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ИЗВЕСТИЯ

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INNOVATIVE METHODS OF INTENSIFICATION IN SITU LEACHING OF URANIUM IN DEPOSITS WITH LOW FILTRATION CHARACTERISTICS OF ORES

Abstract. Improving the efficiency of downhole uranium production by selecting special decolmating solutions and selecting rational parameters of the technology of influencing the near-filter zone of the formation of geotechnical wells, improving the filtration characteristics of the formation depending on the mineralogical composition and structure of sedimentary materials.

The structure and composition of sedimentation causing a decrease in the filtration characteristics of the productive horizon of the Syrdarya and Chu-Sarysui deposits are determined. The effective composition of a special decolmating solution for destruction and prevention of sedimentation in the productive horizon with the use of ammonium bifluoride with the addition of sulfuric acid and surfactants was selected. Rational parameters of an innovative technology for improving the filtration characteristics of a productive horizon with the use of special decolmating solutions have been developed and experimentally confirmed. The effectiveness of the developed complex method for improving the filtration characteristics of reservoirs in uranium deposits worked out by the well method is substantiated.

The use of an innovative technology to improve the filtration characteristics of ores in difficult mining and geological conditions can increase the uptime and utilization rate of geotechnical wells, which in turn will positively affect the intensity of mining of technological blocks and increase productivity and labor safety, as well as reduce the operating costs of mining enterprises.

Key words: In situ leaching, filtration characteristics, sedimentation, decolmating solution, x-ray phase analysis, microscopic studies.

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КЕНДЕРДІҢ СҮЗУ СИПАТТАМАЛАРЫ ТӨМЕН КЕН ОРЫНДАРЫНДА УРАНДЫ ҰҢҒЫМАЛЫҚ ӨНДІРУДІ ҚАРҚЫНДАТУДЫҢ ИННОВАЦИЯЛЫҚ ӘДІСТЕРІ

Аннотация. Арнайы декольматизациялық ерітінділерді таңдау және геотехнологиялық ұңғымалар қабатының сүзгі аймағына әсер ету технологиясының ұтымды параметрлерін таңдау арқылы уранды ұңғымалық өндірудің тиімділігін арттыру, шөгінді материалдардың минералогиялық құрамы мен құрылымына байланысты қабаттың сүзу сипаттамаларын арттыру.

Сырдария және Шу-Сарысу депрессиясы кен орындарының өнімді горизонтының сүзу сипаттамаларының төмендеуіне әкелетін тұнба түзілуінің құрылымы мен құрамы анықталды. Күкірт қышқылы мен беттік белсенді заттар қосылған аммоний бифторидін қолдана отырып, өнімді горизонтта жауын-шашынның пайда болуын жою және болдырмау үшін арнайы декольматизациялық ерітіндінің тиімді құрамы таңдалды. Арнайы декольмат ерітінділерін қолдана отырып, өнімді горизонттың сүзу сипаттамаларын арттырудың инновациялық технологиясының ұтымды параметрлері әзірленді және тәжірибелік түрде расталды. Ұңғыма әдісімен өңделетін уран кен орындарында қабаттардың сүзу сипаттамаларын арттырудың әзірленген кешенді әдісінің тиімділігі негізделген.

Күрделітау-кен-геологиялықжағдайлардакендердіңсүзусипаттамаларын арттырудың инновациялық технологиясын қолдану үздіксіз жұмыс кезеңін және геотехнологиялық ұңғымаларды пайдалану коэффициентін арттыруы мүмкін, бұл өз кезегінде технологиялық блоктарды өңдеу қарқындылығына оң әсер етеді және Еңбек өнімділігі мен қауіпсіздігін арттырады, сондай-ақ өндіруге кәсіпорындардың пайдалану шығындарын азайтады.

Түйін сөздер: ұңғыманы өндіру, сүзу сипаттамалары, тұнба түзілімдері, декольматизациялық ерітінді, рентгенофазалық талдау, микроскопиялық зерттеулер.

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ИННОВАЦИОННЫЕ МЕТОДЫ ИНТЕНСИФИКАЦИИ СКВАЖИННОЙ ДОБЫЧИ УРАНА НА МЕСТОРОЖДЕНИЯХ С НИЗКИМИ ФИЛЬТРАЦИОННЫМИ ХАРАКТЕРИСТИКАМИ РУД

Аннотация. Повышение эффективности скважинной добычи урана за счет подбора специальных декольматирующих растворов и выбора рациональных параметров технологии воздействия на прифильтровую зону пласта геотехнологических скважин, повышение фильтрационных характеристик пласта в зависимости от минералогического состава и структуры осадкообразующих материалов.

