

Research Article

Additional Gold Recovery from Tailing Waste By Ion Exchange Resins

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Abstract

The article describes the gamma activation analysis method used to determine the gold content in rock samples using the Aura measuring complex. The physicochemical basis of gold extraction in the process of cyanide leaching is considered. The technology for extracting gold from solutions of tailing waste “ponds” of tailings dumps of hydrometallurgical plants of the Joint Stock Company “Navoi Mining and Metallurgical Combine” (JSC NMMC) is presented. It has been shown that in the dynamic mode of sorption of tailing waste solutions acidified to pH = 3.3÷3.5 through AM-2B and VP-1P ion exchange resins, gold is sorbed on the AM-2B anion exchanger up to 3.9 mg/g and on the VP-1P anion exchanger up to 1.5 mg/g. It has been shown that when solutions of tailing waste are exposed to ammonia, ammonia complex compounds of base metal impurities are formed, which decompose, while the gold cyanide complex does not decompose and is sorbed on the AM-2B ion exchange resin up to 3.0 mg/g. The mechanisms of the chemical reactions of the process of extracting gold from tailing waste and the technological scheme of the installation for extracting gold from solutions of the tailing waste “pond” are presented.

More Information

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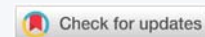
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Keywords: Tailings solutions; Gold; Base metals; Sulfuric acid; Ammonia; Ion exchange resin; Dynamic sorption; Desorption



Introduction

Since 1977 in the Central Laboratory of Gamma Activation Analysis of JSC NMMC at the «Aura» measuring complex has been carrying out gamma activation analysis of the elemental composition of rock samples and quantitative analysis of precious metals using a linear electron accelerator, where the content of gold and 60 different elements is determined. The «Aura» complex has a productivity of over 1 million analyses per year and determines the gold content in 3500 samples in 1 day with productivity of determining gold in 1 sample in 17 seconds [1]. Figure 1 shows a technological diagram of the «Aura» measuring complex.

The gamma activation analysis method is carried out by irradiating rock samples with high-energy gamma quanta on a linear accelerator of the UELR-8-8A and UELR-8-10A type with an electron energy of 7–9 MeV, a beam power of up to 10 kW and recording gamma-rays with a scintillation detector quanta of metastable radionuclide ^{197m}Au, which is formed according to a nuclear reaction:



The radionuclide ^{197m}Au has a half-life $T_{1/2}=7.4$ sec, the gamma quanta recorded by the gamma spectrometer have an energy of 130 and 279 keV, the sensitivity of the gamma activation analysis is 0.2–0.5 g/t [1].

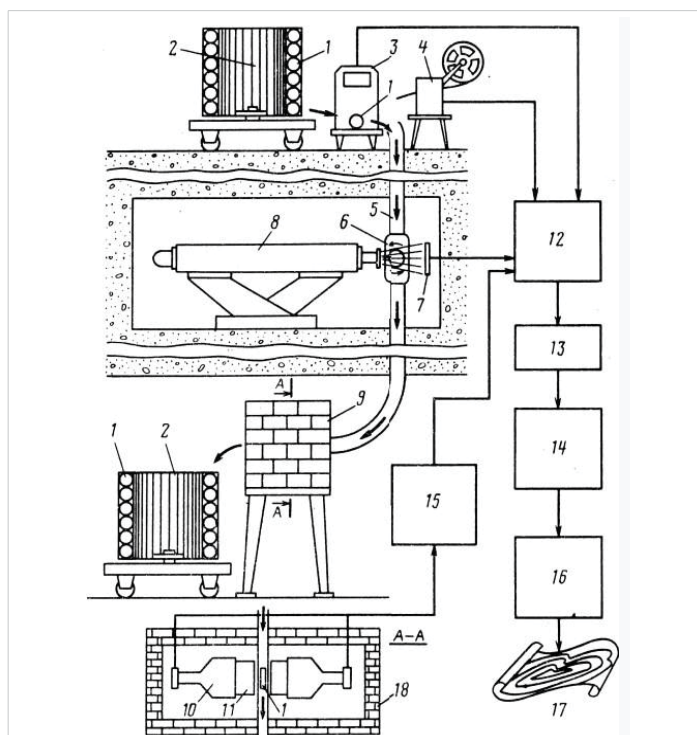


Figure 1: Schematic representation of the “Aura” measuring complex [1]: 1. Plastic containers with samples; 2. Loading drum; 3. Automatic weighing device; 4. Sample code reader; 5. Transport channel; 6. Sample irradiation unit; 7. Activating radiation monitor sensor; 8. Linear electron accelerator installed in a concrete protective chamber; 9. Unit for measuring induced sample activity; 10. Photomultiplier; 11. Scintillation crystal; 12–16. Information accumulation and processing system; 17. Construction of testing plans; 18. Lead protective screen.

