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STUDY OF MINING-GEOLOGICAL CHARACTERISTICS OF URANIUM DEPOSITS OF KAZAKHSTAN FOR DEVELOPMENT BY UNDERGROUND WELL LEACHING

Abstract. Existing traditional uranium mining technologies have major drawbacks, do not meet the requirements of a market economy, are ineffective, require the use of a large number of expensive injection and pumping wells, low leaching rates, require a large consumption of chemical reagent, sulfuric acid (to produce 1 ton of uranium concentrate requires a flow of 100 tons sulfuric acid). Here, a productive solution refers to a chemical solution containing the concentration of the leached therein of various useful components (metals), including uranium, dissolved therein.

In the practice of exploitation of hydrogenous uranium deposits, the arrangement of technological wells has been adopted: linear (or in-line), areal (or cellular) and combined.

Our proposed innovative technology for the exploitation of hydrogenous uranium deposits will be developed on the principle of piston wells using the effect of activation of a chemical solution supplied to the array of a hydrogenated uranium layer for leaching and other useful components. In the process of activation, the chemical solution is heated to t = 70 ° C, the water in the solution becomes a good solvent. Pumping wells are used as piston wells without changing the design, i.e. pumping wells are also used as injection wells.

This article presents the mining and geological characteristics of technogenic uranium deposits in Kazakhstan. The basis of the raw material base of Kazakhstan's uranium is exogenous type deposits, combined into a subgroup called “infiltration”. Uranium infiltration deposits are formed by groundwater associated with regional formation zones and zones of soil-layer oxidation. The development and implementation of the method of underground well leaching of uranium (UWL) 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 developing deposits are as follows: the possibility of involving poor and off-balance ores in deposits with complex geological and hydrogeological conditions, but with large reserves of uranium; Significant reduction in capital investments and terms of commissioning deposits; improving working conditions, reducing the number of miners and increasing labor productivity by 2.5-3.5 times; reducing the negative impact of uranium mining on the environment.

Key words: uranium, deposit, exploration, borehole underground leaching, industrial assessment.

Introduction. The Republic of Kazakhstan has the world's largest raw material base of proven industrial reserves of uranium. Explored reserves in Kazakhstan total about 1 million. 560 thousand tons uranium. The presence in Kazakhstan of significant reserves, well-explored deposits of uranium, 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 the uranium mining industry in Kazakhstan. The basis of the raw material base of Kazakhstan's uranium is exogenous type deposits, combined into a subgroup called “infiltration”. Uranium infiltration deposits are formed by groundwater associated with regional formation zones and zones of soil-layer oxidation.

Development of infiltration uranium deposits was started in Kazakhstan from the 70s of the last century. By the mid-80s, Kazakhstan already provided about 40% of the uranium needs of the former USSR. To develop the deposits, a new method of uranium mining was used at that time - the method of underground leaching through a system of wells drilled from the surface, which consists in transferring uranium to solution at the place of natural ore occurrence.

The development and implementation of the method of underground well leaching of uranium (UWL) 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:

- the possibility of involving in the exploitation of poor and off-balance ores of deposits with complex geological and hydrogeological conditions of occurrence, 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;
- reducing the negative impact of uranium mining on the environment.

Methods. 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, achievements in the field of hydrodynamics, geochemistry, hydrometallurgy.

Underground leaching technology can rightfully be attributed to the revolutionary technology that has changed the conditions and economics of uranium production.

The successful solution of the complex of technical problems in the development of the underground leaching method of uranium was associated with the development and implementation of special technical means and technologies for the construction and operation of wells, instrumentation, as well as with the development and industrial development in the hydrometallurgy of uranium sorption-desorption technology using ion-exchange resins.

Over the past years, collectives of Kazakhstani uranium mining enterprises have done a great job to improve the technology of uranium mining, 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.

