

REGENERATING SOLUTION COMPOSITION FOR SILICON REMOVAL AND ANION-EXCHANGE RESIN RESTORATION IN URANIUM EXTRACTION

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Abstract. The effect of the composition of regenerating solutions on the removal of silicon-containing and related impurities from anion exchange resins used for sorption extraction of uranium from productive solutions of in-situ leaching was investigated. The objects were technological solutions and regenerated resins from the Akdala and South Inkai deposits. The elemental composition was determined by atomic emission and X-ray fluorescence methods, and the phase composition of solid residues was determined by X-ray phase analysis. Screening of the NaOH–Na₂SO₄, H₂SO₄–NH₄HF₂ and HNO₃–NH₄HF₂ systems showed silicon removal at 90.2–97.9; 93.3–95.0 and 95.7–97.5%, respectively. The HNO₃–NH₄HF₂ system, despite its effectiveness, is excluded due to the high affinity of nitrate ions for the resin; NaOH–Na₂SO₄ and H₂SO₄–NH₄HF₂ were then studied. Increasing the concentrations of NaOH and Na₂SO₄ to 75 and 100 g/l increased silicon removal to 97.5–98.7% but could reduce the strength of the resin. A solution of 25 g/l of NaOH + 25 g/l of Na₂SO₄ removed 93.1% of Si, retained strength of 76.5%, increased hydrodynamic index by 30% and uranium capacity from 10.75 to 13.89 g/l; a solution of 150 g/l H₂SO₄ + 150 g/l NH₄HF₂ increased the capacity to 16.69 g/l. The choice of regenerating solution should consider not only the removal of silicon, but also the degree of purification, strength, hydrodynamic and sorption properties of the resin.

Keywords: uranium, anion exchange, resin, regeneration, silicon, in-situ leaching

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1. Introduction

In-situ recovery (ISR) is one of the principal methods used for the development of sandstone-hosted infiltration-type uranium deposits. The process involves mobilization of uranium directly within the ore-bearing horizon, followed by pumping of the uranium-bearing pregnant leach solution to the surface for subsequent recovery and concentration. Modern ISR flowsheets commonly employ ion-exchange sorption on strongly basic anion-exchange resins for uranium recovery from sulfate-bearing pregnant leach solutions. The continuing importance of ISR in uranium production has stimulated research aimed at improving both leaching performance and downstream processing of uranium-bearing solutions [1,7].

The efficiency of uranium sorption depends not only on the uranium concentration in the pregnant leach solution but also on the physicochemical state, functional groups, porosity, and mass-transfer characteristics of the ion-exchange material. Commercial anion-exchange resins can efficiently recover U(VI) from multicomponent sulfate solutions, while their sorption behavior is strongly influenced by solution composition and operating conditions [2,3]. The importance of resin chemistry is further demonstrated by studies of functionalized ion-exchange materials, in which the nature and arrangement of functional groups determine uranium affinity, selectivity, and adsorption mechanism [8].

Recent developments in uranium separation have also focused on alternative functional sorbents with enhanced affinity and selectivity toward U(VI). Amidoxime-based composite sorbents, polyamine-functionalized silica materials, metal-organic frameworks (MOFs), covalent-organic frameworks (COFs), and other functionalized porous materials have demonstrated high uranium uptake from complex aqueous media [10,13 - 15]. These studies indicate that both the chemical accessibility of active sites and the internal structure of the sorbent are critical factors governing uranium uptake. Nevertheless, for industrial ISR operations, conventional strongly basic anion-exchange resins remain particularly important because of their technological maturity, mechanical properties, and compatibility with continuous sorption-desorption circuits.

During long-term industrial operation, anion-exchange resins repeatedly undergo sorption, washing, desorption, and regeneration cycles. At the same time, non-target mineral and colloidal components present in pregnant leach solutions may accumulate on the bead surface and within the porous polymer matrix. Such deposits can progressively block accessible ion-exchange sites, alter mass transfer, and reduce uranium uptake. Deactivation of ion-exchange materials by inorganic and other contaminants has therefore been identified as an important factor affecting the long-term efficiency of uranium recovery [4]. Recent studies of strongly basic anion-exchange resins used in uranium hydrometallurgy have also shown that inorganic deposits, including Fe-containing contaminants, can be removed by appropriately selected chemical regeneration systems [9].

