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STUDY OF DYNAMIC SORPTION AND DESORPTION OF COBALT (II) IONS BY SYNTHETIC IONITES

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Abstract. This article provides information on the possibility of obtaining cobalt (II) ions by the ion-exchange method using the dynamic sorption method on industrially produced KU-2-8 and C-930 ion exchangers. It has been proven that the sorption process is strongly influenced not only by the characteristics of sorbents, but also by the rate of solution passing through the system. It has been experimentally established that the process of incrementation of cobalt ions is reversible. Optimal modes of sorption-desorption processes have been established.

Keywords: cobalt (II) ions, cobalt-containing solutions, ion exchangers, functional group, dynamic sorption, desorption.

Аннотация. В данной статье представлена информация о возможности получения ионов кобальта (II) методом ионного обмена с использованием метода динамической сорбции на промышленно производимых ионообменниках КУ-2-8 и С-930. Доказано, что на процесс сорбции сильно влияют не только характеристики сорбентов, но и скорость прохождения раствора через систему. Экспериментально установлено, что процесс инкрементации ионов кобальта обратим. Установлены оптимальные режимы сорбционно-десорбционных процессов.

Ключевые слова: ионы кобальта (II), кобальтсодержащие растворы, ионообменники, функциональная группа, динамическая сорбция, десорбция.

Annotatsiya. Ushbu maqolada sanoatda ishlab chiqarilayotgan KU-2-8 va S-930 ionitlarida dinamik sorbsiya usulidan foydalangan holda ion almashinish usuli bilan kobalt (II) ionlarini olish imkoniyati haqida ma’lumot berilgan. Sorbsiya jarayoniga nafaqat sorbentlarning xususiyatlari, balki eritmaning tizimdan o‘tish tezligi ham kuchli ta’sir ko‘rsatishi isbotlangan. Kobalt ionlarining o‘sish jarayoni

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qaytar ekanligi tajribada aniqlangan. Sorbsion-desorbsion jarayonlarning optimal rejimlari aniqlandi.

Kalit so‘zlar: kobalt (II) ionlari, tarkibida kobalt bo‘lgan eritmalar, ionitlar, funksional guruh, dinamik sorbsiya, desorbsiya.

INTRODUCTION.

The uniqueness of the physicochemical properties of the element of the periodic system [1] predetermines its wide application in the latest high technologies [2]. Also, its relative natural rarity [3] and, on the other hand, a certain shortage of its main industrial sources [4] make research in the field of cobalt-related research very relevant and in demand. In the medium term, a steady increase in cobalt consumption is projected at 2.5% per year, and higher growth is expected in the use of battery banks by the automotive industry and superalloys in the aerospace industry [5]. Due to this, the price of cobalt in the global market is rising sharply and has reached approximately $33,000 per ton as of the end of July 2025, according to Carbon Credits.com [6]. Simultaneously, a sharp increase in the amount of cobalt-containing secondary raw materials is also observed. Currently, various methods (cementation, leaching, extraction, and others) are used in industry to process such waste [7,8]. However, they have a number of technical shortcomings and do not fully meet the increased environmental requirements. An innovative solution in this field is the application of ion-exchange technology. Ion exchange is widely used in the technologies of separation; extraction; concentration of ions of non-ferrous, noble, rare, heavy and harmful metals; toxic organic compounds and dyes [9,10]. This predetermines the application of various methods and techniques using various ion-exchange materials, depending on the chemical nature of the technological solutions and the tasks set. [11,12].

PURPOSE OF RESEARCH.

The study of the possibility of using KU-2-8 and S-930 brand industrial ion exchangers in the development of an ion-exchange method for extracting cobalt and establishing optimal modes of dynamic sorption-desorption of cobalt (II) ions on them was the goal of our research.

RESEARCH METHODS.

The choice of KU-2-8 and S-930 ionites for research was based on the results of previously published scientific works [13,14] by other scientists in this field. They have a matrix representing a copolymer of styrene and divinylbenzene, which determines their mechanical strength and chemical resistance, as well as the variety of their applications in various fields. Ion exchangers were pre-prepared by immersion in water for 24 hours and subsequent washing with a solution of acid and alkali. [15As functional groups in the KU-2-8 gel type cationite (Russia, NPO

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"POLIMER") there are sulfo groups (-SO_3H) [13]. Polyampholite S-930 (China, Purolite company) is a macroporous structure with an imino-dioxide functional group (-CH_2N (CH_2COOH) 2) [14].

