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GEOLOGICAL ASPECTS OF URANIUM DEPOSITS FOR IN-SITU LEACHING APPLICATION TO DEVELOP ENERGY POTENTIAL OF KAZAKHSTAN

Kazakhstan is among the top ten countries – holders of the largest uranium resources in the world. The main uranium deposits were discovered in the late 1970s and, then, in the mid-1990s. This article describes the geological aspects of the uranium deposits in Kazakhstan with a view to using the in-situ leaching method toward development of the energy potential of the country. In total burning out of 1 kg of uranium enriched to 4%, the energy release is equivalent to combustion of 100 t of high-grade coal (1.5 carload) or 60 t of oil (1 fuel truck). Uranium fission liberates neutrons which collide with the other uranium nuclei and split them. Uranium decay products and neutrons possess high kinetic energy and, when they collide with other atoms, this energy is converted into heat.

Keywords: *geology, structure, power generation, technology, uranium production, in-situ leaching*

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Introduction

The present-day methods of uranium production in the world’s countries, including Kazakhstan, involve the following processes: delivery of chemical solutions via injection well, delivery of pregnant solutions via production wells. Such wells can be laid out in linear or square patterns.

A new formulation of the innovative technology of hydrogen uranium production dictates execution of research activities in two directions — accessing and extraction of the raw material; disclosure of shortages of uranium mining technologies with a view to eliminating them completely. There exists a new innovative technology of uranium mining [1–6]. The authors cultivate efficiency of innovative technologies for hydrogenous-type uranium deposits. A patter of piston wells is design for the Semizbay hydrogenous-type uranium deposit. The consumption rate of chemical solutions for leaching of useful components from uranium deposits is determined. The generality of the innovative technology of obtaining pregnant solutions of useful components (metals) is demonstrated. The innovative procedure for the utilization of hydrogenous-type uranium deposits is developed. The injection wells are similar to the wells meant for delivery of a treatment mixture composed of a sulfuric acid solution (H_2O + n% H_2SO_4) of microorganisms (Thiobacillus Ferrooxydans) to hydrogen reservoirs.

The goal of this research is to create an innovative exploitation technology for pyrogenetic-type uranium deposits toward the benefit of power engineering in Kazakhstan.

Research methodology

To achieve the goal, the methods of theoretical justification of the in-situ uranium leach technologies were used in terms of the Semizbay deposit. In the early 1980s, it was planned to perform pilot tests of uranium production by the hydraulic mining method (HMM) at the Semizbay deposit. The tests were to be carried out on an area 50×25 m between geodetic profiles GP184+75 and GP185+25. All necessary geological, geophysical and hydrogeological preparations were fulfilled at the test site. However, after amendment of the deposit appraisal, it was decided to reject HMM and develop the deposit using in-situ leaching as the resources mineable with HMM were limited to 20–25% of the deposit. The development of the hydrogenous-type uranium deposit used the following patterns of process and production wells: linear (rows), square (cells) and mixed-type. An alternative method to feed chemical solutions to a hydrogenous-type uranium generation plant was elaborated. The annual productivity P was found from the formula of the required volume V of pregnant solutions with the average concentration C of 70 mg/l per 1000 t of uranium and pregnant solutions (PS) annually: $V = P/C$ [1, 2, 7–9].

The process chart is as follows: chemical and biochemical solutions pumped in injection wells seep through pores and cracks in H-bearing plate toward nearby pumping wells. When flowing, the chemical solutions concentrate uranium and become pregnant solutions which pumped out to the surface and sent to a processing plant for treatment using sorption and desorption processes to produce uranium. To this end, a system composed of various equipment called a sorption plant is employed. The plant includes sorption and regeneration columns, pools for rich and poor solutions, reservoirs for treatment of chemical concentrates, pumps, pipelines and auxiliary reservoirs to prepare solutions for leaching, decontamination and purification of waste water. For the hydrogenous-type uranium production at a flow rate more than 0.5 m/day, the most efficient technology is "well-in-well flushing". Thus, the in-situ leach process flow takes into account metal uranium leaching and natural occurrence of uranium reservoirs [7, 10–12].

Research findings

In this manner, the research determined efficiency of the innovative technology at a hydrogenous-type uranium deposit. The cost of chemical additives used in leaching useful uranium compounds is calculated. The generality of metal treatment, including pregnant mixtures of useful compounds, using the innovative technologies is demonstrated. The methodology of the innovative technology for the hydrogenous-type uranium deposits is developed. Owing to pistons arranged in wells, in mining hydrogenous-type uranium on a 100–200 m area, it is possible to reduce the number of the wells by 4 or, for the higher efficiency, by 7 wells.

