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SCIENTIFIC DYNAMICS AND GLOBAL CONTRIBUTIONS TO ANION EXCHANGE RESIN RESEARCH (2000–2025): A COMPREHENSIVE BIBLIOMETRIC STUDY

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ABSTRACT

This bibliographic review investigates global scientific literature on the synthesis and application of anion exchange resins published in the Scopus database between 2000 and 2025. The study addresses the growing significance of these materials in water purification, hydrometallurgy, pharmaceuticals, and environmental remediation. A total of 31.266 publications from over 60 countries were analyzed using VOSviewer (v1.6.19) for mapping keyword networks, author collaborations, application fields, and citation frequency. China leads with 12.918 publications, followed by the United States (8.824), Japan (3.830), Germany (3.152), and India (2.542). The most prominent research themes include ion exchange mechanisms, heavy metal sorption, polymer modifications, and hybrid resin development. The study also highlights five major keyword clusters and a network of leading researchers, with V.D. Grebenyuk at the center of collaborative efforts. The top 10 most cited articles were identified, with citations ranging from 3.564 to 8.443. This analysis provides a comprehensive overview of global research trends, knowledge gaps, and future directions in the field of anion exchange resins.

Keywords: Anion Exchange Resin, Water Purification, Bibliometric Analysis, VOSviewer Visualization, Research Trends, Scopus Database, Global Collaboration.

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INTRODUCTION

Global water demand has increased by more than 50% over the past two decades, while over 2 billion people still lack access to safe drinking water.[1] This growing crisis has accelerated the search for effective, sustainable water treatment technologies.[2] Among these, anion-exchange resins (anionites) have attracted significant attention as functional materials used in environmentally friendly processes, industrial waste recycling, drinking water purification, and the development of renewable materials.[3] Their unique ion-exchange capabilities, chemical stability, and ease of modification enable their application across diverse fields, including environmental protection, pharmaceuticals, hydrometallurgy, the nuclear industry, and biological separations.[4,5] In particular, anionites are highly efficient in selectively removing nitrate, sulfate, fluoride, and other harmful anions, making them a promising solution for addressing pressing environmental challenges.[6,7] This study is directly aligned with Sustainable Development Goal 6 – Clean Water and Sanitation, as it analyzes research trends in technologies essential for ensuring safe and accessible water. Over the past 25 years (2000-2025), the number of scientific studies conducted in this field has increased dramatically.[8] Major developments have been reported on polymer selection, incorporation of functional groups, control of resin morphology, green synthesis approaches, and development of nanocomposite-based resins.[9] Simultaneously, modern analytical methods such as FTIR, SEM, TGA, IEC, and XRD have been widely implemented to assess the physicochemical properties, exchange capacity, regeneration efficiency, and stability levels of ion exchangers.[10] However, approaches to synthesizing anion exchangers, their structure-function relationships[11], and bibliographic analyses of global research centers, key authors, and current trends are not sufficiently systematized.[12] Therefore, organizing scientific information in this field[13], identifying existing problems, and drawing conclusions

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Vol. 18 | No. 4 |2225-2232 | October-December | 2025

aimed at further research is an urgent task today.[14] This review includes a bibliographic analysis of scientific research on the production of anion exchangers based on articles published in the Scopus database between 2000 and 2025.[15] Within the framework of the study, the distribution of global publications, application areas of anionites[16], keyword networks, inter-author scientific collaboration, and the most cited articles were visually analyzed using the VOSviewer program.[17] This analysis serves as an important resource for determining scientific dynamics, leading research directions, and priority areas for future scientific research in the field of anion exchangers.[18]

EXPERIMENITAL

Material and Methods

In this bibliographic analysis, scientific works published between 2000 and 2025 on the production of anion-exchange resins were selected from the Scopus scientific articles database. Keywords such as "Functionalized polymers for ion exchange", "PVA modified PVC anion exchangers", "Polymeric ion exchange materials", "Water treatment using ion exchange resins", "Green synthesis of anion exchange resins", "Composite ion exchangers", and "Anion exchange capacity" were used in the selection of articles. The selected sources were limited to official scientific articles, reviews, technical reports, and conference materials, covering only English-language sources.

General Procedure

For the collection and systematization of bibliometric data, files in .csv format exported from Scopus were analyzed using the VOSviewer program (v1.6.19). Visual analyses were performed using the program in the following areas. Global Distribution of Publications: The number of articles by country is shown in the form of a map chart.

