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PHYSICOCHEMICAL AND TECHNOLOGICAL CHARACTERIZATION OF ION-EXCHANGE RESINS FOR URANIUM SORPTION UNDER LOW-TEMPERATURE CONDITIONS



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Annotatsiya. Ushbu tadqiqotda texnologik eritmalardan uranni sorbsiyalashda qo'llaniladigan ion almashinuvchi smolalarning fizik-kimyoviy va texnologik xossalari o'rganilgan. BO-020, AMP, Purolite A-606, BD-706, Tulsion A-3663, Amberlite IRA-120, Resinacs va Dowex-1 kabi sakkiz turdagi ion almashinuvchi smola granulometrik tarkibi, mexanik mustahkamligi, solishtirma sirt maydoni, zichligi, g'ovak tuzilishi, selektivligi, regeneratsion xossalari hamda manfiy haroratlarga chidamliligi bo'yicha baholangan. Natijalar o'rganilgan smolalarning strukturaviy va texnologik xususiyatlarida sezilarli farqlar mavjudligini ko'rsatdi. BO-020 88% bilan eng yuqori sifat darajasini va 65,00 m²/g bilan eng katta solishtirma sirt maydonini namoyon etgan bo'lsa, AMP 85% sifat darajasi va 54,00 m²/g solishtirma sirt maydonini ko'rsatdi. Past harorat sharoitida o'tkazilgan tajribalar muzlash mexanik mustahkamlik va zarrachalar o'lchamining kamayishiga olib kelishi mumkinligini, bunda parchalanish darajasi smolaning tuzilishi va granulometrik xususiyatlariga bog'liqligini ko'rsatdi. Olingan natijalar texnologik va past haroratli ekspluatatsiya sharoitlarida uranni samarali ajratib olish uchun ion almashinuvchi smolalarni tanlashga kompleks asos yaratadi.

Kalit so'zlar: uran sorbsiyasi; ion almashinuvchi smolalar; fizik-kimyoviy xossalari; mexanik mustahkamlik; solishtirma sirt maydoni; past haroratga chidamlilik.

Аннотация. В данном исследовании изучены физико-химические и технологические свойства ионообменных смол, используемых для сорбции урана из технологических растворов. Восемь ионообменных смол, включая BO-020, AMP, Purolite A-606, BD-706, Tulsion A-3663, Amberlite IRA-120, Resinacs и Dowex-1, были оценены по гранулометрическому составу, механической прочности, удельной площади поверхности, плотности, пористой структуре, селективности, регенерационным свойствам и устойчивости к отрицательным температурам. Результаты показали значительные различия в структурных и технологических характеристиках исследованных смол. BO-020 продемонстрировала наивысшую степень качества — 88% и наибольшую удельную площадь поверхности — 65,00 м²/г, тогда как AMP показала степень качества 85% и удельную площадь поверхности 54,00 м²/г. Эксперименты при низких температурах показали, что замораживание может приводить к снижению механической прочности и размера частиц, при этом степень разрушения зависит от структуры смолы и её гранулометрических характеристик. Полученные результаты создают комплексную основу для выбора ионообменных смол с целью эффективного извлечения урана в технологических и низкотемпературных условиях эксплуатации.

Ключевые слова: сорбция урана; ионообменные смолы; физико-химические свойства; механическая прочность; удельная площадь поверхности; устойчивость к низким температурам.

Abstract. This study investigates the physicochemical and technological properties of ion-exchange resins used for uranium sorption from technological solutions. Eight ion-exchange resins, including BO-020, AMP, Purolite A-606, BD-706, Tulsion A-3663, Amberlite IRA-120, Resinacs, and Dowex-1, were evaluated according to their granulometric composition, mechanical strength, specific surface area, density, porous structure, selectivity, regeneration properties, and resistance to negative temperatures. The results demonstrated significant differences in the structural and technological characteristics of the investigated resins. BO-020 showed the highest quality degree of 88% and the largest specific surface area of 65.00 m²/g, while AMP demonstrated a quality degree of 85% and a specific surface area of 54.00 m²/g. Low-temperature experiments showed that freezing can reduce mechanical strength and particle size, with the degree of destruction depending on resin structure and granulometric characteristics. The obtained results provide a comprehensive basis for selecting ion-exchange resins for efficient uranium recovery under technological and low-temperature operating conditions.

Keywords: uranium sorption; ion-exchange resins; physicochemical properties; mechanical strength; specific surface area; low-temperature resistance.

INTRODUCTION

Uranium recovery from productive solutions is an important stage of hydrometallurgical processing, particularly in technologies based on in-situ leaching. Ion-exchange sorption is widely used for the concentration and recovery of uranium from dilute technological solutions [2]. The efficiency of this process is closely related to the properties of ion-exchange resins and their ability to maintain stable sorption characteristics during technological operation [6].