In the work, the mathematical method of experiment planning was used to establish the influence of factors: ionite morphology and structure, chemical nature and pH of the solution, as well as to reduce the number of experiments in the study of dynamic sorption-desorption of cobalt ions. [16].

The pH of the solutions was determined on the EC-170 pH meter of the "pH-mV-Temp" company (Singapore). The content of cobalt ions in solutions was determined by UV-photo-calorhythmic method, through a pre-constructed calibration graph on the Spektrofotometr UV-1800 spectrophotometer of the "Shimadzu" company (Japan) [17]. Samples were weighed using the AC/ACS (Germany) KERN scale, as well as using second-class precision glassware and first-class automatic pipettes. The experiments were conducted on glass columns with a diameter of 0.5 cm and a height of 7.5 cm, as well as with a diameter of 2.0 cm and a height of 30.0 cm, equipped with tightly closing stoppers and tubes for fastening connecting hoses. The laboratory setup also has a pressure tank and a receiver. The sorbate and desorbate passage rate was carried out through special valves and a peristaltic pump. Artificial cobalt solutions were prepared by dissolving a sample of $CoC_{l2}6H_2O$ salt in distilled water. By adding 98% sulfuric acid and 25% aqueous ammonia solution, the pH of the solution was established. All experiments were conducted at 20-250C [17].

RESULTS AND THEIR DISCUSSION.

The absorption dynamics of cobalt (Co^{2+}) ions by the H-form of ion exchangers were studied using frontal chromatography by constructing sorption yield curves. A column with a diameter of 0.5 cm and a height of 7.5 cm was filled with a swollen sorbent to a layer height of 2.6 to 5.7 cm. In the experiments, ion exchangers with a grain diameter of 0.04+0.07 cm were used. The volumetric flow rate of the solution through the ion exchanger layer was 1.2, 3 ml/min. The constant supply of the solution was ensured using a peristaltic pump. Sorption was carried out from Co^{2+} ion solutions with an initial concentration of 2·10-2 mol/l, at a pH of 2.0+2.2 using KU-2-8 cationite and a pH of 3.8+4.0 S-930 ampholyte. The output curves were represented in the coordinates C/Co=f (Vf), where V is the volume of filtrate passed through the column, C/Co is the ratio of ion concentrations in the portion of filtrate and the initial solution. The working dynamic exchange capacity (DEA) and the total dynamic exchange capacity (TDA) were calculated based on the volume before "jumping" and the saturation volume. The volumetric width of the sorption front ΔV was measured between the points C/C0=0.15 and C/C0=0.85.

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The degree of ionite layer utilization was determined as the DOE/PDOE ratio.The output sorption curves of Co^{2+} by ion exchangers filled with different filling heights in the columns are presented in Figure 1. The curves are characterized by a pronounced S-shaped shape, which practically does not change with increasing ionite layer height. The Co^{2+} output curves have a symmetrical shape. In the case of the S-930 ionite, the curves are less symmetrical, the bend point is shifted to the low-temperature region (volumes of the passed solution), which indicates a slowdown in the diffusion rate of ions in the ionite.

Estimates of the width of the chromatographic front (ΔV=0.15-0.85) and the velocity of the middle point of the front (ω0.5) in columns of varying heights give close values (Table 1). Based on this, it can be concluded that a stationary sorption front forms at the minimum height of the ionite layer in the studied range of 2.6 cm. The formation of a stationary front confirms the high selectivity of Co^{2+} ion absorption.