Among the inorganic impurities, silicon-containing compounds are of technological importance. Depending on concentration, solution acidity, ionic

composition, and residence time, silicic acid can undergo condensation and polymerization, forming progressively less soluble polysilicic species. In strongly basic anion-exchange resins, sorbed silicic acid may polymerize within the resin phase. Low-polymerized forms can be comparatively readily desorbed using alkaline solutions such as NaOH, whereas more extensively polymerized species are considerably more difficult to remove [5, 6].

The accumulation of silicon-containing species within the resin may reduce the accessible pore volume and hinder intraparticle mass transfer. Consequently, silicon removal should be considered not only as chemical purification of the ion exchanger but also as a means of restoring the accessibility of functional groups and the kinetic performance of the sorbent. This interpretation is consistent with broader studies of uranium sorption materials showing that pore accessibility, functional-group chemistry, and competing ions collectively determine uranium uptake from complex aqueous solutions [13 - 15].

2. Experimental part

2.1. Methods and tests

The study examined technological solutions and anion-exchange resins used to process uranium-bearing productive solutions from the Akdala and South Inkai deposits.

Productive, leaching, circulating, wash, and sorption mother solutions, as well as commercial desorbates, were analyzed.

Elemental composition was determined spectrometrically. Solid residues and suspended particles were analyzed by X-ray diffraction on a D8 Advance (Bruker) diffractometer with Cu radiation at 40 kV and 40 mA; diffractograms were processed in EVA, with phase identification using the PDF-2 database.

Elemental content in resin samples before and after regeneration was measured by X-ray fluorescence using an Olympus Vanta C analyzer.

Resin mechanical strength was determined with a Vibratory Ball Mill according to ST NAC 20-2017.

2.2. Rationale for the choice of silicon as the main controlled pollutant

In the productive solutions of the Akdala and South Inkai deposits, the concentration of silicon was 79.68 and 85.48 mg/l, respectively. Along with Si, Fe and Al were characterized by significant concentrations.

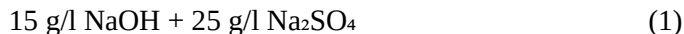
X-ray phase analysis of dry residues of productive solutions showed the presence of silicon dioxide and aluminosilicate phases. Thus, silicon was in the technological system not only in a dissolved form, but also as part of dispersed mineral formations.

The most important circumstance was the accumulation of Si directly in the exploited resin. In the original reclaimed resins, the silicon content was 11.391% for Akdala and 13.062% for South Inkai, significantly exceeding the content of other controlled impurities.

This was the basis for using the degree of Si removal as the main indicator of the efficiency of chemical regeneration.

2.3. Selection of regenerative solutions

Three chemical systems were selected for the initial screening:



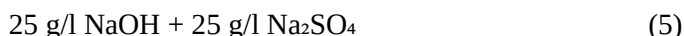
The alkaline system was chosen because NaOH converts silicon compounds into soluble forms, while Na₂SO₄ provides the required ionic medium.

Acid-fluoride systems were selected based on the possibility of chemical destruction of stable silicon-containing deposits when interacting with a fluorine-containing component.

At the laboratory stage, the ratio of solid to liquid phases was T:F = 1:25. Regeneration was carried out with continuous stirring for at least 180 minutes.

The efficiency of the process was evaluated by changing the content of Si, Ca, Fe and Re in the resin.

For subsequent enlarged laboratory experiments, alkaline solutions were studied:



and acid-fluoride solution:



In enlarged laboratory static experiments, the volume of resin was 3 liters, T:F = 1:5, the total volume of the regenerating solution was 15 liters, the duration of treatment was 180 minutes at room temperature.

3. Results and discussion

3.1. Composition of anion exchange resin contamination

The study of process solutions showed that the most significant non-target components were Fe, Al and Si. For Akdala, the content of Fe, Al and Si in the productive solution was 571.71, respectively; 356.16 and 79.68 mg/l, and for South Inkai - 1287.19; 836.09 and 85.48 mg/l.

