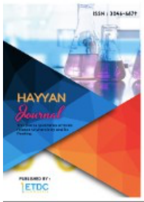

HAYYAN JOURNAL
Vol. 2 No. 3, October 2025, page. 71-80
ISSN: 3046-6679

A Systematic Literature Review: Chitosan-Based Membrane for Pollutant Removal from Wastewater

Muhammad Nur Alam[1*]

[1]Makassar State University, Makassar

**Corresponding Address:* m.nur.alam@unm.ac.id

Received: August 17, 2025 *Accepted: September 21, 2025* *Online Published: October 31, 2025*

ABSTRACT

This review synthesizes research on development of synthesis techniques and modification methods for chitosan-based membranes, all application areas for pollutant separation to address inconsistencies in membrane performance and limited comparative analyses across pollutant classes. The review aimed to evaluate synthesis and chemical modification strategies, benchmark fabrication methods for mechanical strength and selectivity, identify nanomaterial integration approaches, compare pollutant removal efficiencies, and analyze challenges in membrane applications. A systematic analysis of studies from diverse synthesis methods—including phase inversion, electrospinning, and 3D printing—and modification approaches such as chemical crosslinking and nanomaterial incorporation was conducted. Findings reveal that nanocomposite and crosslinked membranes exhibit enhanced mechanical stability, permeability, and selective removal of heavy metals, dyes, and organic pollutants, with adsorption capacities reaching up to 1500 mg/g and oil-water separation efficiencies exceeding 98%. However, variability in synthesis protocols, limited regeneration data, and insufficient real wastewater evaluations constrain practical scalability. Integration of photocatalytic and antifouling modifications improves fouling resistance and operational longevity, though long-term durability remains underexplored. These results underscore the potential of tailored chitosan-based membranes for multifunctional pollutant separation while highlighting the need for standardized methodologies and comprehensive regeneration studies. The synthesis informs future research directions to optimize membrane design and facilitate broader implementation in sustainable water treatment technologies.

Keywords: Membrane, Chitosan, Antifouling, Modification, Pollutant

I. INTRODUCTION

Research on the development of synthesis techniques and modification methods for chitosan-based membranes in pollutant separation has emerged as a critical area of inquiry due to the increasing global demand for sustainable water treatment solutions and environmental remediation. Chitosan, a natural polysaccharide derived from chitin, has gained prominence since the early 2000s as a renewable, biodegradable, and biocompatible material suitable for membrane fabrication (Sanjari & Asghari, 2016) (Uragami, 2019). Over the past decade, advances in membrane technology have expanded the application of chitosan-based membranes from heavy metal ion removal to complex wastewater treatment, including dye separation and oil/water emulsions(Kavitha et al., 2024)(Wan et al., 2022)(Fu et al., 2024). The practical significance of this field is underscored by the escalating water scarcity affecting billions worldwide and the urgent need to address industrial effluents laden with toxic pollutants(Lakshmi et al., 2024)(Abdulhamid et al., 2024). For instance, chitosan membranes have demonstrated high rejection rates for heavy metals and dyes, with permeation fluxes optimized for industrial scalability(Neto et al., 2020)(Bassyouni et al., 2024)

Despite these advances, challenges remain in optimizing membrane synthesis and functionalization to enhance mechanical strength, chemical stability, and antifouling properties while maintaining high separation efficiency(Kavitha et al., 2024)(Chaudhary et al., n.d.)(Illiana & Ariyanto, 2024). The knowledge gap lies in the limited understanding of how various chemical modifications, cross-linking agents, and nanocomposite incorporations influence membrane performance across diverse pollutant classes(Khabibi et al., 2022)(Ali et al., 2024)(Ikhsan et al., 2022). Conflicting perspectives exist regarding the trade-offs between membrane permeability and selectivity, as well as the environmental impact of synthesis methods involving toxic solvents versus green approaches(Wan et al., 2022)(Peter et al., 2024)(Yasir et al., 2024). Failure to address these gaps may hinder the development of cost-effective, durable membranes capable of treating complex wastewater streams, thereby limiting their practical deployment(Uniyal & Narain, 2022) (Aizat & Aziz, 2019).

