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Development of Technology for Purifying Ion Exchangers from Silicon Impurities During the Processing of Productive Uranium-Containing Solutions

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ABSTRACT

The purpose of this work is to investigate the possibility of removing silicon from ion exchangers used in the production cycle, to determine the optimal concentration of alkaline solutions for desilication, and to subsequently analyze the degradation of ion exchangers (resins) employed in sulfuric-acid uranium extraction schemes.

The relevance of this study arises from the fact that in Kazakhstan, the process of selective sorption of uranium ions by ion-exchange resins is widely used as the primary method of uranium extraction. During sulphuric acid leaching of uranium ores, silicic acid enters the solution, which has a negative effect on the processes. The transfer of silicic acid into the solution and its participation in the sorption process lead to the gradual accumulation of silicon in anion exchangers, where its maximum content reaches 12-17%. The data was obtained as a result of monitoring ion exchange resins from the technological process. Since silicon is not washed out of the resin during further processing of the anion exchanger, its accumulation leads to a decrease in the resin's uranium capacity and a loss of mechanical strength. The frequency of regeneration of ion exchangers (ion exchange resins) in industrial conditions depends on several factors: the type of ion exchanger, the composition of the initial solution, the operating mode, and the quality requirements for the product obtained.

In this regard, the problem of an effective method for reducing the negative impact of silicon in the processing of productive solutions appears to be important and necessary for study.

1. Introduction

Sulfuric acid underground leaching of uranium ores leads to the transfer of uranium and a number of other elements from ore-bearing rocks into the production solution, which causes contamination of production solutions with ballast impurities. During ion exchange uranium extraction, these impurities behave differently and, based on their behavior in the sorption process, can be divided into inert, depressing, and poisoning impurities. In sulfuric acid environments, the most significant poisoning impurity is silicic acid or, according to [1], silica. The source of silicon in productive solutions is soluble alkali metal silicates, as well as uranium silicates. When dissolved in water, silicate salts undergo hydrolytic cleavage, forming the corresponding silicic acids. In an equilibrium solution, there are monomeric forms of silicic acids, of which o-silicic acid $Si(OH)_4$ constitutes a significantly larger part.

As a result of the hydrolysis of silicon compounds, silicic acids are formed, which immediately undergo a polycondensation reaction [2]. The rate of polycondensation of silicic acids is minimal at pH 2.0÷3.0, with the reaction being accelerated by hydrogen ions in the pH<2.0÷3.0 range and by hydroxyl ions at pH>2.0÷3.0.

Despite the widespread use of ion exchange uranium extraction technology at enterprises in Kazakhstan, the issue of restoring the operational properties of ion exchangers after their silicification has not been sufficiently studied to date. In particular, there is no systematic analysis of the relationship between silicon concentration, structural changes in the matrix, and functional groups of the resin, as well as a comprehensive assessment of the effectiveness of its regeneration processes. Also, the mechanism of "silicification" of ion-exchange resins itself is still unclear, with only some patterns of this process having been established [3-6]. During

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*Corresponding author: Zh.S. Kenzhetaev; E-mail address: kzhiger@yahoo.com uranium sorption, silica is in the form of monosilicic acid, which penetrates the ionite grain by diffusion as a non-electrolyte, but does not occupy the active ion-exchange groups of the anionite [7]. Inside the ionite grain, monosilicic acid polymerizes under certain conditions, and the polymeric compounds of silicic acid cannot leave the resin on their own due to the large size of the polymer particles [8]. Conditions are created on the anionite when their concentration exceeds their solubility, and the resulting macromolecule of silicic acid gradually grows and turns into a polymer particle with colloidal properties. At an early stage, especially at low pH values, chain and branched polymers are obtained. The absorbed silicic acid in the anionite phase condenses. This is a secondary reaction, the course of which is facilitated by the high concentration of silicic acid in the anionite phase. The transition of silicon into productive solutions is caused by the reactions of sulfuric acid with aluminosilicates, chlorites, hydromicas, and the uranium-containing mineral coffynite.

The scientific novelty of the work lies in the comprehensive studies conducted on the behavior of silicon-containing compounds in the structure of strongly basic ion-exchange resins used in sulfuric acid uranium leaching cycles.

A method for restoring the sorption capacity of ion exchangers by desilication with alkaline solutions was proposed and experimentally validated, with the determination of the optimal reagent concentration and treatment conditions.

