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UNDERGROUND URANIUM BOREHOLE LEACHING

Abstract. Kazakhstan has the world's largest raw material base of proven industrial uranium reserves. The bowels of the Republic of Kazakhstan contain about 25% of the world's proven uranium reserves. A unique feature of uranium reserves is that 75% of them are concentrated in deposits associated with regional zones of formation oxidation, which can be mined using a relatively cheap and environmentally preferred method of underground leaching. The presence in Kazakhstan of significant reserves of well-explored uranium deposits, developed mining and processing capacities of uranium, as well as the current situation on the world uranium market determine the prospects for the development of Kazakhstan's uranium mining industryю.

Existing production technologies for the exploitation of hydrogenous uranium deposits do not meet the requirements of market economy: low labor productivity, high unit costs, require large capital investments, the technology is not competitive, and sulfuric acid is expensive. To create exemplary uranium mines, it is necessary and urgent to develop an innovative technology for the exploitation of hydrogenic uranium deposits. The main operational indicators determining the effectiveness of the application of SST include: leaching rate; average concentration of uranium in productive solutions; reagent consumption; productivity of productive solutions; the degree of extraction of uranium from the bowels; the volume of the solution spent on the extraction of uranium from a unit of ore mass (ratio W: T).

The article presents the results of solving the main technical and technological problems, allowing to develop an innovative technology for the exploitation of hydrogenic uranium deposits: we have developed a method for using pumping wells without changing their design as injection wells; it is not intended to use an inline injection well location system, which makes it possible to drastically reduce capital expenditure; It is planned to use an ordinary pumping well without changing its design using the “x” method; this well can operate both a pumping well and a pumping well. The pumping well will operate under the name “Piston Well” in the mode of pulsating flows when a chemical solution is supplied to an array of uranium hydrogen deposits; the development of a method for intensifying the leaching of useful components, including uranium; a way to drastically reduce the consumption of a chemical reagent (H2SO4). With the existing technology for producing a productive uranium solution, the specific consumption of sulfuric acid per 1 ton of uranium concentrate is 1: 100, i.e. per 1 ton of extraction of uranium concentrate requires a consumption of sulfuric acid of 100 tons

The work performed provides economic efficiency for the listed parameters of leaching of uranium.

Key words: geological features, theoretical justification, technology, mining, borehole underground leaching, uranium.

Introduction. The basis for the development and implementation in practice of uranium mining of the method of underground borehole leaching were achievements in the field of geological exploration and industrial assessment, epigenetic deposits of regional zones of reservoir and soil oxidation, advances in the field of hydrodynamics, geochemistry, hydrometallurgy.

Over the past years, collectives of Kazakhstani uranium mining enterprises have done a lot of work to improve uranium mining technology, increase labor productivity, reduce production costs, and automate production processes. Considerable work has been done in the field of drilling and equipment of wells, improving the means of raising productive solutions, devices for their sorption-desorption redistribution [1,2].

The development and implementation of the method of underground borehole leaching of uranium is one of the most important scientific and technical achievements of the mining industry. The main advantages of the underground leaching method compared to traditional mining methods of field development are as follows [3-5]:

- the possibility of involving in the exploitation of poor and off-balance ores of deposits with complex geological and hydrogeological conditions, but with large reserves of uranium;
- significant reduction in capital investments and terms of commissioning;
- improving working conditions, reducing the number of miners and increasing labor productivity by 2.5-3.5 times;
- reduction of the negative impact of uranium mining on the environment.

Based on the modern achievements of geotechnological science and practice, the development of uranium mining by the method of downhole leaching goes along the path of introducing computer-aided mining technologies based on the full automation of all production processes; optimization of opening, preparation and mining schemes; the introduction and development of new technical means for the construction and development of wells, new structural materials; reduction of solvent costs, ion exchange resins; the introduction of electrodialysis plants, sorption-desorption concentration apparatuses such as SDK, polymer washing liquids, hydraulic fracturing and hydraulic washing of formations, new methods of electro-ultrasonic intensification of leaching and redistribution of productive solutions; the introduction of effective methods for monitoring the hydro-geochemical parameters of underground leaching sites and environmental rehabilitation of spent deposits [6-9].

