concentrate from a particle size of P80 71 microns to a particle size of P80 45, 30, 20, 10 and 7 microns allows increasing gold recovery in the sorption mode of cyanidation by 1.68%, 9.5%, 11.17%, 14.53% and 14.53% (abs.), respectively. At the same time, the gold content in the cake, compared with cyanidation without sorbent loading, is reduced by 0.3 g/t, 1.7 g/t, 2.0 g/t, 2.6 g/t and 2.6 g/t (abs.), respectively.

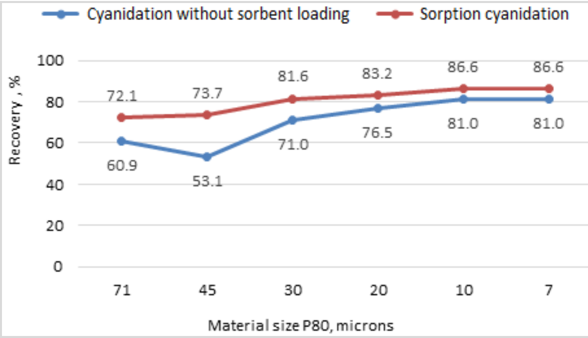

Figure 5. Dependence of gold recovery on flotation concentrate size

The maximum extraction of gold into the solution (86.6%) is achieved when the particle size of the flotation concentrate P80 is 10 microns. Finer grinding of the concentrate does not lead to an increase in gold extraction. Considering this fact, in subsequent experiments, the particle size of the flotation concentrate was fixed at the level of P80 10 microns.

As shown in Figure 5, with a comparable concentrate particle size, the gold recovery rates obtained in two different modes after the leaching process are significantly different. This highlights the importance of conducting additional studies to determine the sorption properties of the concentrate.

3.6 Effect of sodium cyanide concentration on gold recovery during cyanidation of flotation concentrate

To explore the possibility of reducing cyanide consumption during cyanidation of flotation concentrate, leaching tests were performed at different concentrations of sodium cyanide in solution: 0.3%, 0.2%, 0.15% and 0.1%.

Tests were carried out in sorption mode on material with a particle size of P80 10 μm. The pulp density during leaching is 40% solid. Sorption type cyanidation was carried out with coal loading in an amount of 10% of the volume of the liquid phase. Leaching duration is 24 hours. The test results are presented in Table 7.

Table 7. Results of sorption type cyanidation of flotation concentrate at different concentrations of sodium cyanide in solution

Concentration	Reagent consumption, kg/t			Au content, g/t		Recovery
	NaCN					
NaCN, %	total	considering the residue	CaO	in the feed	in a cake	Au, %
0.1	2.3	1.7	1.9	17.9	2.4	86.59
	2.3	1.7	1.9		2.5	86.03
0.15	2.8	1.6	1.9		2.4	86.59
	2.8	1.6	1.9		2.6	85.47
0.2	3	1.6	1.6		2.4	86.59
	3	1.6	1.6		2.4	86.59
0.3	4.5	1.5	1.6		2.4	86.59
	4.5	1.6	1.7		2.4	86.59

An increase in the concentration of sodium cyanide in solution does not affect the extraction of gold into solution (Table 7). The average values of gold extraction in the considered range of NaCN concentration changes (from 0.1 to 0.3%) practically remain at the same level and are: 86.03% – at NaCN = 0.1% and 86.59% – at NaCN = 0.3%.

The results indicate that flotation concentrate particle size is a more significant factor than the cyanide concentration used to determine the percentage dissolution of gold particles. At a cyanide concentration of 0.1% in solution, gold recovery was 86.32% (average). Increasing the concentration above a given limit only slightly increases recovery. This indicates that increasing the cyanide concentration above 0.1% does not have a significant effect on the rate of gold dissolution, and may even slow it down [17]. In addition, an increase in the content of metal cyanide complexes in the solution can complicate the cyanidation process and significantly increase the cost of gold production [18].