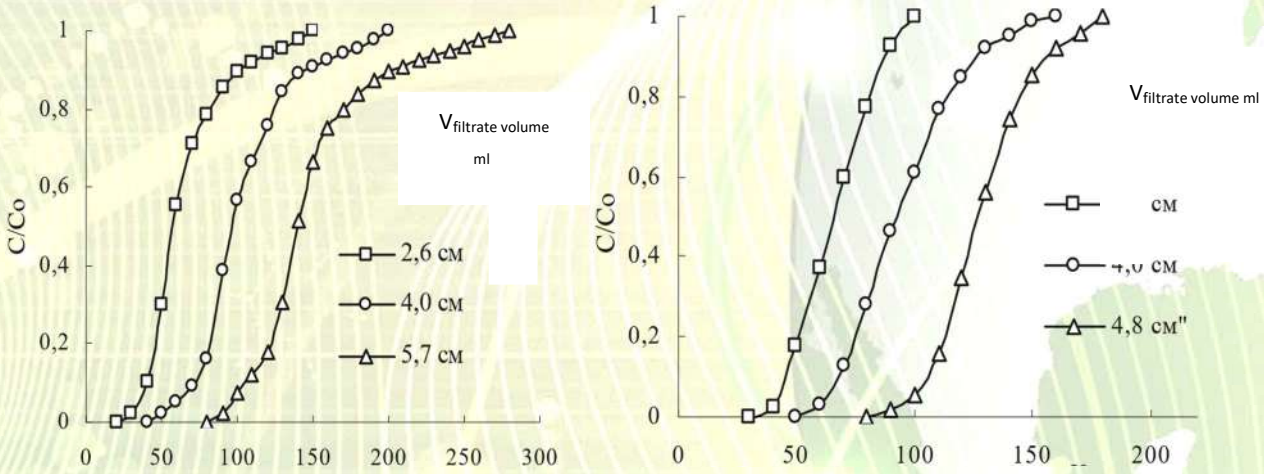


Fig. 1. Exit sorption curves of Co^{2+} ions at different heights of the KU-2-8 (A) and S-930 (B) ionite layer. The rate at which the solution is passed is 1 ml/min.

Table 1.

Co^{2+} sorption output curve parameters in columns with varying layer heights

$l_{сл}$, см	ΔV0,15–0,85, ml	V_{pr}, ml	V_{pres}, ml	ω0,5, см/мин	DOE	PDOE	õ
					mol (eq)/g		
Cu^{2+}							
2,6	44	20	160	0,04	2,67	8,87	0,30
4,0	45	40	200	0,04	3,20	8,40	0,38
5,7	63	80	280	0,04	4,57	8,03	0,57
Co^{2+}							

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2,6	36	35	100	0,04	4,66	8,17	0,57
4,0	41	60	160	0,04	4,80	7,35	0,66
4,8	47	90	180	0,04	6,00	8,33	0,72

Table 1 presents data on leak capacitance (LEC), total dynamic exchange capacitance (TDEC), and the degree of ionite layer utilization.

η=DOE/PDOE. Comparison shows that under close experimental conditions, the values of DEF and η for Co^{2+} are somewhat higher in the CU=2-8 system compared to the S-930 system. This can be explained by the different rates of ion diffusion in the sorbent due to differences in morphology and the nature of Co^{2+} interaction with the functional groups of ion exchangers. According to literature data [13], the sorption of Co^{2+} by KU-2-8 cation exchange occurs mainly due to ion exchange with strong sulfo groups, and the gel-like morphology ensures faster diffusion of Co^{2+} ions into the grains. When using the S-930 polyampholite, along with ion exchange, the coordination interaction of ions with nitrogen and oxygen atoms of its functional groups is realized [14]. However, the values of both the volumes before the "jumping" of Co^{2+} ions and the width of the chromatographic front at their 1:1 molar ratio are close to the initialn(1-table) indicate the absence of ion zone separation in the column.