The social significance of introducing the method of downhole leaching into uranium mining practice is extremely great. Radically, for the better, the nature of the work of miners and the radiation safety of the work have changed. A further increase in uranium production, based on the introduction of the latest scientific and technical achievements in the practice of developing infiltration deposits, will allow Kazakhstan to take a leading place among the world's uranium producers.

Methods. To solve this problem, theoretical substantiation methods were used for the technology of underground borehole leaching of uranium. About 25% of the world reliably explored uranium reserves are concentrated in the bowels of Kazakhstan. Total reserves and resources are estimated at 1,560 thousand tons of uranium, including category reserves (B + C 1 + C2) of 928 thousand tons. A unique feature of the republic’s uranium reserves is that about 75% of them are concentrated in deposits associated with regional zones of formation oxidation. This type of field is not widespread in the world and is being developed by the most progressive, relatively cheap and environmentally preferable method of underground borehole leaching.

The result of these works is the development of technology for underground borehole leaching of uranium in Kazakhstan. Kazakhstani uranium deposits associated with regional zones of formation oxidation are formed in the Shu-Sarysuyskaya and Syr-Darya depressions of the platform cover of the northern part of the Tien Shan uranium megawatch (Northern, Eastern and Western group of deposits). Deposits associated with zones of soil-layer oxidation are developed in the Ili River basin, outside the zone of activity of industrial enterprises and in the Akmola region of Northern Kazakhstan. Uranium deposits suitable for mining with sulfuric acid leaching through a system of wells drilled from the surface belong to the subgroup of infiltration (hydrogen). These deposits are the basis of the raw material base of the uranium industry of Kazakhstan and are concentrated in the Shu-Sarysuyskaya (Mynkuduk, Inkai, Budenovskoye, Zhalpak, Sholak-Espe, Uvanas, Moinkum, Kanzhugan) and Syrdarya (Irkol, Karamurun, Kharasan, Zarechnoye, Asarchik Kyl, Zha , Chayan, Lunar) uranium ore provinces. The largest of the deposits of the soil-formation oxidation zone and promising for development is the Semizbay deposit [10-14]. The distribution of reserves and resources by geological and industrial types of uranium deposits in Kazakhstan is shown in table.

Reserves and resources for geological and industrial types of uranium deposits in Kazakhstan

Type of deposit	Category reserves $B+Ci+C_2$		Reserves and resources $B+Ci+C_2+Pi$	
	thous. tons	%	thous. tons	%
Deposits associated with regional zones of reservoir oxidation	603	65	1160	75,3
Deposits associated with soil formation oxidation zones	82	8,8	97	6,0
Deposits of organogenic phosphate type	29	3,2	29	1,8
Vein stockwork deposits in folded complexes	214	23	274	16,9
Total	928	100	1560	100

The leaching rate is a value equal to the quotient of dividing the length of the ore layer worked out by the solution by the time during which a certain metal fraction is extracted from this layer. Leaching rate V_l is related to the filtering rate V_f by a linear relationship $V_l = \beta \cdot V_f$; where β – constant coefficient for specific ore-solvent combinations. The most important geotechnological parameter, the ratio, is based on this regularity L:S, that is, the ratio of liquid to solid (the ratio of the volume of the solution to the volume of the ore mass).

The reagent consumption for underground leaching of uranium depends on the reagent capacity of ore-bearing rocks, the type and nature of uranium mineralization, rock carbonate, productivity and effective thickness of formations, hydrodynamic conditions for pumping solutions through ore-bearing strata.