At the hydrometallurgical plants of JSC NMMC, the cyanidation method is the main method for gold mining. A study of literary sources showed that the cyanidation method is used in the processing of 90% - 95% of ores in the world, and the share of gold recovered through cyanidation is 80% - 85% [2].

The essence of the cyanidation method is the leaching of precious metals using dilute solutions of cyanide salts of alkali and alkaline earth metals (KCN, NaCN, Ca(CN)₂) in the presence of atmospheric oxygen. Cyanidation of gold is carried out by exposing the pulp (an aqueous solution with crushed rock with a particle diameter of ~0.074 mm) to cyanides of alkali and alkaline earth metals with a concentration of 0.03÷0.3%, and to prevent the decomposition of cyanides and the formation of volatile hydrocyanic acid, which is the strongest poison, the process is carried out in an alkaline environment (pH=11) with the addition of NaOH or CaO (0.005÷0.02%) and additional aeration of the pulp - mixing the pulp with compressed air in pachuks.

In the process of sorption leaching, noble metals (Au, Ag) and base metals (Ni, Cu, Co, Zn, Mg, Ca, Na, K, etc.) dissolve in the cyanide solution, passing into the liquid phase of the pulp and are sorbed on the AM-2B ion exchange resin. After completion of leaching and sorption of gold on the ion exchanger, gold is separated from the pulp by screening on a 0.21 mm sieve, the cell size of which is larger than that of ore particles (0.043-0.074 mm) and smaller than the particle size of ionite granules (0.5÷2 mm). In this case, large particles of resin are retained by the mesh, and small ore particles of the pulp along with the solution pass through it and the pulp emulsion (solid particles and liquid solution) with a low gold content is sent to the tailings storage facility.

Natural losses of AM-2B ion exchange resin during cyanide extraction of gold are 8 g per 1 ton of ore [3] because in technological processes of sorption and filtration under hydrodynamic conditions, natural losses of resin occur due to friction of the ion exchanger matrix against each other, against ore particles, against the walls of apparatus and peptization of the ion exchanger. In the hydrometallurgical plants of JSC NMMC, after technological processing of the pulp emulsion, tailing waste of several million cubic meters is annually discharged into a tailings pond. Processing tailing waste from gold hydrometallurgy using modern technologies for the purpose of additional recovery of gold and precious metals is an urgent task.

The main problem of processing tailings from the tailings of hydrometallurgical plants is the low recovery of difficult-to-concentrate gold. For example, the Marjanbulak Gold Recovery Factory has been in operation since the 80s of the last century and processes the ores of the Marzhanbulak deposit, which is almost completely exhausted, and the issues of processing the old tailings waste are currently being considered.

Now at the gold mining plants of JSC NMMC, an urgent task is to reduce the cost of gold by reducing costs, and technological losses, and increasing the degree of gold recovery, including processing of tailings from tailings.

The purpose of this research is to create a technology for additional recovery of low-concentration gold from alkaline tailing solutions of the tailings pond.

Methods and materials

Solutions of tailing waste from the "pond" of Hydrometallurgical Plant No. 2 in a volume of 2.0 l were evaporated, and dried, and samples of target samples weighing ~ 50 mg were prepared.

Using the X-ray radiometric nuclear geophysical method [4], samples were irradiated with a flux of electromagnetic X-ray ionizing radiation from a ¹⁰⁹Cd source with an activity of 5.0·10⁸ Bq and a ²⁴¹Am source with a source activity of 3.8·10⁹ Bq. Secondary characteristic emission X-ray spectra were measured with a Si(Li) detector (150 eV resolution at 5.89 keV line) with a low-background charge-sensitive preamplifier coupled to an InSpector 2000 analyzer and processed using modified Genie 2000 software.