The performance of ion-exchange resins depends on a combination of physicochemical and technological parameters, including granulometric composition, mechanical strength, specific surface area, density, porosity, selectivity, ion-exchange capacity, and regeneration degree. These characteristics determine the sorption capacity, mass-transfer conditions, hydraulic behavior, and operational stability of the resin. Therefore, a comprehensive evaluation of ion-exchange materials is important for selecting suitable resins for uranium recovery.

The structure and porosity of resin granules play a significant role in the sorption process. The porous structure provides conditions for the diffusion of uranium-containing species into the resin matrix, while the polymer structure influences swelling, mechanical strength, and ion-exchange properties. For uranium-processing applications, ion-exchange resins are required to have high mechanical strength, suitable granulometric composition, high sorption capacity, and favorable regeneration properties [11].

Temperature is an important factor affecting the stability of ion-exchange resins. At sub-zero temperatures, freezing of water inside the resin pores can cause mechanical stresses, leading to cracking, deformation, and cryodestruction. The results indicate that resistance to freezing depends on particle size and structural characteristics, with smaller particles showing greater stability [4].

This study assesses ion-exchange resins used for uranium sorption according to their granulometric composition, mechanical strength, structural properties, selectivity, and regeneration characteristics. Particular attention is given to changes caused by low temperatures in order to identify the factors affecting resin stability and sorption efficiency [12].

LITERATURE REVIEW

A number of studies have investigated the application and improvement of ion-exchange materials for uranium recovery from aqueous and technological solutions. Mahmoud O. A. investigated the sorption of uranium ions using ion-exchange resins containing nanomagnetic particles. The study demonstrated increased uranium sorption capacity, with maximum uptake values of approximately 92 and 158 mg/g under the investigated experimental conditions.

Kononov A. B. studied the intensification of uranium sorption from productive solutions using ultrasonic treatment. The results showed that ultrasonic exposure increased the efficiency of the ion-exchange sorption process. The effect depended on the uranium concentration in the solution, demonstrating the potential of ultrasonic treatment for improving mass transfer during uranium sorption.

Spirin E. K. investigated the effect of low temperatures on ion-exchange processes and the behavior of ion-exchange materials during freezing. His research examined temperatures down to approximately -50°C and investigated structural changes in ion-exchange resins under low-temperature conditions. These studies are important for understanding the stability of resins exposed to freezing conditions.

Previous studies have mainly addressed uranium sorption capacity, process intensification, mechanical stability, and the influence of low temperatures on ion-exchange materials. However, the combined evaluation of granulometric composition, mechanical strength, porosity, selectivity, regeneration characteristics, and resistance to sub-zero temperatures remains important. Therefore, the present study focuses on a comprehensive evaluation of different ion-exchange resins used for uranium sorption, with particular attention to their stability and performance under low-temperature conditions.

RESEARCH METHODOLOGY

The research was conducted to investigate the physicochemical and technological properties of ion-exchange resins used for uranium sorption from technological solutions and to evaluate their stability under low-temperature conditions. The study examined BO-020, AMP, Purolite A-606, BD-706, Tulsion A-3663, Amberlite IRA-120, Resinacs, and Dowex-1 ion-exchange resins. The main parameters investigated were granulometric composition, mechanical strength, porosity, density, specific surface area, ion-exchange capacity, selectivity, regeneration degree, and resistance to negative temperatures (Table 1).

Table 1.

Main parameters investigated

No.	Parameter	Evaluation
1	Granulometric composition	Particle-size distribution
2	Mechanical strength	Resistance to mechanical destruction
3	Specific surface area	Available sorption surface
4	Density	Structural characteristics of the resin
5	Porosity	Pore volume and pore structure
6	Ion-exchange capacity	Uranium sorption capacity
7	Selectivity	Ability to preferentially sorb uranium
8	Regeneration degree	Efficiency of uranium desorption
9	Low-temperature resistance	Stability after freezing

Source: Author's elaboration

The granulometric composition of the ion-exchange resins was determined using wet and dry sieve methods. The resin samples were separated into different particle-size fractions, and the proportion of each fraction was determined. The results were used to characterize the particle-size distribution and evaluate changes in the resin granules after exposure to low temperatures.

The porous characteristics of the resins were determined by measuring their specific surface area, density, total pore volume, and average pore diameter. The results obtained for the investigated ion-exchange resins are presented in Table 2 (Table 2).

Table 2.