Using IR Fourier spectroscopy (ATR method), data were obtained on the restoration of active functional groups and a decrease in the degree of polycondensation of silicon-containing phases after treatment.

The main practical goal of the work is to develop and experimentally validate a method for removing silicon from spent ion exchange resins at uranium mining enterprises in order to restore their sorption capacity and extend their service life in sorption-desorption cycles. Solving this problem will increase the efficiency of ion exchangers, reduce technological losses of uranium, and lower the operating costs of PSV enterprises by extending the service life of sorbents.

Based on the average annual sorbent consumption rate per tonne of uranium (0.039 m^3), the average ionite loading for sorption of 92 tonnes, and the average production capacity of the enterprise of 1,000 tonnes of uranium per year, the wear and tear of ionite due to silicification is 10%. Then, at a sorbent cost of about 2.5 mln tenge per 1 m^3, the enterprise's losses due to silicon accumulation in the resin will amount to at least 9.75 mln tenge per year.

2. Experimental part

Method for obtaining initial sorbent samples used in the production cycle and subjected to desilication. Samples of macroporous ion exchangers were selected for research at operating uranium mining enterprises.

In the first stage, experiments were conducted to determine the effect of alkali concentration on the desilication of the sorbent in static mode. A laboratory setup shown in Fig. 1 was used to perform the desilication operation. This setup is standard for conducting experimental work in agitation mode.

The experiments were conducted with a resin load of 250 cm^3 at “W:T = 3.0”. Preliminarily, silicon determination was carried out in desilication crucibles at different W/T ratios and is shown in Table 1. The results showed a preference for using a W:T ratio of 3:1. The alkali solutions had the following caustic soda concentrations (g/dm^3): 5; 10; 20; 30; 40; 50; 60; 70; 80; 100. The results are shown in Table 3. Preliminary monitoring of the available literature showed that silicon was removed from sorbents of various grades using alkaline solutions with a mass concentration in this range. It was necessary to find the optimal concentration for resins used in the sorption-desorption cycle of uranium production. At concentrations below 5 g/dm^3, the desiliconisation process does not occur, and at concentrations above 100 g/dm^3, the sorbent is destroyed.

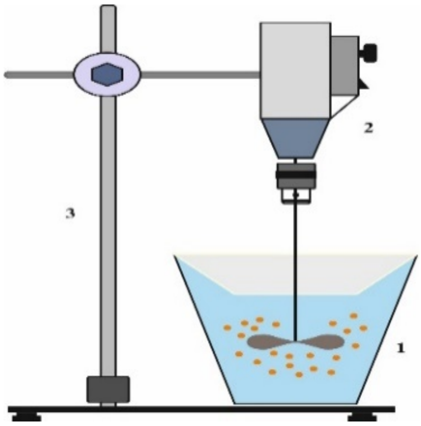

Fig. 1. Installation for removing silicon from anion exchangers in agitation mode: 1 – laboratory beaker; 2 – stirrer; 3 – stand. Stirrer rotation speed: 25 rpm.

**The experiments were conducted at room temperature (25-27 °C) without additional heating.*

The volume of the alkali solution was 750 cm^3. The mixing time was 2 h. Preliminarily, to determine the duration of the desilication process, it was studied at intervals of 0.5-3 h. The results showed that 2 h of contact with the reagent is sufficient to obtain a satisfactory result. The data are shown in Table 2.

Silicon was determined using spectrophotometric and gravimetric analysis methods.

Figure 2 shows a graph of the dependence of the effect of alkali concentration on the desilication of anion exchange resin.

Samples of sorbents after desilication, together with samples of sorbent before desilication and a sample that did not participate in the technological process, were sent for sample preparation. Sample preparation was carried out as follows: the required amount of wet resin was pre-dried to a constant mass, then the resulting precipitate, consisting of spherical granules, was subjected to mechanical grinding to obtain a finely dispersed powder, which was used for further study by IR Fourier spectroscopy, one of the variants of IR spectroscopy [9].

