Selection of sorption materials for the extraction of nickel and cobalt from the ore of the Gornostaevskoye deposit

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Oxidized nickel ores account for the majority of industrial ores suitable for nickel production. The processing of such ores using traditional pyrometallurgical technology is not economically viable due to the low nickel content. One of the most cost-effective methods of processing oxidized nickel ores is sulfuric acid leaching technology followed by sorption extraction. The aim of this work is to establish the kinetic and thermodynamic parameters of the sorption extraction of nickel and cobalt using iminodiacetate chelating ion-exchange sorbents from various manufacturers, to select a desorbing solution and to determine the degree of desorption. The sorption of nickel and cobalt was carried out in a weakly acidic medium from a model solution containing impurities of other metals in static and dynamic modes. The limiting sorption capacity for the studied sorbents is 18-26 mg/g for nickel and 1-2 mg/g for cobalt in the static mode. The sorption capacity in the dynamic mode for nickel is equal to 25.5 g/L for Purolite S 930, 29.2 g/L for Lewatit TP 207, 1.4 g/L, and 1.8 g/L for cobalt, respectively. The best desorption parameters are achieved when using a 2 M sulfuric acid solution. The degree of desorption for sorbents Purolite S 930 and Lewatit TP 207 exceeds 90%. The use of the Lewatit TP 207 sorbent for the extraction of nickel from the leaching solution of nickel ore of the Gornostaevskoye deposit in 5 cycles made it possible to obtain a commercial desorbate with a nickel content of 18 g/L. The use of a part of the commercial desorbate obtained in the previous cycle, further strengthened to the initial concentration of sulfuric acid, for re-extracting nickel from the saturated sorbent during a cyclic process leads to a deterioration in desorption characteristics. It is recommended to remove the commercial desorbate from the process after several cycles of desorption and supply new solution of sulfuric acid for desorption to restore the sorption parameters.

Keywords: nickel; sorption; desorption; iminodiacetate sorbents; kinetics; sorption capacity; output curves; commodity desorbate.

Горностаев кен орнының кендерінен никель мен кобальтті бөлу үшін сорбциялық материалдарды таңдау

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Тотыққан никель кендері никель өндіруге жарамды өнеркәсіптік кендердің көп бөлігін құрайды. Мұндай кендерді дәстүрлі пирометаллургиялық технология бойынша өңдеу никельдің төмен болуына байланысты экономикалық тұрғыдан тиімді емес. Тотыққан никель кендерін өңдеудің ең тиімді әдістерінің бірі күкіртқышқылды шаймалау технологиясы, содан кейін сорбциялық экстракция. Бұл жұмыстың мақсаты әртүрлі өндірушілердің иминодиацетатты хелатирлейтін ион алмастырғыш сорбенттерінің көмегімен никель мен кобальтты сорбциялық алудың кинетикалық және термодинамикалық параметрлерін белгілеу болып табылады. Никель мен кобальттың сорбциясы басқа металдардың қоспалары бар модельдік ерітіндіден сәл қышқыл ортада жүргізілді. Зерттелген сорбенттер үшін шекті сорбциялық сыйымдылық никель бойынша 18-26 мг/г және кобальт бойынша 1-2 мг/г құрайды. Десорбцияның ең жақсы параметрлеріне 2 М күкірт қышқылы ерітіндісін қолдану арқылы қол жеткізіледі. Purolite S 930 және Lewatit TP 207 сорбенттеріне арналған десорбция дәрежесі 90% – дан асады. Горностаев кен орнының никель кендерін 5 циклде сілтісіздендіру ерітіндісінен никельді алу үшін пайдалану құрамында 18 г/л никель бар тауарлық десорбат алуға мүмкіндік берді, алдыңғы циклде алынған күкірт қышқылының бастапқы концентрациясына дейін нығайтылған тауарлық десорбаттың бір бөлігін пайдалану, циклдік процесс кезінде қаныққан сорбенттен никельді қайта алу үшін десорбциялық сипаттамалардың нашарлауына әкеледі. Десорбцияның бірнеше циклын өткізгеннен кейін тауарлық десорбатты процестен шығару және десорбцияға күкірт қышқылының жаңа ерітіндісін беру ұсынылады, бұл сорбциялық көрсеткіштерді қалпына келтіруге мүмкіндік береді.