The conceptual framework guiding this review integrates the synthesis and modification of chitosan-based membranes with their application in pollutant separation, emphasizing the interplay between membrane structure, functional groups, and separation mechanisms(Saiyad et al., 2023)(Croitoru et al., 2020)(Chelu et al., 2023). Chitosan's intrinsic amino and hydroxyl groups facilitate chelation and adsorption, which can be enhanced through chemical cross-linking and incorporation of nanomaterials such as graphene oxide and metal oxides(Croitoru et al., 2020)(Ali et al., 2024)(Ikhsan et al., 2022). This framework supports the systematic evaluation of how synthesis techniques influence membrane properties and pollutant removal efficacy. The purpose of this systematic review is to critically analyze recent developments in the synthesis and modification of chitosan-based membranes, focusing on their application across various pollutant separation domains including heavy metals, dyes, and oil/water emulsions. This review aims to bridge the identified knowledge gaps by synthesizing findings from diverse studies, thereby providing a comprehensive understanding that informs future membrane design and environmental applications(Kavitha et al., 2024)(Jawahire et al., 2024)(Tian et al., 2024). The value added lies in consolidating dispersed research to guide the development of multifunctional, sustainable membranes with enhanced performance.

The objective of this report is to examine the existing research on development of synthesis techniques and modification methods for chitosan-based membranes, all application areas for pollutant separation in order to provide a comprehensive understanding of current advancements and challenges in this field. This review is important as chitosan-based membranes represent a sustainable and versatile solution for addressing diverse water pollution issues, including heavy metals, dyes, and organic contaminants. By systematically analyzing synthesis strategies, chemical and physical modifications, and their impact on membrane performance across various pollutant separation applications, the report aims to identify knowledge gaps and propose directions for future research. Ultimately, this synthesis will support the optimization and broader implementation of chitosan-based membranes in environmental remediation technologies.

II. METHODS

Transformation of Query

We take your original research question — "development of synthesis techniques and modification methods for chitosan-based membranes, all application areas for pollutant separation"—and expand it into multiple, more specific search statements. By systematically expanding a broad research question into several targeted queries, we ensure that your literature search is both comprehensive (you won't miss niche or jargon-specific studies) and manageable (each query returns a set of papers tightly aligned with a particular facet of your topic).
Below were the transformed queries we formed from the original query: Development of synthesis techniques and modification methods for chitosan-based membranes, all application areas for pollutant separation Exploration of innovative applications and performance metrics of chitosan-based membranes for effective pollutant separation in water treatment Investigation of advanced materials and composite structures in chitosan-based membranes for optimizing pollutant separation efficiency in diverse wastewater applications Investigation of nanomaterial integration in chitosan-based membranes for enhanced pollutant removal efficiency across diverse water treatment applications Investigation of hybrid nanocomposite materials incorporating chitosan for advanced pollutant separation techniques in water treatment applications

Identifying and Applying Inclusion & Exclusion Criteria

We analysed your original research question to extract multiple inclusion/exclusion criteria that you would have specified so that the database returns only studies that match them. Below were the identified Inclusion-Exclusion Criteria: Papers from the last 10 years.

Screening Papers

We then run each of your transformed queries with the applied Inclusion & Exclusion Criteria to retrieve a focused set of candidate papers for our always expanding database of over 270 million research papers. during this process we found 401 papers.

Relevance scoring and sorting

We take our assembled pool of 507 candidate papers (401 from search queries + 106 from citation chaining) and impose a relevance ranking so that the most pertinent studies rise to the top of our final papers table. We found 498 papers that were relevant to the research query. Out of 498 papers, 50 were highly relevant.