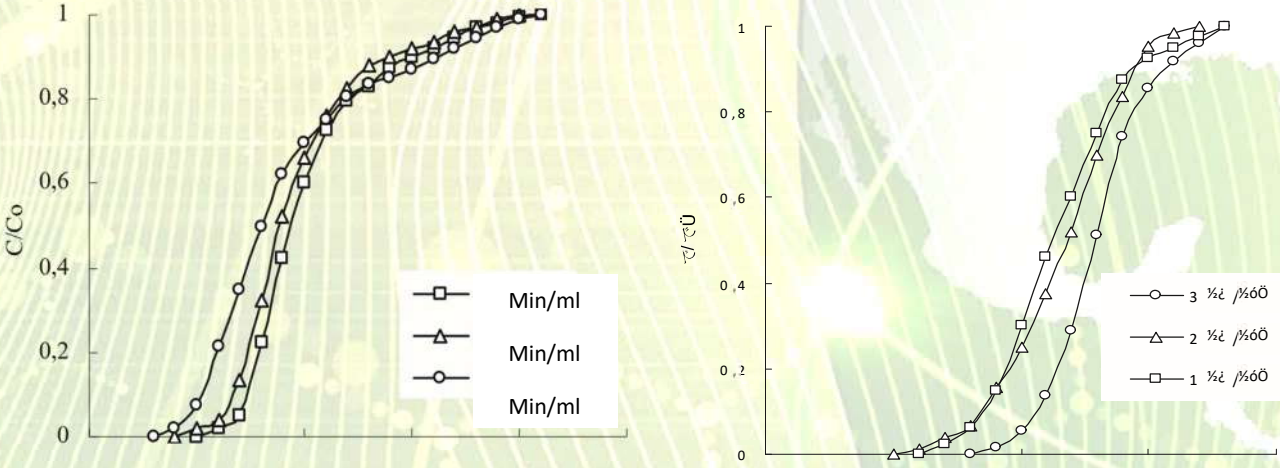


Fig. 2. Exit sorption curves of Co^{2+} ions at a layer height of 4.8 cm of KU-2-8 (A) and S-930 (B) ionite at different solution pass rate.

The yield curves of Co^{2+} ion sorption on ion exchangers at different solution filtration rates are shown in Figure 2. As can be seen from Figure 2, for with an increase in the speed of both ionites from 1 to 3 ml/min, leakage occurs significantly earlier, the width of the chromatographic front increases, the total dynamic exchange capacity and the degree of ionite layer utilization decrease (table. 2).

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Table 2.

Parameters of the output sorption curves of Co^{2+} ions in cationite columns at different solution pass rate

F, ml/min	ΔV0,85–0,15, ml	$V_{пр}$, ml	$V_{нас}$, ml	DOE	PDOE	õ
				mol (eq)/g		
Cu^{2+}						
1	52	60	210	4,00	13,25	0,30
2	65	50	200	3,33	12,20	0,27
3	85	40	210	2,67	13,18	0,20
Co^{2+}						
1	48	90	180	6,00	8,33	0,72
2	50	60	170	4,00	7,42	0,54
3	50	70	180	4,67	5,76	0,81

This dependence of the output curve parameters on the solution's pass rate indicates the control of the Co^{2+} ion sorption process by mixed diffusion and corresponds to other literature data [18,19].

For the developed sorption-desorption regimes, a laboratory setup was assembled (Figure 3), on which columns of the following sizes were used: diameter - 2.0 cm; height - 30.0 cm. In subsequent experiments, the adsorbate transfer rate was 1 ml/min. A 5% aqueous solution of $CoC_{l2}6H_2O$ salt was used as an adsorbate, and a 25% aqueous solution of ammonia was used as a regenerate. From the data in Table 4, it can be seen that the incrementation of Co^{2+} ions in the studied ionites under dynamic conditions was high. The obtained results also confirmed once again that the chemical composition of ion exchangers strongly influences the interpreted process. As we explained above, Co^{2+} ions in cationite can be bonded by relatively strong ion-ion bonds compared to groups containing polyampholyte.