Определена структура и состав осадкообразования, вызывающие снижение фильтрационных характеристик продуктивного горизонта месторождений Сырдарьинской и Чу-Сарысуйской депрессии. Выбран эффективный состав специального декольматирующего раствора для разрушения и предотвращения осадкообразования в продуктивном горизонте с применением бифторида аммония с добавлением серной кислоты и поверхностно-активных веществ. Разработаны и опытным путем подтверждены рациональные параметры инновационной технологии повышения фильтрационных характеристик продуктивного горизонта с применением специальных декольматирующих растворов. Обоснована эффективность разработанного комплексного метода повышения фильтрационных характеристик пластов, на урановых месторождениях отрабатываемых скважинным способом.

Применение инновационной технологии повышения фильтрационных характеристик руд в сложных горно-геологических условиях может увеличить период бесперебойной работы и коэффициент использования геотехнологических скважин, что в свою очередь положительно повлияет на интенсивность отработки технологических блоков и повысит производительность и безопасность труда, а также сократит эксплуатационные расходы предприятий на добычу.

Ключевые слова: скважинная добыча, фильтрационные характеристики, осадкообразования, декольматирующий раствор, рентгенофазовый анализ, микроскопические исследования.

Introduction. Uranium is the most representative element of the actinides, which is of fundamental importance in the nuclear fuel cycle. The nuclear power market is expected to grow significantly over the next 20 years. For example, in the US alone, it is projected to grow by 50% by 2030. According to the Ministry of Energy of the Republic of Kazakhstan global electricity consumption will double by 2030 (Khawassek, 2016: 12). The Intergovernmental Panel on Climate Change (IPCC) highlights the urgent need to use all available low-carbon technologies to prevent climate change. The International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) predict that the world's nuclear potential will double by 2050 (Rashad, 2020:12, Atia, 2018:11). Combined with the expected growth of nuclear power, the demand for uranium will also increase dramatically in the future (Chen, 2018: 10). Kazakhstan's uranium industry, which relies on progressive, highly efficient downhole production of uranium ores, can make a worthy contribution to solving the problem.

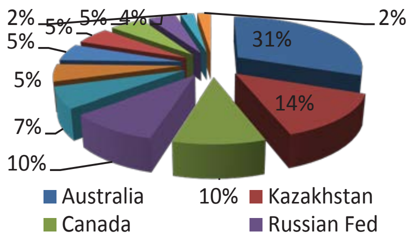

Figure 1. Proven uranium reserves by country

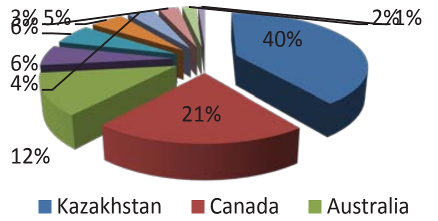

Figure 2. Shared production of uranium by the countries of the world

Uranium deposits in Kazakhstan are located in six provinces: Shu-Sarysu, Syrdarya, North Kazakhstan, Caspian, Balkash, Ile. The main production is carried out in the first two provinces located in the Kyzylorda and Turkestan regions. They are shown schematically on in the figure 3.

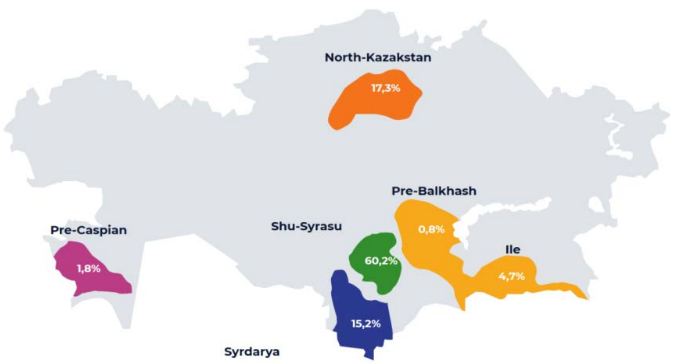

Figure 3. Scheme of location of regions of explored uranium deposits in Kazakhstan

The technology of borehole uranium extraction involves the dissolution of the useful component by a moving flow of solvent at the location of the ore body, followed by the removal and lifting of the formed compounds to the surface (Kuandykov, 2020:8, Rakishev, 2019 a:6). The use of sulfuric acid as a solvent reagent at enterprises in Kazakhstan is due to its low cost, availability, and the possibility of relatively complete conversion of uranium to solution. However, the high kinetics of the interaction of sulfuric acid with carbonate and clay minerals of the ore-bearing rocks causes sedimentation, which prevents the dissolution process (Rakishev, 2022b:11, Kenzhetaev, 2022a:13). The practice of operating geotechnical well systems in the development of uranium deposits by the method of in situ leaching of uranium (ISL) of uranium shows that over time there is a decrease in their productivity. One of the main reasons for the decrease in the throughput capacity of technological wells is an increase in hydraulic resistances and a decrease in the filtration characteristics of the formation due to the formation of colmatation due to the deposition of substances dissolved in technological solutions, or mechanical movement of particles of the ore-containing horizon (Kenzhetaev, 2021b:7, Issayeva, 2022:8). Figure 4 shows a schematic diagram of the flow of process fluids during downhole uranium mining.