Particular attention was given to the behavior of silicon. In the Akdala samples, its concentration decreased from 79.68 mg/l in the productive solution to 71.93 mg/l in the sorption mother liquor, indicating partial retention of silicon-containing compounds in the resin phase.

The presence of Si in commercial desorbates - 68.00 mg/l for Akdala and 53.13 mg/l for South Inkai - additionally indicated the accumulation of silicon-containing compounds in the resin during the technological cycle with subsequent partial removal during desorption.

X-ray phase analysis confirmed the complex nature of the silicon-containing component of productive solutions. SiO_2 and aluminosilicate phases were identified in the dry residues. After the solution passed through the sorption system, the content of several silicon-containing phases in the dry residue of the mother cell decreased, and free SiO_2 was not detected.

The combination of the results of elemental and phase analysis allows us to consider the accumulation of silicon as one of the factors in the deterioration of the anion exchange resin.

3.2. Initial selection of a chemical system for regeneration

The results of the initial comparative test of the three systems are presented in Table 1.

Table 1 – Efficiency of regenerating solutions in removing the main impurities from anion exchange resins

Regenerative System	Deposit	Removal of Si, %	Removal of Ca, %	Removal of Fe, %	Removal of Re, %
$\text{NaOH} + \text{Na}_2\text{SO}_4$	Akdala	90.2	49.0	27.0	23.0
$\text{NaOH} + \text{Na}_2\text{SO}_4$	South Inkai	97.9	20.0	—*	—*
$\text{H}_2\text{SO}_4 + \text{NH}_4\text{HF}_2$	Akdala	93.3	54.0	—*	17.4
$\text{H}_2\text{SO}_4 + \text{NH}_4\text{HF}_2$	South Inkai	95.0	100	100	23.3
$\text{HNO}_3 + \text{NH}_4\text{HF}_2$	Akdala	95.7	100	100	100
$\text{HNO}_3 + \text{NH}_4\text{HF}_2$	South Inkai	97.5	100	62.5	88.5

Note – The removal efficiency was not calculated because the measured content of the element after treatment exceeded that in the initial regenerated resin.

All three systems provided a high degree of silicon removal - at least 90%.

An alkaline solution of $\text{NaOH} - \text{Na}_2\text{SO}_4$ removed 90.2% Si from Akdala resin and 97.9% from South Inkai resin. This indicates the possibility of effective destruction or dissolution of a significant part of silicon-containing contaminants in an alkaline environment.

The $\text{H}_2\text{SO}_4 - \text{NH}_4\text{HF}_2$ solution provided removal of 93.3 and 95.0% Si, respectively. For the South Inkai resin, complete removal of the detectable compounds Ca and Fe was observed at the same time.

The maximum cumulative degree of impurity removal at the laboratory stage was provided by the $\text{HNO}_3 - \text{NH}_4\text{HF}_2$ solution. For Akdala, the removal of Si was 95.7%, and Ca, Fe and Re were 100%. For South Inkai, 97.5% Si, 100% Ca, 62.5% Fe, and 88.5% Re were removed. If only the chemical efficiency of treatment is evaluated, the $\text{HNO}_3 - \text{NH}_4\text{HF}_2$ system could be considered as the most effective. However, when choosing a regenerant, it is necessary to consider the subsequent state of the anion exchange resin. Nitrate ions are characterized by a high affinity for strongly basic anion exchange functional groups, because of which their subsequent displacement from the resin by sulfate solutions can complicate the technological cycle.

Therefore, the $\text{HNO}_3 - \text{NH}_4\text{HF}_2$ system was not selected for further optimization, despite the high degree of impurity removal.

According to the results of the first stage, two systems were left for enlarged laboratory research:



This approach is fundamentally important: the chemically most aggressive reagent is not necessarily the technologically optimal regenerant.

3.3. Effect of NaOH and Na₂SO₄ concentration on regeneration efficiency

The next step was to optimize the alkaline system. The main results are shown in Table 2.