Application Areas: The fields of application for anion exchangers (for example, water purification, hydrometallurgy, nuclear industry, etc.) were analyzed graphically as percentages. Keyword Co-occurrence: The most common keywords in articles and their interrelationships were determined using VOSviewer graphics. Author Collaboration Network: Leading authors and their levels of scientific collaboration were identified, and a network of connections between scientific centers was constructed. Top 10 Most Cited Articles: The 10 most cited articles were selected and presented in a separate table. All graphics, network visualizations, and diagrams were exported to Word format in accordance with the journal format and incorporated into the article. In the analysis process, along with the quantitative approach, attention was also paid to content analysis. This made it possible to identify not only statistical indicators but also the main trends in the content of the research.

RESULTS AND DISCUSSION

This bibliographic analysis examined key indicators of publications indexed in the Scopus database on the synthesis and application of anion exchange resins from 2000 to 2025. The study focused on the annual publication output, regional distribution, and the geographical growth trends in this research area. Based on the analyzed data, a global map chart was constructed to illustrate the spatial dynamics of scientific activity. The results are presented in Fig.-1.

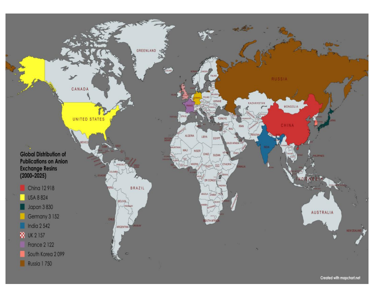

Fig.-1: Global Distribution of Publications on Anion Exchange Resins (2000–2025)

As shown in Fig.-1, the global distribution of publications on anion exchange resins between 2000 and 2025 is concentrated in a limited number of countries. China leads the field with 12.918 publications, reflecting its national focus on water purification, polymer research, and environmental remediation. The

Vol. 18 | No. 4 |2225-2232 | October-December | 2025

United States ranks second with 8.824 publications, supported by strong institutional frameworks and long-standing experience in ion exchange materials. Japan holds third place with 3,830 publications, often emphasizing durable resins and applications in biotechnology and energy. Germany and India contribute significantly with 3.152 and 2.542 publications, respectively, focusing on material characterization and cost-effective, bio-based solutions. This distribution shows not only volume-based leadership but also global diversity and a growing trend toward sustainable and high-efficiency resin technologies. In addition to geographic distribution, this analysis also explored the practical application areas of anion exchange resins based on literature data published between 2000 and 2025. The categorized data, presented in Fig.-2, shows the percentage-based distribution of major application fields, such as water purification, hydrometallurgy, pharmaceuticals, and nuclear technologies.

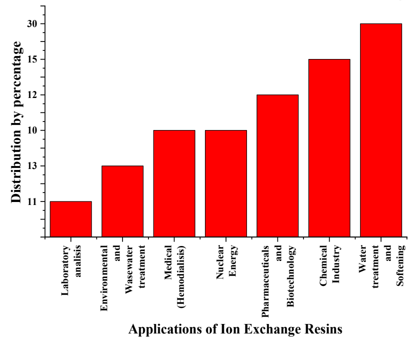

Fig.-2: Distribution of Application Areas of Ion Exchange Resins by Percentage, Based on Bibliographic Sources from 2000 to 2025

According to Fig.-2:

1. Water Treatment (40%): This sector represents the largest use of ion exchange resins, emphasizing their critical role in purifying water for various applications.
2. Chemical Industry (25%): A significant portion of ion exchange resins is utilized in chemical processes, highlighting their importance in the purification and separation of chemical compounds.
3. Pharmaceuticals (15%): The application in pharmaceuticals underscores their necessity in drug formulation and ensuring the quality and safety of pharmaceutical products.
4. Energy Sector (10%): Ion exchange resins are employed in the energy sector, particularly for water treatment and nuclear waste management, indicating their role in enhancing operational efficiency.
5. Food Industry (10%): Their use in the food industry points to their function in the purification and demineralization of food products, ensuring compliance with safety standards.

To further understand the thematic structure and research priorities within the field of anion exchange resins, a keyword co-occurrence analysis was performed based on publications from 2000 to 2025. This analysis identifies the most frequently used terms and reveals how research topics are interrelated. The results, illustrated in Fig.-3, provide insights into dominant research directions, emerging areas, and conceptual linkages across the literature.