In the practice of underground leaching of uranium, the specific consumption of the reagent is 50-150 kg per 1 kg of metal, which is due to the reaction of the acid with other minerals and the spreading of solutions. Carbonates almost completely react with acid (1 kg of sulfuric acid is consumed per 1 kg of CaCO3), minerals of oxide iron, less intensely ferrous iron and some aluminosilicates (up to 10%) dissolve well (40-50%) [15-17]. At the stage of formation acidification, the reagent (sulfuric acid) consumption is usually 8-10 g / l for ores with high carbonate content and 20-30 g / l for non-carbonate ores. At the leaching stage, the concentration of sulfuric acid in working solutions ranges from 8 to 15 g / l.

The data in table, the data can be used in the evaluation of deposits for the use of underground borehole leaching. The developed classification system for signs of the suitability of infiltration uranium deposits for leaching is recommended for use in the design of PSV technology in Kazakhstan deposits.

The conditions for the formation of exogenous infiltration deposits are associated with the behavior of uranium in the upper parts of the earth's crust, in the zone of so-called hypergenesis, where the migration of chemical elements occurs at low temperatures and pressures. The formation of exogenous uranium deposits is associated with the epigenetic accumulation of uranium minerals during their migration and deposition.

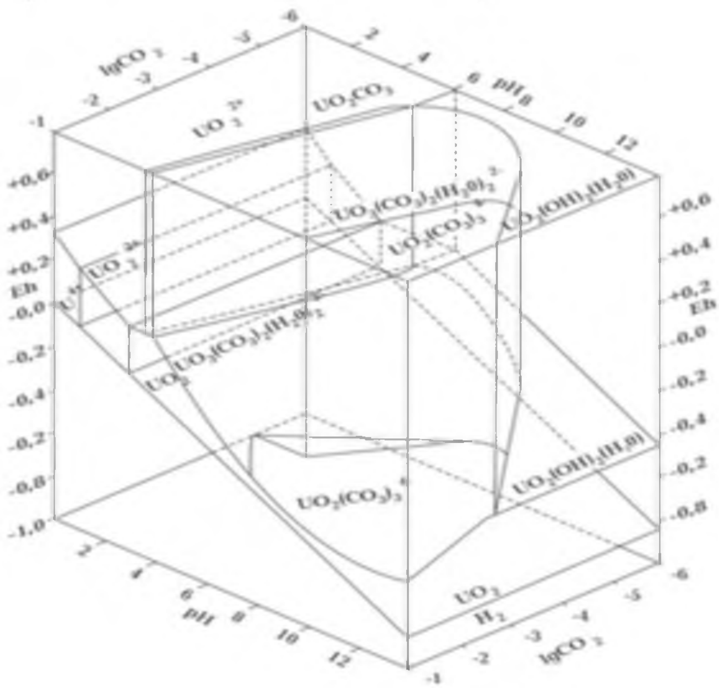
Under the surface conditions of the hypergenesis zone, under the influence of water, air and organic matter, the minerals of the ore-bearing rocks are oxidized and uranium migrates (transfers) by infiltration flows. Natural waters of the hypergenesis zone are true and colloidal solutions of various concentrations. The intensity of migration of chemical elements depends on the acidity and alkalinity of natural waters.

In natural waters in the form of ions and undissociated molecules contains almost all chemical elements, most of which are in a state of strong scattering (about n × 10-5 g / l or less) and only Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, SiO_2 are contained in significant quantities. A strong influence on the physicochemical characteristics of natural waters is exerted by H + and OH- ions [18]. The oxidizing environment of groundwater is characterized by the content of free oxygen, the redox potential is Eh> 0.1 V, often above 0.4 V and can reach 0.6-0.7 V. Uranus is in U^{6+} shape, iron is predominantly in the shape Fe^{3+} and only in strongly acidic environments can Fe^{2+} exist. Sulfur is exclusively in form SO_4^{2-}. Under certain conditions, there are VO_4^{3-}, SeO_3^{2-} and SeO_4^{2-}, MoO_4^{2-}, MoS_2, ReS_2.