New deposits are involved in commercial exploitation, including those with complex geological and hydrogeological conditions, characterized by weakly permeable areas with high carbonate content, filtration heterogeneity, unstable spatial arrangement of ore bodies in ore-bearing horizons and large depths of their occurrence, lack of reliable water confines, etc. Expanding the boundaries of the application of the underground borehole leaching method of uranium requires further improvement of this progressive mining method and determines its high science intensity.

Based on 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 technology based on the complete 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; reducing the cost of solvents, 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 waste.

The social significance of introducing the method of downhole leaching into uranium mining practice is extremely great. Fundamentally, 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.

Results. About 25% of the world reliably explored uranium reserves are concentrated in the bowels of Kazakhstan. Total reserves and resources are estimated at 1560 thousand tons of uranium, including category reserves ($B+C_1+C_2$) 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 well leaching. (UWL).

Geological and industrial types of Kazakhstani uranium deposits: deposits of regional zones of reservoir oxidation; deposits of soil-bed oxidation zones; organogenic phosphate deposits; vein stockwork deposits.

Kazakhstan uranium deposits associated with regional formation oxidation zones 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.

The development of vein stockwork type deposits is, in principle, possible with a minimum level of profitability, subject to selective mining of rich areas in combination with heap leaching. The scale of this direction of production directly depends on the situation on the natural uranium market.

The development of deposits of organogenic phosphate type is not profitable and is possible only with the integrated extraction and marketing of uranium, scandium, rare earths, sulfur sulfide and phosphorus pentoxide. However, global market demand for these types of products is still limited.

A prerequisite for the implementation of underground leaching technology should be good permeability of the medium containing uranium mineralization for the solution. With sufficiently 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 average concentration of uranium in the productive solutions depends on the productivity of the ore-bearing stratum and the effective thickness of the ore-bearing rocks involved in the leaching process.

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 $CaCO_3$), minerals of oxide iron, less intensely ferrous iron and some aluminosilicates (up to 10%) dissolve well (40-50%) [1,2].

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.

Productivity in productive solutions is determined by the total production rate of pumping wells, and the metal yield in solutions by its concentration in solutions. The degree of uranium extraction from the bowels depends on many natural factors, geotechnological parameters of the deposits of the deposit and technological indicators of the leaching process. The ratio of liquid to solid L:S is determined by the ratio of the volume of pumped solutions through the ore-bearing formation to the volume of the rock mass of the formation [4].

The solution to the question of determining the degree of suitability of a uranium deposit for mining by underground sulfuric acid leaching in each particular case, first of all, should be based on a study of the geotechnological parameters of the deposits. In this case, the development of a geotechnological classification of the suitability of the field for sulfuric acid underground leaching through a system of wells drilled from the surface acquires practical significance [5,6].

When constructing the classification, the basis can be taken of general geotechnological features that apply to all infiltration deposits and particular parameters of these features that characterize one or another degree of suitability of the deposit for sulfuric acid underground leaching of uranium.

The developed classification is given in table 1. The classification allows, according to existing field exploration data, an aggregate assessment of the degree (class) of suitability of a deposit (deposit) for underground leaching of uranium.

Table 1 – Classification of signs of suitability of uranium deposits for sulfuric acid leaching

Geotechnological features of uranium deposits	Suitability of the deposit for sulfuric acid leaching of uranium according to parameters of geotechnological features		
	High (1st class fitness)	Sufficient (2nd class of suitability)	Low (3rd class fitness)
1. The length of ore deposits, km	> 1,0 – 2,0	1,0 – 2,0	< 1,0
2. Depth width, km	50-100	30-50	< 10
3. Depth of mineralization, m	100 - 200	200 – 400	> 400
4. Mineralization power, M	> 3 – 5	3 – 5	< 1,0
5. The content of clay-silt fractions, %	< 20	20 - 30	> 30
6. Uranium content in ore, %	> 0,05 – 0,1	0,05 – 0,1	<0,05
7. Content CO_2, %		1,0 – 2,0	> 2,0
8. Type of ore mineralization: Activation energy, E, kJ / mol; The order of the reaction of sulfuric acid leaching, α	Oxide < 10 > 0,3	Mixed 10 – 20 0,25 – 0,3	Coffinite > 20 0,25
9. Ore productivity, kg/m^2	> 5,0	3,0 – 5,0	< 3,0 - 1,0
10. Groundwater level, m	< 50	Up to 50	> 50
11. Groundwater pressure on the horizon roof, m	> 50	Up to 50	< 50
12. The oxygen content in formation water, mg/l	8-10	5-6	< 5
13. The ratio of iron ions in produced water	$Fe^{3+} > Fe^{2+}$	$Fe^{3+} = Fe^{2+}$	$Fe^{3+} < Fe^{2+}$
14. The filtration coefficient of ore-bearing rocks, KF, m/day	> 1,0	1,0 – 0,5	< 0,5
15. The rate of filtration apisotropy of the productive horizon	< 0,1	0,1 – 0,3	0,7 – 1,0