Neutron activation analysis [5] determined the elemental composition of sample samples and the qualitative and quantitative content of gold and other impurity metals in the tailing waste. To determine the thermal neutron flux density, ⁵⁹Co monitors (Ø=3.0 mm, m=3·10⁻⁵ g) made of aluminum alloy with a cobalt content of 0.1% were used. Tracking monitors ⁵⁹Co are a well-studied monitor for determining the thermal neutron flux density, ⁶⁰Co has an activation cross section σ=37.35 barn, a decay constant of ⁶⁰Co λ=4.169·10⁻⁹/sec and a half-life of ⁶⁰Co T_{1/2}=5.271 years. For quantitative analysis of the content of noble and base metals, sample samples of targets together with a ⁵⁹Co tracking monitor were irradiated in a quartz ampoule in cadmium foil and without a cadmium screen for 35-40 hours at a thermal neutron flux density of 1.1 × 10¹² neutron/cm²·sec. Cadmium serves to reduce the flux density of thermal neutrons (E_n=0.0253 eV) and reduce the yield of radionuclides ²⁴Na and ⁵⁹Fe, which are well activated by these neutrons and interfere with the determination of gold. The test subjects, together with ⁵⁹Co monitors with a cadmium screen 0.1 cm thick and without a cadmium screen, were packed in aluminum foil and irradiated in the vertical channel of the reactor. Cadmium has a very large capture cross section (~20600 barn) of thermal neutrons, so it effectively "absorbs" them [6]. The remaining neutron flux reaching the sample consists of intermediate neutrons (E_n ≤ 200 keV). The efficiency of cadmium use can be assessed using the formula:

$$R = \frac{(\text{sumple activity})_{\text{without Cd coating}}}{(\text{sumple activity})_{\text{with Cd coating}}} \quad (2)$$

The thermal neutron flux density was determined using the following formula [7]:

$$\varphi = \frac{A e^{\lambda t_B} \cdot S}{0,6 \cdot \sigma \cdot R_\gamma \cdot \theta \cdot \varepsilon \cdot P \cdot m \cdot (1 - e^{-\lambda t_0}) \cdot \tau_{mes}} \quad (3)$$

$$\frac{A e^{\lambda t_B(Cd)} \cdot S(Cd)}{0,6 \cdot \sigma \cdot R_\gamma \cdot \theta \cdot \varepsilon \cdot P \cdot m_{Cd} \cdot (1 - e^{-\lambda t_0(Cd)}) \cdot \tau_{mes(Cd)}} \quad n / cm^2 \cdot sec$$

where: φ – thermal neutron flux density, neutron/cm²·sec;

S – area of the photopeak of the detector without a Cd screen, pulses/sec;

S_(Cd) – detector photopeak area in the Cd screen, pulses/sec;

A – atomic weight of Co-59 (59);

λ – isotope decay constant, s⁻¹;

σ – activation cross-section of Co-60, barn (1·10⁻²⁴ cm²);

R_γ – output of gamma quanta (0.9998);

θ – isotope content in the detector (1.0);

ε – efficiency of the analyzer sensor (3.53·10⁻³);

P – reactor power, MW (10.0);

m – detector mass, g (3·10⁻⁵);

m_{Cd} – mass of the detector in the Cd screen, g;

t₀ – detector irradiation time without Cd screen, sec

t_{0(Cd)} – irradiation time of the detector in the Cd screen, sec;

t_{ex} – exposure time of the monitor without Cd – screen, sec;

t_{ex(Cd)} – exposure time of the monitor in the Cd screen, sec;

τ_{mes} – detector measurement time without Cd screen, sec;

$\tau_{mes(Cd)}$ – measurement time of a detector with a Cd screen, sec.

To measure the gamma spectra of the resulting radionuclides, a semiconductor HPGE detector made of ultra-pure germanium with a resolution of 1.8 keV was used using a standard source of gamma radiation ⁶⁰Co with energy E_γ = 1173.2 (99.9%) and E_γ = 1332.5 (100 %) with a relative efficiency of 15% with a DSA-1000 analyzer and processing of gamma spectra was carried out using the Genie 2000 program. Measurement of the gamma spectrum of short-lived radionuclides (¹⁹⁸Au, ²³Na, ⁵⁵Mg, ⁵⁵Mn) was carried out 5-8 days after irradiation of the sample targets, and gamma spectra of long-lived radionuclides (^{110m}Ag, ⁶⁰Co, ⁵⁹Ni) were measured 40-45 days after irradiation.

Table 1 shows the nuclear physical characteristics of radionuclides that are formed during neutron activation analysis of sample samples.

The weight (m) of the element being determined in the sample sample was calculated using the formula:

$$m = \frac{Aa}{\varphi \sigma \theta} \frac{\exp(t_1)}{[1 - \exp(1-t)] N_a} \quad (4)$$

where: A is the atomic weight of the element being determined; a – activity (rate of decay of the element being determined); λ is its decay constant; σ – nuclear reaction cross section; θ is the proportion of abundance of an element undergoing a nuclear reaction; φ is the thermal neutron flux density of the WWR-SM reactor, N_a is Avogadro's number; t – irradiation time; t₁ – time after irradiation.