Table 1. SiO_2 content in the decarbonisation beds of sorbents from the technological process using an alkali solution

Sample	SiO_2 content in solution, g/dm^3		
	W:T= 1:1	W:T = 2:1	W:T = 3:1
1	1.07	2.12	4.13
2	6.42	12.84	22.12

Table 2. Results of analyses of anion exchangers and solutions for silicon content at different mixing times

Parameter	Anionite 1					Anionite 2					Anionite 3				
Initial SiO_2 content in ionite, %	4.07					16.51					9.63				
Contact time, min	30	60	90	120	180	30	60	90	120	180	30	60	90	120	180
SiO_2 content in ions after desilication process, %	0.05	0.03	н/о	н/о	н/о	4.67	3.48	2.42	0.61	0.66	1.52	0.07	0.04	0.05	0.03
SiO_2 content in solution after desilication, g/dm^3	6.14	6.21	6.28	5.87	6.04	4.28	4.65	5.42	6.42	6.26	6.18	7.06	7.13	7.27	7.31

Table 3. Results of resin desilication in agitation mode at various concentrations of caustic soda solution

№	NaOH, g/dm^3	Si in resin, %	Si in solution, g/dm^3	Mechanical strength, %
1	5	15.0	0.16	93
2	10	13.64	0.56	93
3	20	6.45	3.96	93
4	30	2.91	5.44	94
5	40	1.66	6.12	94
6	50	1.15	6.24	94
7	60	0.57	6.62	94
8	70	0.83	6.16	93
9	80	0.96	5.96	93
10	100	0.67	5.62	92

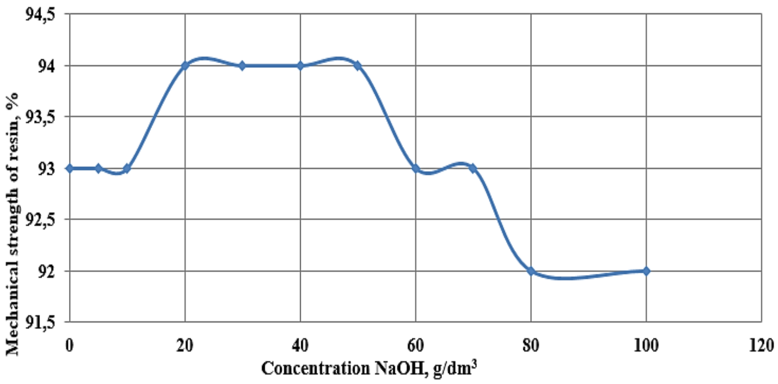

Fig. 2. Effect of alkali concentration on the desilication of anion exchange resin.

2.1 Infrared Fourier spectroscopy.

The study of the most probable mechanism of chemical degradation of strong base ion exchangers was carried out using a Carry 660 Agilent (USA, 2013) IR Fourier spectrometer equipped with an accessory for the attenuated total internal reflection (ATR) method with a germanium (Ge) element. This method of physicochemical analysis for studying the chemical structure of ion exchange resins has the following advantages:

– High informative value: IR Fourier spectroscopy allows the identification of various functional groups present in the structure of ion exchange resins, such as carboxyl groups, hydroxyl groups, amino groups, etc. This provides detailed information about the structure of the resin and allows its properties to be determined;

– Non-invasiveness: IR Fourier spectroscopy does not affect the structure of the ion exchange resin, which allows its chemical structure to be studied without affecting its properties;

– High sensitivity: IR Fourier spectroscopy can detect even small changes in the chemical structure of ion exchange resin, such as changes in the concentration of functional groups or changes in their location;

– Can be used as a monitoring tool: IR Fourier spectroscopy can be used as a monitoring tool to control water purification processes and their effectiveness. For example, it can be used to monitor changes in the structure of ion exchange resins that may occur during use and to determine whether they need to be replaced.

Figure 3 shows the principle of operation of the ATR (ATR) method in IR Fourier spectroscopy when analyzing ion exchange resin before and after desilication using a Ge crystal:

Left (before desilication): resin granules with silicon deposits that distort the spectrum, enhancing the Si-O-Si bands (1080-1090 cm^{-1}) and reducing the intensity of the characteristic band of quaternary ammonium groups (890 cm^{-1}).

Right (after desilication): purified granules, the surface is more accessible for the penetration of the evanescent wave. The Si-O-Si bands are weakened in the spectrum, and the $N^+(CH_3)_3$ band becomes more pronounced.

The IR beam passes inside the Ge crystal, reflects at its boundary with the sample, and forms an evanescent wave, which penetrates to a depth of 0.5-2 µm into the resin granules and interacts with the molecules.

The resulting spectrum allows the detection of residual silicon compounds and the degree of preservation of functional groups.