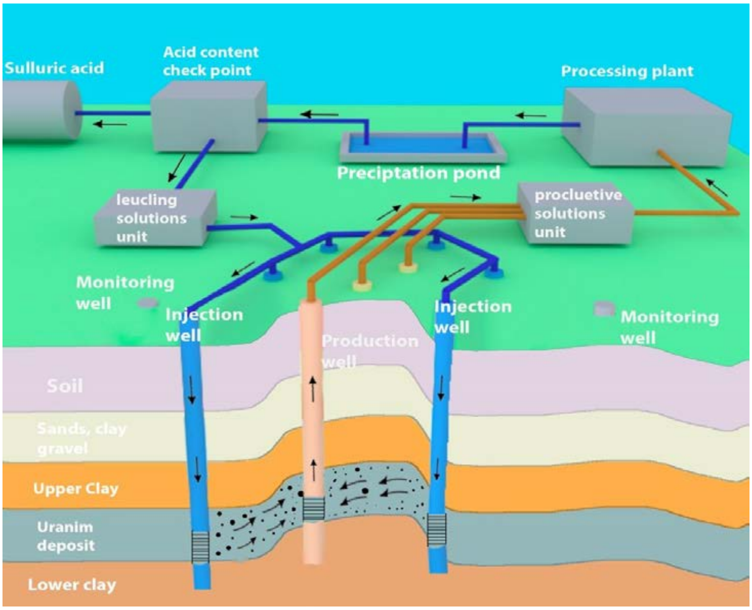

Figure 4. Flow diagram of process fluids during downhole extraction of uranium ores

Difficult-to-dissolve sediments and displaced clay particles in the productive horizon increase hydraulic resistance and form impenetrable sections of geochemical barriers that overlap the lines by current solutions. As a rule, a decrease in the filtration characteristics of a productive horizon leads to a decrease in the uranium content in the productive solution (PS), and a decrease in the flow rate and the period of uninterrupted operation of wells. This increases the period of working out of technological units, as a result of which, the consumption of sulfuric acid, electricity and other operational components increases (Yusupov, 2017a:4). Wells in these blocks are often stopped for repair and restoration work (RRW) and there is a need for an additional increase in the permeability of the near-filter zone of the formation (NZF). In some cases, it is necessary to carry out costly, heavy complex treatments using drilling rigs, including washing, chemical treatment, swabbing and compressor pumping (Yusupov, 2018b:4).

The efficiency of downhole uranium production largely depends on the methods used to restore the initial filtration characteristics of the formation and the ability to increase the flow rate and the period of uninterrupted operation of wells. The main methods for restoring the permeability of rocks in the bottom-hole zone of the formation during restoration work are physical, chemical and combined types of restoration work (Rakishev, 2022c:12).

The choice of a method for restoring production or injection well performance depends on the characteristics of each individual method, budget, equipment and well design, hydrogeological and other field features. A brief description of the main methods of reservoir permeability restoration and their average cost is given in table 1.

Table 1. Applied RRW methods at uranium mining enterprises

Nature of theimpact	Implementation method	Main purpose	Cost price, USD
Hydro-dynamic	Compressor pumping	Removal of clay solution, mechanical suspended	142.5
		particles and impurities from the NZF	
	Flushing with industrialwater	Removal of fine pulverized particles and clay materialsfrom NZF	112.3
Chemical	Sulfuric acid	Dissolution of ferrous and aluminium chemicaldeposits	225.0
	Clay-acidic	Dissolution of carbonate and silicon chemical andmechanical deposits	397.5
Combined	Reagent treatments withmechanical action	Removal of sand plugs from the well column and filter section, dissolution of chemical deposits, intensification by swabbing, clarification of solutionsby compressor pumping.	2250

As can be seen from Table 1, the RRW methods used by type are divided into hydrodynamic, chemical and combined, aimed at effectively eliminating a certain type of sedimentation. Hydrodynamic methods, such as compressor pumping and well flushing with process water, are based on the impact and pressure difference and are aimed at destroying and dispersing mechanical sedimentation (Kenzhetaev, 2022c:10, Zammit, 2014:9). The costs of these methods are relatively low due to the use of high-performance technological equipment. Chemical methods of exposure to dissolution are mainly aimed at destroying and eliminating sediments formed as a result of the interaction of technological solutions with the host rocks of the productive horizon (Panfilov, 2016:13). The costs of these methods are relatively high, due to the use of technological equipment and the consumption of chemical reagents. Combined methods include carrying out complex operations using drilling rigs and auxiliary equipment, combining well flushing with subsequent chemical treatment, swabbing and compressor pumping (Nikitina, 2019:6, Mamytbekov, 2014). This method is the most expensive due to the use of a large number of equipment, chemical reagents, maintenance personnel and a long duration of work. At the same time, these methods are ineffective in difficult mining and geological conditions, multicomponent sedimentation accumulates in the NZF and forms cemented impenetrable areas that do not respond to traditional methods of impact. This required conducting appropriate laboratory and pilot-industrial experiments.