In the experiments, for the sorption of cyanide complex compounds, an anion exchanger AM-2B was used in chlorine form based on a copolymer of styrene with divinylbenzene containing strong and weakly basic functional groups and a highly basic vinyl pyridine anion exchanger VP-1P.

Anion exchanger AM-2B has a macroporous matrix and an increased grain size (0.8÷2.0 mm) of the working fraction, which allows it to be used for separating cyanide complexes of noble metals during sorption from ore pulps of complex salt composition. The framework of the synthetic ion exchanger AM-2B is a cross-linked polymer, a product of copolymerization of styrene and divinylbenzene, and the presence of bifunctional active groups allows for the selective extraction of gold cyanide complexes from solutions, ensuring a high exchange capacity of the resin for low-basic groups (mg-equivalent/g) and high gold capacity (5.61 mg/g) [6,7] Table 2.

Figure 2 shows the structural formula of the AM-2B ion exchanger [8] and the VP-1P ion exchanger.

Figure 3 shows that if the solution contains only the cyanide complex of gold, then on the AM-2B anion exchanger the complete saturation with gold is ~12 mg/g. However, when gold is extracted from a tail pulp solution on the AM-2B resin, impurities of base metals are also sorbed, several times greater than gold [9], so the sorption of gold on the AM-2B ion exchanger is significantly reduced.

Experimental technique

The following 2 methods were used to extract gold from tailings waste solutions.

First method: Concentrated sulfuric acid (98.3%) was added to the solution of tailing waste from the “pond” with pH≥8.5 and the acidity was adjusted to pH=3.3÷3.5. The acidified solution was passed through chromatographic column No. 1 with an AM-2B anion exchanger weighing 2.0 g,

Table 1: Nuclear physical characteristics of radionuclides.

Irradiated isotope, content in natural mixture, %	Nuclear reaction	Half-life, T _{1/2} hour	Activation cross-section, barn	Output, Ry	Gamma peak energy, E _γ , keV	Neutron energy, E _n , eV
¹⁹⁷ Au, 100	¹⁹⁷ Au(n,γ) ¹⁹⁸ Au	64,662	98,7	0,9548	412	≤0,025
¹⁰⁹ Ag, 48,65	¹⁰⁹ Ag(n,γ) ^{110m} Ag	5998,8	-	-	658	≤0,025
⁵⁹ Co, 100	⁵⁹ Co (n,γ) ⁶⁰ Co	46182,43	37,35	0,9998	1332	≤0,025
⁵⁵ Mg, 100	⁵⁵ Mg(n,γ) ⁵⁶ Mg	2,579	13,23	0,9997	847	≤0,025
²³ Na, 100	²³ Na(n,γ) ²⁴ Na	14,9	0,531	1,000	1368	≤0,025
⁵⁵ Mn, 100	⁵⁵ Mn (n,γ) ⁵⁶ Mn	61,92	3,4 · 10 ³	0,997	84	337
⁵⁸ Ni, 67,88	⁵⁸ Ni (n,γ) ⁵⁹ Ni	1699	0,337	0,9945	811	>2,3 MэВ
⁵⁴ Fe, 5,84	⁵⁴ Fe(n,p) ⁵⁴ Mn	7501,95	0,386	1,000	835	>3 MэВ
⁵⁸ Fe, 91,68	⁵⁸ Fe(n,γ) ⁵⁹ Fe	1094,4	1,01	0,9887	142,4, 1099,2 1291,6	≤0,025

Table 2: Main technical characteristics of AM-2B ion exchange resin.

Characteristics	Meaning
Appearance	Opaque spherical granules of white-yellow color
Functional groups	benzyltrimethylamine and dibenzyltrimethylammonium
Ionic form	chloride
Grain size, mm	0.6-1.2
Bulk mass of dry resin	0.42 g/cm ³
Swelling coefficient in water	2.7
Size of grains in the swollen state, mm	0.8-2.0
Mass fraction of moisture, %	48-56
Specific volume, cm ³ /g	3,0-3,2
Volume fraction of working fraction, %	95
Total exchange capacity for chlorine ion, mEq/g	1.5
Capacity for low-basic groups, mEq/g	2.4
Mechanical strength, not less, %	96
Maximum permissible operating temperature, 70 °C	70
Guaranteed shelf life	2 years