Түйін сөздер: никель; сорбция; десорбция; иминодиацетатты сорбенттер; кинетика; сорбциялық сыйымдылық; шығу қисықтары; тауарлық десорбат.

Подбор сорбционных материалов для извлечения никеля и кобальта из руды Горностаевского месторождения

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Окисленные никелевые руды составляют большую часть промышленных руд, пригодных для производства никеля. Переработка таких руд по традиционной пирометаллургической технологии экономически не выгодна ввиду низкого содержания никеля. Одним из наиболее рентабельных способов переработки окисленных никелевых руд является сернокислотная технология выщелачивания с последующим сорбционным извлечением. Целью данной работы является установление кинетических и термодинамических параметров сорбционного извлечения никеля и кобальта с помощью иминодиацетатных хелатирующих ионообменных сорбентов различных производителей. Сорбцию никеля и кобальта проводили в слабокислой среде из модельного раствора, содержащего примеси других металлов. Предельная сорбционная емкость для изученных сорбентов составляет 18-26 мг/г по никелю и 1-2 мг/г по кобальту. Наилучшие параметры десорбции достигаются при использовании 2 М раствора серной кислоты. Степень десорбции для сорбентов Purolite S 930 и Lewatit TP 207 превышает 90%. Использование сорбента Lewatit TP 207 для извлечения никеля из раствора выщелачивания никелевой руды Горностаевского месторождения в 5 циклах позволило получить товарный десорбат с содержанием никеля 18 г/л. Использование части полученного в предыдущем цикле товарного десорбата, доукрепленного до исходной концентрации серной кислоты, для повторного извлечения никеля из насыщенного сорбента при циклическом ведении процесса приводит к ухудшению десорбционных характеристик. Рекомендуется после проведения нескольких циклов десорбции выводить товарный десорбат из процесса и подавать на десорбцию новый раствор серной кислоты, что позволяет восстановить сорбционные показатели.

Ключевые слова: никель; сорбция; десорбция; иминодиацетатные сорбенты; кинетика; сорбционная емкость; выходные кривые; товарный десорбат.

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1. Introduction

Nickel is a strategic metal due to the use of a large number of different alloys. The main consumers of nickel in the world market are China, the USA and Japan. Nickel is produced for large-scale commercial use in 23 countries around the world, including Russia, Canada, Indonesia and South Africa.

There are over 30 nickel and cobalt deposits on the territory of the Republic of Kazakhstan. "Kaznickel" LLP, a subsidiary of Fincraft Resources, is currently investing in the launch of mines at Gornostaevskoye, one of the largest cobalt and nickel deposits in Kazakhstan. The field is located in the East Kazakhstan region, 110 km west of Semipalatinsk. The reserves of the field are estimated at more than 1 million tons of nickel and more than 65 thousand tons of cobalt. In 2018, it was decided to choose a new strategy for the development of the field by applying the method of underground borehole sulfuric acid leaching.

Productive solutions obtained in the process of sulfuric acid leaching of oxidized nickel ores are characterized by a rather low content of the base metal (1.0-2.0 g/dm³) and an increased content of impurities (depending on the composition of the original ore: iron, aluminum, magnesium, etc.) [1-3], which significantly complicates their further processing. The most economical method for extracting nickel from such solutions can be sorption concentration using selective ion-exchange materials.

For the sorption of nickel, cation-exchange sorbents with carboxyl, iminodiacetate, phosphonic groups, as well as polyampholytes with complexing properties are used. A number of works [4-8] describe the results of studying the sorption of nickel from solutions of various compositions on weakly acidic macroporous cation exchangers with chelate groups of iminodiacetic acid. The authors of [9] synthesized a

number of new polymeric organic sorbents with functional groups of iminodipropionic acid and showed the possibility of their use for group extraction of copper, nickel, zinc, and cobalt ions.

In [10], for the concentration of copper and nickel, nitrogen and sulfur-containing polyampholyte based on granular polyvinyl chloride was used. The established regularities of sorption suggest the possibility of selective extraction of non-ferrous metal ions from technological solutions of metallurgical enterprises.