Thus, the ATR method on a Ge crystal allows a direct comparison of the chemical state of the resin before and after desiliconization and confirms the restoration of its sorption properties.

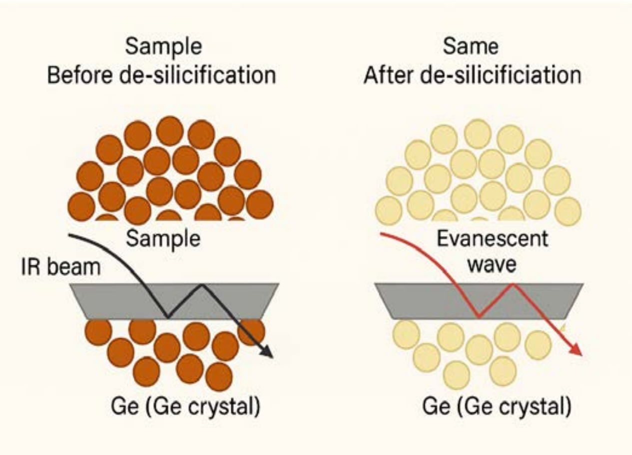

Fig. 3. Operating principle of the Agilent Carry 660 spectrometer.

2.2 Samples of ion exchange resins

Four samples of ion exchange resins that had been used in production were used in the studies, including samples No. 1 and 2, which were ion exchange resins prior to the desilication process, and samples No. 3 and 4, which were samples after purification from silicon compounds. A sample of a new ion exchange resin that had not been used in the uranium sorption process was also provided as a reference sample (comparison sample) of a strong base anion exchanger under the trade name Biolite 200U.

Figures 4 and 5 show photographs of the research objects – ion exchange resins samples No. 1-4 and Biolite 200U. The images show that the physical condition of the resins did not change after the sorbents were cleaned of silicon.

3. Results and discussion

The results of experiments to determine the effect of alkali concentration on the desilication of anionite showed the following:

Alkaline treatment of anionite with an alkali concentration above 10-20 g/dm^3 leads to a sharp decrease in the silicon content in the anionite, and at an alkali concentration above 50 g/dm^3, the residual silicon content in the anionite stabilizes and is less than 1%.

The optimal alkali concentration is in the range of 30 to 50 g/dm^3. In this case, the residual silicon content in the resin is 1 to 2.5%.

Based on the graph shown in Fig. 2, we can identify a range between alkali concentrations of 10 and 60 g/dm^3 in which the mechanical strength of the anionite exceeds the initial mechanical strength

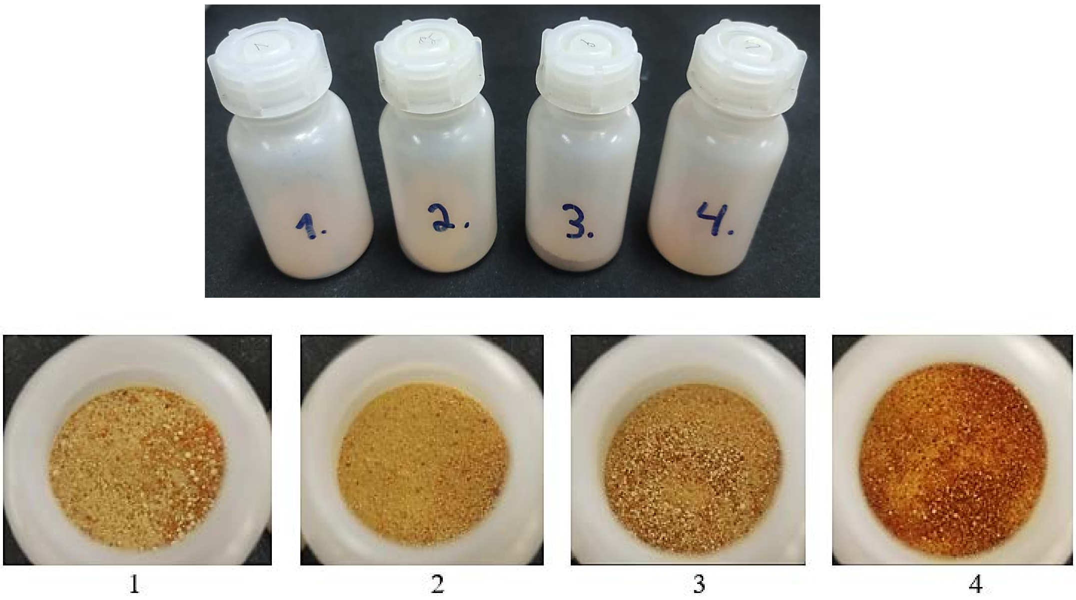

Fig. 4. Samples of ion exchange resin from production, No. 1,2 – resins before desiliconization, No. 3,4 – resins after purification from silicon compounds.