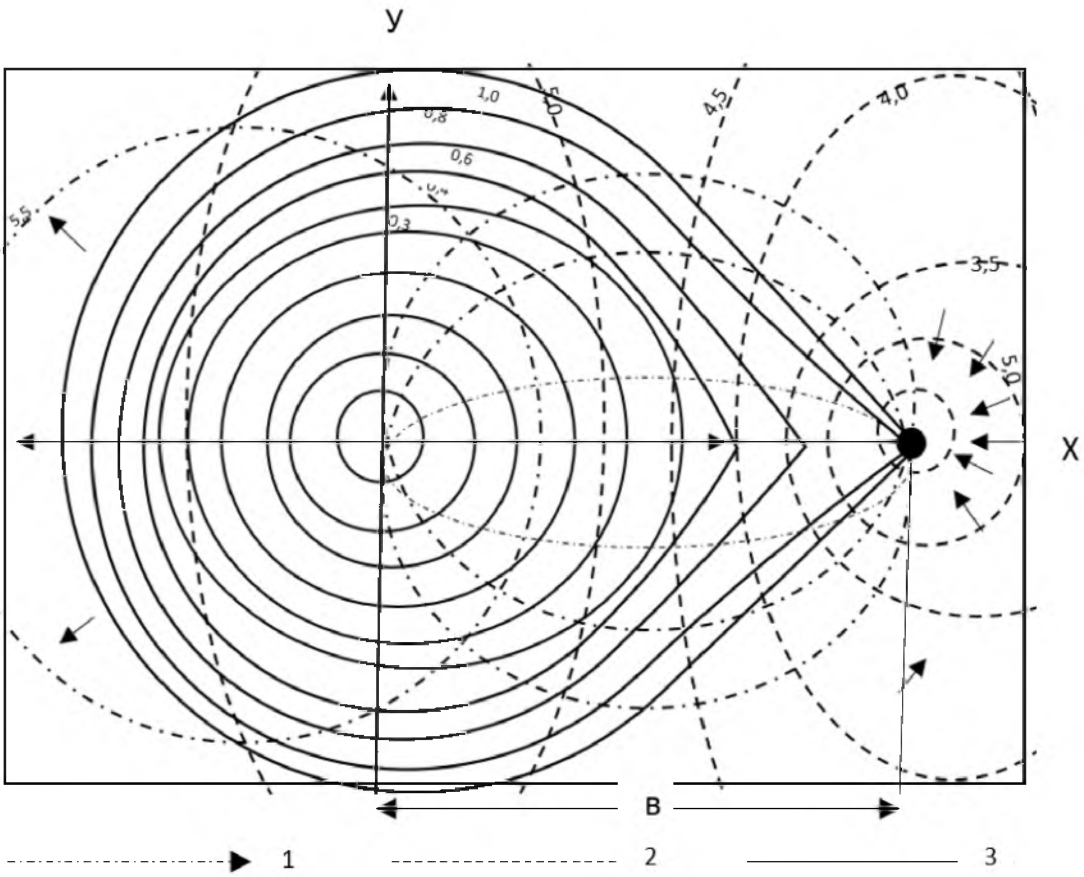
The analysis of table 1 shows that the parameters of geotechnological features can have a significant impact on the conditions and indicators of leaching of uranium.