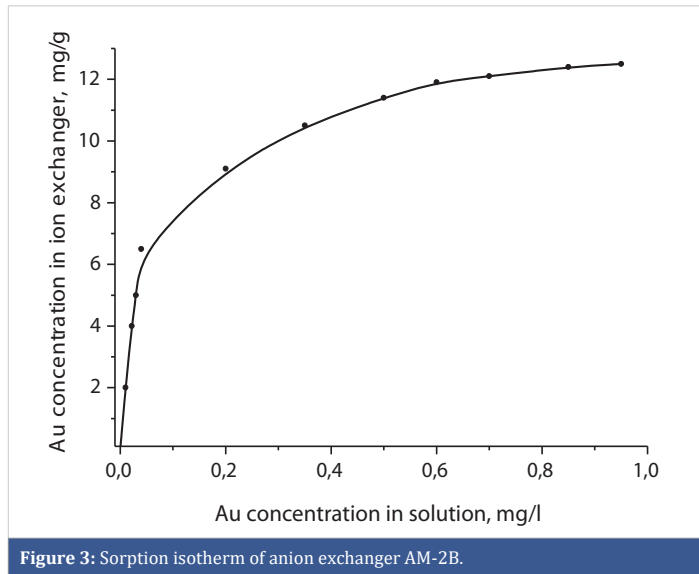


Figure 3: Sorption isotherm of anion exchanger AM-2B.

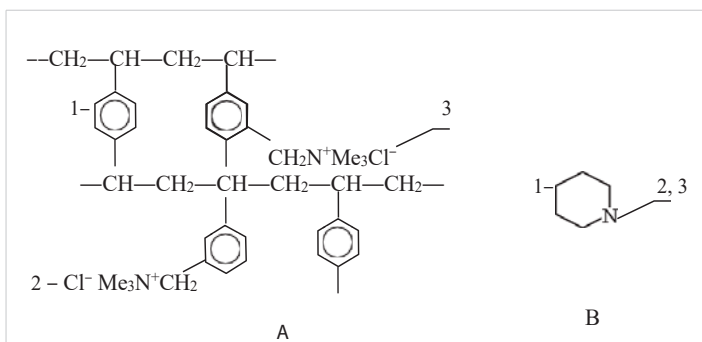


Figure 2: Structural formula of the AM-2B ion exchanger based on copolymers of styrene and divinylbenzene (A) and the structure of the highly basic vinylpyridine ion exchanger VP-1P (B): 1 - polymer matrix (framework); 2 - counter ion; 3- anchor ion.

through which 100 l of the “pond” solution was passed in dynamic mode at a speed of 3 ml/min, and through chromatographic column No. 2 with an anion exchanger VP-1P weighing 2.0 g passed 120 liters of tailings solution from the “pond” in dynamic mode at a speed of 3 ml/min. Then, qualitative and quantitative analysis of the saturated resin was carried out.

Second method: An aqueous technical solution of ammonia (25%) with a volume of 50.0 ml was added to a solution of tailing waste from the “pond” with a volume of 100 liters and passed through a chromatographic column No. 3 with an

AM-2B anion exchanger weighing 2.0 g in dynamic mode at a speed of 3 ml /min in dynamic mode. Then, qualitative and quantitative analysis of the saturated resin was carried out.

Results and discussion

The results of X-ray radiometric and neutron activation analysis of the qualitative and quantitative composition of elements in solutions of tailings from the “pond” are shown in Table 3.

The results of the study showed that in alkaline solutions of tailing waste the content of impurities of noble, alkali and alkaline earth metals (Ag, Ni, Cu, Co, Zn, Mg, Fe, Ca, K, Na) is more than 750÷800 mg/l, while the gold content is only ≤0.06 mg/L. It is shown in [9] that in the liquid phase of tailings solutions, the gold content should be ≤ 0.05 mg/l (≤ 0.05 g/t).

The results of laboratory experiments of gold extraction from acidified (pH=3.3÷3.5) solutions of tailing waste with AM-2B ion exchanger are shown in Table 4.

From Table 4 it can be seen that at pH = 3.3÷3.5 gold is quantitatively sorbed on the AM-2B anion exchanger (3.9 mg/g), and on the VP-1P anion exchanger up to 1.5 mg/g. At the same time, the capacity of the AM-2B anion exchanger exceeds the capacity of the VP-1P anion exchanger by 2.6 times. The VP-1P anion exchanger is completely saturated

Table 3: Content of gold, silver, and base alkali and alkaline earth metals in tailings solutions.

Sample number	Metal content, mg/l										
	Au	Ag	Ni	Cu	Co	Zn	Mg	Fe	Na	K	Ca
1.	0,05	0,12	1,14	11,0	0,03	0,14	0,3	1,6	190	330	146
2.	0,05	0,13	1,16	8,6	0,02	0,14	0,4	1,5	193	340	142
3.	0,06	0,15	1,14	9,7	0,03	0,13	0,3	1,5	185	335	140
4.	0,04	0,11	1,15	10,2	0,05	0,16	0,3	1,5	190	335	148
5.	0,06	0,14	1,14	10,7	0,04	0,15	0,5	1,6	192	330	145

Table 4: Content of gold and base, alkali, and alkaline earth metals on the AM-2B ion exchanger.