Fig. 5. Biolite 200U ion exchange resin.

(93%) by 1%. Only at high alkali concentrations of 80 to 100 g/dm^3 is the mechanical strength lower than the initial strength, at 92%. The mechanical strength of ionites is determined by their ability to resist abrasion and crushing and is one of the main physical characteristics of sorbents.

The mechanical strength of resins depends on two processes: the negative effect of alkali on the one hand and the increase in mechanical strength with a decrease in silicon content on the other. Fig. 2 shows three distinct areas. In the first area, where the alkali concentration is low, as is the amount of silicon removed, these processes are balanced. In the second area, where the amount of silicon removed is high (the degree of desilication is up to 90%) and the alkali concentration is not too high, the second process prevails. In the area of high alkali concentrations, mechanical strength decreases due to the dominance of the first process.

Based on the data obtained, it can be noted that alkali treatment of silicon-saturated resin in the alkali concentration range up to 60 g/dm^3 does not have a negative effect on mechanical strength; more precisely, the reduction in silicon content outweighs the possible negative effect of alkali.

The sufficiently high degree of resin desilication obtained in the experiments allows us to judge the effectiveness of alkali treatment for restoring the sorption properties of sorbents used in uranium hydrometallurgy.

Further research was aimed at establishing the degradation of sorbents after the desilication operation. The identification of ion exchangers was achieved by comparing the recorded spectra with the spectra of a sample of the strongly basic ion exchanger Biolite 200U (Fig. 5).

The functional groups of anion exchange resins are moderately stable and are destroyed at high temperatures [10-13]. When treated with cold water, this degradation occurs very slowly. However, when exposed to hot condensate or heated caustic regenerant, anion exchangers lose their capacity. This technical fact discusses various usage scenarios and the behavior of anion exchange resins under these conditions.

The samples of strongly basic ion exchangers under investigation are polymeric materials used in the process of uranium extraction from ore, water treatment, etc. Synthetic anion exchangers (resins) contain functional groups of a basic nature in their macromolecules and are solid polymeric bases. Anion exchangers dissociate in water into a low-mobility macrocation (matrix) and mobile anions: $RK_t^+ \mid An^-$.

Weakly basic anion exchangers contain primary, secondary, tertiary, and quaternary amino groups, while strongly basic anion exchangers contain quaternary amino groups. Strongly basic anion exchangers exchange counterions in alkaline, neutral, and acidic environments, while weakly basic anion exchangers exchange counterions only in acidic environments. Strong base anion exchangers have a higher anion exchange capacity than weak base anion exchangers. They can effectively capture anions such as chlorides, sulfates, nitrates, and others from solutions. They are also more resistant to acids and alkalis and can operate in high pH conditions. Weakly basic anion exchangers, on the other hand, have a lower anion exchange capacity and lower alkali resistance than strongly basic anion exchangers. They can only effectively capture certain types of anions, such as carbonates and bicarbonates, and can operate under low pH conditions [14].

The mechanism of ionite degradation during alkaline treatment is associated with the chemical decomposition of their polymer matrix and/or functional groups under the action of hydroxide ions (OH^-). The main mechanisms may be:

– elimination (Goffmann degradation). Under the action of OH^-, a β-proton is cleaved off with the formation of an alkene and a tertiary amine. As a result, the functional group is lost and the resin loses its ability to undergo anion exchange. This is particularly characteristic of strongly basic type I anion exchangers (with $-N^+(CH_3)_3$ groups);

– Hydrolysis of functional groups: Prolonged exposure to alkali may result in:

$$R–N+(CH_3)_3OH^- \rightarrow R–N(CH_3)_2+CH_3OH;$$

– the formation of weak bases, which reduces exchange capacity.

Currently, the resin desilification process is carried out by washing with an alkali solution (sodium hydroxide) at different temperatures. The main reaction of thermal decomposition is described by the two-stage Hoffman reaction [15, 16].