Recovery environment without H_2S - water does not contain free oxygen, Eh обычно ниже 0,4в, иногда ниже нуля. Under these conditions, iron and manganese are in the form Fe^{2+} and Mn^{2+}, migrate easily. If H_2S is present in water, If H is present in water, then Eh<0, iron, manganese, copper, zinc and other chalcophilic elements precipitate. Uranium precipitates to form U^{4+}compounds. The presence of dissolved oxygen in natural waters increases the solubility of primary uranium minerals in an acidic sulfate medium, and less intensively in alkaline carbonate. The tetravalent uranium oxides and mixed oxides are completely dissolved in the carbonate medium only in the presence of oxidizing agents. Uranium silicates, phosphates and humates dissolve in an alkaline medium. In natural waters, depending on the total mineralization, chemical composition, pH of the medium and the concentration of uranium in water, ions may be present: UO_2^{2+}, $UO_2(OH)^+$, $[UO_2(CO_3)_2\ (H_2O)_2]^{2-}$ $[UO_2(CO_3)_3]^{4-}$, as well as undissociated molecules of UO2 (OH) 2. Chemical reactions in the zone of hypergenesis occur at a pressure close to 1 atm. and temperature not exceeding the first ten degrees.

The conditions of existence of uranium compounds in the hypergenesis zone are graphically represented by the diagram in the parameters Eh, pH, pressure CO_2, since these parameters are the most important characteristics of natural waters. The diagrams depict the equilibrium conditions, that is, the relations between the compounds after reaching thermodynamic equilibrium. Figure by R. Garrels [5,19] shows a diagram of the stability field of uranium compounds as a function of Eh, pH and general $\Sigma\ CO_2$ the amount of carbonate in produced water (P=1 Atmosphere pressure, T=25°C).

Figure shows that hexavalent uranium is almost completely complexed with the formation of uranyl dicarbonate and uranyl tricarbonate ion complexes.



Stability of some uranium compounds in formation water at 25 ° C
and 1 atm total pressure as a function of pH, Eh and amounts of dissolved carbonate components

With noticeable ΣCO_2 the stability field of uranyl oxide hydrate is displaced. Such complexation proceeds so efficiently that, at a relatively high ΣCO_2 value, the fields of these complexes displace the stability field UO_2 (uraninite). From this it becomes clear that carbonate-containing waters are strong solvents of uranium. Watering the hypergenesis zone with water containing up to 8-10 mg / oxygen increases the water Eh and promotes the conversion of $U4^+$ to $U6^+$. If natural water contains up to 2g / l or more carbon dioxide, then uranium migration is also enhanced.

H_2S hydrogen sulfide present in water, which reduces uranium to the tetravalent state, contributes to its precipitation from solution.

When uranium minerals are dissolved by natural waters in the hypergenesis zone, especially under oxidizing conditions, the state of chemical equilibrium between the solid and liquid phases is practically not achieved due to the mobility of the water and the buffer effect of the host rocks on the pH of the water. The forms of uranium in natural waters are very diverse. According to V.V. Shcherbina [5,20], in the zone of hypergenesis, uranium in aqueous solutions can be transported in the following forms:

- soluble uranyl sulfate UO_2SO_4;
- colloidal solution of hydroxide composition $[UO_2(OH)_2]_n$, negative charge carrier;
- readily soluble complex carbonates composition $Na_4[UO_2(CO_3)_3]$;
- readily soluble complex alkaline humate compounds.

The possibility of migration of uranium in aqueous solutions in the form of compounds arises from the chemical properties of uranium, its ability to react with other elements, form ions of different valencies, form soluble complexes and be sorbed by colloids.

Natural waters have a high dissolving power. The dissolving ability of water is caused by large dipole moments of molecules (μ = 1.8) and a high dielectric constant (80.0) of water [1,5,21].