An increase in gold recovery with a decrease in the size of the flotation concentrate is fully explained by an increase in the contact surface area for leaching reactions to occur [19]. The obtained results convincingly show that the P80 concentrate size of 10 microns and the sodium cyanide concentration of 0.1% are the best combination of the concentrate cyanidation process providing a high gold recovery of 86.59%.

3.7. Effect of cyanidation process duration on gold extraction from flotation concentrate

Agitation cyanidation of the flotation concentrate was carried out in sorption mode on a material with a grain size of P80 10 microns at a constant concentration of sodium cyanide equal to 0.1%. The duration of the process was: 8, 12, 16, 20, 24, 32, 40 and 48 hours. The pulp density during leaching is 40% solid, pH = 10.5. The acidity level was maintained at 10.5 by adding lime. The results of the concentrate cyanidation tests at different process times are shown in Table 8.

Table 8. Results of cyanidation of flotation concentrate at different process durations

Duration process, h.	Reagent consumption, kg/t			Au content, g/t		Recovery
	NaCN					
	Total	considering the residue	CaO	in the feed	in the cake	Au, %
8	1.9	1	1.9	17.9	2.6	85.47
12	1.9	1.4	1.9		2.6	85.47
16	1.9	1.6	1.9		2.5	86.03
20	1.9	1.6	1.9		2.4	86.59
24	2.4	1.7	2		2.4	86.59
32	2.6	1.9	2.4		2.4	86.59
40	2.7	2.2	2.4		2.5	86.03
48	2.7	2.2	2.4		2.5	86.03

An analysis of the data obtained shows that the majority of gold is extracted in the first 8-12 hours of cyanidation, reaching 85.47%. Increasing the processing time to 32 hours has little effect on gold recovery, leading only to an increase of 1.12% (abs.).

To ensure the stability of technological parameters during the industrial processing of flotation concentrate obtained from stubborn ores of Central Kazakhstan, it is recommended to carry out cyanidation for at least 24 hours, which will allow 86.59% of gold to be extracted into the solution.

A further increase in the duration of cyanidation, as studies show, is not economically feasible. The cost of reagents, energy consumption and depreciation of equipment in this case exceeds a slight increase in gold extraction. Therefore, optimization of the cyanidation process should be aimed at maintaining optimal conditions during the first 24 hours, ensuring maximum speed and completeness of gold extraction.

The key factors influencing cyanidation efficiency are cyanide concentration and the pH of the medium. Maintaining the optimal acidity of the solution in the pH range of 10.5-11.5 contributes to the stable formation of soluble cyanide complexes of gold. The cyanide concentration should be sufficient to maintain the dissolution process, but not excessive, in order to avoid reagent loss and the formation of undesirable by-products.

Thus, in order to achieve optimal results in cyanidation of flotation concentrate from stubborn ores in Central Kazakhstan, it is necessary to carefully monitor and maintain optimal technological parameters during the first 24 hours of the process. This will ensure stable and economically profitable extraction of gold.

4. Conclusions

The flotation concentrate obtained from gold-bearing ore mined in Central Kazakhstan is a promising raw material for the extraction of gold by cyanidation. However, an analysis of the component composition of the concentrate and the forms of gold finding indicates potential difficulties in extracting stubborn forms, especially from sulfide minerals. This concentrate demonstrates favorable characteristics for the process of agitation cyanidation.

The determination of the PRI index showed that the material has a very high sorption activity in relation to gold. The PRI indices for the concentrate with P80 particle sizes of 71, 30, and 10 microns were 5.02, 4.08, and 3.66, respectively.

When cyanidation of a concentrate with a particle size of P80 71 microns without the use of a sorbent achieved gold recovery at the level of 60.89%. The use of sorption cyanidation with the addition of activated carbon made it possible to increase gold extraction to 72.07%.