The first stage of the reaction converts strongly basic groups into weakly basic groups with the formation of methanol as a by-product, and the second stage of the reaction converts the ammonium group into an alcohol that is not capable of ion exchange and produces trimethylamine as a by-product.

It should be noted that in the first stage of the reaction, the resin loses its strongly basic centers with the formation of a weakly basic group in the form of a tertiary amine, but the total capacity remains unchanged, while in the second stage of the reaction, the entire exchange capacity (for this particular functional group) is lost.

In practice, both reactions occur to approximately the same extent. The Hoffman reaction is catalyzed by OH^- ions. When the resin is constantly in the salt form, where the counterion is Cl^-, SO_4^-, etc., the decomposition is much weaker. The thermal stability of strongly basic resins decreases in the following order for different ionic forms:

$$Cl^- > HCO_3^- > CO_3^{2-} > OH^-$$

Thermal degradation is one of the most common problems with anion exchange resins because regeneration processes are usually carried out at temperatures ranging from 30 °C to 45 °C and, in some cases, higher for limited periods of time, and because the resin spends a significant amount of time in the OH^- form during the desilification process. The presence of oxidants, metals, or other impurities in the contact water and regeneration solutions can accelerate the chemical destruction process and shorten the service life of the resins. Fig. 6 shows the IR Fourier spectra obtained for samples of strongly basic ion exchange resins.

The most significant difference is noticeable in the absorption range of 1750-750 cm^{-1} (Fig. 7) [17]. The range of 1500-500 cm^{-1} corresponds to the valence vibrations of simple XY bonds: C–C, C–N, C–O, and deformation vibrations of simple X–H bonds: C–H, O–H, N–H. This region is called the "fingerprint region" because the position and intensity of the absorption bands in this range are unique to each specific organic compound. Samples of ionites 1 and 2 containing silicon deposits differ significantly from samples obtained after the desilication process and the original Biolite 200U resin. The broad peak at the absorption band 1610-1640 cm^{-1}, as well as the peaks at 1510 cm^{-1} and 1455 cm^{-1}, belong to the C=C conjugated bonds of the aromatic ring. The broad absorption band in the 1480 cm^{-1} region belongs to the deformation vibrations of the C–C bonds of the benzene rings, as well as to the $N^+–CH_3$ groups present in the hydrochloride form. The absorption band with a maximum in the wavelength range of 1080-1090 cm^{-1} belongs to the deformation vibrations of Si-O-Si, the double peak in the absorption range of 1300-1400 cm^{-1} corresponds to $–NO_3^-$ nitrate groups and/or, possibly, $–NO_2^-$ nitrite complexes. Similar absorption bands are not observed in the IR Fourier spectrum of pure Biolite 200U ionite, while

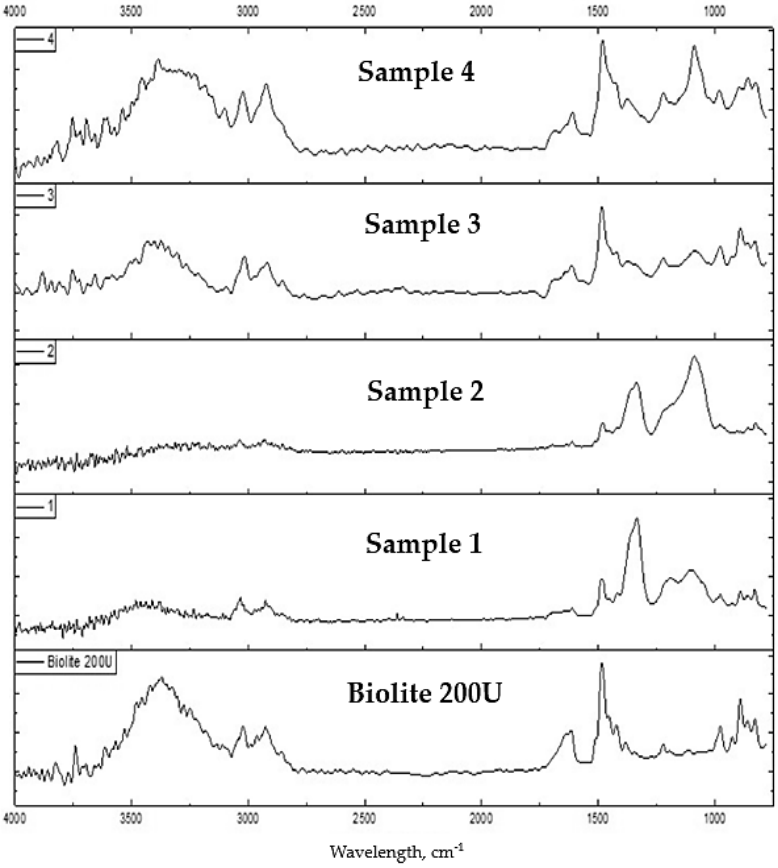

Fig. 6. IR Fourier spectra of strongly basic ionites.