Purpose of the work is improving the efficiency of downhole uranium production by selecting special decolmating solutions, improving the filtration characteristics of the formation, by destroying it, and preventing sedimentation in the productive horizon, depending on the mineralogical composition and structure of sedimentary materials.

Material and methods. Identification of the type and mineralogical composition of sedimentation plays an important role in solving the filtration characteristics of a productive reservoir. These data allow to select the most suitable solutions for processing both the filter and the near-filter zone of geotechnical wells. To determine the quantitative and qualitative characteristics of sedimentation, sediment samples were taken from the Chu-Sarysu and Syrdarya deposits (Carla, 2014:9).

X-ray diffractometric analysis was performed on an automated DRON-3 diffractometer with $Cu_{K\alpha}$ - radiation, β - filter. Conditions for shooting diffractograms: U=35 kV; I=20 mA; shooting θ-2θ; detector 2 deg/min. X-ray phase analysis on a semi-quantitative basis was performed based on diffractograms of powder samples using the method of equal weightings and artificial mixtures. Quantitative ratios of crystal phases were determined.

Interpretation of diffractograms was carried out using data from the file cabinet ICDD: powder diffractometric data base PDF2 (Powder Diffraction File) and diffractograms of minerals free of impurities. For the main phases, the content was calculated (Kassenov, 2020: 6).

According to X-ray phase analysis, colmatant has a high crystallization of several phases. In table 2 The results of X-ray phase analysis of sedimentation from the uranium deposits of the Chu-Sarysu and Syrdarya regions are presented.

Table 2. Mineralogical composition of sediments from the uranium deposit

Minerals	Formula	Syrdarya deposit, (Concentration,%)	Chu-Sarysu deposit, (Concentration,%)
Gypsum	$Ca(SO_4)\ (H_2O)_2$	52.0	81.8
Quartz	SiO_2	42.3	3.2
Potassium feldspar	$KAlSi_3O_8$	5,7	2.2
Sillimanite	$AL_2O_3.SiO_2$		12.8

Data tables 2 It is shown that the basis of the sample from the Syrdarya deposit deposit is made up of chemical compounds $Ca(SO_4)(H_2O)_2$ (52%) and SiO2 (42%), minerals-gypsum and quartz. The rest of the sample is potassium feldspar (5.7%). Characteristics of samples from the Syrdarya deposit indicate a combined origin of sedimentation, chemical-gypsum, and mechanical-quartz. The bulk of the sample from the Chu-Sarysu deposit consists of a chemical compound $Ca(SO_4)(H_2O)_2$ (81,8 %), mineral gypsum. The rest of the sample consists of quartz (3.2%), potassium feldspar (2.2%), and sillimanite (12.8%). Data from samples from the Chu- Sarysui deposit indicate the predominance of the chemical origin of gypsum sedimentation and the presence of mechanical impurities of quartz.

Analysis of X-ray images of samples from different deposits shows that the main sedimentary component of colmatant is calcium sulfate $CaSO_4{\bullet}2H_2O$. In this regard, it can be said that the main cause of colmatation is the interaction of the leaching solution of uranium ISL with calcium carbonate, which proceeds according to the formula:

$$CaCO_3 + H_2SO_4 = CaSO_4\downarrow + H_2\ CO_3 \quad (1)$$

For effective destruction and prevention of such sedimentation, it is necessary to develop a decolmating solution using hydrofluoric acid with the addition of surfactants with complexing properties. To improve the solubility, sulfamic acid was used as a surfactant, which has the properties of reducing the pH and bind metal ions.

Experiments on the treatment of sediments were carried out on samples from the same sample with different compositions of chemical reagents of decolmating solutions. To determine the effective composition of the solution, the most solvent properties were selected. For example, experiment № 1 included treatment with a solution of hydrofluoric acid (10% by weight) and industrial water (90%). Experiment № 2 included treatment with a solution of ammonium bifluoride (5.0%) and sulfuric acid (10.0%) Surfactants (1%) and industrial water (84%). Experiment No. 3 included treatment with a solution of sulfuric acid (10%) and industrial water (90%). Table 3 shows the parameters of decolmating solutions for laboratory studies.