Name of ion exchange resin	Metals content in ion exchangers resin, mg/g					
	Au	Ag	Ni	Cu	Co	Zn
AM-2B	3.9	0.22	0.12	0.05	3.2	0.78
VP-1P	1.5	0.08	0.12	0.05	2.6	0.15
Concentration of solution, mg/l						
Pond tailing solutions	0.06	0.12	1.5	0.6	0.5	0.4

with gold and impurity metal cyanides, and the AM-2B anion exchanger is 45% saturated because the total capacity of the AM-2B anion exchanger is 8.7 mg/g. In alkaline solutions of tailing waste at pH = 89, gold and impurities of base, alkali, and alkaline earth metals are in the form of cyanide complex compounds, and from alkaline solutions of tailing waste only 0.06 mg/g of gold is sorbed on the AM-2B ion exchanger, i.e. cyanide complex compounds of base, alkali and alkaline earth metals are well sorbed on the AM-2B ion exchanger, and thereby reduce the efficiency of sorption of the gold cyanide complex [12]. A study [13] shows that on an industrial scale, when using a local sorption unit from alkaline tailings on an AM-2B ion exchange resin, up to 2.85 mg of gold per 1 g of sorbent is sorbed with gold recovery from tailing solutions up to 52.44%, while According to the proposed technology, up to 8.5 mg per 1 g of sorbent can be collected on AM-2B resin with gold recovery from tail solutions up to 98.2%.

Gold is a very heavy noble metal ($\rho = 19.32 \text{ g/cm}^3$), which is chemically inert. The reason for the inertness of gold is its high oxidation potential ($E_0 = +1.7 \text{ V}$). However, in the presence of a cyanide ion ligand and oxygen, gold enters into a complexation reaction with it, because The redox potential of gold decreases according to the Nernst reaction [14]:

$$E = E_0 + 2,303 (RT/nF) \lg [Au^+/Au^0] \quad (5)$$

where: E - electrode potential, E_0 - standard electrode potential (B);

R - universal gas constant equal to 8.314 J/(mol K);

T - absolute temperature;

F - Faraday constant (96485.33 C mol⁻¹);

n - number of electrons participating in the process;

Au^+/Au^0 - molar concentrations of gold in oxidized (Ox) and reduced (Red) forms.

From formula (5) it follows that the oxidation potential of gold can be reduced by reducing the activity of Au^+ ions in the solution. This circumstance underlies the cyanidation process. During the cyanidation of a pulp emulsion, a cyanide ion is formed according to the Elsner reaction [14]:



During cyanidation, the activity of Au^+ ions sharply decreases in the presence of CN^- ions, and the oxidation of gold is ensured by the complexation of the gold aqua ion according to the reaction:



where: Au^0 - elemental gold; $Au^+ (aq)$ - complexing ion - cyanide ion $[Au(CN)_2]^{-1}$; e - electron.

The oxidation potential of gold according to reaction (7) is -0.54 V , i.e. by binding gold cations into a stable complex, cyanide ions sharply reduce the oxidation potential of gold and thereby create conditions for the oxidation of gold with oxygen and the conversion of gold into the complex anion $[Au(CN)_2]^{-1}$, which is a very stable complex.

At the same time, the balance

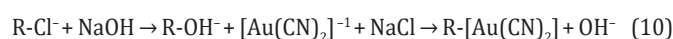


shifted to the left, because the dissociation constant (instability) of the complex has a very small value ($\beta = 1.1 \cdot 10^{-41}$):

$$\beta = \frac{a_{Au^+} \times a_{CN^-}^2}{a_{[Au(CN)_2]^-}} = 1,1 \times 10^{-41} \quad (9)$$

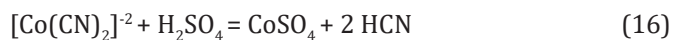
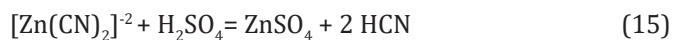
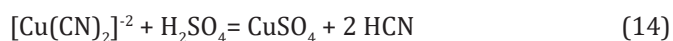
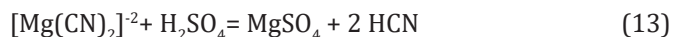
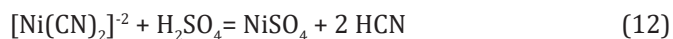
During the cyanidation process, simultaneously with the formation of complex compounds of noble metals, complex compounds of base alkali and alkaline earth metals are also formed. The sequence of increasing complexing ability for base metal ions with the same charge observed during cyanidation confirms this assumption: $Li^+ > Na^+ > K^+ > Rb^+ > Cs^+$; $Mg^{2+} > Ca^{2+} > Sr^{2+} > Ba^{2+} > Ra^{2+}$; $Al^{3+} > Sc^{3+} > Y^{3+} > La^{3+}$ [15].