The work [11] shows the advantages (selectivity, extraction efficiency, simplicity of the sorption and desorption process) of the use of polymer complexing sorbents containing in their structure hydroxyazofunctional-analytical groups and n-substituents of various electronic nature for the concentration of trace amounts of nickel ions from various objects of complex chemical composition.

The technological scheme of processing real technological solutions developed by the authors [12] after leaching ores from a number of Ural deposits provides for sorption concentration of nickel on aminocarbon ion exchangers with subsequent desorption and precipitation of nickel hydroxide concentrate. This scheme ensures the recovery of nickel from solution into concentrate at the level of 96-98%.

Due to the wide range of sorption materials used and the complex salt composition of real technological solutions, the problem of developing effective hydrometallurgical technologies for extracting nickel and cobalt at low costs is an urgent ecological and economic problem. The aim of the work is to determine the parameters of sorption of nickel (II) and cobalt (II) ions on iminodiacetate chelating ion-exchange sorbents from a model solution and a solution of sulfuric acid leaching of ore from the Gornostaevsky cobalt-nickel ore deposit (East Kazakhstan).

2. Experiment

2.1 Preparation of a model solution

Solutions of nickel (II) chloride ("Ukrainalitika" LLC, Ukraine, pure for analysis), calcium (II) chloride (JSC "Bashkir Soda Company", Russia, pure for analysis), cobalt (II), magnesium (II), iron (II), aluminum (III) sulfates (CJSC "Khimreaktivsnab", Russia, pure for analysis) with the desired concentration were prepared by dissolving the appropriate salt samples in distilled water. The pH value was determined by adding the required amount of 1 M of sulfuric acid solution.

2.2 Sorbent preparation for research

The sorbent was placed in a glass filled with distilled water. Water was added in such an amount that its level was 10 cm above the level of the sorbent. The sorbent was left to swell for 8 h, stirred, and then the water was decanted off. This operation was repeated until a clear and colorless wash water was obtained. To convert the sorbent into the Na$^+$-form, treatment was performed with a sodium hydroxide solution (1-2 mol/L) for 1-2 h with periodic stirring. The solution was decanted, the sorbent was washed with distilled water until the wash water was neutral.

2.3 Method for studying the kinetics of sorption

The study of the kinetics of sorption was carried out in a static mode. 1 g of a saturated sorbent and 100 mL of a model solution were placed in a glass. The solution with the sorbent was stirred using a mechanical stirrer at room temperature for different time intervals for each beaker (45-300 min). At the end of the sorption, the sorbent was separated from the solution by filtration through a paper filter "red ribbon" ("Chemical technologies" LLC, Russia). The filtrate was analyzed for nickel and cobalt content. Based on the data obtained, kinetic curves were plotted for the dependence of the element content in the solution on the stirring time.

The sorption capacity of ion exchanger A (mg/g) was calculated by the formula:

$$A = (C_{init} - C_{equil}) \cdot V/m,$$

where, C_{init} – initial concentration of metal in solution, mg/L;

C_{equil} – equilibrium concentration of metal in solution, mg/L;

V – volume of test solution, L;

m – mass of sorbent, g.

2.4 Selection of an eluent for desorption of the sum of elements

Desorption of nickel and cobalt was carried out by washing the saturated sorbent with different specific volumes (1-4 volumes of solution/volume of sorbent) aqueous solutions of mineral acids of various concentrations (0.25-4.0 M). The sorbent was analyzed for the content ofmetal.

2.5 Method for studying the kinetics of desorption

The study of the kinetics of desorption was carried out in a static mode. The glass was filled with 1 g of saturated sorbent and 100 mL of desorbing solution. The solution with the sorbent was stirred with a mechanical stirrer at room temperature for different time intervals for each beaker (1-10 h). At the end of desorption, the sorbent was separated from the solution by filtration through a paper filter. The sorbent was analyzedfor the content of metal.

2.6 Method for studying sorption in a dynamic mode

The adsorption of elements in a dynamic mode was carried out in a sorption column equipped with a container for feeding the leach solution. A model solution was passed through a column loaded with a sorbent from bottom to top at a specific load of 5 h^{-1}. The volume of the loaded sorbent is 30 mL. Sorption was carried out in a clamped layer. At the outlet of the column, at certain time intervals, samples of the solution were taken, which were analyzed for the content of sorbed elements. Sorption was continued until the concentration of the element in the solution at the exit from the column approaches or becomes equal to its concentration in the initial solution. At the end of the sorption, the sorbent was removed from the columns, washed with distilled water, and analyzed for the content of sorbed elements. The obtained experimental data were used to plot the output sorption curves.