A decrease in the particle size of the concentrate from P80 71 microns to P80 45, 30, 20, 10 and 7 microns, compared with cyanidation without the addition of activated carbon, leads to an increase in gold extraction in the sorption regime by 1.68%, 9.5%, 11.17%, 14.53% and 14.53% (abs.), respectively. At the same time, the gold content in the cake decreases by 0.3 g/t, 1.7 g/t, 2.0 g/t, 2.6 g/t and 2.6 g/t (abs.).

For industrial applications, sorption cyanidation of Norit RO 3520 activated carbon flotation concentrate is recommended under the following optimal conditions: particle size of the flotation concentrate – P80 10 microns; coal consumption of Norit RO 3520 – 10% of the volume of the liquid phase; concentration of sodium cyanide – 0.1%; consumption of sodium cyanide – 2.3 kg/t; pH – 10.5; density the pulp content is 40%; the duration of the process is 24 hours, which ensures the extraction of gold into solution at a level of at least 86%.

Optimization of the sorption cyanidation process using Norit RO 3520 activated carbon and ultrafine flotation concentrate grinding opens up new horizons for improving the efficiency of gold extraction. Reducing the particle size to P80 10 microns significantly increases the surface area available for interaction with cyanide and sorbent, which, in turn, contributes to a more complete release of gold from the mineral matrix.

The choice of Norit RO 3520 activated carbon as a sorbent is due to its high adsorption capacity and kinetic characteristics that are optimal for extracting gold from cyanide solutions. Maintaining the optimal concentration of sodium cyanide at 0.1% ensures the necessary concentration of cyanide ions for complexation with gold, while the consumption of sodium cyanide 2.3 kg/t is economically feasible and environmentally acceptable.

Maintaining the acidity of the solution at pH = 10.5 is necessary to ensure the stability of cyanide complexes and prevent cyanide hydrolysis. The pulp density of 40% is optimal to ensure good mixing and contact between the solid and liquid phases. The 24-hour process duration provides sufficient time to achieve maximum gold recovery.

The application of the proposed optimal conditions ensures the achievement of gold recovery in solution at a level of at least 86%, which significantly exceeds the indicators achieved by cyanidation without the use of a sorbent. This leads to a decrease in the gold content in the cake and an increase in the overall economic efficiency of the gold extraction process from the gold-bearing ores of Central Kazakhstan.

Author contributions

Conceptualization: NKD; Data curation: ZAY; Formal analysis: EEZ; Funding acquisition: ZAY; Investigation: ZAY; Methodology: AAA; Project administration: VAK, NKD; Resources: ZAY; Software: EEZ, AAA; Supervision: VAK, NKD; Validation: NKD; Visualization: VAK, NKD; Writing – original draft: NKD, ZAY; Writing – review & editing: EEZ, AAA. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Acknowledgements

The authors express their sincere gratitude to the editor and anonymous reviewers for their constructive comments and valuable suggestions, which have significantly improved the quality of this manuscript.

Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

References

[1] Ghobadi, B., Noaparast, M., Shafaei, S.Z. & Unesi, M. (2014). Optimization of cyanidation parameters to increase the capacity of Aghdarre gold mill. *Journal of Mining and Environment*, *5(2), 121-128*

[2] Marsden, J., & House, C. (2006). The chemistry of gold extraction, vol 2. Society for Mining. *Metallurgy and Exploration (SME), Littleton (CO), USA*

[3] Medina, D., & Anderson, C.G. (2020). A Review of the cyanidation treatment of copper-gold ores and concentrates. *Metals*, *(10), 897.* http://doi.org/10.3390/met10070897

[4] Stapper, D., Dales, K., Velasquez, P. & Keane, S. (2021). Best management practices for cyanide use in the small-scale gold mining sector. *PlanetGOLD Program (Global Environment Facility and United Nations Environment Programme)*