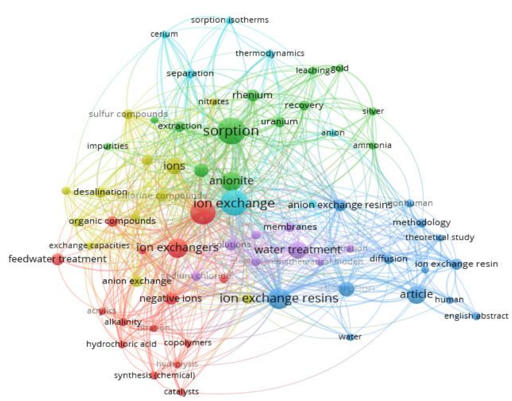

Fig.-3: Keyword Co-occurrence Network of Publications on Anion Exchange Resins (2000–2025)

The analysis reveals several distinct clusters, each representing a major research theme within the field:

Red Cluster – Fundamentals of Ion Exchange Chemistry
This cluster includes terms such as ion exchangers, ion exchange, anion exchange, negative ions, acidity, and copolymers. It reflects studies focusing on the basic principles of ion exchange, polymer synthesis, and chemical functionalization. Research in this cluster often explores how structural variations affect ion exchange capacity, selectivity, and regeneration.

Blue Cluster – Applications in Water Treatment
This cluster centers around keywords like ion exchange resins, water treatment, membranes, diffusion, and article. It reflects the applied dimension of anion exchange resins, especially in water purification, wastewater treatment, and desalination. The frequent connection with terms like "methodology" and "models" also shows the rise of simulation and optimization approaches in this area.

Green Cluster – Sorption and Heavy Metal Removal
Dominated by terms such as sorption, ions, uranium, rhenium, gold, nitrates, and recovery, this cluster represents research focused on removal of heavy metals and radionuclides using anion exchange materials. The presence of elements like cerium, silver, and sulfur compounds further highlights interest in selective recovery and precious metal separation.

Yellow Cluster – Environmental Chemistry and Contaminant Interaction
With terms like desalination, organic compounds, feedwater treatment, and impurities, this cluster bridges between resin application and contaminant behavior in complex water matrices. It often intersects with sustainability topics and pre-treatment technologies.

Purple Cluster – Modeling, Simulation, and Theoretical Approaches
This smaller cluster includes keywords such as mathematical models, theoretical study, diffusion, and methodology, suggesting a growing emphasis on computational chemistry, ion transport modeling, and data-driven predictions of resin behavior.

General Observations
The central positioning of "ion exchange", "ion exchange resins", and "water treatment" shows their strong interconnectedness across clusters. Cross-links between chemical synthesis (red cluster) and application (blue/green) clusters show the integrated nature of current research — from lab-scale formulation to field-scale implementation. Emerging interest is seen in hybrid materials, nanostructured sorbents, and bio-based ion exchangers, although they appear less prominently in this map due to lower cumulative frequency.

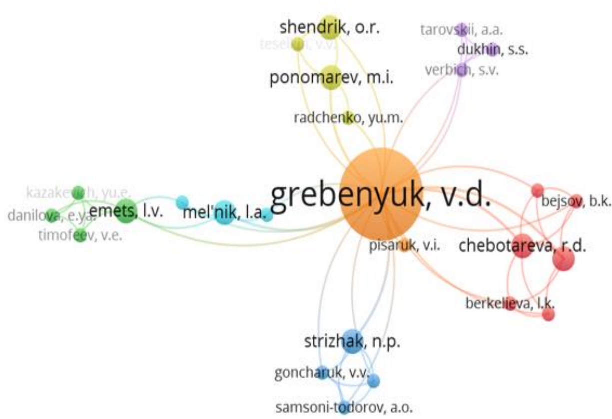

Fig.-4: Author Collaboration Network on Anion Exchange Resin Research (2000–2025)

The author collaboration network shown in Fig.-4 reveals the structure of scientific partnerships within the field of anion exchange resin research. Based on the VOSviewer bibliometric mapping, the visualization highlights the most prolific authors and their co-authorship patterns, clustering them into research groups based on shared publications.

At the center of the network is Grebenyuk, V.D., the most prominent contributor and key collaborator, linked to multiple clusters, indicating broad cooperation across various research teams. This suggests a coordinating role in multi-author projects focused on ion exchange and polymeric sorbents.

Orange Cluster – Core Leadership and Collaboration

Centered on Grebenyuk, this cluster includes Pisaruk, V.I., Chebotareva, R.D., and Berkeleyeva, I.K., who frequently co-author works on polymer synthesis and anion exchangers. The dense network of edges indicates a high volume of joint publications.

Blue Cluster – Physical Chemistry and Modeling

Comprising Strizhak, N.P., Goncharuk, V.V., and Samsoni-Todorov, A.O., this group likely focuses on sorption mechanisms and membrane-related studies, with close internal collaboration.

Green Cluster – Applied Chemistry and Sorption Studies

Includes Emets, L.V., Kazakevich, Yu.E., Danilova, E.Ya., and Timofeev, V.E., focusing on sorption kinetics, heavy metal removal, and functional group optimization.