2.7 Method for studying desorption in dynamic mode

The saturated sorbent was sent for desorption when it reached an equilibrium state with the initial solution. Desorption in a dynamic mode was carried out in a laboratory column. A desorbing solution is passed through a column loaded with a sorbent from bottom to top at a specific load of 1 h^{-1}. At the outlet of the column, at regular intervals, samples of the solution were taken, which were analyzed for the content of extracted components. After the end of desorption, the column was unloaded, and the sorbent was washed with distilled water. Then the content of the recoverable components in the sorbent was determined. The output desorption curves were plotted from the experimental data.

2.8 Method for ore leaching

Ore samples were pre-crushed to – 150 meshes on the ID 175M disc eraser ("Vibrotechnik" LLC, Russia) and sifted using a set of soil sieves according to State standard 12536-2014 ("Vibrotechnik" LLC, Russia). Leaching was carried out in a laboratory reactor IKA LR-2.ST (Germany) with heating and constant stirring. Leaching conditions: temperature – 60-75°C; duration – 6 h; the ratio L/S= 5/1; the initial concentration of sulfuric acid is 150 g/L. At the end of leaching, the pulp was filtered and the solution was analyzed for the content of the main components.

2.9 Method for analytical measurement

The metal content in the solution and sorbents was

determined using an inductively coupled plasma emission spectrometer ICAP 7400 Duo manufactured by Thermo Fisher Scientific (USA). The relative standard deviation of the output signal is 1.0%. The accuracy of determining the elements at the level of 0.01-0.05% rel., complete analysis of the sample in 20 sec.

For the analysis of the sorbents, decomposition was performed. The suspension of the sorbent 0.5 g is taken in a polypropylene container, determining the weight of the suspension on the analytical balance MS-4002S (Mettler Toledo) by the difference in the mass of the container. The container is filled with ~2.5 mL of concentrated nitric acid ("Technochemistry" LLP, Russia, chemical pure), the lid is screwed on and placed in a heat block heated to 80°C. They are kept in a thermoblock until the sample is homogenized. After that, take an aliquot of 0.25 mL of concentrated hydrofluoric acid (Sigma-Aldrich, Canada, pure for analysis), pour it into the solution, place it in a thermoblock heated to 80°C. Stand with the lid open for no more than 5 min. After that, the sample is cooled and brought to the mark with deionized water.

Working standard solutions were prepared from the multi-element standard High Purity Standards (USA) 48 element standards ICP-MS-68A-100 Solution A in 2% HNO_3. The metal content was determined according to ST RK ISO 8288-2005 (ISO 8288-1986) "Water quality. Determination of cobalt, nickel, copper, zinc, cadmium and lead. Flame atomic absorption spectrometric methods".

3. Results and Discussion

For testing the sorption extraction of nickel and cobalt from solutions, the following commercially available iminodiacetate chelating ion-exchange sorbents were selected:
1. Amberlite IRC 748 (Dow Chemical Company, USA)
2. Lewatit TP 207 (Lanxess, Germany)
3. Lewatit TP 208 (Lanxess, Germany)
4. Purolite S 930 (Purolite, UK)
5. Dowex A1 (Dow Chemical Company, USA)
Iminodiacetate chelating sorbents of this class show positive results in the extraction of nickel [4-8]. The 5 brands of

sorbents selected by us are produced on an industrial scale. The parameters of the sorbents are given in Table 1. No characteristics were found for Dowex A1 sorbent.

It is known that nickel ore leaching solutions are characterized by high acidity (pH = 0.3-0.5). In the strongly acidic region, sorbents containing weakly acidic groups are in an undissociated state and have a low capacity with respect to metal cations. At these pH values, the solution also contains a significant amount of ferric and aluminum ions, which have a competing effect on the sorption of nickel and cobalt, reduce the selectivity of extraction and contaminate sorbents, since they are difficult to desorb. In this regard, the sorption extraction of target components should be carried out after removing the main amount of interfering impurities by bringing the pH of the solution to 3.8-4.6 and precipitation. To oxidize iron, a small amount of hydrogen peroxide is preliminarily introduced into the solution. The most accessible substances for neutralization are lime, limestone, caustic, soda ash, ammonium hydroxide. By this operation, up to 95% of iron, copper, aluminum (if present in the solution) can be removed from solutions.