Depending on the parameters of geotechnological features of the fields, each of the fields selected for leaching can be classified as high, sufficient and low suitability for sulfuric acid leaching through a system of wells drilled from the surface.

During the operation of two equally-produced wells (pumping-out), a sufficiently high rate of movement of the solution is ensured, however, the leaching process is carried out with significant spreading of the solutions outside the zone of interaction of the wells. Working solutions are almost always diluted with produced water, but this does not affect the amount of uranium removed and the effluent, since a decrease in concentration corresponds to the same increase in the flow rate (volume) of the pumped liquid. The true concentrations of uranium and solvent in the leach solutions are equal to their values in the pumped liquid, multiplied by the unbalance coefficient. The dilution ratio of solutions is equal to the unbalance coefficient. In practice, due to the need to maintain a balance of pumped and injected solutions, it is rather difficult to reliably determine the contours of the leached volume. For this, hydrodynamic grids obtained in various ways (electro-analog modeling, calculations, etc.) are used with the results of laboratory or experimental work on metal extraction superimposed on them.

Figure shows the grid current of the solution and the position of the boundaries of its distribution with a linear (in-line) arrangement of technological wells [2-5].

In this case, leaching occurs in a linear section limited by a pair of technological wells.



The grid current of the solution and the position of the boundaries of its distribution during the operation of two wells in an unlimited aquifer. 1- streamlines; 2 - equal pressure lines (numbers indicate filtration resistance); 3 - the boundaries of the distribution of the leach solution (the numbers show the dimensionless relative time the solutions reach the boundaries)

The accumulated experience in the exploitation of deposits of zones of formation oxidation allows us to group natural geological and hydrogeological factors and the conditions of occurrence of deposits in favorable and unfavorable conditions for the use of underground downhole leaching of uranium (table 2).

Table 2 – Geological and hydrogeological factors and conditions determining the operating conditions of uranium deposits by underground leaching

Natural factors determining the in-situ leaching process	The conditions of operation of the deposit by underground leaching method	
	favorable	unfavorable
1. Mineralization position in the ore-bearing aquifer	Compact, there are no barren interbeds inside the ore deposit	Complex, with frequent alternation of mineralization and barren rocks in the aquifer
2. Lithological and filtrational features of the ore-bearing aquifer section	Mineralization uniformity, low thickness (up to 20 m) of the aquifer, filtration uniformity of rocks	Mineralization heterogeneity, increased thickness (over 20 m) of barren aquifers, the possibility of spreading and dilution of productive solutions
3. Tectonic environment in the ore zone	Faults and vertical displacements of the ore zone are absent; formation hydrodynamics is stable	The presence of faults and displacements along the faults of mineralization and aquifers, a complex hydrodynamic situation, which makes it difficult to control the process of leaching of uranium
4. The presence of water storage	Apertures are available; ore bearing aquifers are located between mature aquifers	There are no mature aquifers; there are hydrodynamic windows between productive and barren aquifers
5. The composition of ore-bearing rocks	Quite homogeneous, mainly quartz-silicate, easily soluble ballast impurities are absent, low content of clay particles, carbonates, sulfides.	High content of harmful readily soluble compounds, carbonates, phosphates, sulfides, the presence of clay minerals of the montmorillonite group
6. Explosiveness of mineral forms of uranium	Easy opening with slightly acidic aqueous solutions, low acid consumption	High persistence of mineral forms of uranium by dissolution with acid solutions, the need for oxidizing agents, high acid consumption
7. Ore Productivity	High enough (more than 4-5 kg /m^2)	Low (1-3 kg/m^2)
8. The ratio of productivity to the effective power of the ore-bearing horizon	From 1: 5 to 1:10, allows you to maintain a high concentration of uranium in solutions	More than 1:10, has a negative effect on the concentration of uranium in solutions
9. Achieved in exploration flow rates of pumping wells	2 to 5 l / s or more	Less than 2 l / s
10. Form of deposits	Elongated wide deposits with good permeability of ore-bearing rocks	Irregular complex shape with low permeability of ore-bearing rocks

The data in tables 1 and 2, the data can be used in the evaluation of deposits for the use of underground borehole leaching [6-10].