Table 3. Parameters of decolmating solutions

Composition	HF, %	$NH4_4F$ * HF, %	H_2SO_4, %	CAK, %
HF	10			
$H_2SO_4 + NH_4F*HF$		5	10	1
H_2SO_4			10	

In experiment 1 preparation of a decolmating solution HF – (10%), industrial water (90%) was produced from semi-finished hydrofluoric acid. The choice of semi-finished hydrofluoric acid is due to its low cost, high reactivity with gypsum, aluminosilicates, and siliceous compounds that are part of ore-bearing rocks and colmating sediments. Interaction reactions proceed according to the formulas:

$$CaSO_4 \cdot 2\,H_2\,O + 2HF \;=\; CaF_2 + H_2\,SO_4 + 2H_2O \qquad (2)$$

$$CaAl_2SiO_8 + 16HF = 2AlF_3 + 2SiF_4 + 8H_2O + CaF_2, \qquad (3)$$

$$(3)\;\; 6HF + SiO_2 = SiF_4 + 2\,HF + 2H_2\,O. \qquad (4)$$

In experiment 2 the decolmating solution was prepared on the basis of ammonium bifluoride and sulfuric acid surfactants at the following ratios NH_4HF_2 – 10%, H_2SO_4 – 10%, surfactant-1.0%, industrial water-79%. The choice of ammonium bifluoride as the main component is due to its high ability to exchange reactions with mineral acids (sulfuric, hydrochloric, nitric acids) and the formation of hydrofluoric acid according to the formula:

$$NH_4HF_2 + H_2SO_4 = NH_4SO_4 + HF. \qquad (5)$$

As a result of the interaction of hydrofluoric acid with sedimentation, both the colmatant and part of the terrigenous component of the sands are dissolved, which increases the effective porosity of the ore block massif. The addition of surfactants increases the interaction of hydrofluoric acid with sedimentary minerals. At the same time, hydrofluoric acid is completely utilized due to the large amount of quartz contained in the sands.

In experiment 3, the decolmating solution was prepared on the basis of a combination of sulfuric acid H_2SO_4 (10%), industrial water (90%). The choice of sulfuric acid as a solvent reagent is due to its reactivity with aluminum oxide, iron and potassium hydroxide, low cost and availability at mining enterprises. The reaction of interaction proceeds according to the formula:

$$Al_2O_3 + H_2SO_4 = Al_2(SO_4)_3\downarrow + H_2O \quad (6)$$

Discussion of laboratory results. After conducting laboratory experiments on the processing of samples by the drip method with various compositions of decolmating solutions, the sediments were dried at room temperature. A scanning electron microscope was used for a detailed study of the sample surface. A comparative analysis of the images after processing with a particular solution and comparing it with the original image made it possible to visually establish the effectiveness of the composition of the decolmating solution.

Images of the sediment surface before and after treatment with various solutions were recorded using a high-resolution analytical scanning electron microscope. It is manufactured for a wide range of research tasks and quality control at the Tescan MIRA 3 FEG-SEM submicron level. SEM TESCAN MIRA electron column, electron source: Schottky autoemission cathode. The energy range of the electron beam incident on the sample is from 200 eV to 30 keV (from 50 eV with the option of beam deceleration BDT). To change the beam current, an electromagnetic lens is used as an aperture changer. Beam current: from 2 pA to 400 nA with continuous adjustment. Maximum field of view: more than 8 mm at WD = 10 mm, more than 50 mm at maximum WD. Electron column resolution, high vacuum mode 1.2 nm at 30 keV, Detector SE. 3.5 nm at 1 keV, In-Beam detector SE. 1.8 nm at 1 keV, beam deceleration option BDT. In the figure 5 shows images of samples from the Syrdarya deposit before and after treatment with special solutions.

On figure 5, a It can be seen that the surface of the initial sample is formed from dense lamellar crystals with dimensions from 5 to 30 μm with a characteristic skeleton structure without breaks or cracks in the body. The crystal shapes are elongated with a chaotic arrangement and uniform surface relief. Figure 5, b it can be seen that after treatment with decolmating solution 1, there was a noticeable destruction of the structure and a change in the shape of crystals with a decrease in their size and density with the formation of small loosened flakes. It can be seen the rounded edges of the crystals and the formation of cracks in the bodies.

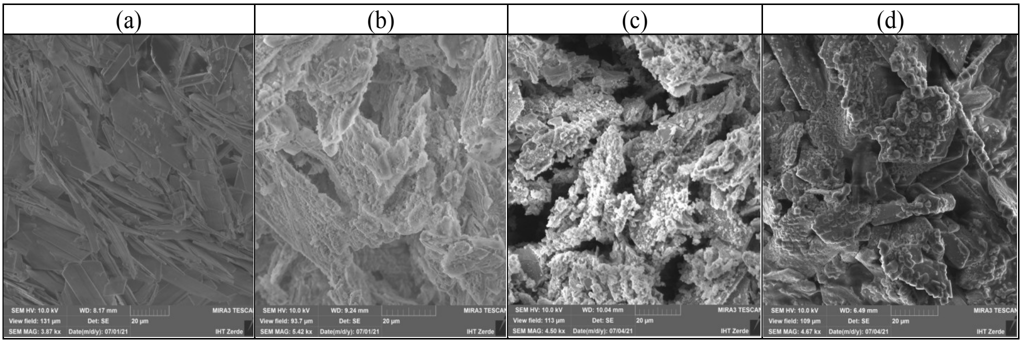

Figure 5. Image of the sample surface of the Syrdarya deposit: (a) – the initial sample. (b) – samples of experiment 1. (c) – samples of experiment 2. (d) – samples of experiment 3;

