## ABSTRACT

of a Doctoral thesis for the degree of Doctor of Philosophy (PhD),
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# DEVELOPMENT OF A TECHNOLOGY FOR FLUSHING SORBENT DURING IN-SITU LEACHING OF URANIUM USING THE CAVITATION EFFECT

**Evaluation of the Current State of a Solvable Scientific and Technical Problem**

In the past decade, substantial efforts have been undertaken in the development and implementation of large-scale geotechnological uranium extraction, known as the in-situ leaching (ISL) method. At certain enterprises, the ISL method has become the primary method for uranium extraction, and it is expected that the number of such enterprises will increase in the future. The resource base for ISL uranium extraction primarily consists of low-grade deposits of hydrogenic genesis found in water-permeable sandy-clay deposits in the depressions of the Earth's crust. Despite its advantages, one of the challenges when employing this technology is the reduction of productivity due to the low filtration characteristics of the ore. This issue arises from the use of sulfuric acid solutions as the uranium mineralization solvent, which interacts with carbonate and clay minerals in the productive horizon, resulting in the precipitation of quartz, gypsum, and clay minerals. This adversely affects the productivity of production wells and the uranium content in the productive solution. Improving filtration characteristics in low-permeability ores necessitates the application of new approaches and scientific and technical solutions to prevent salt deposition in the productive horizon.

Various technological solutions have been proposed to address this problem, which often do not yield the desired results and are characterized by their costliness and complexity of implementation. One approach to solving this problem is the application of chemical reagents as inhibitors. Years of experience in combating the deposition of inorganic salts have shown that methods based on salt deposition prevention are the most effective.

However, the technological process for processing productive solutions in the productive solution processing workshop includes uranium sorption on strongly basic anion-exchange resins in sorption pressure columns, uranium desorption, denitration, and resin washing. The sorption method is based on ion-exchange processes and the selectivity of specific types of ion-exchange resins toward uranium compounds present in the solution or pulp. Resin or activated carbon is used for sorption. Ion-exchange resins are applied in the form of small spherical granules and are introduced into the process in various ways: as a fixed bed, periodically moved, or continuously circulated together with the substance solution. Tens of thousands or even hundreds of thousands of resin granules, washed by the solution, selectively sorb predominantly uranium compounds on their surfaces and, to a very small extent, compounds of some other elements present in the solution.

To achieve effective uranium desorption, reagents that exert the greatest displacing influence during its sorption are used. The nitrate method also falls within the category of displacing desorption methods.

As is well-known, ion-exchange resins are used repeatedly in the process of processing the productive solution. Therefore, after completing uranium desorption, it is necessary to convert the anion-exchange resin into its working ionic form. The condition for their reapplication is thorough washing (denitration) and the restoration of their sorption capacity.

Chronometric observations conducted at the research site have shown that presently, after denitration, the residual nitrate ion content in the resin falls within the range of 6-11%, even when the sulfuric acid concentration is between 25-36%. In other words, even with an elevated concentration of sulfuric acid in the washing solution, the degree of denitration is clearly insufficient. This leads to a deterioration of the resin's uranium sorption properties, a loss of nitrate ions, and consequently, an increased consumption of ammonium nitrate and sulfuric acid.

**The necessity of conducting this research work** is driven by the need to apply new approaches and scientific-technical solutions to prevent the precipitation of salts in the productive horizon and to develop a technology that enhances the denitration of the sorbent. This, in turn, will lead to a reduction in reagent consumption and, ultimately, cost savings for the company.

**Information on the planned scientific and technical development level, patent research, and conclusions** drawn from them are determined by the comprehensiveness of the review of research related to preventing precipitation in the productive horizon and the denitration problem. It has been identified that various technological solutions exist for addressing the issue of precipitation, but there is insufficient coverage of questions related to reducing reagent consumption during denitration. The scientific and technical development level is characterized by establishing the relationship between the uranium content in the productive solution and the introduction of various inhibitors over leaching time, residual nitrate content in the resin over the cavitation time of the washing solution at various sulfuric acid concentrations. The obtained results will allow determining the optimal leaching time, inhibitor type, cavitation time of the washing solution, and ensuring maximum denitration.

**Information on the metrological support of the dissertation:**

The results obtained in this work are based on established theoretical knowledge and are supported by the application of modern scientific methods of analysis and research.

X-ray diffraction analysis was carried out using an automated diffractometer DRO-3. In the course of laboratory research, a mechanical mixer BP 8000 EKROS was used, pH was determined using the IT-1101 instrument, special laboratory sorption setups were employed, and data collection and analysis were conducted using Microsoft Excel.