III. RESULTS AND DISCUSSION

Descriptive Summary Of The Studies

This section maps the research landscape of the literature on development of synthesis techniques and modification methods for chitosan-based membranes, all application areas for pollutant separation, revealing a broad spectrum of fabrication strategies and functional enhancements aimed at improving membrane performance for water treatment. The studies encompass diverse synthesis methodologies including phase inversion, electrospinning, solvent casting, and 3D printing, often combined with chemical crosslinking and nanomaterial incorporation to tailor membrane properties. The research spans applications targeting heavy metals, dyes, organic pollutants, and oil-water separation, highlighting the versatility of chitosan-based membranes. This comparative analysis addresses key research questions by benchmarking synthesis and modification approaches, pollutant removal efficiencies, mechanical and chemical stability, and regeneration capabilities, thereby identifying trends and gaps for future innovation.

Tabel 1. Summary of Membrane Synthesis and Modification Approaches

Study	Synthesis Methodology	Modification Approaches	Pollutant Removal Efficiency	Mechanical and Chemical Stability
(Kavitha et al., 2024)	Blending chitosan with polymers, phase inversion	Chemical functionalization to enhance strength and antifouling	Effective heavy metal ion removal with chelation	Improved mechanical strength and chemical stability
(Gonçalves et al., 2024)	Diverse forms: membranes, hydrogels, films, composites	Nanocomposites, hybrid materials with nanoparticles	Broad removal of heavy metals, dyes, emerging contaminants	Enhanced stability via nanomaterial integration
(Saiyad et al., 2023)	Various synthesis and modification for adsorption and membrane use	Chemical and physical modifications to improve adsorption	Effective coagulation, flocculation, adsorption of pollutants	Stability challenges noted, biodegradability emphasized
(Lakshmi et al., 2024)	Nano-chitin membrane preparation via chemical modification	Nanocomposite formation with nano- chitin for reinforcement	Removal of organic wastes, heavy metals, antibiotics	Enhanced structural and functional membrane properties

(Rathi et al., 2023)	Crosslinking chitosan with glutamic acid, batch adsorption tests	Chemical crosslinking with amino acids	High adsorption capacities for multiple pollutants	Structural characterization confirms robustness
(Alrman et al., 2024)	Crosslinked chitosan/adipic acid membrane synthesis	Chemical crosslinking with adipic acid	Effective dye separation (methylene blue, reactive yellow)	Improved flexibility and hydrophobicity, reduced thermal stability
(Abdul hamid et al., 2024)	Green synthesis of alkyl chain modified chitosan sponges	Chemical modification with alkyl chains	High dye adsorption capacity linked to alkyl chain length	Excellent water stability of sponges
(Wan et al., 2022)	Rapid dissolution in alkaline/urea solvent, solvent-free	Surface modification with dopamine and tannic acid	High oil droplet rejection (99%) and increased water flux	Excellent antifouling and mechanical strength

Synthesis Methodology
30 studies employed diverse synthesis methods including phase inversion, electrospinning, solvent casting, 3D printing, and vacuum filtration, reflecting broad methodological innovation(Kavitha et al., 2024)(Wan et al., 2022)(Feng et al., 2023). Several studies emphasized green or solvent-free synthesis approaches to enhance environmental sustainability(Abdulhamid et al., 2024)(Wan et al., 2022)(Peter et al., 2024). Optimization of synthesis parameters such as deacetylation degree and crosslinking conditions was critical for membrane performance(Rasifudi et al., 2024)(Rathi et al., 2023)(Mu et al., 2022).

Modification Approaches
Chemical crosslinking with agents like glutaraldehyde, citric acid, and adipic acid was widely used to improve mechanical strength and stability(Rathi et al., 2023)(Khabibi et al., 2022)(Illiana & Ariyanto, 2024). Nanomaterial incorporation, including graphene oxide, carbon nanotubes, TiO_2, and metal nanoparticles, was a common strategy to enhance adsorption, antifouling, and photocatalytic properties(Feng et al., 2023)(Croitoru et al., 2020)(Alzahrani et al., 2020)(Kolangare et al., 2019). Functionalization with polymers such as polyethyleneimine and dopamine improved selectivity and hydrophilicity(Mousavi et al., 2023)(Bandara et al., 2019)(Tian et al., 2024).