Typical components of leach solutions such as magnesium, manganese and calcium are not removed during the precipitation process and are recovered to a small extent by this type of sorbent.

For the initial experiments on the sorption of nickel and cobalt from salt solutions, a model solution with a pH of 4.5 was prepared (Table 2). These metals are always present in leaching solutions and can have a competing effect on the sorption process of the target components.

The kinetic curves of the sorption of nickel and cobalt from a given solution by the studied sorbents in the Na^+-form is shown in Figure 1 and Figure 2.

The time to reach equilibrium during sorption in a static mode for the studied sorbents is about 5 h. During this time, all sorbents come into equilibrium with the solution and no further increase in capacity is observed. In Table 3, values of the equilibrium capacity for nickel and cobalt, achieved at a sorption time of 5 h in a static mode.

Table 1 – Characteristics of sorbents

Parameter	Amberlite IRC 748	Lewatit TP 207	Lewatit TP 208	Purolite S 930
Capacity, eq/L	1.35	2.0	2.9	1.8
Water content, %	60-65	55-60	55-60	55-65
Particle density, g/mL	1.7	1.1	1.17	1.13
Shipping weight, g/L	750	720	740	710-745

Table 2 – Composition of the model solution

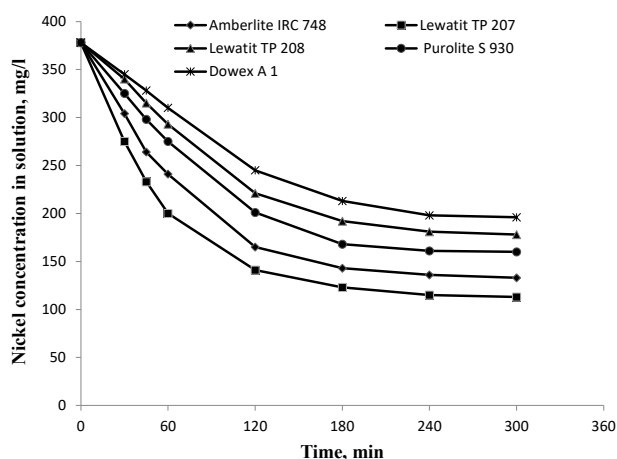| Element	Ni	Co	Fe	Al	Mg	Ca
Concentration, g/L	0.378	0.030	0.025	0.044	3.500	0.580

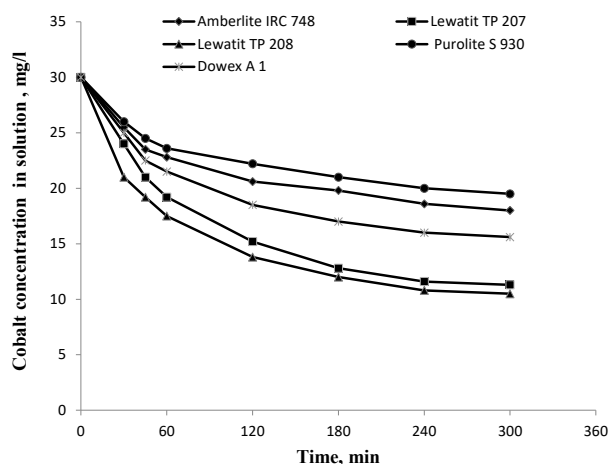**Figure 1** – Kinetic curves of nickel sorption by sorbents in Na⁺-form

Figure 2 – Kinetic curves of cobalt sorption by sorbents in Na⁺-form

According to the values of the equilibrium capacity for nickel from a solution of the investigated composition, the sorbents can be arranged in the following row:

Lewatit TP 207>Amberlite IRC 748>Purolite S 930>Lewatit TP 208>Dowex A1.