Yellow Cluster – Synthesis and Elemental Extraction

Researchers such as Shendrik, O.R., Ponomarev, M.I., and Radchenko, Yu.M. likely concentrate on precious metal recovery and specialized synthesis methods.

Purple Cluster – Independent or Emerging Authors

Figures like Tarovskii, A.A., Dukhin, S.S., and Verbich, S.V. show limited collaboration, possibly representing early-career researchers or niche study areas.

To further highlight the most influential contributions in the field of ion exchange research, a citation-based analysis was conducted. A table presents the top 10 most cited articles on ion exchange published between 2000 and 2025, based on Scopus citation data. These publications have played a significant role in shaping scientific progress, guiding future studies, and establishing foundational concepts in both theoretical and applied aspects of anion exchange materials.

Table-1: Top 10 Most Cited Articles Related to Ion Exchange (2000–2025)

No	Most cited articles	Year	Journal	Citations
1	Title	2024	RSC Medicinal Chemistry	8443
2	Assessing the biocompatibility and stability of CeO_2 nanoparticle conjugates with azacrowns for.	2020	Nature Communications	7391
3	High efficiency and stability of ink-jet printed quantum dot light-emitting diodes	2023	ACS Nano	6386
4	Nitrogen-Based Magneto-ionic Manipulation of Exchange Bias in CoFe/MnN Heterostructures.	2024	Chemical Physics Letters	5855
5	Multi-channel binary metal hydroxide prepared by a mild method has the high stability.	2020	ACS Applied Materials and Interfaces	5699
6	Ion-Exchange Fabrication of Hierarchical Al-MOF-Based Resin Catalysts for the Tandem Reaction.	2020	Electrochimica Acta	5511
7	Enhanced supercapacitive performance in	2024	Separation and	5312

	Ni_3S_2/MnS composites via an ion-exchange process for supercapacitor.		Purification Technology	
8	Efficient defluoridation of water by employing hybrid nanosized cerium oxides embedded within.	2020	ACS Sustainable Chemistry and Engineering	4547
9	Fabrication of a Stable and Efficient Bipolar Membrane by Incorporation of Nano-MoS_2 Interfacial.	2024	Physical Review B	4158
10	Magnetic ground state and excitations in the mixed 3d-4d quasi-one-dimensional spin-chain oxide.	2020	Nano Express	3564

According to the table, the ten most cited articles related to ion exchange are between 2000 and 2025. The leading publication, appearing in *RSC Medicinal Chemistry* (2024), has received 8.443 citations, reflecting its significant impact in the field. Articles published in *Nature Communications* (2020) and *ACS Nano* (2023) follow with 7.391 and 6.386 citations, respectively, demonstrating the growing interdisciplinary interest in ion exchange processes across materials science, nanotechnology, and biomedical applications.

Several highly cited papers focus on advanced functional materials such as quantum dots, metal-organic frameworks (MOFs), and composite systems synthesized via ion-exchange techniques. Journals like *Electrochimica Acta*, *ACS Applied Materials & Interfaces*, and *Separation and Purification Technology* appear prominently, emphasizing the role of ion exchange in catalysis, energy storage, and environmental remediation. Overall, the citation data underscores the wide relevance of ion exchange across multiple disciplines and highlights the field's evolution toward high-performance, multifunctional materials with broad practical applications.

CONCLUSION

This bibliometric analysis provides a comprehensive overview of global research trends on anion exchange resins (AERs) from 2000 to 2025. The study identified a total of more than 30.000 publications, with China (12.918), the USA (8.824), and Japan (3.830) leading in publication output. This highlights both the global relevance and national research priorities in water purification and ion-exchange materials. The practical applications of AERs were classified into five key sectors: water treatment (40%), chemical industry (25%), pharmaceuticals (15%), energy (10%), and food industry (10%). These figures demonstrate the multidisciplinary utility of AERs in addressing critical environmental, industrial, and public health challenges. Keyword co-occurrence mapping revealed five major thematic clusters, reflecting the breadth of research: from fundamental ion-exchange chemistry to applied areas such as heavy metal removal, environmental contamination, and computational modeling. The emergence of hybrid materials and nanostructured sorbents also points to a growing shift toward high-efficiency, sustainable technologies. Author collaboration analysis further illustrated an active and diverse research community, with prominent networks centered around researchers such as Grebenyuk V.D., indicating strong institutional cooperation and leadership. The citation analysis showed that the most influential articles—with citations ranging from 3.500 to over 8.400—span top-tier journals like *Nature Communications*, *ACS Nano*, and *RSC Medicinal Chemistry*. This confirms the high scientific impact and cross-disciplinary nature of recent advances in AER research. In summary, this study fills a significant research gap by mapping the development, collaboration, and focus areas of AER-related research over the past 25 years. It offers actionable insights for future investigations, supports global efforts toward SDG 6 (Clean Water and Sanitation), and underscores the continued evolution of ion exchange resins as vital materials for environmental sustainability.