Pollutant Removal Efficiency
Heavy metals such as Cr(VI), Pb(II), Cu(II), Ni(II), and Co(II) were effectively removed with adsorption capacities ranging from moderate to very high (up to 1500 mg/g)(Ali et al., 2024)(Croitoru et al., 2020) (Silva et al., 2024). Dye removal efficiencies were high, often exceeding 90%, with some membranes achieving complete photodegradation under UV light(Alzahrani et al., 2020)(Bassyouni et al., 2024)(Abdulhamid et al., 2024). Oil-water separation membranes demonstrated high rejection rates (>98%) and fluxes, with some achieving superhydrophilic and superoleophobic properties(Wan et al., 2022)(Zhu et al., 2024)(Zhang & Guo, 2024).

Mechanical and Chemical Stability
Enhanced mechanical strength and chemical resistance were achieved through crosslinking and nanocomposite formation, with some membranes showing acid/base resistance and corrosion stability(Mu et al., 2022)(Zhu et al., 2024)(Tian et al., 2024). Antifouling properties were improved by surface modifications and nanoparticle incorporation, leading to better flux recovery(Wan et al., 2022)(Mousavi et al., 2023)(Kolangare et al., 2019). Some membranes maintained structural integrity and performance after multiple operational cycles(Feng et al., 2023)(Ali et al., 2024)(Zhu et al., 2024).

Critical Analysis and Synthesis
The reviewed literature on chitosan-based membranes for pollutant separation reveals significant advancements in synthesis techniques and modification methods, demonstrating the material's versatility and sustainability. Many studies emphasize the enhancement of membrane performance through chemical crosslinking, nanomaterial integration, and hybrid composite fabrication, which have collectively improved mechanical strength, permeability, and selectivity. However, challenges remain in achieving consistent membrane stability, fouling resistance, and scalability for industrial applications. Furthermore, while diverse pollutant classes have been targeted, comparative analyses across different contaminants and operational conditions are limited. The following table critically synthesizes these themes, highlighting the strengths and weaknesses across key aspects of chitosan membrane research. The literature on chitosan-based membranes for pollutant separation reveals several major themes centered on synthesis and modification techniques, application areas, and performance enhancement strategies. A significant focus is placed on chemical cross-linking, nanomaterial incorporation, and membrane fabrication methods that improve mechanical strength, permeability, and selectivity for diverse pollutants such as heavy metals, dyes, and organic compounds. Emerging themes highlight advancements in antifouling, regeneration, and multifunctional membrane capabilities, especially for oil-water separation and complex wastewater treatment. The evolution of these themes demonstrates growing integration of nanotechnology, eco-friendly processes, and multifunctional design to address environmental challenges effectively

Tabel 2. Result of Critical Analysis and Synthesis

Aspect	Strengths	Weaknesses
Synthesis Techniques	The literature demonstrates a broad range of synthesis methods including phase inversion, electrospinning, solvent casting, and 3D printing, allowing tailored membrane structures with enhanced porosity and surface area. Techniques such as crosslinking with glutaraldehyde, citric acid, and adipic acid have improved mechanical stability and chemical resistance, as evidenced by improved tensile strength and acid/alkali resistance in several studies(Mu et al., 2022)(Khabibi et al., 2022)(Illiana & Ariyanto, 2024). The use of green solvents and low- temperature processes further supports environmental sustainability(Wan et al., 2022)(Silva et al., 2023).	Despite diverse synthesis approaches, many studies lack standardized protocols, leading to variability in membrane properties and performance metrics. Some methods, such as electrospinning, may face scalability issues for industrial production(Silva et al., 2024). Additionally, the trade-off between membrane permeability and selectivity is not always optimized, with some membranes exhibiting reduced flux after modification(Machodi & Daramola, 2020)(Illiana & Ariyanto, 2024).
Chemical and Nanomaterial Modifications	Incorporation of nanomaterials such as graphene oxide, TiO_2 nanoparticles, carbon nanotubes, and metal oxides has significantly enhanced adsorption capacity, antifouling properties, and pollutant rejection efficiency(Feng et al., 2023)(AlAbduljabbar et al., 2021)(Croitoru et al., 2020)(Chaudhary et al., n.d.) (Ali et al., 2024). Functionalization with amino-rich groups and crosslinking agents has improved selective adsorption for heavy metals and dyes(Xinwen et al., 2020)(Bandara et al., 2019). Nanocomposite membranes exhibit superior mechanical strength and stability, enabling multi- pollutant removal(Rathi et al., 2023)(Abbas et al., 2023)(Ali et al., 2024).	The complexity of nanomaterial integration often introduces challenges in achieving uniform dispersion and stable bonding within the chitosan matrix, potentially leading to agglomeration and reduced membrane lifespan(Mousavi et al., 2023)(Chaudhary et al., n.d.). Some studies report decreased thermal stability or flexibility post-modification(Alrman et al., 2024). Moreover, the environmental impact and cost-effectiveness of nanomaterial synthesis and incorporation remain underexplored(Chaudhary et al., n.d.).