[5] Ashley, P.M., Creagh, C.J. & Ryan, C.G. (2000). Invisible gold in ore and mineral concentrates from the Hillgrove gold - antimony deposits, NSW, Australia. *Mineralium Deposit*, *35(4), 285-301*. https://doi.org/10.1007/s001260050242

[6] Kovalev, K.R. (2011). Gold content of arsenopyrite in gold-sulfide deposits of Eastern Kazakhstan. *Geology and Geophysics, 52(2), 225-242*. https://doi.org/10.1016/j.rgg.2010.12.014
[7] Sanakulov, K.S. (2016). On the feasibility of using combined technologies for processing particularly refractory gold sulfide ores. *Non-ferrous metals, (2), 9-14*
[8] Kanaeva, Z.K., Kanaev, A.T. & Semenchenko, G.V. (2014). Geological structure of the Bakyrchik gold-arsenic deposit in Eastern Kazakhstan. *Fundamental Research, (11), 45*
[9] Meretukov, M.A. (2007). Gold and natural carbonaceous matter. *Moscow: Ore and Metals*
[10] Zakharov, B.A., & Meretukov M.A. (2013). Gold: refractory ores. *Moscow: Ore and metals*
[11] Földvári, M. (2011). Handbook of the thermogravimetric system of minerals and its use in geological practice. *Occasional Papers of the Geological Institute of Hungary, 213, 1-118*
[12] Schmidt, C.M., & Heide, K. (2001). Thermal analysis of hydrocarbons in Paleozoic black shales. *Journal of Thermal Analysis and Calorimetry, 64(3), 1297-1302*. https://doi.org/10.1023/A:1011530020564
[13] Gallagher, P.K., & Brown, M.E. (2003). Handbook of thermal analysis and calorimetry. *Netherlands, Amsterdam: Elsevier Science*
[14] Chanturia, V.A. (2000). Change in the structural state of the surface of pyrite and arsenopyrite during electrochemical opening of refractory gold ores. *Mining Journal, (2), 24-27*
[15] Hilson, G., & Monhemius, A.J. (2006). Alternatives to cyanide in the gold mining industry: what prospects for the future? *Journal of Cleaner Production, (14), 1158-1167*. https://doi.org/10.1016/j.jclepro.2004.09.005
[16] Adams, M.D. (2016). Gold ore processing: project development and operations. *Gold Ore Processing, 525-531*. http://doi.org/10.1016/B978-0-444-63658-4.00029-3
[17] Habashi, F. (1967). Kinetics and mechanism of gold and silver dissolution in cyanide solution. *Bureau of Mines and Geology, State of Montana, 1-42*
[18] Parga, J.R, Valenzuela, J.L. & Diaz, J.A. (2012). New technology for recovery of gold and silver by pressure cyanidation leaching and electrocoagulation. *Noble Metals. InTech, 71-94*. http://doi.org/10.5772/32673
[19] Mular, A.L., Halbe, D.N. & Barrate, D.J. (2002). Mineral processing plant design, Practice and control. *Society for Mining, Metallurgy and Exploration, 1*

Құрамында алтыны бар кендерін байытқаннан кейін алынған флотоконцентратты циандау процесінің оңтайлы технологиялық режимін және параметрлерін айқындау

Ж.А. Юсупова[1], Н.К. Досмухамедов[1], В.А. Каплан[2], Е.Е. Жолдасбай[3*], А.Ә. Арғын[3]

[1]*Satbayev University, Алматы, Қазақстан*
[2]*Вейцман атындағы Ғылыми институт, Реховот, Израиль*
[3]*Ө.А. Байқоңыров атындағы Жезқазған университеті, Жезқазған, Қазақстан*

