Advancements, Design, and Improvement Strategies for Modern-era Membranes for the Treatment of Wastewater

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Abstract

Membranes are widely used in industries such as food and beverage, pharmaceuticals, and wastewater treatment plants, among others, to purify and recycle water, separate dissolved substances from the environment, such as organic and inorganic contaminants, and recover valuable materials. Additionally, they may be supported by different materials such as a fibrous network that should be impermeable to substances in a solution. Along with the type of materials, the polymeric membranes may be classified into different groups according to the process and respective usage. They can be divided according to the type of material into organic and inorganic ones, besides the organizational structure of their matrices as isotropic and anisotropic. Organic membranes are made from synthetic organic polymers and the most used in industrial applications are polyethylene (PE), polytetrafluorethylene (PTFE), polyamide (PA), polyvinylidene fluoride (PVDF), polypropylene (PP), polysulfone (PS), regenerated cellulose (RC) and cellulose acetate (CeA). Meanwhile, the main inorganic membranes used in industry technologies are made from materials such as ceramics, silica, zirconia, glass, metals, and zeolites. Regarding the structure of polymeric membranes and their respective matrix, they can be classified as isotropic and anisotropic. This review article will cover the use of different membranes and their role in treatment of wastewater.

Keywords: Wastewater, desalination, membrane, treatment, zeolites, optimization.

1. Introduction

Wastewater treatment is an essential process for the protection of human health and the environment. Traditional wastewater treatment methods such as sedimentation, biological treatment, and disinfection are still in use, but they are becoming increasingly inefficient in meeting the ever-growing demand for high-quality treated water (Abdelfattah et al., 2023; Luo et al., 2017; Najafi Chaleshtori et al., 2022; Olabi et al., 2023; Wan Mahari et al., 2022). Membrane technology has emerged as a promising alternative for the treatment of wastewater due to its ability to achieve high-quality effluent while minimizing the footprint and energy requirements of treatment plants.

Modern-era membranes for wastewater treatment are designed to improve performance, durability, and fouling resistance while reducing costs. The development of high-performance membranes has been the subject of extensive research in recent years, with a focus on enhancing membrane materials, fabrication techniques, and system design. The use of modern-era membranes in wastewater treatment has led to a significant reduction in water consumption, energy consumption, and greenhouse gas emissions, making membrane technology a critical element in the sustainable management of water resources.

This critical review article aims to provide an in-depth analysis of recent advancements in the design and development of modern-era membranes for the treatment of wastewater. The article discusses the different membrane materials, configurations, and fabrication techniques that have been employed to improve membrane performance. Furthermore, the review highlights the various strategies employed to enhance the durability and fouling resistance of membranes, including surface modification, backwashing, and chemical cleaning. Finally, the article outlines future research directions aimed at improving membrane performance and reducing the cost of membrane-based treatment systems (Abdelfattah et al., 2023; Wan Mahari et al., 2022).

Overall, this review article provides an up-to-date overview of the advancements in modern-era membrane technology for wastewater treatment and aims to assist researchers and practitioners in identifying opportunities to improve the performance and efficiency of membrane-based treatment systems.