Pollutant Separation Performance	Chitosan-based membranes have demonstrated high removal efficiencies for a wide range of pollutants including heavy metals (Cr(VI), Cu(II), Pb(II)), dyes (methylene blue, methyl orange), organic contaminants, and oil/water emulsions(Kavitha et al., 2024)(Rathi et al., 2023)(Wan et al., 2022)(Khabibi et al., 2022)(Zhu et al., 2024). Membranes modified with nanocomposites or crosslinkers show enhanced selectivity and flux, with some achieving near-complete rejection and high adsorption capacities(Wan et al., 2022)(Croitoru et al., 2020)(Ali et al., 2024). The multifunctionality of membranes enables simultaneous removal of multiple contaminants(Rathi et al., 2023)(Tian et al., 2024).	Comparative performance data across different pollutant classes and operational conditions are limited, hindering comprehensive benchmarking. Some membranes exhibit reduced flux or fouling under prolonged use, and regeneration capabilities are not consistently reported(Rathi et al., 2023)(Kolangare et al., 2019). The influence of real wastewater matrices on membrane efficacy is insufficiently addressed, limiting practical applicability assessments(Peter et al., 2024)(Yasir et al., 2024).
Mechanical Strength and Stability	Crosslinking and nanomaterial incorporation have improved mechanical properties such as tensile strength, elasticity, and chemical resistance, enabling membranes to withstand harsh environmental	Some modifications lead to brittleness or reduced flexibility, compromising membrane integrity under dynamic filtration conditions(Alrman et al., 2024)(Mu et al., 2022).

Limitations of the Literature

Tabel 3. Various of Limitations of the literature

Area of Limitation	Description of Limitation	Papers which have limitation
Limited Long-Term Performance Data	Many studies focus on short-term membrane performance without extensive evaluation of long-term stability, fouling resistance, and regeneration capacity. This limits external validity regarding membrane durability and practical applicability in real-world wastewater treatment.	(Rathi et al., 2023) (Feng et al., 2023) (Zhu et al., 2024)

Narrow Pollutant Spectrum	Several investigations concentrate on specific pollutant classes (e.g., heavy metals or dyes) without comprehensive assessment across diverse contaminants, restricting the generalizability of findings to broader pollutant separation scenarios.	(Kavitha et al., 2024) (Khabibi et al., 2022) (Jawahire et al., 2024)
Insufficient Scale-Up Studies	Most research is conducted at laboratory scale with limited pilot or industrial-scale validation, which constrains the understanding of scalability, economic feasibility, and operational challenges in practical applications.	(Yasir et al., 2024) (Yasir et al., 2024) (Silva et al., 2024)
Methodological Variability	Diverse synthesis and modification protocols, characterization techniques, and performance metrics across studies hinder direct comparison and synthesis of results, affecting the consistency and reproducibility of conclusions.	(Alrman et al., 2024) (Mousavi et al., 2023) (Sanjari & Asghari, 2016)
Environmental Impact Assessment Gaps	Few studies thoroughly evaluate the environmental implications of membrane fabrication, use, and disposal, including potential toxicity of nanomaterials, which is critical for sustainable development and regulatory acceptance.	(Chaudhary et al., n.d.) (Peter et al., 2024)
Limited Focus on Mechanical Stability	While chemical and adsorption properties are well-studied, mechanical strength and durability under operational stresses are less frequently addressed, reducing confidence in membrane robustness for long-term use.	(Kavitha et al., 2024) (Illiana & Ariyanto, 2024) (Rasifudi et al., 2024)
Lack of Standardized Testing Conditions	Variability in experimental conditions such as pH, temperature, pollutant concentration, and flow regimes across studies limits the comparability and external validity of membrane performance data.	(Rathi et al., 2023) (Machodi & Daramola, 2020) (Silva et al., 2023)
Underexplored Fouling Mechanisms	Although fouling is recognized as a major challenge, detailed mechanistic studies on fouling types, progression, and mitigation strategies remain limited.	(Wan et al., 2022) (Mousavi et al., 2023) (Kolangare et al., 2019)