There is a relationship between solubility, heat and dissolution entropy:

$$nRTlna = L + T\Delta S = L + T\sum_{L}^{i} S$$

where, *n* – number of ions forming a molecule of uranium salt; *a* – saturated solution activity; *L* - heat of dissolution; *T* - absolute temperature; *ΔS* – entropy of dissolution; $\sum S^{i}_{L}$ - the sum of dissolution entropy ions equal to the change in the entropy of an ion upon its transition from the crystal lattice to a solution with an activity equal to 1.

Discussion. A prerequisite for the implementation of underground leaching technology should be good permeability of the medium containing uranium mineralization for the solution. With fairly good permeability indicators, even deposits of poor uranium ores prove to be profitable for mining. Each uranium deposit is always individual in its natural features, the technical and economic indicators of the exploitation of deposits by underground leaching depend on these features. Moreover, the feasibility of using underground leaching technology for mining a particular uranium deposit is based on the parameters of two factors: the possible volume of uranium production per unit time and the possible cost of producing a unit of uranium.

The main operational indicators that determine the effectiveness of the use of UBL include:

- leaching rate;
- average concentration of uranium in productive solutions;
- reagent consumption;
- productive solution performance;
- the degree of extraction of uranium from the bowels;
- the volume of solution spent on the extraction of uranium from a unit of ore mass (ratio L:S).

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УРАНДЫ ЖЕРАСТЫ ҰҢҒЫМАЛАРЫН ШАЙМАЛАУ

Аннотация. Қазақстан әлемдегі ең ірі уран өнеркәсінтік қорының шикізат базасына ие. Қазақстан Республикасының жер қойнауында әлемдік барланган уран қорының шамамен 25 %-ы бар. Уран қорларының бірегей ерекшелігі, олардың 75 %-ы жерасты ұңгылап шаймалаудың салыстырмалы арзан және экологиялық жагынан қолайлы тәсілмен өңделуі мүмкін қабаттық тотығу аймақтарымен байланысты кен орындарында шогырланган. Қазақстанда қорлар бойынша елеулі, жақсы барланган уран кен орындарының, дамыган өндіруші және өңдеуші уран қуаттарының болуы, сондай-ақ әлемдік уран нарыгының қазіргі замангы конъюнктурасы Қазақстанның уран өндіру өнеркәсібін дамыту перспективасын алдын ала айқындайды.

Уранның гидрогенді кен орындарын пайдаланудың қазіргі технологиялары нарықтық экономика талаптарына сай емес: еңбек өнімділігінің төмендігі, өнім бірлігінің өзіндік жогары құны көп мөлшерде тамшыландыруды талап етеді, технология бәсекеге қабілетсіз, күкірт қышқылының шыгыны көп. Үлгілі уран кеніштерін құру үшін гидрогенді уран кен орындарын пайдаланудың инновациялық технологиясын әзірлеу қажет және өзекті. Жерасты ұңғылап шаймалауды (ЖҰШ) қолданудың тиімділігін анықтайтын негізгі пайдалану көрсеткіштеріне мыналар жатады: сілтілеу жылдамдығы; өнімді ерітінділердегі уранның орташа концентрациясы; реагенттің шығыны; өнімді ерітінділер бойынша өнімділік; жер қойнауынан уранды алу дәрежесі; тау-кен массасы бірлігінен уранды алуға жұмсалатын ерітіндінің көлемі (С:Қ қатынасы).