For the sorption of cobalt, the following dependence on the values of the equilibrium capacity is observed:

Lewatit TP 208>Lewatit TP 207>Dowex A1>Amberlite IRC 748>Purolite S 930.

At the same time, it can be noted that under the studied conditions all sorbent samples show similar characteristics. The highest sorption capacity for nickel is observed for AmberliteIRC

Table 3 – Equilibrium capacity of the studied sorbents for nickel and cobalt

Sorbent model	A, mg/g	
	Nickel	Cobalt
Amberlite IRC 748	24.5	1.2
Lewatit TP 207	26.5	1.9
Lewatit TP 208	20.0	2.0
Purolite S930	21.8	1.1
Dowex A1	18.3	1.4

Table 4 – Results of desorption of nickel and cobalt from the saturated sorbent AmberliteIRC 748 with acid solutions

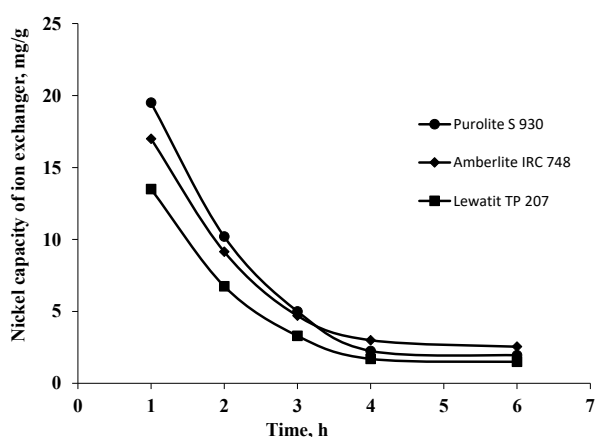| Acid	Concentration, M	Specific volume	Degree of desorption, %	
			Nickel	Cobalt
HNO₃	0.5	1	61	56
		2	74	68
		4	90	84
	1	1	94	88
		2	95	95
		4	95	99
	2	1	100	100
	4	1	100	100
HCl	0.5	1	54	61
		2	68	83
		4	77	89
	1	1	65	87
		2	72	91
		4	89	95
	2	1	93	97
		2	95	100
		4	98	100
	4	1	98	100
		2	100	100
H₂SO₄	0.25	1	64	67
		2	69	74
		4	81	80
	0.5	1	79	75
		2	82	84
		4	85	87
	1	1	91	95
		2	93	98
		4	93	100
	2	1	95	100
		2	100	100

Figure 3 – Kinetic curves of nickel desorption by solution 1 M sulfuric acid
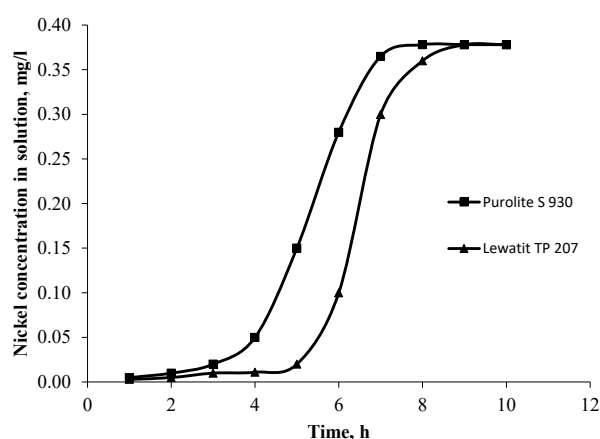

Figure 4 – Output curves of nickel sorption in dynamic mode

748 and LewatitTP 207 ion exchangers, for cobalt – for LewatitTP 208 and LewatitTP 207 ion exchangers. Analysis of resin samples after sorption does not reveal significant amounts of aluminum and iron.

The dependence of the degree of desorption of nickel and cobalt on the nature of the eluent for the Amberlite IRC 748 sorbent was studied (Table 4).

As shown by the results, the quantitative desorption of nickel and cobalt occurs when they are eluted from the sorbent 1sp.vol.2 M HNO_3, 4 sp.vol. 2 M HCl, 2 sp.vol. 2M H_2SO_4. The degree of desorption in these cases is 98-100%.

Next, we studied the kinetics of nickel desorption from samples of saturated sorbents AmberliteIRC 748, LewatitTP 207, PuroliteS 930, which showed the best performance at the sorption stage. In Figure 3 shows the kinetic curves of nickel desorption with a 1 M sulfuric acid solution.