IV. CONCLUSION

The collective body of literature on chitosan-based membranes for pollutant separation reveals a dynamic and evolving field marked by significant progress in synthesis and modification methodologies. Diverse fabrication techniques such as phase inversion, electrospinning, solvent casting, and emerging approaches like 3D printing have been successfully employed to tailor membrane structure, porosity, and surface properties. These methods are frequently augmented by chemical crosslinking agents and the integration of nanomaterials—including graphene oxide, carbon nanotubes, TiO2, and metal oxides—to enhance mechanical strength, chemical stability, and antifouling capabilities. Notably, green and solvent-free synthesis approaches have gained momentum, aligning membrane development with environmental sustainability goals. Modification strategies have proven critical in enhancing pollutant separation efficiency, where nanomaterial incorporation and surface functionalization improve selectivity and adsorption capacity. Chitosan-based membranes demonstrate high efficacy in removing a wide spectrum of pollutants, such as heavy metals (Cr(VI), Pb(II), Cu(II)), dyes, organic compounds, and oil-water emulsions, with some systems achieving near-complete rejection and impressive adsorption capacities. Multifunctional membranes capable of simultaneous multi-pollutant removal highlight the versatility of chitosan composites. However, comparative analyses across different pollutant classes and real wastewater matrices remain limited, restricting comprehensive benchmarking and practical applicability assessments. Mechanical and chemical stability have generally improved through crosslinking and nanocomposite formulations, yielding membranes resistant to harsh environmental conditions and operational stresses. Antifouling properties and fouling mitigation have been enhanced by surface modifications and photocatalytic self-cleaning capabilities, facilitating improved flux recovery and membrane longevity. Nevertheless, membrane fouling persists as a significant challenge, and regeneration studies are often constrained to a few operational cycles, underscoring the need for long-term durability investigations.

V. REFERENCES

Abbas, M. A., Khan, M. Z., Saleem, M., Khan, A. U., Deen, K. M., Batool, M., Khan, A. L., Zhu, S., & Ahmad, N. M. (2023). Response surface methodology modeling correlation of polymer composite carbon nanotubes/chitosan nanofiltration membranes for water desalination. ACS ES&T water, 3 (5), 1406- 1421. https://doi.org/10.1021/acsestwater.3c00107

Abdulhamid, M. A., Abdulhamid, M. A., & Abdulhamid, M. A. (2024). Rapid eco-friendly selective dye removal using modified chitosan-based sponges: Synthesis, characterization, and application. International Journal of Biological Macromoleculesnull, 133577-133577. https://doi.org/10.1016/j.ijbiomac.2024.133577

Aizat, M. A., & Aziz, F. (2019). Chitosan nanocomposite application in wastewater treatments. https://doi.org/10.1016/B978-0-12-813902-8.00012-5

AlAbduljabbar, F. A., Haider, S., Ali, F. A. A., Alghyamah, A., Al-Masry, W. A., Patel, R., & Mujtaba, I. M. (2021). Tio2 nanostructured coated functionally modified and composite electrospun chitosan nanofibers membrane for efficient photocatalytic degradation of organic pollutant in wastewater. Journal of materials research and technology, 15 null, 5197-5212. https://doi.org/10.1016/J.JMRT.2021.10.119

Ali, D. A., Ismail, G. G., Osman, A. I., AlReshaidan, S., & Al-Fatesh, A. S. (2024). Novel nanocomposite of carbonized chitosan-zinc oxide-magnetite for adsorption of toxic elements from aqueous solutions. ACS omega, 9 null, 47567-47584. https://doi.org/10.1021/acsomega.4c06541

Alrman, K. H., Alhariri, S., & Bakri, I. A. (2024). Ultrafiltration membrane based on chitosan/adipic acid: Synthesis, characterization and performance on separation of methylene blue and reactive yellow-145 from aqueous phase. Heliyonnull, . https://doi.org/10.1016/j.heliyon.2024.e31055

Alzahrani, E., Ahmed, R. A., & Alotaibi, R. S. (2020). Tio2nps embedded in chitosan membrane for efficient photodegradation of various dyes. Oriental journal of chemistry, 36 (1), 144-160. https://doi.org/10.13005/OJC/360120

Bandara, P. C., Nadres, E. T., & Rodrigues, D. F. (2019). Use of response surface methodology to develop and optimize the composition of a chitosan-polyethyleneimine-graphene oxide nanocomposite membrane coating to more effectively remove cr(vi) and cu(ii) from water.. ACS Applied Materials & Interfaces, 11 (19), 17784-17795. https://doi.org/10.1021/ACSAMI.9B03601

Bassyouni, M., Eteba, A., ElZahar, M. M. H., & Elshikhiby, M. Z. (2024). Utilization of biodegradable nanofiltration membrane for efficient removal of anionic textile dye. Egyptian Journal of Chemistry, 0 (0), 0-0. https://doi.org/10.21608/ejchem.2024.296854.9846

Chaudhary, R., Banerjee, P., Gaur, N., Bajpai, S., & Joshi, K. (n.d.). Environmental implications of chitosan nanostructures. International Journal of Antibioticsnull, . https://doi.org/10.37591/ijab.v01i01.131610

Chelu, M., Musuc, A. M., Popa, M., & Moreno, J. M. C. (2023). Chitosan hydrogels for water purification applications. Gels, 9 null, . https://doi.org/10.3390/gels9080664

Croitoru, A., Ficai, A., Ficai, D., Trusca, R., Dolete, G., Andronescu, E., & Turculet, S. C. (2020). Chitosan/graphene oxide nanocomposite membranes as adsorbents with applications in water purification.. Materials, 13 (7), . https://doi.org/10.3390/MA13071687

Dhillon, A., & Kumar, D. (2018). Chitosan-based natural biosorbents: Novel search for water and wastewater desalination and heavy metal detoxification. https://doi.org/10.1007/978-3-319-68708-7_6

Du, X., Rashid, S. A., Abdullah, L. C., & Rahman, N. A. (2024). Preparation of electrospun cellulose acetate/chitosan membranes for efficient sorption of heavy metals from aqueous solutions. Colloids and Surfaces A: Physicochemical and Engineering Aspectsnull, 134698-134698. https://doi.org/10.1016/j.colsurfa.2024.134698

Feng, Z., Xu, Y., Ding, W., Wei, X., Hakkarainen, M., & Wu, M. (2023). Nano graphene oxide creates a fully biobased 3d-printed membrane with high-flux and anti-fouling oil/water separation performance. https://doi.org/10.2139/ssrn.4646121

Fu, C., Li, Y., & Guo, Z. (2024). Biomass chitosan-based complexes with superwettability for oil-water separation. Materials Today Chemistry, 40 null, 102265-102265. https://doi.org/10.1016/j.mtchem.2024.102265

Gonçalves, J. O., Strieder, M. M., Silva, L. F., Reis, G. S. D., & Dotto, G. L. (2024). Advanced technologies in water treatment: Chitosan and its modifications as effective agents in the adsorption of contaminants. International Journal of Biological Macromolecules, . https://doi.org/10.1016/j.ijbiomac.2024.132307

Griggs, C. S., Mattei-Sosa, J. A., Gurtowski, L. A., Greenlee, L. F., & Abolhassani, M. (2018). Chitosangraphene oxide membranes and process of making the same.