Table 2 – Effect of the composition of the alkaline regenerating solution on the purification and mechanical strength of the resin

Solution composition, g/l	Resin	Removal of Si, %	Removal of Fe, %	Removal of Zn, %	Mechanical strength, %
25 NaOH + 25 Na ₂ SO ₄	Akdala	93.1	89.6	69.4	76.5
75 NaOH + 100 Na ₂ SO ₄	Akdala	97.5	Almost complete	90.2	60
75 NaOH + 100 Na ₂ SO ₄	South Inkai	98.7	50.0	91.7	-
75 NaOH + 100 Na ₂ SO ₄ , Dynamic Mode	Akdala	97.1	93.8	-	52

In the initial experimental materials for this experiment, two different values of mechanical strength are given - 82 and 63%.

At concentrations of 25 g/L NaOH and 25 g/L Na₂SO₄, the Si removal efficiency from the Akdala resin was 93.1%. At the same time, 89.6% of Fe and 69.4% of Zn were removed. The mechanical strength after treatment was 76.5%, remaining close to that of the initial regenerated resin.

Increasing the concentrations to 75 g/L NaOH and 100 g/L Na₂SO₄ increased Si removal to 97.5% for the Akdala resin. Thus, for the Akdala resin, increasing the regenerant concentration resulted in an additional 4.4 percentage points of Si removal compared with the 25 g/L NaOH + 25 g/L Na₂SO₄ solution. A high Si removal efficiency of 98.7% was also obtained for the South Inkai resin using 75 g/L NaOH + 100 g/L Na₂SO₄; however, a direct concentration-dependent comparison could not be made because the South Inkai resin was not tested with the 25 g/L NaOH + 25 g/L Na₂SO₄ solution under the same scaled-up laboratory conditions.

For the Akdala resin, the higher Si removal achieved with the more concentrated alkaline solution was accompanied by a decrease in mechanical strength. After static treatment, the mechanical strength decreased from 76.5% to 60%. This effect became more pronounced during the 36-h dynamic experiment:

although 97.1% of Si and 93.8% of Fe were removed, the mechanical strength decreased to 52%.

These results demonstrate that increasing Si removal alone cannot be considered sufficient for selecting regeneration conditions. The removal efficiency should be evaluated together with preservation of the mechanical integrity of the resin. For the Akdala resin, increasing Si removal from 93.1% to 97.5% was accompanied by a decrease in mechanical strength from 76.5% to 60%, while prolonged dynamic treatment resulted in a further decrease to 52%. Therefore, 25 g/L NaOH + 25 g/L Na₂SO₄ provided a more balanced combination of Si removal efficiency and mechanical strength for the Akdala resin.

3.4. Efficiency of the H₂SO₄ - NH₄HF₂ System

When using 150 g/L of H₂SO₄ + 150 g/L of NH₄HF₂, the Si removal rate was 89.0% for Akdala resin and 86.9% for South Inkai.

Table 3 – Results of treatment with a solution of 150 g/l H₂SO₄ + 150 g/l NH₄HF₂

Indicator	Akdala	South Inkai
Removal of Si, %	89.0	86.9
Removal of Fe, %	16.6	86.0
Removal of Zn, %	27.6	24.5
Removal of Ca, %	4.9	50.0
Mechanical strength, %	61.0	81.0

In terms of the degree of siliconization, this composition was inferior to optimized alkaline solutions. At the same time, its effect significantly depended on the origin of the resin.

For Akdala, an increase in NH₄HF₂ concentration was accompanied by a decrease in mechanical strength of up to 61%. For South Inkai, a value of 81% was recorded after treatment, meaning the result did not indicate a similar degradation of the material.

The difference in the behavior of the two industrial designs indicates that the effectiveness of a regenerant is determined not only by its chemical composition. The history of operation, the degree and nature of the resin contamination and, probably, the condition of its polymer matrix are significant.

Therefore, a universal choice of a reagent only by the Si removal index seems to be insufficiently substantiated.

3.5. Effect of regeneration on hydrodynamic characteristics

If the removal of silicon-containing deposits does free up the pore space of the resin, this should be manifested not only by a decrease in the Si content, but also by a change in the passage of the liquid through the sorbent bed.

Experimental verification confirmed this assumption.