Discussion. 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 possibility and effectiveness of applying the technology of underground leaching of uranium with sulfuric acid solutions through a system of wells drilled from the surface is determined by a combination of a number of geotechnological and economic factors and parameters [11].

The determining factors and parameters for the use of underground leaching of uranium include the availability of reserves for the organization of work on UWL; parameters of water cut and permeability of ore-bearing rocks; mineralization depth; type of ore mineralization; the material composition of ore-bearing rocks; parameters of carbonate and sulfuric acid solubility of minerals; parameters of occurrence and groundwater pressure; presence of water storage; expected uranium mining costs. The degree of suitability of the field for efficient exploitation by underground leaching depends on specific combinations of parameters of natural and production conditions [12-22].

Based on the results of this work, an assessment was made of the existing technology for exploitation of hydrogenic uranium deposits in Kazakhstan to select the object of study; an analysis is made of existing

production technologies for the exploitation of hydrogenous uranium deposits that do not meet the requirements of a market economy: low labor productivity, high cost per unit of production; a comparative analysis of boreholes with the main technical facilities providing the injection of a chemical or biochemical solution was made; An alternative method for supplying chemical solutions to an array of hydrogenous uranium reservoir has been developed; losses and dilution of chemical solutions are determined.

The work was performed according to the results of study No. AP05130987 "Development of innovative technology for exploitation of hydrogen deposits of uranium for industrial and energy development of the contra"

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КЕН ОРНЫН ЖЕРАСТЫ ҰҢҒЫЛАП ШАЙМАЛАУ ӘДІСІМЕН ИГЕРУ ҮШІН ҚАЗАҚСТАННЫҢ УРАН КЕН ОРЫНДАРЫНЫҢ ТАУ-КЕН-ГЕОЛОГИЯЛЫҚ СИПАТТАМАЛАРЫН ЗЕРТТЕУ

Аннотация. Уран өндірудің дәстүрлі технологияларының едәуір кемшіліктері бар, нарықтық экономика талаптарына жауап бермейді, тиімділігі аз, қымбат тұратын құю-сору ұңғымаларын көп қолдануды талап етеді, сілтілеудің төмен қарқындылығы химиялық реагент пен күкірт қышқылының көп мөлшердегі шығынын қажет етеді (1 т уран концентратын алу үшін 100 т күкірт қышқыл шығыны). Мұндағы өнімді ерітінді – ерітілген сілтісізденген түрлі пайдалы компоненттердің (металдар), оның ішінде уран концентрациясын қамтитын химиялық ерітінді.

Уранның гидрогенді кен орындарын пайдалану тәжірибесінде технологиялық ұңғымалардың орналасу схемасы қабылданған: желілік (немесе қатар), алаңдық (немесе ұяшық) және құрама болып саналады.

Біз ұсынатын гидрогенді уран кен орындарын пайдаланудың инновациялық технологиясы оны сілтісіздендіру және басқа да пайдалы компоненттер үшін уранның гидрогенді қабат массивіне берілетін химиялық ерітіндіні белсендіру әсерін қолдана отырып, поршеньді ұңғымалардың жұмыс істеу қағидатында әзірленеді. Белсендіру үдерісінде химиялық ерітінді t = 70 ° C дейін қызады, ерітіндідегі су жақсы еріткішке айналады. Сорғыш құдық конструкцияны өзгертпестен поршеньдік ұңғылар ретінде пайдаланады, яғни айдау ұңғымалары сору ұңғымалары ретінде де қолданылады.