**Корреспонденция үшін автор:* zhte@mail.ru

Аңдатпа. Флотоконцентраттың заттық құрамын және алтынның табылу нысандарын кешенді зерттеу нәтижесінде концентраттың химиялық құрамы 55.17%-ға литофильді компоненттермен ұсынылғаны анықталды, олардың массалық үлесі 55.17% құрайды. Олардың негізгілері сәйкесінше 36.4% және 8.26% массалық үлестері бар кремний диоксиді және глинозем болып табылады. Флотоконцентраттың кенді минералдануы пиритпен ұсынылған, оның массалық үлесі – 40.7%. Флотоконцентрат үлгісіндегі алтын табиғи түрде болатыны анықталды. Алтын дәндерінің негізгі бөлігі 10-38 мкм – 82.89% тұрады. Алтынның шамамен 63%-ы еркін күйде. Жабық дәндердің үлесі 9.23% құрайды. Алтын ассоциацияланған флотоконцентрат үлгісіндегі негізгі минерал – пирит - 25%. Кварцпен байланысты алтынның үлесі 3.07% құрайды. Өнеркәсіпте пайдалану үшін оңтайлы режим ретінде сұйық фаза көлемінің 10% мөлшерінде Norit RO 3520 белсендірілген көмір шығыны бар флотоконцентратты сорбциялық циандау ұсынылады. Флотоконцентратты сорбциялық циандау параметрлері белгіленді: флотациялық концентраттың ірілігі - P80 10 мкм; натрий цианидінің концентрациясы – 0.1% (натрий цианидінің шығыны – 2.3 кг/т); pH – 10.5; пульпаның тығыздығы - 40% (қатты); процестің ұзақтығы – 24 сағат, белгіленген параметрлерде жоғары, ерітіндіге кемінде 86% алтынды бөліп алу қол жеткізілді.

Негізгі сөздер: *алтын, флотоконцентрат, циандау, натрий цианиді, концентрация, белсендірілген көмір, сорбциялық циандау.*

Определение оптимального технологического режима и параметров процесса цианирования флотоконцентрата, полученного после обогащения упорных золотосодержащих руд

Ж.А. Юсупова[1], Н.К. Досмухамедов[1], В.А. Каплан[2], Е.Е. Жолдасбай[3*], А.А. Арғын[3]

[1]*Satbayev University, Алматы, Казахстан*

[2]*Научный институт имени Вейцмана, Реховот, Израиль*

[3]*Жезказганский университет имени О.А. Байконурова, Жезказган, Казахстан*

**Автор для корреспонденции: zhte@mail.ru*

Аннотация. В результате комплексных исследований вещественного состава флотоконцентрата и форм нахождения золота установлено, что химический состав концентрата на 55.17% представлен литофильными компонентами, массовая доля которых составляет 55.17%. Основными из них являются кремнезем и глинозем с массовыми долями 36.4% и 8.26%, соответственно. Рудная минерализация флотоконцентрата представлена пиритом, массовая доля которого составляет 40.7%. Установлено, что золото в пробе флотоконцентрата присутствует в самородной форме. Основная масса зерен золота представлена частицами размером 10-38 мкм – 82.89%. Порядка 63% золота находится в свободном виде. Доля закрытых зерен составляет 9.23%. Основным минералом в пробе флотоконцентрата, с которым золото находится в ассоциации, является пирит – 25%. Доля золота, ассоциированного с кварцем, составляет 3.07%. Для промышленной эксплуатации в качестве оптимального режима рекомендуется сорбционное цианирование флотоконцентрата с расходом активированного угля Norit RO 3520 в количестве 10% от объема жидкой фазы. Установлены параметры сорбционного цианирования флотоконцентрата: крупность флотационного концентрата – P80 10 мкм; концентрация цианида натрия – 0.1% (расход цианида натрия – 2.3 кг/т); pH – 10.5; плотность пульпы – 40% (твердого); продолжительность процесса – 24 ч. При установленных параметрах достигнуто высокое, не менее 86%, извлечение золота в раствор.

Ключевые слова: *золото, флотоконцентрат, цианирование, цианид натрия, концентрация, активированный уголь, сорбционное цианирование.*

Publisher's note

All claims expressed in this manuscript are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers.