Research on the choice of the composition of the leaching solution during the extraction of gold by the method of underground leaching from used uranium wells

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Abstract. The use of sodium hypochlorite and thiourea as reagents-solvents for extracting gold from spent uranium deposits by underground leaching was determined as optimal based on the laboratory experiments. Activated carbon of the AG-3 grade has been determined as the most effective for gold extraction from the productive solution. Qualitative parameters of underground leaching, lithology thickness, planar and cross-sectional shapes, as well as filtration properties of wells along with infiltration flow irrigation zones have been established through bench-scale testing. A new model of solution filtration by high-pressure and free flooding onto the reservoir has been developed using the results obtained.

1 Introduction

One of the priority tasks for the development of the mining and metallurgical industry in Uzbekistan is to increase the extraction of ores by the method of underground leaching.

In the late 80s of the twentieth century, with the widespread introduction of underground, borehole mining technology (Downhole Hydrotechnology Production) of uranium, several thousand tons of metal were extracted. In parallel with the extraction of uranium, technologies were introduced for the extraction of other minerals of titanium-zircon sands, rich iron ores and polymetallic ores. The method of underground borehole leaching has proven to reduce the cost of obtaining the final product, along with a significant reduction in time.

In recent years, there has been a significant demand for gold, making additional highly efficient low-cost complex technologies for extracting gold from ores are important. During the research work, the following advantages were identified:

- the presence of small deposits with favorable mining and geological conditions;
- occurrence of epigenetic mineralization in loose watered rocks;
- seasoned top and bottom layers for in-situ teaching applications.

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The object of research was determined based on the study objectives and included the following areas [1].

1) Selection of the optimal mode and the list of reagents for gold leaching.
2) Development of new technical solutions for the processing of solutions containing gold.

The results of the performed analyzes are substantiated by the fact that the research topic is innovative and the applied technologies for extracting gold from depleted uranium mines have been developed only in recent years. The technology of extracting gold by in-situ leaching will be carried out from depleted wells at the depleted uranium deposit of Sugraly.

The geological structure of the Sugraly deposit area is similar to other areas of the Kyzylkum uranium province and is characterized by a number of features due to the specifics of geological and structural development. As in adjacent areas, they are subdivided into two structural stages of geological formation: the Paleozoic basement, and the Meso-Cenozoic cover, represented by sedimentary rocks of the Upper Cretaceous, Paleogene, Neogene, and Anthropogen.

The performance of laboratory studies ultimately makes it possible to obtain geotechnological data, which are used as the initial results for conducting a pilot test for the extraction of gold by in-situ leaching from depleted uranium wells [2]. Laboratory studies on core material were carried out to determine the permeability of the medium and the nature of its change in the leaching process, clarify the geotechnological regime and solve some special problems associated with the subsequent use of the results in natural conditions. The research is based on the method of studying fluid filtration in a porous medium, known in the practice of laboratory hydrogeological work. To select the most effective leaching solution for gold recovery, using the Underground Leaching method from depleted uranium wells, based on world experience in gold leaching, it was decided to test solutions of the following compositions:

1) I (iodine);
2) H_2SO_4 + NaClO; (mixture of sulfuric acid with sodium hypochlorite);
3) NaClO; (sodium hypochlorite);
4) $CS(NH_2)_2$ (thiourea);

The Study focused on gold leaching in filtration columns, which were conducted using specialized setup. The setup comprised a plexiglass filtration column placed vertically within a metal frame. The dimensions of the filtration column were 50 mm in diameter and 1 m in length. Throughout the experiments, various solutions were tested and their pH levels, as well as the concentrations of Au (gold), U (uranium), and REE (rare earth elements), were analyzed. The reagent feed rate was carefully controlled, and the sample weight used was 3.2 kg. [3].

Liquid samples were collected once a day, spanning a duration of 3 days for the leaching process. During the study, the solution levels were closely monitored to ensure maximum filtration speed at a constant pressure level (j=1.0–2.0). Core samples were obtained from the well at intervals corresponding to supra-ore, ore, and sub-ore levels for use in the experiments. The leaching process was carried out under static conditions, at room temperature, within a laboratory setup. After a predetermined period, the solutions were filtered from the cake and sent for analysis to determine the gold content.

Table 1. Analysis of gold leaching from core samples obtained from a depleted uranium well.

Sample number	**Leaching solution g/l concentration,**	**Name of solvents and quantity of products**	**Actual averages over test results**	**Note**
	I_2	pH= 9.00 Oxidation-reduction process = 762		
1007	4	Concentration of gold, mg/l	178	

		Concentration of gold, mg/l	180	Surplus test ε = 92%
		Concentration of gold, mg/l	184	
1026	4	Concentration of gold, mg/l	18.1	Ore sample ε = 92%
		Concentration of gold, mg/l	18.2	
		Concentration of gold, mg/l	18.4	
1049	4	Concentration of gold, mg/l	498	Ore sample ε = 92%
		Concentration of gold, mg/l	505	
		Concentration of gold, mg/l	515	
NaClO pH=3.00 Oxidation-reduction process = 1164.1				
1007	4	Concentration of gold, mg/l	165	Surplus test ε = 90%
		Concentration of gold, mg/l	176	
		Concentration of gold, mg/l	180	
1026	4	Concentration of gold, mg/l	17.1	Ore sample ε = 90%
		Concentration of gold, mg/l	17.7	
		Concentration of gold, mg/l	18	
1049	4	Concentration of gold, mg/l	495	Ore sample ε = 90%
		Concentration of gold, mg/l	505	
		Concentration of gold, mg/l	515	
NaClO + acidic solution of $H_2SO_{4\,(c)}$ pH = 3.00 Oxidation-reduction process = 1150.8.				
1007	4	Concentration of gold, mg/l	178	Surplus test ε = 96%
		Concentration of gold, mg/l	186	
		Concentration of gold, mg/l	192	
1026	4	Concentration of gold, mg/l	18.1	Ore sample ε = 96%
		Concentration of gold, mg/l	18.6	
		Concentration of gold, mg/l	19.2	
1049	4	Concentration of gold, mg/l	518	Ore sample ε = 96%
		Concentration of gold, mg/l	525	
		Concentration of gold, mg/l	537	
$2CS(NH_2)_2$ pH=3.5 Oxidation-reduction process = 500.				
1007	4	Concentration of gold, mg/l	176	Surplus test ε = 97%
		Concentration of gold, mg/l	188	
		Concentration of gold, mg/l	194	
1026	4	Concentration of gold, mg/l	18.1	Ore sample ε = 97%
		Concentration of gold, mg/l	18.7	
		Concentration of gold, mg/l	19.4	
1049	4	Concentration of gold, mg/l	527	Ore sample ε = 97%
		Concentration of gold, mg/l	538	
		Concentration of gold, mg/l	543	

2 Materials and methods

The most significant results were observed in the solution extracted from the well within the ore interval, in thiourea concentrations of 4 g/l. This is due to the fact that the core samples were acidified. Additionally, it can be stated that the use of sodium hypochlorite together with sulfuric acid and thiourea reagent showed the highest result of gold extraction, which amounted to 537 mg/l and 543 mg/l. [4, 5, 6].

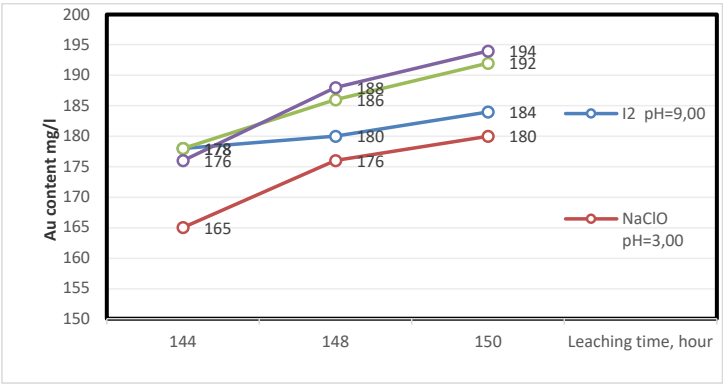

Fig. 1. Dependence of gold recovery from overore core samples by various reagents and time.

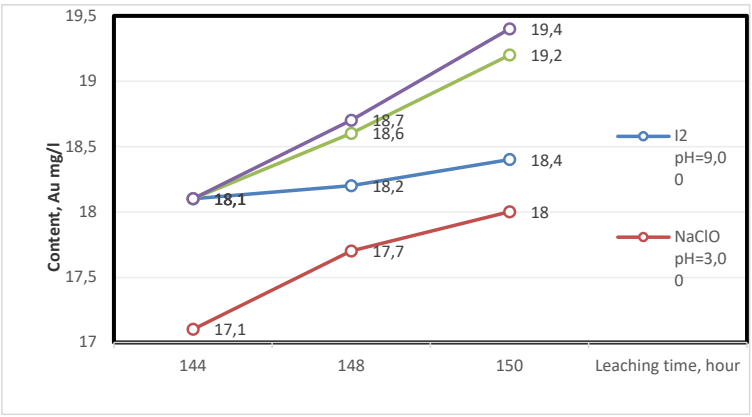

Fig. 2. Dependence of gold extraction from ore core samples by various reagents and time.

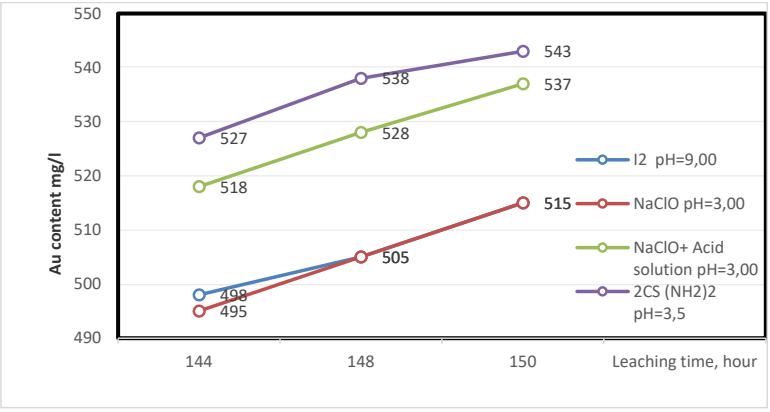

Fig. 3. Dependence of gold extraction from underore core samples by various reagents and time.

The purpose of the scientific experiments was to extract gold from a productive solution under laboratory conditions. The sorption process was conducted using different grades of activated carbon to identify a promising sample. To saturate the sorbent with the solution

from the productive solution, studies were performed using three types of activated carbons: AG-3, AG-5, and AG-95.

The sorption process took place in a pressure column, with a dense layer of activated carbon weighing 3 kg. The productive solution was supplied from the bottom and the processing time in the sorption column was 20 hours. A total volume of 6 liters of the solution was processed. [7].

Figure 3 illustrates the ratio of the volume of processed solutions to the volume of the sorbent. The results of the solution processing are presented, indicating that the amount of gold in the activated carbon was 515 mg/kg, with a gold extraction efficiency of 95%[8]. Table 2 displays the results of the study on the sorption properties of three types of activated carbons for gold from the productive solution.

Table 2. The results of studies on the sorption of gold from a productive solution using activated carbons of various grades.

Measured parameter	Unit rev.	Types of activated carbon		
		AG-3	AG-95	AG-5
Sorption time	h	20	20	20
Volume of solutions	l	6	6	6
Average gold content in the productive solution	mg/l	543	543	543
The content of gold in the sorbent at the time of stopping the adsorber (3 kg)	g /kg	0.515	0.368	0.501

According to Table 2 for the extraction of gold from the productive solution, the most promising sorbent is activated carbon grade AG-3.

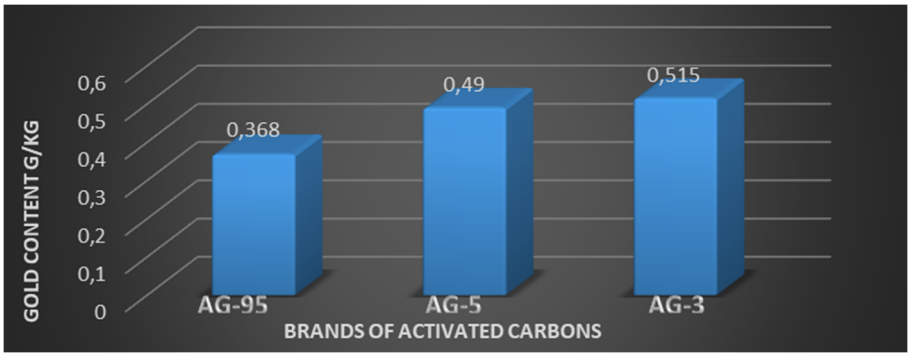

Fig. 4. Comparative analysis of the gold content in various types of activated carbon.

Control of hydrodynamic parameters in in-situ leaching is an integral part of the process. The complexity of this control arises from the inability to visually observe changes in the hydrodynamics due to the process occurring within the thickness of the Earth's crust, which is inaccessible to the human eye. Consequently, control relies on a system of data collection through geophysical and hydrogeological surveys. [9].

To examine the hydrogeological data of the test site, the following parameters were investigated: permeability, filtration properties, and the geometry of the "depression funnel".

On the laboratory stand, the progression of the in-situ leaching process with different loading heads into the ore layer was studied. The stand had dimensions of 2 m in length, 1 m in height, and 40 cm in width, constructed from organic glass. To simulate the leaching process and the lithology of the Sugraly deposit, a four-layer backfill of rocks was used. The

deposit section comprised a 30 cm thick permeable sandstone layer with fine-grained sand layered on top. The rock exhibited a permeability of 2 m/day based on the filtration coefficient.

The upper layer had a thickness of 30 cm. A vacuum rubber gasket was placed beneath the lid in the upper part of the stand. To simulate the dispersion of leaching solutions, technical water was injected through a pressure hose between the cover and the gasket to create excess pressure. The magnitude of the excess pressure could vary from 0.02 to 0.1 MPa, depending on the specific task.

Injection of the leaching solution into the stand occurred through injection wells equipped with a 35 mm diameter filter. The solution was then pumped out through a pumping well with a 70 mm diameter filter. The well filters were perforated stainless steel tubes with hole diameters of 0.6-0.8 mm. Injection wells were used to introduce the solution, while the pumping well, located in the center of the model cell, facilitated the extraction of the solution. [10].

Overall, these experimental setups and procedures provide a controlled environment for studying the hydrodynamic aspects of in-situ leaching and allow for the investigation of various parameters critical to the process.

3 Results

The results of measuring the decrease in water levels on the stand using a piezometer embedded in the rock in the lithological difference Hgr in the well filter model, Hcp depending on the filtration time t.

For non-pressure supply of the solution, the Kusakin formula was used:

$$R = 2\sqrt{H \cdot K_f} \tag{1}$$

where, S – level decrease value, cm;

H – thickness of the groundwater layer, cm;

K_f – layer filtration coefficient, cm /min.

The following formula was used to pump out the productive solution:

$$Q = 1{,}366 \cdot K_f \frac{H^2 - h^2}{lgR - lgr} \tag{2}$$

where h – height of the unlowered column in the well, m;

R – funnel radius, m;

r – radius of the well, m.

Table 3. The results of measuring the decrease in the levels of the solution in the stand using a piezometer and determining the radii of the funnel.

T, c	1st filling					2nd filling					3rd filling				
	H_d, cm	H_c, cm	S, cm	R, cm	Q_1 l/min	H_d, cm	H_c, cm	S, cm	R, cm	Q_2 l/min	H_d, cm	H_c, cm	S, cm	R, cm	Q_3 l/min
60	135	124	11	66	4.3	145	132	13	78	4	148	134	14	84	3.6
120	127	121	6	36	8	138	128	10	60	4.2	142	131	11	66	4.3
180	121	119	2	12	15	133	126	7	42	12	137	129	8	48	11
240	118	116	2	12	15	129	124	5	30	9	133	127	6	36	8
600	115	114	1	6	20	125	122	3	18	12	129	125	4	24	9
900	113	112	1	6	20	123	121	2	12	6.8	126	123	3	18	12

Note: Fluid level drawdowns in the well model shown in this table are defined as the difference

$$S = H_d - H_c, \text{ cm.} \quad (3)$$

4 Conclusion

According to the results of the studies on gold extraction from the productive solution, it was found that activated carbon of the AG-3 brand exhibited the highest effectiveness. Bench tests allowed for the determination of qualitative parameters for in-situ leaching, including the lithology thickness, plan and section shapes, as well as the filtration properties of the wells and infiltration flow irrigation zones. Based on the obtained results, a new model was developed for fluid filtration through high-pressure and free filling into the formation.

These findings highlight the significance of selecting the appropriate activated carbon brand, with AG-3 proving to be the most efficient for gold extraction. The bench tests provided valuable insights into the qualitative parameters necessary for optimizing the in-situ leaching process, considering factors such as lithology thickness, well filtration properties, and the distribution of infiltration flow. The development of a new model for fluid filtration under high-pressure conditions and free filling into the formation offers potential improvements in the efficiency and effectiveness of gold extraction.

Further research and field-scale experiments are recommended to validate and refine the findings and models proposed in this study. The optimized approach to gold extraction using AG-3 activated carbon and the newly developed fluid filtration model have the potential to contribute to more efficient and sustainable gold recovery processes in mining operations.

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