The arrangement of crystals became less dense with the formation of voids and gullies in the pore space. Partial dissolution of the sample is noticeable, and the crystal size is significantly reduced from 30 to 15 μm. This is due to the dissolution of part of the sample in hydrofluoric acid. From figure 5.c showing the data from experiment 2, it can be seen that the changes in the sample structure are similar to the previous experiment with a more pronounced character. Also noticeable is the dissolution of sedimentation with decolmating solution and the formation of gullies and large cracks along the path of the solution movement. Deformed forms of crystals with altered shapes and structures, the size of voids is larger compared to experiment 1. This is due to the dissolution of precipitation in hydrofluoric and sulfuric acids. On figure 5,d, depicting the data of experiment 3, it is shown that changes in the structure of the sample after treatment with decolmating solution 3 are less pronounced. The crystals acquired round shapes without changing their size. The minor impact is due to the low content of aluminum in the sedimentation composition. Figure 6 shows samples taken from the Chu-Sarysu deposit before and after treatment with special solutions.

(a) (b) (c) (d)

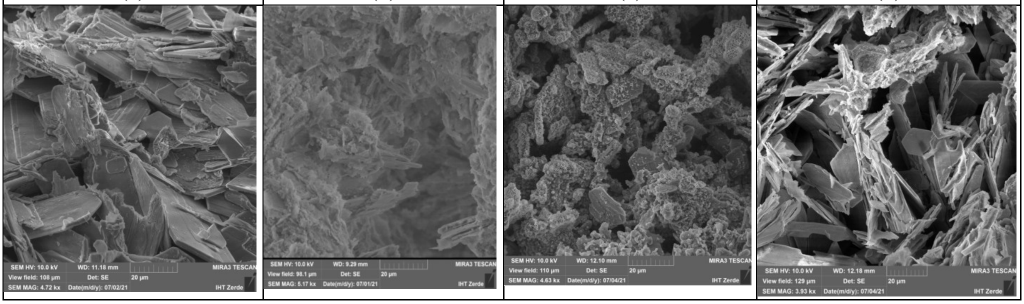

Figure 6. Image of samples of Chu-Sarysu deposit: (a) – initial sample; (b) – sample of experiment 1; (c) - sample of experiment 2; (d) - sample of experiment 3;

From figure 6, a It can be seen that the surface of the initial sample is formed from dense crystals of various sizes from 3 to 20 µm with a characteristic skeleton structure without breaks or cracks in the body. The crystal shapes are rectangular with a chaotic arrangement and uniform surface relief. figure 6, b it can be seen that after treatment with decolmating solution 1, the structure was destroyed and the shape of the crystals changed with a decrease in their size and the formation of small loosened flakes. It can be seen the formation of holes and cracks in the sample body with the formation of voids and deposits. Partial dissolution of the sample is noticeable, and the crystal size decreases from 20 to 10 µm. Significant changes are caused by the dissolution of precipitation with hydrofluoric acid. figure 6, c with the data of experiment 2 shows that the sample structure has changed more significantly, the formation of many deep voids and cracks along the path of the solution movement is noticeable. It draws attention to the deformed shapes of crystals with rounded shapes. Destruction is caused by the dissolution of precipitation in hydrofluoric and sulfuric acids, and penetration due to the action of surfactants. figure 6,d, with the data of experiment 3, it can be seen that the structure of the sample after treatment with a decolmating solution changed less pronounced. The crystal shapes retained their shape, however, voids appeared and the crystal density became smaller. The minor impact is due to the dissolution of only aluminum and potassium sedimentation minerals in sulfuric acid.

The use of decolmating solution must be carried out according to a special method on special technological equipment. The innovative method involves treating the filter area of the well directly with decolmating solution and maximizing the destruction and prevention of sedimentation in the reservoir. The method provides an increase in the productivity of production units and the completeness of metal extraction from them, due to the removal and prevention of sedimentation in a porous medium. In addition, it reduces the specific costs of sulfuric acid, electricity, labor and other production costs in the process of downhole extraction of uranium from various mining and geological blocks.