Table 4 – Change in the hydrodynamic index after chemical regeneration

Sample	Volume flow, m ³ /h	Relative change, %
Akdala's Original Resin	0.180	–
Akdala, 150H ₂ SO ₄ + 150NH ₄ HF ₂	0.219	+21.67
South Inkai, 150H ₂ SO ₄ + 150NH ₄ HF ₂	0.223	+17.40
Akdala, 25NaOH + 25Na ₂ SO ₄	0.234	+30.00
Akdala, 75NaOH + 100Na ₂ SO ₄	0.225	+24.99

The maximum effect was obtained for the formulation of 25 g/l NaOH + 25 g/l Na₂SO₄: the hydrodynamic index increased by 30%.

For the more concentrated alkaline solution, the improvement was 24.99% despite the higher degree of Si removal.

Thus, the higher Si removal efficiency achieved with the more concentrated alkaline solution did not result in a corresponding improvement in the hydrodynamic characteristics of the resin.

H₂SO₄ - NH₄HF₂ treatment also improved fluid flow, with an increase of 21.67% for Akdala and 17.40% for South Inkai.

Consequently, chemical regeneration does change the state of the ion exchange resin layer and improve its hydrodynamic properties.

3.6. Restoration of the uranium sorption tank

A key criterion for evaluating the practical effectiveness of regeneration is the ability of the treated resin to recover uranium during subsequent sorption.

To evaluate this parameter, comparative sorption experiments were performed using the initial regenerated Akdala resin and resin samples treated with the two selected regenerating solutions.

Table 5 – Effect of regeneration on the uranium sorption capacity of the Akdala resin

Resin Condition	U content after sorption, g/l	Change relative to the original resin, %
Initial regenerated resin	10.75	–
After treatment with 25 g/L NaOH + 25 g/L Na ₂ SO ₄	13.89	+29
After treatment with 150 g/L H ₂ SO ₄ + 150 g/L NH ₄ HF ₂	16.69	+55

After treatment with the alkaline regenerating solution, the uranium sorption capacity increased from 10.75 to 13.89 g/L, corresponding to an increase of approximately 29%. Treatment with the H₂SO₄ - NH₄HF₂ solution resulted in a greater increase in uranium sorption capacity, reaching 16.69 g/L, approximately 55% higher than that of the initial regenerated resin.

These results demonstrate that chemical regeneration not only removes accumulated impurities but also improves the subsequent uranium sorption performance of the resin.

The solution containing 25 g/L NaOH + 25 g/L Na₂SO₄ provided the most balanced combination of properties for the Akdala resin: 93.1% Si removal, a

mechanical strength of 76.5%, a 30% improvement in hydrodynamic performance, and a 29% increase in uranium sorption capacity.

Treatment with 150 g/L H_2SO_4 + 150 g/L NH_4HF_2 resulted in the greatest increase in uranium sorption capacity, reaching 16.69 g/L, approximately 55% above that of the initial regenerated Akdala resin. However, the mechanical strength of the resin decreased to 61%.

Thus, the preferred regeneration conditions depend on the selected performance criterion. The acid-fluoride system provided the greatest restoration of uranium sorption capacity for the Akdala resin, whereas the moderately concentrated alkaline solution provided a more balanced combination of Si removal, mechanical strength, hydrodynamic performance, and uranium sorption capacity.

3.7. Comprehensive assessment and selection of the regenerating solution

Comparison of the results allows us to distinguish three consecutive levels of reagent selection.

At the first level, HNO_3 - NH_4HF_2 demonstrated the maximum removal of a number of impurities, but the technological features of the interaction of nitrate ions with the anion exchange resin limit the feasibility of its further use.

At the second level, an increase in the concentrations of NaOH and Na_2SO_4 made it possible to obtain the maximum degree of Si removal - up to 98.7%. However, for Akdala's resin, the increase in chemical action was accompanied by a significant decrease in mechanical strength.

At the third level, a set of operational characteristics was taken into account. This is where the formulation of 25 g/L NaOH + 25 g/L Na_2SO_4 showed the most balanced result.