Мақалада уранның гидрогенді кен орындарын пайдаланудың инновациялық технологиясын әзірлеуге мүмкіндік беретін негізгі техникалық-технологиялық міндеттерді шешу нәтижелері келтірілген: біз айдау ұңғымалары ретінде конструктивтік ресімдеуін өзгертпей, сору ұңғымаларын пайдалану тәсілін әзірледік; айдау ұңғымаларын орналастырудың бірқатар жүйесін қолдану көзделмеген, бұл капитал салу шығынын күрт қысқартуға мүмкіндік береді; қарапайым сору ұңғымасын «х» тәсілінің көмегімен конструктивті рәсімдеуін өзгертпей қолдану қарастырылған, бұл ұңғыма сору және айдау ұңғымасы ретінде жұмыс істей алады. Сору ұңғымасы уранның гидрогенді шоғырының массивіне химиялық ерітінді беру кезінде пульсациялайтын ағын режимінде «поршенді ұңғыма» атымен жұмыс істейтін болады; пайдалы компоненттерді, оның ішінде уранды шаймалау үдерісін қарқындату тәсілін әзірлеу; химиялық реагент шығынын күрт қысқарту тәсілі (H2SO4) қарастырылды. Уранның өнімді ерітіндісін өндірудің қазіргі технологиясы кезінде 1 т уран концентратына күкірт қышқылының үлес шығыны 1: 100 қатынасын құрайды, яғни уран концентратын өндірудің 1 т күкірт қышқылының шығыны 100 т болады.

Орындалған жұмыс уранды сілтілеудің аталған параметрлері бойынша экономикалық тиімділікті қамтамасыз етеді.

Түйін сөздер: геологиялық ерекшеліктер, теориялық негіздеу, технология, өндіру, ұңғымалық жерасты сілтілеу, уран.

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ПОДЗЕМНОЕ СКВАЖИННОЕ ВЫЩЕЛАЧИВАНИЕ УРАНА

Аннотация. Казахстан обладает крупнейшей в мире сырьевой базой разведанных промышленных запасов урана. Недра Республики Казахстан содержат около 25% мировых разведанных запасов урана. Уникальной особенностью запасов урана является то, что 75% из них сосредоточены в месторождениях, связанных с региональными зонами пластового окисления, которые могут быть отработаны относительно дешевым и экологически предпочтительным способом подземного скважинного выщелачивания. Наличие в Казахстане значительных по запасам, хорошо разведанных месторождений урана, развитых добывающих и перерабатывающих уран мощностей, а также современная конъюнктура мирового рынка урана предопределяют перспективу развития уранодобывающей промышленности Казахстана.

Существующие технологии добычи эксплуатации гидрогенных месторождений урана не отвечают требованиям рыночной экономики: низкая производительность труда, высокая себестоимость единицы продукции, требуют в больших размерах капвложения, технология не конкурентоспособная, большие расходы серной кислоты. Для создания образцовых урановых рудников необходима и актуальна разработка инновационной технологии эксплуатации гидрогенных урановых месторождений. К основным эксплуатационным показателям, определяющим эффективность применения СПВ, относятся: скорость выщелачивания; средняя концентрация урана в продуктивных растворах; расход реагента; производительность по продуктивным растворам; степень извлечения урана из недр; объём раствора, расходуемого на извлечение урана с единицы горнорудной массы (отношение Ж:Т).

В статье приведены результаты решения основных технико-технологических задач, позволяющих разработать инновационную технологию эксплуатации гидрогенных месторождений урана: нами был разработан способ использования откачных скважин без изменения их конструктивного оформления в качестве закачных скважин; не предусмотрено применение рядной системы расположения закачных скважин, что дает возможность резко сократить расход капиталовложения; предусмотрено применение обыкновенной откачной скважины без изменения ее конструктивного оформления с помощью «х» способа эта скважина может работать как откачная, так и закачная скважина. Откачная скважина будет работать под именем «Поршневая скважина» в режиме пульсирующих потоков при подаче химического раствора в массив

гидрогенной залежи урана; предусмотрена разработка способа интенсификации процесса выщелачивания полезных компонентов, в том числе урана; способ резкого сокращения расхода химического реагента (H2SO4). При существующей технологии добычи продуктивного раствора урана удельный расход серной кислоты на 1 т концентрата урана составляет 1:100, т.е. на 1 т добычи концентрата урана требует расход серной кислоты 100 т.

Выполненная работа обеспечивает экономическую эффективность по перечисленным параметрам выщелачивания урана.

Ключевые слова: геологические особенности, теоретическое обоснование, технология, добыча, скважинное подземное выщелачивание, уран.

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