Methods of conducting production experiments. To increase the efficiency of uranium production by intensifying geotechnical processes and restoring the permeability of the reservoir's near-filter zone, the authors developed and tested a method for chemical treatment of wells with a special solution. This method of impact on the formation provides for the supply of solutions of a complex of chemical reagents to the filter zone, to the productive horizon for its reaction with sedimentation, dissolution and removal of reaction products outside the well by airlift pumping. On in the figure 7 shows the developed scheme of components of work on the intensification of uranium production.

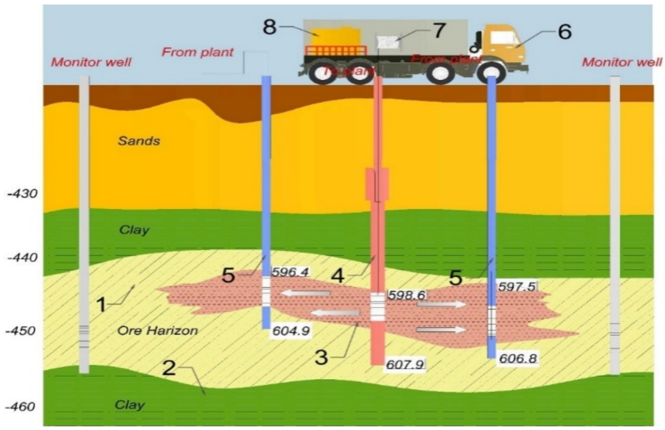

Figure 7. Scheme for the intensification of downhole uranium production
1 – productive horizon; 2 – impenetrable rocks; 3-sedimentation in the NZF; 4 – pumping wells; 5 – injection well; 6 – equipment for chemical treatments; 7 – pressure hose; 8 – tank.

As seen from of the figure 7, the bulk of sedimentation 3 occurs in the productive horizon 1, directly in the zone of unloading solutions and increasing the speed of movementI solutions from injection wells 5, to pumping wells 4. Chemical treatment using a complex of chemical reagents provides for the preparation of solutions on special equipment 6, and feeding through the pressure sleeve 7 to the filter part of wells 4. At the same time, the prepared special solution is fed from the tank 8 by a pump. The supply of decolmating solutions based on ammonium bifluoride (10%), sulfuric acid (10%) directly to the filter part of technological wells reduces the consumption of chemical reagents and increases the penetration of water. At high capacity for greater destruction and dispersion of precipitation.

For the organization of experimental work in downhole uranium mining, compliance with the leaching process mode, and calculation of the required volume of decolmating solutions and chemical reagents, it was necessary to calculate the following geotechnological parameters: the ratio of liquid to solid (L:S), calculated spreading radius. L:S ratio was calculated using the formula:

$$L:S = \frac{\sum_{i=1}^{n} Q_{ls}}{S\,h_э\,\delta}, \quad (7)$$

where: Q_{ls} – the amount of leaching solution delivered to the subsurface during the time period t, m^3; S – leached area, m^2; $h_в$ – effective capacity of the productive horizon, m; δ - volume mass of ore-bearing rocks and ores, t / m3. The calculated area of spreading of solutions from the filter along the productive horizon was determined by the formula:

$$S = \frac{Q_D}{0{,}22h_э}, \quad (8)$$

Where: Q_D – the volume of decolmating solutions supplied to the well, m^3; 0.22 – average porosity coefficient of the host rocks of the productive horizon. The spreading radius of decolmating solutions was determined by the formula:

$$R = \left(\frac{S}{\pi}\right)^{\frac{1}{2}}, \quad (9)$$

The equipment for the preparation and supply of chemical reagent solutions consists of a container and a pump, which are made of corrosion-resistant material. Due to the fact that they are in contact with sulfuric and hydrofluoric acids.

Results & discussion. Pilot tests to study the effectiveness of chemical treatments directly to the filter part of technological wells were carried out at the Syrdarya deposit field. A photo of the manufactured and implemented equipment for improving the filtration characteristics of ores according to the developed method at the Syrdarya and Chu-Sarysu deposits is shown in figure 8.

Figure 8. Developed technological equipment for improving the filtration characteristics of ores using the developed compositions

The actual geotechnological conditions of the Syrdarya and Chu-Sarysu deposits were taken into account when developing, manufacturing and adapting the units. When conducting production experiments, the developed and approved technological regulations were strictly coordinated. These results are high and confirm the indisputable effectiveness of an innovative integrated method for intensifying downhole uranium production in deposits with low filtration characteristics of ores.

Below are data on 20 production wells using various formulations of decolmating solution. The developed decolmating solution includes: industrial water, ammonium bifluoride, sulfuric acid in various proportions. Table 4 shows the parameters of the formulations of the decolmating solution and the processed results of experimental work.