Ikhsan, S. N. W., Yusof, N., Aziz, F., Ismail, A. F., Shamsuddin, N., Jaafar, J., Salleh, W. N. W., Goh, P. S., Lau, W. J., & Misdan, N. (2022). Synthesis and optimization of superhydrophilic-superoleophobic chitosan– silica/hnt nanocomposite coating for oil–water separation using response surface methodology. Nanomaterials, 12 (20), 3673-3673. https://doi.org/10.3390/nano12203673

Illiana, F. F., & Ariyanto, H. D. (2024). Development of chitosan/glutaraldehyde cross-linked film with silica addition as membrane material for sls rejection in detergent wastewater. Journal of Vocational Studies on Applied Research, 6 (1), 1-6. https://doi.org/10.14710/jvsar.v6i1.22145

Jawahire, S., Patil-Sankpal, P., Patil, A., Choudhari, P., & Rathod, S. (2024). Chitosan-based nanomaterials in decontamination of phenols and biphenyls. https://doi.org/10.1016/b978-0-443-21891-0.00013-5

Kavitha, E., Yuvaraj, K., & Kapoor, A. (2024). Chitosan-blended membranes for heavy metal removal from aqueous systems: A review of synthesis, separation mechanism, and performance. International Journal of Biological Macromolecules, 134996-134996. https://doi.org/10.1016/j.ijbiomac.2024.134996

Khabibi, Prasetya, N. B. A., Lusiana, R. A., Suyati, L., Nuryanto, R., Rohmah, L., & Khoirunnisa, I. A. (2022). Synthesis of citric acid-crosslinked chitosan membrane with zeolite filler and its application as cu(ii) ion separation membrane. Nucleation and Atmospheric Aerosolsnull, . https://doi.org/10.1063/5.0104558

Long, Q., Zhang, Z., Qi, G., Wang, Z., Chen, Y., & Liu, Z. (2020). Fabrication of chitosan nanofiltration membranes by the film casting strategy for effective removal of dyes/salts in textile wastewater. ACS Sustainable Chemistry & Engineering, 8 (6), 2512-2522. https://doi.org/10.1021/ACSSUSCHEMENG.9B07026

Machodi, M. J., & Daramola, M. O. (2020). Synthesis of pes and pes/chitosan membranes for synthetic acid mine drainage treatment. Water SA, 46 (1), 114-122. https://doi.org/10.17159/WSA/2020.V46.I1.7891

Makaremi, M., Lim, C. X., Pasbakhsh, P., Lee, S. M., Goh, K. L., Chang, H., & Chan, E. S. (2016). Electrospun functionalized polyacrylonitrile–chitosan bi-layer membranes for water filtration applications. RSC Advances, 6 (59), 53882-53893. https://doi.org/10.1039/C6RA05942B

Mousavi, S. R., Asghari, M., Mahmoodi, N. M., & Salahshoori, I. (2023). Water decolorization and antifouling melioration of a novel peba1657/pes tfc membrane using chitosan-decorated graphene oxide fillers. Journal of environmental chemical engineering, 11 (3), 109955-109955. https://doi.org/10.1016/j.jece.2023.109955

Mu, T., Wang, Q. S., Cao, L., Zhu, X., & Zhao, Z. (2022). Preparation and characterization of a novel emphatically charged strengthened chitosan composite nanofiltration membrane. MATEC web of conferences, 358 null, 01025-01025. https://doi.org/10.1051/matecconf/202235801025

Nawawi, M. G. M., Zamrud, Z., & Alamaria, A. M. (2015). Novel hydrophilic chitosan and sago based membranes for pervaporation of organic-water mixtures. Advanced Materials Research, 1125 null, 250- 254. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMR.1125.250