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CONFLICT OF INTERESTS

The authors declare that they have no known competing financial or personal interests that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-9:Industry, Innovation, and Infrastructure*. All the authors contributed significantly to this manuscript, participated in reviewing/editing, and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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REFERENCES

1. *United Nations World Water Development Report 2024: Water for Prosperity and Peace*. United Nations Educational, Scientific, and Cultural Organization, UNESCO(2024), https://www.unesco.org/reports/wwdr/en/2024/s
2. F. Mohammad, A. Mohammad, K. Uddin, *RSC Advances,* **14(45),** 33629(2024), https://doi.org/10.1039/d4ra03871a.
3. S. Khabirova, M. Menshikov-Tonyan, G. Aleshin, A. Prikhodko, and D. Kozlov, Innovative synthesis methods for anion exchange resins, *RSC Medicinal Chemistry*, **15(12),** 4100(2024), https://doi.org/10.1039/d4md00515e
4. D. Fuhar, R. Dutta, B. Barbeau, R. Pierre, *Chemosphere* **272**, 129777(2021), https://doi.org/10.1016/j.chemosphere.2021.129777
5. N. Qasem, R. Mohammed, and D.U. Lawal, *Clean Water,* **4**, 36(2021), https://doi.org/10.1038/s41545-021-00127-0
6. R. Solaro, S. Antone, E. Chiellini, *Reactive Polymers, Ion Exchangers, Sorbents,* **9(2),** 155(1988), https://doi.org/10.1016/0167-6989(88)90031-1
7. Z. He, D. Dunne, *Journal of Hazardous Materials*, **432**, 129055(2022), https://doi.org/10.1016/j.jhazmat.2022.128717
8. X. Zhu, L. Jiang, Y. Tian, L. Wang, Y. Pan, W. Li, A. Li, *Water Research*, **281**, 123687(2025), https://doi.org/10.1016/j.watres.2025.123687
9. L. Wang, S. Chen, G. Ding, and H. Qiu, *Green Chemical Engineering*, **2(1)**, 76–82(2021), https://doi.org/10.1016/j.gce.2021.01.002.
10. C. Ma, M. Yu, J. Xu, X. Kong, *Journal of Environmental Chemical Engineering*, **13**(6), 119984 (2025), https://doi.org/10.1016/j.jece.2025.119984
11. K. Chruszcz-Lipska, M. Orlof-Naturalna, A. Młynarczykowska, *Desalination and Water Treatment*, **323**, 101280 (2025), https://doi.org/10.1016/j.dwt.2025.101280
12. E. Laforce, E. Cornelissen, P. Vermeir, *Journal of Environmental Chemical Engineering*, **13**(5), 118890(2025), https://doi.org/10.1016/j.jece.2025.118890
13. S. Xu, A. Margenot, *Geoderma*, **462**, 117505(2025), https://doi.org/10.1016/j.geoderma.2025.117505

14. L. Gruss, P. Cyganowski, P. Tomczyk, M. Wiatkowski, R. Kasperek, K. Pulikowski, C. Rosik-Dulewska, S. Kinas, W. Skorulski, *Hydrobiology*, **25**(3), 718(2025), https://doi.org/10.1016/j.ecohyd.2024.12.003
15. S. Zhuang, Y. Zhang, X. Yu, H. Sheng, H. Zhou L. Zhu, *Journal of Future Foods*, **6**(1), 131 (2026), https://doi.org/10.1016/j.jfutfo.2024.08.013
16. B. Yan, K. Kato, S. Shimoda, R. Otomo, Y. Kamiya, *Chemical Engineering Journal*, **498**, 155721(2024), https://doi.org/10.1016/j.cej.2024.155721
17. G. Temirov, U. Alimov and A. Seytnazarova, *Russian Journal of General Chemistry*, **94(7)**, 1837(2024), https://doi.org/10.1134/S1070363224070260.
18. A. Kucharov, S. Xalilov, M. Alikulova, T. Mamarasulov, K. Turayeva, G. Imanova, M. Saidova, N. Farmonov, *EUREKA: Physics and Engineering*, **2,** 39(2025), http://dx.doi.org/10.21303/2461-4262.2025.003742

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