Table 4 - Parameters of decolmating solution sand results of experimental work

Composition	Volume LS,m3	H_2SO_4, kg	NH_4F*HF, kg	Number of wells processed	inter- repair cycle before, day	inter- repair cycle after, day
$H_2SO_4 + NH_4F*HF$	3	150	19	5	16	127
$H_2SO_4 + NH_4F*HF$	2	100	12	5	22	118
$H_2SO_4 + NH_4F*HF$	1	50	6	5	21	95
H_2SO_4	3	300		5	11	36

As can be seen from Table 4, decolmating solutions with a volume of 3 m3 2 m3, and 1 m3 were prepared, based on ammonium bifluoride, with a concentration of HF – 1.2%, and H_2SO_4 – 5%. For comparative analysis, a decolmating solution based on 10% sulfuric acid with a volume of 3 m3 was prepared. Analysis of production wells ' performance before and after experimental operations allowed determining the efficiency of chemical treatment of wells using an innovative method. Figure 9 shows a diagram of the periods of uninterrupted operation of wells before and after experimental work. The blue color shows the average values of the period of uninterrupted operation of selected wells after restoration of reservoir filtration characteristics by traditional methods. The red color shows the periods of uninterrupted operation of wells after chemical treatment using an innovative method using developed formulas.

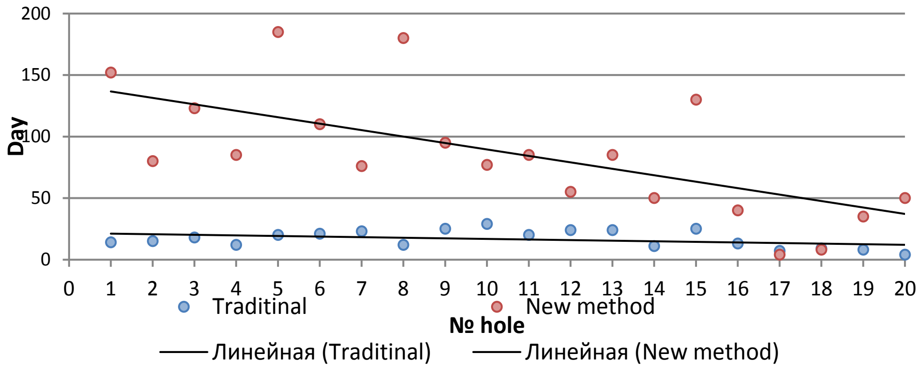

Figure 9. Results comparative analysis of the period of uninterrupted operation of geotechnical parameters of wells

A comparative analysis of the above data shows that the average uptime of the selected geotechnical wells before the experiments was 16 days. After applying the innovative method of restoring filtration characteristics, the average value of the uptime period of wells was 84 days. On wells treated with 3,2 and 1 m3 decolmating solution based on H_2SO_4 + NH_4F*HF the period of uninterrupted operation exceeded 127, 118, and 95 days on average, respectively. At the same time, the period of uninterrupted operation of wells treated with the compound H_2SO_4 3 m3 It was 36 days, which exceeds the traditional indicator by more than two times.

Conclusions. Quantitative and qualitative studies of the sedimentation composition of deposits in the Chu-Sarysu deposit indicate that the main part of the sample is gypsum (81.8%). The rest of the sample consists of quartz (3.2%) and sillimanite (2.2%). $Al_2O_3 \cdot SiO_2$ (12,8%). Field sample basis The Syrdarya deposit consists of gypsum (52%) and quartz (42.3%), the rest of the sample consists of KPS (5.7%).

As a result, due to the interaction of sulfuric acid solutions with carbonate minerals, the structure of sedimentation is strongly deposited in the discharge zone. They cause low efficiency of hydrodynamic methods and difficulties in working out technological blocks, lead to a decrease in the productivity of production and injectivity of injection wells due to a deterioration in the reservoir filtration characteristics. They raise additional costs for restoring the permeability of the productive horizon and increasing the productivity of production and injectivity of injection wells, increase the operating costs for working out blocks.

Preparation of a decolmating solution based on ammonium bifluoride (5%), sulfuric acid (10%), and surfactants in small amounts increases the solubility of the decolmating solution and prevents sedimentation in the reservoir for a longer time.

The developed method for restoring the filtration characteristics of a productive horizon based on the treatment of the filter part of wells allows reducing the specific consumption of chemical reagents and increasing the efficiency of decolmating solution.

In the conditions of industrial downhole uranium mining, rational parameters for applying an innovative method for restoring filtration characteristics in ores with low filtration characteristics were established at geotechnical wells. The new method effectively restores the productivity of production wells and injectivity of injection wells, increases the period of uninterrupted operation of wells by 70-80%. Reduces operating costs for production, ensures compliance with environmental and industrial safety requirements.

Further research on improving the efficiency of dissolution and preventing sedimentation of the productive horizon in various conditions using physico-chemical methods of exposure will reduce the cost of finished products and increase labor productivity.

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