The residual concentration of nickel in the sorbent is about 2 mg/g. According to this indicator, the studied sorbents are arranged in a row:

LewatitTP 207 >PuroliteS 930 >AmberliteIRC748.

A more substantiated answer about the parameters of the sorption extraction of nickel from solutions can be obtained from the results of an experiment carried out under dynamic conditions. Dynamic studies were carried out for two sorbents PuroliteS 930 and LewatitTP 207 and included the process of sorption until the equilibrium concentration for nickel was reached and the process of desorption with a sulfuric acid solution.

The experimental data were used to plot the output sorption curves (Figure 4).

The capacity of the studied sorbents when studying the sorption of nickel in a dynamic mode from a solution of this composition was 25.5 g/l for Purolite S 930 and 29.2 g/l for Lewatit TP 207. At the end of saturation, the sorbent was also

analyzed for the cobalt content. The following data were obtained: for Purolite S 930 – 1.4 g/L, for Lewatit TP 207 – 1.8 g/L.

Next, we studied the desorption of nickel in a dynamic mode with a sulfuric acid solution with a concentration of 120 g/L. The output desorption curves are shown in Figure 5
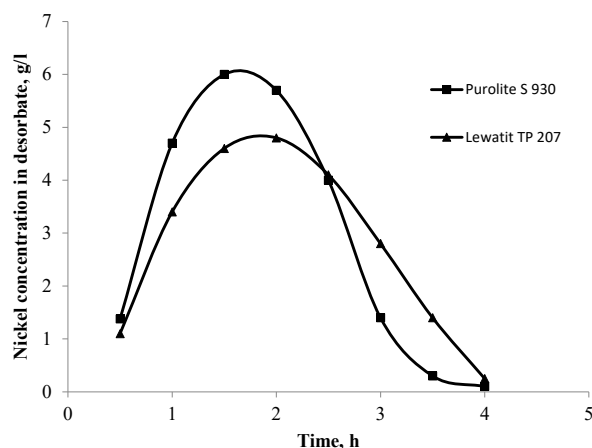

Figure 5 – Output curves of nickel desorption in dynamic mode

Tabe 5 lists some parameters of the dynamic desorption process.

Thus, in the dynamic mode, the best sorption indices were obtained for the Lewatit TP 207 sorbent, and for the desorption, for the Purolite S 930 sorbent.

The sorbent Lewatit TP 207 was subsequently used for the sorption extraction of nickel from a real solution of leaching ore from the Gornostaevskoyedeposit after a solution of hydrolytic cleaning (Table 6) in a closed cyclic mode.

The hydrometallurgical processing scheme included 5 cycles of sorption and desorption in a closed dynamic mode.

Table 5 – Nickel desorption parameters in dynamic mode

Sorbent	Maximum concentration of nickel in the desorbate, g/L	Residual concentration of nickel in the sorbent, g/L	Degree of desorption, %
Purolite S 930	5.7	1.5	94
Lewatit TP 207	4.8	2.9	90

Table 6 – The composition of the solution for leaching nickel ore after hydrolytic cleaning

Element	Ni	Co	Fe	Al	Cr
Content, g/L	1.38	0.055	0.014	<0.005	<0.005

Two series of experiments were performed. In the first series, the desorption of nickel in each cycle was carried out with a new solution of sulfuric acid; in the second series, a part of the commercial desorbate obtained in the previous cycle was used for desorption, backed up to an initial sulfuric acid concentration of 120 g/L. Table 7 and 8 show the main parameters of the investigated processes.

In the second series of experiments, after five cycles, a commercial desorbate with a sufficiently high nickel content was obtained. However, in this case, after desorption, a more significant accumulation of nickel, cobalt and iron is observed in the sorbent than in the first series of experiments. As one of the factors that can limit the process of nickel desorption, an increase in the concentration of nickel in the desorbate can be considered when the process is carried out in a closed mode.