Uranium production is one of the critical branches of the mining industry in Kazakhstan. The country is the world's first producer of uranium and the world's second holder of uranium reserves. Annually, Kazakhstan produces more than 20 Kt of uranium. This is around 20% of the total uranium production in the world. Since 2018 uranium is on the first place in terms of the volume of production in the world. The main uranium deposits in Kazakhstan occur in the Turkestan, Kyzyl-Orda and Akmolinsk Regions. The first commercial deposit Korday in Kazakhstan was explored and proved in 1951. In the late 1960s, the Shu-Sarysy, Ile and Syrdaria uranium mines were opened. Those territories became the world's largest holders of uranium reserves. At the present day, uranium reserves registered in the Mineral Fund of the Republic of Kazakhstan total more than 450 Kt. This involves 26 proven deposits, including 14 deposits belonging to Kazatomprom [1, 7, 13, 14].

The process of uranium mining consists of drilling, well placement and production stages. Uranium is mainly produced by the method of in-situ leaching (ISL). The method was used for the first time in the world in the 1960s. In 2017 more than 50% of the world uranium was produced by this method. The main reasons of the wide application of the method are its simplicity, safety and low price. Kazakhstan has achieved the lowest cost of uranium production in this respect. The in-situ uranium leaching technology has no adverse effect on the earth crust as compared with other underground and opencast methods. Experts in the field of in-situ geotechnologies of mineral mining state that in ISL, no ground subsidence or soil damage takes place, no dumps are left on ground surface while it is possible to control production processes using geophysical methods [15–27]. More than 65% of global proven uranium reserves mineable by in-situ leaching occur in the area of Kazakhstan [1, 2, 28].

The geotechnology applied at all uranium deposits in Kazakhstan, including the Inkay deposit in the Turkestan Region, has three stages. These are drilling, mining and processing. The operation starts with drilling into uranium deposits located at a depth of 300–350 m. Dozens of technological facilities are operated here, and more than 1000 wells are active. Flushing of wells uses an eco-friendly technique, and all water is pumped out to ground surface. Environmentally, this method is safer than opencast or underground technologies. Annually, 900–1000 new wells are commissioned on one production site. Industrial infrastructure is continuously expanded. Because of the local climate in Kazakhstan, pipelines are laid below ground, and no liquid freezing takes place in winter months. After completion of exploration, more than 1 month is spent before the first uranium is produced. Drilling of one well takes 3–3.5 days. Then, fastening, coupling and acidification are executed. Acid is fed not in pure but in mixed form. Approximately, in 30–35 days, uranium can be delivered to the surface. Recovered uranium is reduced to the condition of yellowcake and is sent to processing plants. The plants are located in the Turkestan and Eastern Kazakhstan Regions [1, 2, 7, 10, 29].

The **Table** informs on uranium reserves per the test field and per its deposits.

Discussion

For the first time in the world's practice, all-year in-situ uranium leaching has been performed in the conditions of harsh climate. A critical point to address in this regard is, whether it is hazardous for people to live in the area after production completion. Moreover, the time required for disinfection and closure of each production site is estimated. The mines can operate for 30–50 years in accordance with the size of the uranium reserves and initial contract project. After completion of operations at a production site, reclamation is to be carried out. All surface infrastructure and pipelines should be liquidated. No contamination is expected. However, if any contamination is detected, soil is removed down to a clean layer. Ground is expected to recovery completely in 3–5 years. The place will restore its natural state as a result. In-situ uranium leaching has a weaker environmental effect as compared with traditional underground and opencast method. Furthermore, the main feature is small quantity of sand in production of metals from uranium ores. The authors use the method with water or an alternative solution with sulfuric acid, which is sent via injection wells and pipelines to the subsoil, which, naturally, has an adverse influence on the surface environment. Uranium ore in underground strata is converted from solid state to liquid phase and is then recovered to ground surface through wells. Then, via pipelines, it is sent to uranium processing plants [1, 7, 30, 31].

Uranium reserves at Semizbay deposit (relative percentage)

Reserves	Field	Deposit				
Whole reserves:	100		21.1	6.5	3.0	6.2
total (LSH and USH*).	42.2	62.2	11.5	6.5	3.0	6.2
Including to a depth to 100 m		15.5				
Including in conglomerates	6.6		2.8	–	0.9	2.9
LSH.	13.1	–	2.2	–	0.7	–
Including to a depth to 100 m	8.2	–	2.2	–	0.7	–
Including in conglomerates	–	–	–	–	–	–
USH.	86.9	53.0	18.9	6,5	2.3	6.2
Including to a depth to 100 m	43.0	9.7	9.3	6.5	2.3	6.2
Including in conglomerates	6.6	–	2.8	–	0.9	2.9
Whole reserves:						
total (LSH and USH*).	–	100	100	100	100	100
Including to a depth to 100 m	–	23.8	54.5	100	100	100
Including in conglomerates	–	–	13.0	–	31.6	46.6
*LSH — lower stratification horizon; USH — upper stratification horizon						

In 2020 Kazatomprom purchased a uranium processing and conversion technology from Canadas' CAMECO Corporation. Accordingly, additional value appears in uranium production, and income grows. However, Kazakhstan yet lacks a uranium enrichment technology. Kazakhstan participates in a Russian project of uranium enrichment and sends uranium to the northern neighbor country for that. Production of uranium oxide powder and fuel pellets is executed at the ULBA Metallurgical Plant since 1973. Furthermore, ULBA carries out a project connected with manufacture of fuel assemblies together with CGNPC from China [1, 10, 31–33].