Thus, it is advisable to formulate the criterion for selecting a regenerating solution not as the achievement of the maximum degree of Si removal, but as the achievement of a sufficient degree of silicon desilica with a minimum negative impact on the structure of the sorbent and the simultaneous restoration of its hydrodynamic and sorption characteristics.

From this point of view, for Akdala resin, the most rational of the studied alkaline formulations is 25 g/l of NaOH + 25 g/l of Na_2SO_4 .

The H_2SO_4 - NH_4HF_2 acid-fluoride system is also of practical interest, especially given the pronounced reduction of uranium capacity. However, the need to control its impact on mechanical strength requires further optimization of NH_4HF_2 concentration and processing time.

4. Conclusion

Chemical regeneration of anion-exchange resins from the Akdala and South Inkai uranium deposits was evaluated with respect to silicon removal and recovery of resin performance. Silicon contents in the regenerated industrial resins reached 11.4% for Akdala and 13.1% for South Inkai. The tested regenerants provided Si removal efficiencies of 90.2 - 97.9% for NaOH - Na_2SO_4 , 93.3 - 95.0% for H_2SO_4 - NH_4HF_2 , and 95.7 - 97.5% for HNO_3 - NH_4HF_2 . Despite

its high Si removal efficiency, the HNO_3 - NH_4HF_2 system was excluded from further optimization because nitrate ions have a high affinity for strongly basic anion-exchange resins, which may complicate their subsequent displacement during operation in sulfate-based uranium recovery circuits.

For the Akdala resin, 25 g/L NaOH + 25 g/L Na_2SO_4 provided the most balanced regeneration performance, achieving 93.1% Si removal while maintaining a mechanical strength of 76.5%, improving hydrodynamic performance by 30%, and increasing the uranium sorption capacity from 10.75 to 13.89 g/L. Increasing the concentrations to 75 g/L NaOH + 100 g/L Na_2SO_4 enhanced Si removal to 97.5%, but reduced the mechanical strength to 60% and, after prolonged dynamic treatment, to 52%; therefore, the more concentrated alkaline system is not recommended for prolonged treatment of the Akdala resin.

For the South Inkai resin, both alkaline and acid-fluoride regeneration showed high Si removal efficiency. The NaOH - Na_2SO_4 system provided up to 98.7% Si removal, whereas H_2SO_4 - NH_4HF_2 achieved 95.0% Si removal at the laboratory screening stage and simultaneously provided efficient removal of Fe and Ca. Thus, both systems can be considered for South Inkai resin, with the final selection depending on the required degree of impurity removal and preservation of resin mechanical properties.

Overall, the results demonstrate that regenerant selection should not be based solely on maximum Si removal. Resin mechanical strength, hydrodynamic behavior, and recovery of uranium sorption capacity should also be considered when selecting regeneration conditions for industrial application.

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УРАН ЭКСТРАКЦИЯСЫ КЕЗІНДЕ КРЕМНИЙДІ КЕТПУГЕ ЖӘНЕ АНИОН АЛМАСУ ШАЙЫРЫН ҚАЛПЫНА КЕЛТПУГЕ АРНАЛҒАН ЕРІТІНДІНІҢ РЕГЕНЕРАЦИЯЛЫҚ ҚҰРАМЫ

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Түйіндемe. Ұңғымалық жерасты шаймалау әдісімен алынатын уранқұрамды өнімді ерітінділерді өңдеу кезінде қолданылатын анионалмастырғыш шайырларды кремнийқұрамды және ілеспе қоспалардан тазартуға регенерациялаушы ерітінділер құрамының әсері зерттелді. Зерттеу нысандары ретінде Ақдала және Оңтүстік Инкай кен орындарында пайдаланылатын технологиялық ерітінділер мен регенерацияланған анионалмастырғыш шайырлар алынды. Үлгілердің элементтік құрамы атомдық-эмиссиялық және рентгенфлуоресценттік әдістермен, ал қатты қалдықтардың фазалық құрамы рентгенфазалық талдау әдісімен анықталды. NaOH - Na_2SO_4 , H_2SO_4 - NH_4HF_2 және HNO_3 - NH_4HF_2 негізіндегі регенерациялаушы жүйелерді сынау нәтижесінде кремнийді жою дәрежесі тиісінше 90,2 - 97,9; 93,3 - 95,0 және 95,7 - 97,5% құрады. HNO_3 - NH_4HF_2 жүйесі кремнийді жоюдың жоғары тиімділігін көрсеткенімен, нитрат-иондарының анионалмастырғыш шайырға жоғары сорбциялық бейімділігіне байланысты кейінгі зерттеулерден