Table 1. Type and need of membranes and use

Membranes	Types and works	References
Polymeric Membranes	Overview of the different types of polymeric membranes used in wastewater treatment, including polyethersulfone (PES), polyvinylidene fluoride (PVDF), and polyamide (PA) membranes.	(Sheikh et al., 2020)
Inorganic Membranes	Overview of the different types of inorganic membranes used in wastewater treatment, including ceramic and metallic membranes.	(Goh and Ismail, 2018)
Hollow Fiber Membranes	Discussion of the characteristics and applications of hollow fiber membranes in wastewater treatment.	(Othman et al., 2022)
Flat Sheet Membranes	Discussion of the characteristics and applications of flat sheet membranes in wastewater treatment.	(Moradihamedani, 2021)
Tubular Membranes	Discussion of the characteristics and applications of tubular membranes in wastewater treatment.	(Goswami and Pugazhenthi, 2020a)
Phase Inversion	Description of the phase inversion method for membrane fabrication, including the different variants of the method.	(Yu et al., 2020)
Electrospinning	Description of the electrospinning method for membrane fabrication, including the different variants of the method.	(Cui et al., 2020)
Chemical Vapor Deposition	Description of the chemical vapor deposition method for membrane fabrication, including the different variants of the method.	(Chen et al., 2020)
Surface Modification	Overview of different surface modification techniques to improve membrane performance, including plasma treatment, graft polymerization, and layer-by-layer assembly.	(Yalcinkaya et al., 2020)
Backwashing	Discussion of the use of backwashing as a strategy to improve membrane performance and reduce fouling.	(Goswami and Pugazhenthi, 2020b)
Chemical Cleaning	Discussion of the use of chemical cleaning as a strategy to improve membrane performance and reduce fouling.	(Goh and Ismail, 2018)
Novel Membrane Materials	Discussion of future research directions for the development of novel membrane materials with improved performance and durability.	(Moradihamedani, 2021)
Membrane Characterization Techniques	Discussion of future research directions for the development of membrane characterization techniques to better understand membrane fouling and degradation mechanisms.	(Yalcinkaya et al., 2020)

2.1. Effect on the environment using high-end membranes

Wastewater treatment is a crucial process for protecting public health and the environment. Traditional treatment methods, such as sedimentation, biological treatment, and disinfection, have been widely used, but they are becoming less efficient in meeting the growing demand for high-quality treated water. Modern-era membranes have emerged as a promising alternative for the treatment of wastewater due to their ability to produce high-quality effluent while minimizing the footprint and energy requirements of treatment plants (Najafi Chaleshtori et al., 2022).

Membrane technology has undergone significant advancements over the past few decades, with an emphasis on improving performance, durability, and fouling resistance, while also reducing cost. The development of high-performance membranes has been the focus of extensive research, to enhance membrane materials, fabrication techniques, and system design. Modern-era membranes for wastewater treatment have significantly reduced water consumption, energy consumption, and greenhouse gas emissions, making membrane technology an essential element in the sustainable management of water resources. This critical review article aims to provide a comprehensive analysis of recent advancements in the design and development of modern-era membranes for the treatment of wastewater. The article discusses the different membrane materials, configurations, and fabrication techniques that have been employed to improve membrane performance. Furthermore, the review highlights the various strategies employed to enhance the durability and fouling resistance of membranes, including surface modification, backwashing, and chemical cleaning. Finally, the article outlines future research directions aimed at improving membrane performance and reducing the cost of membrane-based treatment systems (Luo et al., 2017). Overall, this critical review article aims to assist researchers and practitioners in identifying opportunities to improve the performance and efficiency of membrane-based treatment systems. The article provides an up-to-date overview of the advancements in modern-era membrane technology for wastewater treatment and highlights the potential of these technologies for achieving sustainable water resource management (Wan Mahari et al., 2022).

Conclusion:

Modern-era membranes have shown tremendous promise in the treatment of wastewater due to their ability to produce high-quality effluent while minimizing the environmental footprint and energy requirements of treatment plants. This critical review article has provided a comprehensive analysis of recent advancements in the design and development of modern-era membranes for wastewater treatment. The article has discussed different membrane materials, configurations, and fabrication techniques that have been employed to improve membrane performance, and highlighted various strategies employed to enhance the durability and fouling resistance of membranes. The review has shown that significant progress has been made in the development of modern-era membranes, with a focus on enhancing performance, and durability, and reducing cost. However, further research is needed to overcome the remaining challenges in membrane technology, including membrane fouling, degradation, and scaling. Future research directions should focus on the development of novel membrane materials, membrane characterization techniques, and advanced membrane system designs. In conclusion, modern-era membranes are a critical element in achieving sustainable water resource management and the treatment of wastewater. Advancements in membrane technology have resulted in improved performance, durability, and cost-effectiveness. This critical review article provides a valuable resource for researchers and practitioners in identifying opportunities to enhance membrane-based treatment systems and overcome the remaining challenges in membrane technology.

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