The countries–holders of major uranium resources are the USA, Australia, Canada, the United Arab Emirates, Namibia, Nigeria, France, Spain and Portugal. Large deposits contain more than 10 Kt U_3O_8, mean deposits — from 1 to 10 Kt, and small deposits — to 1 Kt. Foreign countries demand 80–100 Kt of U_3O_8 while its production is around 42 Kt. Nearly 200 000 t is stored at warehouses in the countries–producers. The largest producers are the USA, Canada and the Republic of Uzbekistan [1, 10, 31–33].

Kazakhstan holds around 25% of global uranium reserves, which totals 1.5 Bt of uranium. Proven uranium reserves equal 470 Kt. This figure sets the country on one of the first places in the world, including the largest uranium provinces of Sarusyn and Syr-Daria in the south of Kazakhstan. More than 200 uranium deposits are concentrated here, including the largest deposits of Inkay, Budennov, Myng-Kudyk, Uanas, Tort-Kudyk, Moiynkum, Kandzugan and other. The first three deposits in this list are unique [1, 10, 31].

The largest deposit in the Syr-Daria Region is Kharasan, and the other large deposits are the Northern and Southern Karamuryn, Iirkol and Zarechnoe. As per the contour map of the Chu-Sarysui uranium province (Volkovgeologia, 2002), large organophosphorus uranium deposits (Melovoe, Tomak, Taybagar, Tasmuryn) occur on the Mangistau Peninsula, Mangistau–Caspian uranium province. The Northern Kazakhstan uranium province contain 298 endogenous deposits, including the extra-large Kosash deposit, and the largest deposits of Grachevskoe, Zaozernoe, Manybay and other. The Chu–Ile–Betpak-Dala Regions accommodates the Botaburym, Kyzyl-Say, Zhideli and other deposits (almost all are developed). In recent years, the percentage of the endogenous deposits, assumed as the most critical, greatly reduced. The reason is development of stratification hydrogen deposits (around 75% of actual reserves of category R1) which are mineable using the most advanced and efficient method of in-situ leaching. Today the stratified deposits are the main source of uranium in Kazakhstan. Along with uranium, in-situ leaching recovers rhenium, vanadium, selenium, rare earths and other elements. Useful components of organogenous phosphorus–uranium ore are scandium, rare earths and phosphorus, while uranium coal contains molybdenum, rhenium, cobalt, silver, germanium and selenium. Commercial-value uranium occurs at deposits of various genetic types in Kazakhstan [1, 7, 10, 33].

Conclusions

Uranium is a main feedstock for the nuclear power generation. Furthermore, uranium is used in the analytical chemistry, photography, glass industry, geochemistry and mineralogy. The average amount of uranium produced per a site of wells with the diameter of 10 cm and 7 m long, given that the well penetration zone is 2.5 m in diameter and 10 m deep is 4%.

This amount grows from the ultrabasic rocks to basic rocks and to acidic rocks. Uranium concentration ratio (at average uranium content of 0.1%) is around 400. There are nearly 100 minerals which contain uranium. Amongst them, the commercial value is a feature of uraninite (uranatennite, broggerite) UO_2 (92% U) and its amorphous form — uranium ingot (60% U). All uranium-bearing minerals are radioactive, and this property is utilized in exploration, mining and processing of ore. Uranium-bearing minerals are readily dissolved in weak acids and alkalis. This property is also used in underground and hydrometallurgical processing. The main commercial place is taken by oxide ores, sometimes — uranium vanadates (carnotites), phosphates (torbernite, autunite) and arsenate (zeunerite). The minimal quantity of U_3O_8 is 0.1% in small deposits and to 0.05% in large deposits. Uranium reserves are appraised at different levels of actual cost of the end product. Kazatomprom, together with its subsidiary and joint organizations, performs production activities in 26 industrial areas in the Republic of Kazakhstan, which are united in 14 mining assets. The method of in-situ leaching was for the first time used in the 1960s and attained 50% of the global uranium production by 2017. As compared with the traditional technologies, the in-situ leach technology has a weaker environmental impact, and ensures the lowest production cost at the high indicators of industrial and occupational safety [1, 3, 4, 10, 33–35].

Kazatomprom is an absolute leader in uranium production by the in-situ leaching method and beats rivals by producing 21.2 Kt of uranium in 2022 as against 11.4 Kt (22% of the world's uranium production). The geological conditions favorable for in-situ leaching in Kazakhstan ensure the unique competitive advantage of Kazatomprom. All processes involved in uranium production are automated and subjected to permanent control at the Company, and equipment employed in Kazatomprom's mines is entirely up to the environment and safety standards such as OHSAS 18001 and ISO 14001 [1, 10, 32, 34, 36].

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