алынып тасталды. Одан әрі NaOH - Na₂SO₄ және H₂SO₄ - NH₄HF₂ жүйелерінің тиімділігі зерттелді. NaOH және Na₂SO₄ концентрацияларын тиісінше 75 және 100 г/л-ге дейін арттыру кремнийдің жойылу дәрежесін 97,5 - 98,7%-ға дейін жоғарылатты, алайда шайырдың механикалық беріктігінің төмендеуіне әкелді. Құрамында 25 г/л NaOH және 25 г/л Na₂SO₄ бар ерітінді кремнийдің 93,1%-ын жоюды қамтамасыз етті, бұл ретте шайырдың механикалық беріктігі 76,5% деңгейінде сақталып, гидродинамикалық сипаттамалары 30%-ға жақсарды, ал уран бойынша сорбциялық сыйымдылығы 10,75-тен 13,89 г/л-ге дейін артты. 150 г/л H₂SO₄ және 150 г/л NH₄HF₂ ерітіндісімен өңдегеннен кейін шайырдың уран бойынша сорбциялық сыйымдылығы 16,69 г/л-ге дейін жоғарылады. Алынған нәтижелер регенерациялаушы ерітіндіні таңдауда кремнийді жою дәрежесімен қатар шайырдың механикалық беріктігін, гидродинамикалық сипаттамаларын және уран бойынша сорбциялық қасиеттерінің қалпына келуін кешенді түрде ескеру қажеттігін көрсетті.

Түйінді сөздер: уран, анион алмасу шайыры, регенерация, кремний, ұңғыманы шаймалау

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РЕГЕНЕРИРУЮЩИЙ СОСТАВ РАСТВОРА ДЛЯ УДАЛЕНИЯ КРЕМНИЯ И ВОССТАНОВЛЕНИЯ АНИОННО-ОБМЕННОЙ СМОЛЫ ПРИ ЭКСТРАКЦИИ УРАНА

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Резюме. Исследовано влияние состава регенерирующих растворов на удаление кремнийсодержащих и сопутствующих примесей из анионообменных смол, используемых для сорбционной экстракции урана из продукционных растворов скважинного подземного выщелачивания. Объектами исследования были технологические растворы и регенерированные смолы с месторождений Акдала и Южный Инкай. Элементный состав определяли атомно-эмиссионным и рентгенофлуоресцентным методами, а фазовый состав твердых остатков — рентгенофазовым анализом. При испытании систем NaOH–Na₂SO₄, H₂SO₄–NH₄HF₂ и HNO₃–NH₄HF₂ было установлено, что степень удаления кремния составляет 90,2–97,9; 93,3–95,0 и 95,7–97,5% соответственно. Система HNO₃–NH₄HF₂, несмотря на свою эффективность, была исключена из-за высокого сродства нитрат-ионов к смоле. Затем были изучены системы NaOH–Na₂SO₄ и H₂SO₄–NH₄HF₂. Повышение концентрации NaOH и Na₂SO₄ до 75 и 100 г/л увеличило степень удаления кремния до 97,5–98,7%, но могло снизить прочность смолы. Раствор с концентрацией 25 г/л NaOH + 25 г/л Na₂SO₄ удалил 93,1% Si, сохранил прочность на уровне 76,5%, повысил гидродинамический индекс на 30% и ёмкость по урану с 10,75 до 13,89 г/л; раствор с концентрацией 150 г/л H₂SO₄ + 150 г/л NH₄HF₂ повысил ёмкость до 16,69 г/л. При выборе регенерирующего раствора следует учитывать не только степень удаления кремния, но и степень очистки, прочность, гидродинамические и сорбционные свойства смолы.

Ключевые слова: уран, анионообменная смола, регенерация, кремний, скважинное выщелачивание

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