Porous characteristics of the investigated ion-exchange resins

Ion-exchange resin	Specific surface area, m ² /g	Apparent density, g/cm ³	True density, g/cm ³	Total pore volume, cm ³ /g	Average pore diameter, Å
BO-020	65.00	0.6732	1.1040	0.580	356
AMP	54.00	0.5500	1.0621	0.877	650
Purolite A-606	30.50	0.5740	1.0950	0.828	1090
BD-706	51.69	0.4690	1.0500	1.1798	913
Tulsion A-3663	29.50	0.4840	1.2529	1.2529	1700
Amberlite IRA-120	29.44	0.5260	1.0322	0.9323	1300
Resinacs	40.00	0.7442	1.0793	0.4130	410
Dowex-1	35.05	0.5523	1.1070	0.5337	570

Source: Author's elaboration

The regeneration properties of saturated ion-exchange resins were also investigated. Uranium was desorbed from the saturated resin using regenerating solutions under dynamic conditions. The regeneration degree was determined from the amount of uranium removed from the resin and its residual content after regeneration.

ANALYSIS AND RESULTS

The analysis showed that the investigated ion-exchange resins differ in their granulometric, mechanical, structural, sorption, and regeneration properties. The studied resins included BO-020, AMP, Purolite A-606, BD-706, Tulsion A-3663, Amberlite IRA-120, Resinacs, and Dowex-1.

Granulometric analysis indicated that BO-020 had the highest working fraction, while Purolite A-606, Dowex-1, Amberlite IRA-120, and Tulsion A-3663 had finer particle compositions. These differences can affect the interaction of the resin with technological solutions and its mechanical stability during operation.

The quality assessment showed that BO-020 (88%) and AMP (85%) had the highest quality degrees, followed by Purolite A-606 (80%) and Amberlite IRA-120 (77%). The specific surface area was also highest for

BO-020 (65.00 m²/g), followed by AMP (54.00 m²/g) and BD-706 (51.69 m²/g). Low-temperature tests showed that freezing reduced both mechanical strength and particle size. The A-606 and AMP samples showed greater changes, while BO-020 demonstrated comparatively higher resistance to freezing and cryodestruction (Figure 1).

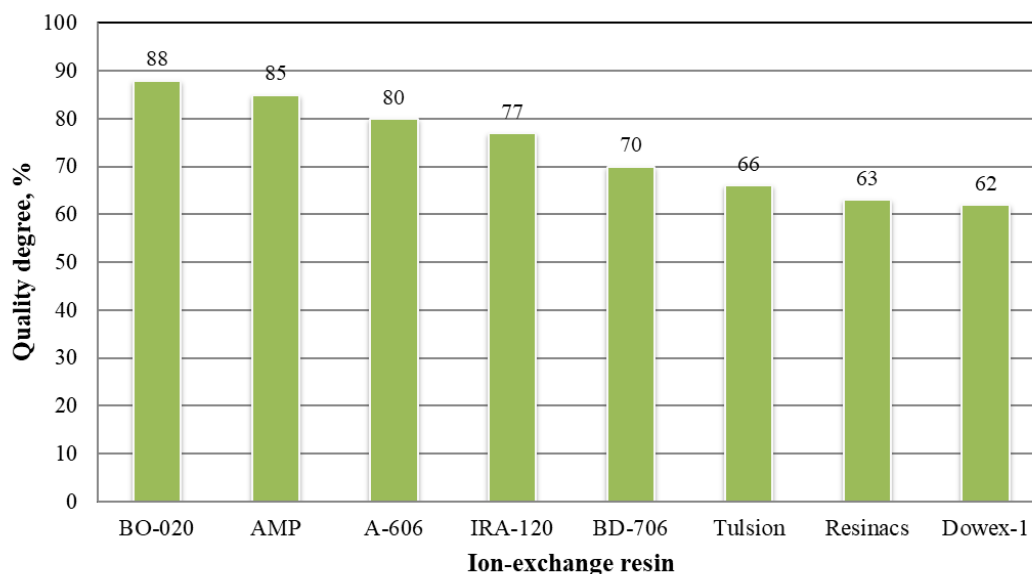


Figure 1. Quality degree of the investigated ion-exchange resins.

(Source: Author's elaboration).

The results presented in Figure 1 show clear differences in the quality degree of the investigated ion-exchange resins. BO-020 had the highest value (88%), followed by AMP (85%) and A-606 (80%), while IRA-120, BD-706, Tulsion, Resinacs, and Dowex-1 showed 77%, 70%, 66%, 63%, and 62%, respectively. These results demonstrate that the overall quality of the resins is determined by the combined effect of granulometric composition, mechanical strength, specific surface area, density, selectivity, and regeneration properties. selectivity, and regeneration characteristics rather than a single parameter (Table 3).

Table 3.