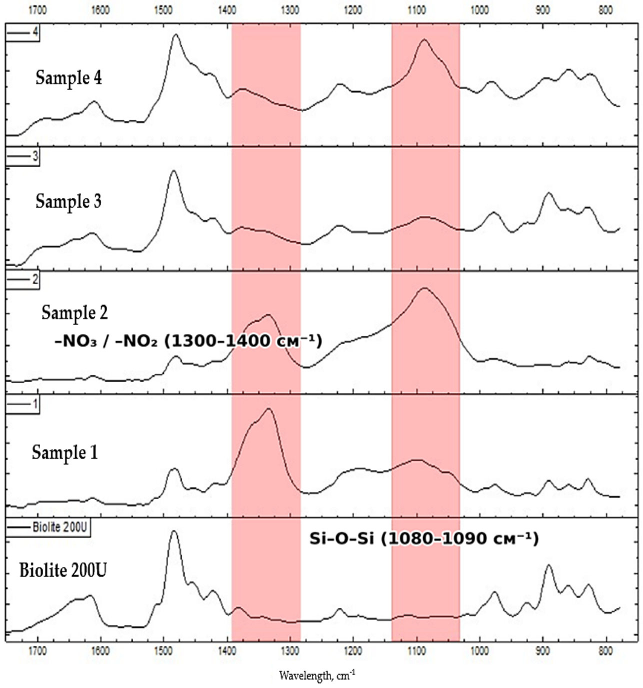

Fig. 7. IR Fourier spectra of strong ion exchange resins, “fingerprint” region.

they are present in samples 3 and 4. Apparently, the desilication process is not complete, and SiO_2 residues are present in the spectrum of ion exchangers 3 and 4, but in smaller quantities compared to the initial contaminated ion exchangers 1 and 2. The silicon content in the samples was preliminarily determined gravimetrically. The residual Si content in sample 3 after desilication was 1.65% (9.63% in the initial sorbent before desilication). The residual Si content in sample 4 after desilication was 2.9% (16.51% in the initial sorbent before desilication).

The most characteristic absorption band for strongly basic anion exchangers, belonging to the quaternary amino group $–N^+(CH_3)_3$, appears in the wavelength region of 890 cm^{-1}. The intensity of this band is significantly affected by alkali treatment. The Biolite 200U resin sample has the most pronounced peak in this spectral region, while resin samples 1 (after desilication, sample 3) and 2 (after desilication, sample 4) have less pronounced peaks in this region. These results confirm the chemical destruction of the strongly basic quaternary amino group. The absorption band at 820-830 cm^{-1} corresponds to the vibrations of $–CH_2–NH_2$ and/or –N–C deformation vibrations in the $–N(CH_3)_2$ group.

4. Conclusion

The work achieved the following objectives: the possibility of removing silicon from ion exchangers used in the production cycle was assessed; the optimal range of alkali solution concentrations for desilication was determined; an analysis of the degradation of resins used in sulfuric acid uranium extraction schemes was conducted. Experiments showed that treatment with NaOH solutions significantly reduces silicon content (to ~1-2.5% in the range of 30-50 g/dm^3) while maintaining or slightly reducing mechanical strength; ATR-FTIR spectroscopy confirms a decrease in Si-O-Si contributions and the fixation of resin functional group markers, indicating a partial restoration of sorption properties. The scientific novelty lies in the comprehensive comparison of the degree of desilication, mechanical strength, and spectral signs of degradation, which allows us to justify the boundaries of technologically feasible alkali treatment modes. The practical significance lies in the possibility of extending the service life of strongly basic anion exchangers operated under conditions of intense silicon contamination and increasing the stability of sorption characteristics in subsequent operating cycles. The limitations of the study are related to the laboratory scale, static mode, and range of resins; long-term stability during repeated cycling and a technical and economic assessment are required. Prospects include optimization of temperature-time modes, study of the influence of counterions, and development of regulations for industrial implementation.