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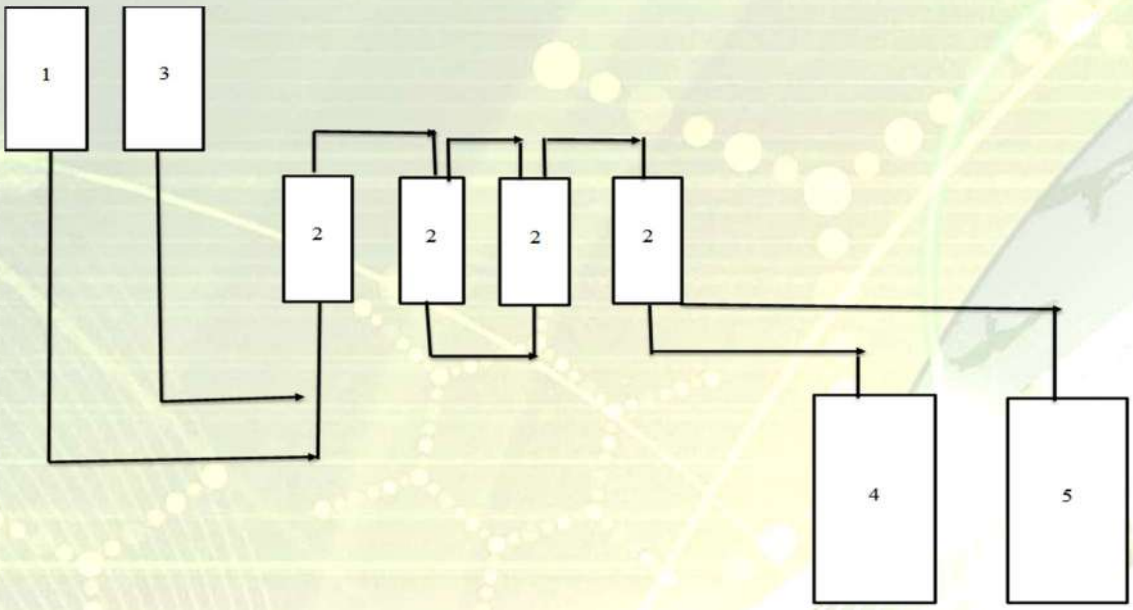


Fig.3. Technological scheme of the laboratory installation. 1-adsorption tank; 2-package of columns filled with sorbent; 3-regenerator tank; 4-collector for the purified solution; 5-collector for regenerate

Table 4.

Dynamic sorption indicators of Co^{2+} ions in C-930 and KU-2-8 ionites

F, ml/min	V, ml (past volume)	Vion, ml (ionite volume in the column)	DAS mol-eq/m^3	LUCK mol-eq/m^3	α
when using cationite S 930					
1	590	30	836	983	0,85
2	520	30	676	867	0,78
3	480	30	608	800	0,76
when using KU-2-8 cationite					
1	720	30	972	1200	0,81
2	620	30	816	1033	0,79
3	560	30	635	933	0,68

As indicated in the literature [20,21], one of the requirements for ion-exchange materials used in industry is their repeated use in the ion exchange process. That is, it is important that the ionite is desorbed after sorption and restores its sorption properties during regeneration. The results of a 6-fold study of the sorption and desorption of Co^{2+} ions in the studied ion exchangers are presented in Table 5.

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Table 5

Repeated dynamic sorption of Co^{2+} ions on C-930 and KU-2-8 ion exchangers

№	F, ml/min	V, ml (past volume)	V_{ion}, ml (ionite volume in the column)	DAS mol-eq/m3	LUCK mol-eq/m3	α
when using KU-2-8 cationite						
1	1	720	30	972	1200	0,81
2	1	720	30	972	1200	0,81
3	1	720	30	972	1200	0,81
4	1	720	30	972	1200	0,81
5	1	720	30	972	1200	0,81
6	1	700	30	933	1167	0,88
when using cationite S 930						
1	1	590	30	836	983	0,85
2	1	590	30	836	983	0,85
3	1	590	30	836	983	0,85
4	1	590	30	836	983	0,85
5	1	590	30	836	983	0,85
6	1	560	30	765	933	0,82

As a result of desorption with a 25% ammonia solution for use in the repeated sorption of Co^{2+} ions in the studied ion exchangers, the DAS value did not change in Table 5. This proves that ionites possess a high level of mechanical and physicochemical properties.

CONCLUSIONS.

The obtained results complement the field of science on high-molecular-weight compounds, in particular, knowledge of the sorption properties of ion exchangers. The research results once again confirm the previously established patterns regarding the influence of the chemical structure and morphology of the matrix, the chemical composition of the solution on the ion sorption process by ion exchangers. It has been established that KU-2-8 ionite, which has a gel structure and contains strongly acidic sulfo groups, has a higher sorption capacity compared to the macroporous S-930, which contains imino-diacetic functional groups. The possibility of repeated sorption-desorption of Co^{2+} ions on the studied ion exchangers has been shown.

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