Integrated quality assessment of the ion-exchange resins

Ion-exchange resin	I	II				IVb	Total points	
BO-020	1	2	2	1	1	1	8	1
AMP	6	1	1	3	3	6	20	2
Purolite A-606	2	3	5	6	7	3	26	3
Amberlite IRA-120	6	6	3	4	6	2	27	4
BD-706	7	6	4	6	4	4	31	5
Tulsion	5	5	7	5	5	5	32	6
Resinacs	8	7	8	2	2	7	34	7
Dowex-1	3	8	4	8	8	8	39	8

Source: Author's elaboration

The specific surface area is one of the important structural characteristics determining the sorption properties of ion-exchange resins. In the present study, considerable differences were observed among the investigated materials. BO-020 exhibited the highest specific surface area of 65.00 m²/g, followed by AMP (54.00 m²/g) and BD-706 (51.69 m²/g). The specific surface areas of Resinacs and Dowex-1 were 40.00 and 35.05 m²/g, respectively, whereas A-606, Tulsion, and IRA-120 showed lower values of 30.50, 29.50, and 29.44 m²/g, respectively (Figure 2).

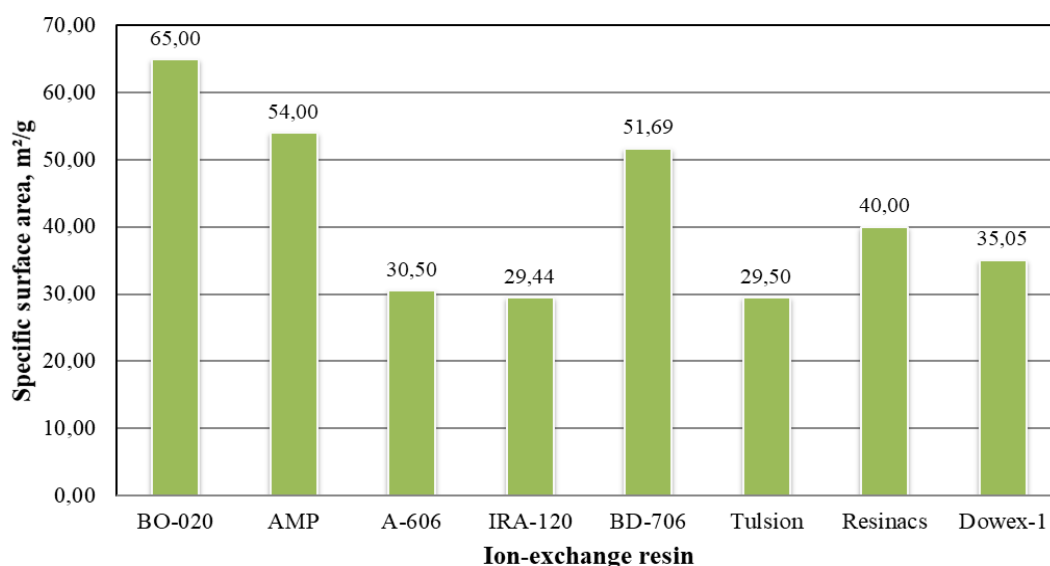


Figure 2. Specific surface area of the investigated ion-exchange resins.

(Source: Author's elaboration).

The integrated results show that the quality of the ion-exchange resins is controlled by the interaction of several parameters. The quality-degree assessment and specific-surface-area comparison provide complementary information: the resin with the largest specific surface area is not necessarily characterized by the highest overall quality degree. Therefore, selection for uranium sorption should consider granulometric composition, mechanical strength, porous structure, sorption properties, regeneration behavior, and resistance to low-temperature effects as a combined set of characteristics.

CONCLUSIONS AND RECOMMENDATIONS

The obtained results demonstrate that the physicochemical and technological characteristics of ion-exchange resins significantly differ depending on their granulometric composition, mechanical strength, porous structure, specific surface area, density, selectivity, and regeneration properties. Among the investigated resins, BO-020 showed the highest quality degree (88%) and the largest specific surface area (65.00 m²/g), followed by AMP with 85% and 54.00 m²/g, respectively. These results indicate that the combined evaluation of structural and technological parameters provides a more complete assessment of the suitability of ion-exchange resins for uranium sorption.

The results showed that low-temperature exposure can reduce the mechanical strength and particle size of ion-exchange resins. BO-020 demonstrated comparatively higher stability after freezing, while A-606 and AMP showed greater changes. Therefore, effective resin selection for uranium recovery should consider physicochemical, mechanical, sorption, and low-temperature properties together.

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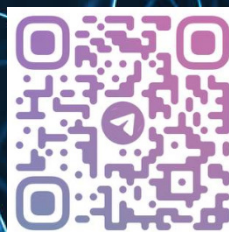
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