Мақалада Қазақстанның техногендік уран кен орындарының тау-геологиялық сипаттамасы берілген. Қазақстандық уранның шикізат базасының негізін «инфильтрациялық» деп аталатын кіші топқа біріктірілген экзогендік үлгідегі кен орындары құрайды. Уранның инфильтрациялық кен орындары қабатты өңірлік және топырақтық-қабаттық тотығу аймақтарымен байланысты жерасты суы негізінде қалыптасқан. Уранды жерасты ұңғылап шаймалау әдісін әзірлеу және енгізу тау-кен өнеркәсібінің маңызды ғылыми-техникалық жетістіктеріне жатады. Жерасты сілтісіздендіру әдісінің дәстүрлі кен орындарын игеру әдістерімен салыстырғанда мынадай артықшылығы бар: күрделі геологиялық-гидрогеологиялық жағдайда ірі уран қоры бар кен орындарын нашар және баланстан тыс кен орындарын пайдалануға тарту мүмкіндігі; күрделі салым және кен орындарын пайдалануға беру мерзімін едәуір қысқарту; еңбек жағдайын жақсарту, тау-кен жұмысшылар санын қысқарту және еңбек өнімділігін 2,5-3,5 есе арттыру; уран өндірудің қоршаған ортаға теріс әсерін азайту болып саналады.

Түйін сөздер: уран, кен орны, геологиялық барлау, ұңғымалық жерасты шаймалау, өнеркәсіптік бағалау.

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ИЗУЧЕНИЕ ГОРНО-ГЕОЛОГИЧЕСКИХ ХАРАКТЕРИСТИК УРАНОВЫХ МЕСТОРОЖДЕНИЙ КАЗАХСТАНА ДЛЯ РАЗРАБОТКИ МЕТОДОМ ПОДЗЕМНОГО СКВАЖИННОГО ВЫЩЕЛАЧИВАНИЯ

Аннотация. Существующие традиционные технологии добычи урана обладают большими недостатками, не отвечают требованиям рыночной экономики, малоэффективны, требуют применения большого количества дорогостоящих закачных и откачных скважин, большого расхода химического реагента, серной кислоты (для получения 1 т концентрата урана требуется расход 100 т серной кислоты), отличаются низкой интенсивностью выщелачивания. Здесь под продуктивным раствором понимается химический раствор, содержащий концентрацию растворенных там выщелоченных различных полезных компонентов (металлов), в том числе урана.

В практике эксплуатации гидрогенных месторождений урана приняты схемы расположения технологических скважин: линейные (или рядные), площадные (или ячеистые) и комбинированные.

Предлагаемая нами инновационная технология эксплуатации гидрогенных урановых месторождений будет разработана на принципе работ поршневых скважин с применением эффекта активации химического раствора, подаваемого в массив гидрогенного пласта урана для его выщелачивания и других полезных компонентов. В процессе активации химический раствор подогревается до t = 70°С, вода в растворе становится хорошим растворителем. В качестве поршневых скважин применяются откачные скважины без изменения конструктивного оформления, т.е. откачные скважины используют и как закачные скважины.

В этой статье даны горно-геологические характеристики техногенных урановых месторождений Казахстана. Основу сырьевой базы казахстанского урана составляют месторождения экзогенного типа, объединенные в подгруппу, получившую название «инфильтрационного». Инфильтрационные месторождения урана сформированы подземными водами, связанными с региональными зонами пластового и зонами грунтово-пластового окисления. Разработка и внедрение метода подземного скважинного выщелачивания урана (ПСВ) относится к важнейшим научно-техническим достижениям горнодобывающей промышленности. Основные преимущества метода подземного выщелачивания по сравнению с традиционными горными способами разработки месторождений заключаются в следующем: возможность вовлечения в эксплуатацию бедных и забалансовых руд месторождений со сложными геолого-гидрогеологическими условиями залегания, но имеющими крупные запасы урана; значительное сокращение капитальных вложений и сроков ввода месторождений в эксплуатацию; улучшение условий труда, сокращение численности горнорабочих и повышение производительности труда в 2,5-3,5 раза; уменьшение отрицательного воздействия уранодобычи на окружающую среду.

Ключевые слова: уран, месторождение, геологоразведка, скважинное подземное выщелачивание, промышленная оценка.

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