At present, there are a number of methods for purifying resin and raw productive solutions from silicon. The main methods for purifying silica are coagulation (including heterocoagulation: joint precipitation of orthosilicic acid (OSA) with hydroxides of multivalent metals, e.g. with aluminium and iron (3+) hydroxides, OSA forms aluminosilicic and ferrosilicic acids, respectively), flocculation, baromembrane method, sorption, etc. The most effective method is sequential coagulation or flocculation of silica followed by ultrafiltration. Currently, alkaline desilication and bifluoride treatment of resin are considered the most optimal methods for removing silicon from anionite. After reviewing the available literature, the alkaline method of desilication of sorbents was selected as the most suitable in terms of technological feasibility.

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Разработка технологии очистки ионитов от кремниевых примесей в условиях переработки продуктивных урансодержащих растворов

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АННОТАЦИЯ

Целью настоящей работы является изучение возможности удаления кремния с ионитов, бывших в производственном цикле, определение оптимальной концентрации щелочных растворов для обескремнивания и последующий анализ деградации ионитов (смол), используемых в сернокислотных схемах извлечения урана.

Актуальность работы обусловлена тем, что в Казахстане селективная сорбция ионов урана ионообменной смолой широко применяется в качестве основного метода его извлечения. При выщелачивании урановых руд серной кислотой в раствор попадает кремниевая кислота, которая оказывает негативное влияние на процессы. Переход кремниевой кислоты в раствор и вовлечение ее в сорбционный процесс ведет к постепенному накоплению кремния в анионитах, предельное содержание которого достигает 12-17%. Данные получены в результате мониторинга ионообменных смол с технологического процесса. Поскольку при дальнейшей переработке анионита кремний из смолы не вымывается, его накопление приводит к снижению емкости смолы по урану и потере механической прочности. Частота регенерации ионитов (ионообменных смол) в промышленных условиях зависит от нескольких факторов – типа ионита, состава исходного раствора, режима эксплуатации и требований к качеству получаемого продукта.

В связи с этим проблема эффективного способа снижения негативного влияния кремния в процессах переработки продуктивных растворов представляется важной и необходимой для изучения.

Ключевые слова: кремний, деградация, восстановление ионообменных свойств.

Құрамында ураны бар өнімді ерітінділерді өңдеу жағдайында кремний қоспаларынан иониттерді тазарту технологиясын әзірлеу

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АҢДАТПА

Бұл жұмыстың мақсаты-өндірістік циклде болған иониттерден кремнийді кетіру мүмкіндігін зерттеу, кремнийсіздену үшін сілтілі ерітінділердің оңтайлы концентрациясын анықтау және уранды алудың күкірт қышқылды схемаларында қолданылатын иониттердің (шайырлардың) деградациясын кейіннен талдау.

Жұмыстың өзектілігі Қазақстанда уран иондарын ион алмасу шайырымен селективті сорбциялау процесі уран алудың негізгі әдісі ретінде кеңінен қолданылатындығына байланысты. Уран рудаларын күкірт қышқылымен шаю кезінде силикат қышқылы ерітіндіге еніп, бұл процестерге теріс әсер етеді. Кремний қышқылының ерітіндіге ауысуы және оны сорбциялық процеске тарту аниониттерде кремнийдің біртіндеп жиналуына әкеледі, оның шекті мөлшері 12-17% жетеді. Деректер технологиялық процестен ион алмасу шайырларының мониторингі нәтижесінде алынды. Анионитті одан әрі өңдеу кезінде шайырдан алынған кремний жуылмайтындықтан, оның жиналуы шайырдың уран сыйымдылығының төмендеуіне және шайырдың механикалық беріктігінің жоғалуына әкеледі. Өнеркәсіптік жағдайда иониттердің (ион алмасу шайырларының) регенерация жиілігі бірнеше факторларға байланысты – ионит түрі, бастапқы ерітіндінің құрамы, жұмыс режимі және алынған өнімнің сапасына қойылатын талаптар.

Осыған байланысты өнімді ерітінділерді өңдеу процестерінде кремнийдің теріс әсерін төмендетудің тиімді әдісі мәселесі зерттеу үшін маңызды және қажет болып көрінеді.

Түйін сөздер: кремний, деградация, сорбенттерді қалпына келтіру.