**Relevance of the Topic:**

Leading global analytical and marketing companies specializing in the uranium market predict a sustained increase in demand for uranium in the long term. According to scenarios for the development of the global nuclear energy sector, reactor requirements for uranium are expected to rise from the current 73,000 tons per year to 86,000-88,000 tons per year by 2030. Starting in 2024, uranium demand is projected to exceed supply, resulting in a deficit of more than 18,000 tons by 2030. In an aggressive scenario for the development of nuclear energy, this deficit could reach 48,000 tons per year.

The Republic of Kazakhstan holds the second-largest reserves and ranks first in uranium production worldwide. It is anticipated that by 2025-2030, Kazakhstan's uranium production volume will constitute 32% of the global production. Approximately 74% of all uranium reserves in the country are amenable to extraction through in-situ leaching. Despite the advantages, a challenge in applying this technology is the reduced productivity due to the low filtration characteristics of the ore. This is primarily caused by the use of sulfuric acid solutions as a uranium mineralization solvent, which interacts with carbonate and clay minerals in the productive horizon, leading to the precipitation of quartz, gypsum, and clay minerals. This reduces the efficiency of mining and the injectivity of injection wells, creates impermeable zones, and lowers uranium content in the productive solution.

Furthermore, following desorption, the concentration of nitrates in the resin ranges from 5.27 g/l to 11.2 g/l. The ion-exchange resin is washed with sulfuric acid solutions with concentrations ranging from 18 g/l to 35 g/l. The degree of washing (denitration) averages 43%, which is evidently insufficient and results in the deterioration of the resin's sorption properties for uranium and the loss of nitrate ions, consequently increasing the consumption of ammonium nitrate. Various technological methods exist to increase the degree of resin denitration, such as raising the washing solution's temperature, altering the design of the denitration column, and using distilled water for washing. However, these well-known technological methods require significant material and labor costs.

To enhance the efficiency of the denitration process, it is proposed to alter the rheological properties of the denitrating solution through mechanical activation (cavitation) before its introduction into the washing column of the resin. Cavitation of the denitrating solution entails an increase in its chemical activity after treatment in a cavitation unit.

**Link to Other Research Work:**

The dissertation work was carried out within the framework of the commercial agreement No. 50 - LLP - 19 dated February 20, 2019, titled "Development of Technology for Intensifying Denitration and Leaching Processes in the Central Area of the Mynkuduk Deposit."

**Research Objective:** The goal of the dissertation research is to enhance the efficiency of leaching by employing inhibitor reagents and denitration of the sorbent using cavitation of the washing solution.

**Research Object:** The research object is the “A” deposit located in the Turkestan region.

**Research Subject:** The subject of the research is the technology of uranium ISR (In-Situ Recovery).

**Research Tasks and Their Place in the Overall Research Work:** In line with the stated objective, the dissertation formulated and addressed several key tasks, including X-ray phase analysis of precipitation samples, studying the effects of inhibitor reagents on the leaching process, laboratory investigations of the impact of cavitated solutions on denitration levels under various technological conditions, and industrial-scale testing of the proposed technology.

**Methodological Basis for Scientific Research:** To achieve the research goal and address the dissertation tasks, both traditional and modern scientific research methods were employed. Traditional methods encompassed analyzing scientific and patent literature, systematic classification, description, comparison, applying engineering formulas and scientific facts, heuristic models, planning computational experiments, and processing experimental data.

**Scientific Novelty:**

- Dependencies of uranium content in the productive solution upon the introduction of different inhibitor reagents as a function of leaching time were established, enabling the determination of optimal reaction time and inhibitor selection.

- Dependencies of well flow and uranium extraction when using the base technology and introducing inhibitor reagents were determined, demonstrating the prevention of precipitation resulting from the reaction of sulfuric acid with carbonate minerals and the enhancement of ore filtration characteristics.

- Dependencies of residual nitrate-inhibitor content in the resin as a function of cavitation time for washing solution with varying sulfuric acid concentrations were established, allowing for the determination of the optimal cavitation time for the washing solution and achieving maximum denitration.

**Practical Significance of the Work:** The practical significance of the dissertation lies in the development of a technology that employs inhibitor reagents and cavitation of the washing solution to enhance leaching efficiency and denitration of the sorbent.

**Publication and Presentation of the Work:** The research results were presented at international scientific and technical as well as scientific-practical conferences.

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