Sorption of cyanide complexes of noble metals and metal impurities (Me) on the AM-2B anion exchanger occurs according to the reactions:



The results of the study showed that when tailing waste solutions are acidified to pH = 3.3÷3.5, cyanide complexes of base metal anions are destroyed due to the formation of cationic forms of sulfate metals ($NiSO_4$, $MgSO_4$, $CuSO_4$, $CoSO_4$, $ZnSO_4$, etc.), which are poorly sorbed on the AM-2B anion exchanger, with the exception of $CoSO_4$, which is sorbed on the AM-2B anion exchanger up to 3.2 mg/g (Table 4).

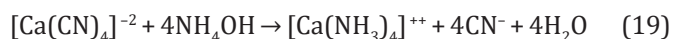
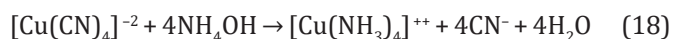
Metal sulfates are formed by the following reactions:



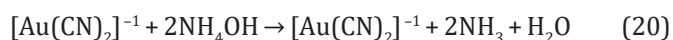
Studies have shown that in an acidic environment with $\text{pH}=3.3\div 3.5$, the gold cyanide complex is not destroyed, and as a result is quantitatively sorbed on the AM-2B anion exchanger in a dynamic mode (Table 4).

The results of the study showed that if an aqueous solution of ammonia (25%) is added to the alkaline solution of tailing waste, then gold is sorbed on the AM-2B anion exchanger up to 3.0 mg/g in a dynamic mode. The results of gold extraction using AM-2B ion exchange resin from tailing waste solutions treated with an aqueous ammonia solution are shown in Table 5.

From Table 5 it can be seen that in dynamic mode on the AM-2B anion exchanger, gold is sorbed up to 3.0 mg/g. When an aqueous solution of ammonia is exposed to alkaline tailing waste, cyanide complexes of base metals easily transform into ammonia complexes with the formation of ammine complexes, which are poorly sorbed on the ion exchanger:



With the addition of an aqueous ammonia solution to the tail waste solution, the stable gold cyanide complex is not destroyed and, as a result, is quantitatively sorbed on AM-2B according to the reaction:



Thus, if the tailing waste solution is acidified with sulfuric acid or neutralized to a slightly alkaline medium with an aqueous solution of ammonia, in both cases the cyanide complex $[\text{Au}(\text{CN})_2]^{-1}$ is not destroyed, because the gold cyanide complex has a stability coefficient $K_n=2\cdot 10^{38}$ [16]. In aqueous solutions, gold is a typical complexing agent: gold is well polarized, and Au^+ and Au^{3+} ions are characterized by empty s- and d-orbitals, and the filling of orbitals is accompanied by the formation of stable complex compounds with strong hybrid bonds [17].

Table 5: Content of gold and base, alkali, and alkaline earth metals sorbed on the AM-2B ion exchanger.

Name of ion exchange resin	Metals content in ion exchangers resin, mg/g					
	Au	Ag	Ni	Cu	Co	Zn
AM-2B	3.0	0.25	0.13	0.08	3.0	0.8
Concentration of solution, mg/l						
Pond tailing solutions	0.06	0.12	1.5	0.6	0.5	0.4

AM-2B and VP-102 ion exchangers effectively sorb gold even in the presence of impurities, the concentration of which is hundreds of times higher than the concentration of gold [18]. When the composition of the initial solutions is Au - 0.55 mg/l, Cu - 455 mg/l, Zn - 50 mg/l, KCN - 500 mg/l, the average gold capacity of the ion exchanger VP-102 is 3.0 mg/g, and the maximum is 5.9 mg/g. When the copper content in the initial solution is up to 160.0 mg/l, after sorption the capacity of the VP-102 anion exchanger for copper decreases from 18.4 to 10.5 mg/g with an increase in the sorbent capacity for gold from 0.01 to 12.3 mg/g, which indicates the displacement of copper in the anion exchanger by gold cyan complexes.