Table 7 – Parameters of sorption-desorption processes for the extraction of nickel and cobalt in the first series of experiments (desorption with sulfuric acid solution)

№ cycles	Content in sorbent, g/L						Content in commercial desorbate, g/L	
	Ni		Co		Fe		Ni	Co
	Sorption	Desorption	Sorption	Desorption	Sorption	Desorption		
1	39.4	3.7	2.58	0.33	0.28	0.031	8.92	0.56
2	39.4	3.9	2.57	0.35	0.30	0.039	8.89	0.56
3	39.1	3.9	2.57	0.37	0.33	0.045	8.80	0.55
4	39.0	4.2	2.55	0.39	0.33	0.042	8.70	0.54
5	38.7	4.4	2.51	0.39	0.34	0.048	8.58	0.53

Table 8 – Parameters of sorption-desorption processes for the extraction of nickel and cobalt in the second series of experiments (desorption with an additional fortified commercial desorbate)

№ cycles	Content in sorbent, g/L						Content in commercial desorbate, g/L	
	Ni		Co		Fe		Ni	Co
	Sorption	Desorption	Sorption	Desorption	Sorption	Desorption		
1	39.4	3.7	2.58	0.33	0.28	0.031	8.92	0.56
2	39.7	3.9	2.66	0.38	0.32	0.039	10.80	0.77
3	39.8	4.6	2.70	0.41	0.34	0.052	12.65	0.89
4	39.8	5.1	2.74	0.43	0.39	0.061	15.14	1.05
5	40.2	6.4	2.70	0.49	0.45	0.069	18.21	1.24

To study the effect of the accumulation of nickel in the solution on the desorption indices, experiments were carried out on model solutions with a nickel content from 3 to 12 g/L (sulfuric acid concentration of 120 g/Ll). Nickel was desorbed from a saturated sorbent containing 39.5 g/L of nickel at a solution/sorbent ratio of 100/1 and stirring for 2 h. The experimental results are shown in Table 9.

The accumulation of nickel in the desorption solution up to 12 g/L leads to a decrease in the degree of its desorption from 90 to 58%.

Table 9 – Influence of the nickel content in the desorbate on the indicators of its desorption from the saturated sorbent

Nickel content in desorption solution, g/L	Residual nickel content in sorbent, g/L	Degree of desorption, %
0	3.7	90.6
3	6.4	83.8
4	8.7	78.0
6	10.5	73.4
8	13.7	65.3
10	15.0	62.0
12	16.4	58.0

4. Conclusion

All the sorbent brands studied in this work belong to the same class of materials –iminodiacetate chelating ion-exchange sorbents, which are used for selective concentration and separation of components by adjusting pH and sorption conditions. During the study, such parameters as the time required for sorption extraction, the equilibrium capacity of the sorbents, and the degree of desorption were determined. Under the conditions of sorption of nickel and cobalt from the model solution, all sorbents exhibit similar kinetic and thermodynamic properties. The highest sorption capacity for nickel is observed for AmberliteIRC 748 and LewatitTP 207 ion exchangers, for cobalt – for LewatitTP 208 and LewatitTP 207 ion exchangers. DowexA1 resin exhibits the worst kinetic and capacitive characteristics. Desorption of nickel with a solution of sulfuric acid with a concentration of 120 g/L for Purolite S 930 yielded a commercial desorbate with a maximum nickel content of 5.7 g/L (desorption degree 94%).

The use of the Lewatit TP 207 sorbent for the sorption extraction of nickel from the leaching solution of nickel ore from the Gornostaevskoyedeposit in 5 cycles made it possible to obtain a commercial desorbate with a nickel content of 18.2 g/L. However, when the process is conducted cyclically, a deterioration in desorption characteristics is observed. This is confirmed by an additional experiment on desorption by solutions containing nickel in different concentrations. An increase in the concentration of nickel in the desorbate during the process in a closed mode leads to a decrease in the degree of its desorption from 90 to 58%. Therefore, after several cycles of desorption, it is necessary to remove the commercial desorbate from the process and supply a new solution of sulfuric acid for desorption, which makes it possible to restore the sorption parameters. The use of this technique in the 6th cycle of the second series of experiments made it possible to restore the sorption properties of the sorbent and to obtain the sorption indices comparable with the 1st cycle.

Further experiments should be aimed at the selection of sorbents that provide the best indicators for the recovery of nickel and cobalt, and optimization of the parameters of sorption-desorption processes.

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