Figure 4 shows a technological diagram of a gold recovery plant using the method of acidification of tail waste and sorption on an AM-2B ion exchanger.

The installation (Figure 4) works as follows: the initial alkaline ($\text{pH} = 8.4-8.6$) solution of the "pond" (1) is pumped into a container (3) using a pump (2) and technical conc. H_2SO_4 from a container (4) to obtain an acidified solution with $\text{pH}=3.3\div 3.5$. Then the acidified solution is pumped using a pump (5) into two sorption columns (6) with a volume of 5 m³ each with an AM-2B anion exchanger (total weight 2 tons) and in a dynamic mode, gold is sorption on an AM-2B anion exchanger.

After dynamic sorption of gold on the AM-2B anion exchanger with the achievement of saturation of the anion exchanger with gold (7-8 mg/g), the anion exchanger is

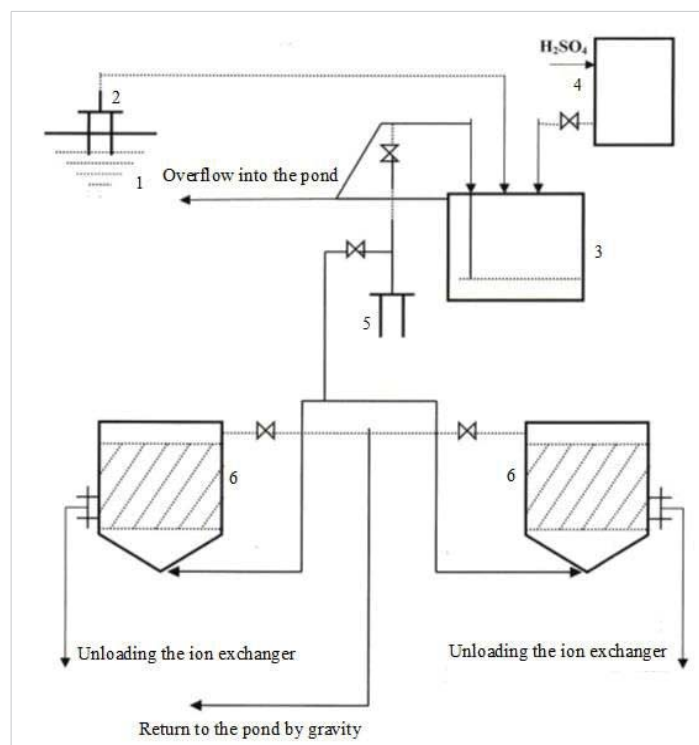


Figure 4: Technological diagram of the installation: 1 - tailing solution "pond" of the tailings dump; 2 - submersible pump; 3 - container for acidifying the tail solution; 4 - container for H_2SO_4 ; 5 - chemically resistant pump; 6 - sorption columns with AM-2B anion exchanger.



filtered, unloaded from the column into bags and, after gold analysis, is sent to the desorption technological process. Desorption of gold from the AM-2B anion exchanger is carried out with a solution of thiourea (9%) in sulfuric acid (3%),

Desorption of gold from the AM-2B ion exchanger by sulfuric acid thiourea solutions is achieved due to the formation of a thiocarbamide complex compound, which is not retained in the ion exchanger phase by ionogenic groups:



Next, the ion exchanger is treated with a NaOH solution (2-3%) to neutralize residual sulfuric acid and convert the ion exchanger into the OH⁻ form, and gold is precipitated at pH = 8÷9, the precipitate is filtered and calcined at a temperature of 800 °C, then the gold is dissolved in aqua regia and elemental gold is obtained by electrolysis reduction.

After desorption of gold from the anion exchanger, the ion exchanger is treated with a NaOH solution (2-3%) to neutralize residual sulfuric acid and convert the ion exchanger into the OH⁻ form, and the gold is precipitated at pH = 8÷9, the precipitate is filtered and calcined at a temperature of 800 °C, then gold is dissolved in aqua regia and elemental gold is obtained by electrolysis reduction.

Conclusion

Preliminary financial and economic calculations showed that the installation for extracting gold from tailing waste solutions has a productivity of 882 000 m³/year with an operating mode of 120 m³/hour for 7 350 hours per year. With this installation mode, up to 44 kg of gold per year can be obtained from the tailing waste solutions of the “pond”. However, here it is also necessary to take into account the loss of the AM-2B ion exchanger, which is ~ 10% per year (400 kg/year).

This method of additional extraction of gold from solutions of tailing waste “ponds” was tested in the Central Plant Laboratory of NMMC JSC and was recognized as promising for implementation in the divisions of this enterprise [20].

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