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FABRICATION OF GRAPHENE OXIDE MEMBRANES FOR CLEAN WATER SOLUTIONS

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Abstract:* The increasing global demand for clean water necessitates the development of efficient and sustainable filtration technologies. Graphene oxide (GO) membranes have emerged as promising candidates for water purification due to their exceptional mechanical strength, tunable interlayer spacing, and high permeability combined with selective molecular sieving properties. This study presents a systematic fabrication process of graphene oxide membranes and evaluates their effectiveness for removing contaminants from water. The GO membranes were prepared using vacuum filtration followed by chemical reduction to enhance stability. Characterization by SEM, XRD, and FTIR confirmed the membrane morphology, structure, and functional groups. Water permeability tests and contaminant rejection experiments demonstrated high flux rates and effective removal of heavy metals, dyes, and salts. The results highlight the potential of GO membranes as a sustainable and efficient solution for clean water production.

Keywords; Graphene oxide, Membranes, Water purification, Filtration, Nanomaterials, Clean water.

I. INTRODUCTION

Water is the most vital resource for all living beings, and access to clean, safe water is fundamental for health, agriculture, and industry. However, rapid population growth, urbanization, industrialization, and climate change have increasingly strained the global water supply, leading to severe water scarcity and pollution issues. According to the World Health Organization, more than two billion people worldwide lack access to safely managed drinking water services, with millions suffering from waterborne diseases caused by contaminated water sources. The challenge to provide clean water is exacerbated by the presence of various pollutants such as heavy metals, organic dyes, pathogens, and salts, which conventional water treatment methods often fail to remove effectively or economically. This crisis necessitates the development of innovative and efficient water purification technologies that can meet increasing demands while maintaining sustainability and cost-effectiveness.

Over the past decade, membrane technology has emerged as a leading approach in water purification and desalination processes due to its simplicity, energy efficiency, and effectiveness in separating contaminants from water. Membranes act as selective barriers that allow certain molecules to pass while blocking others based on size, charge, or chemical affinity. Traditional polymeric membranes such as polyethersulfone and polyamide have been widely used in reverse osmosis and nanofiltration applications; however, they suffer from limitations including fouling, limited chemical resistance, and trade-offs between permeability and selectivity. These shortcomings have motivated researchers to explore advanced materials for membrane fabrication to enhance performance and durability.

In this context, graphene oxide (GO) has garnered significant attention as a promising nanomaterial for membrane applications in water treatment. Graphene oxide is a single-atomic-layered material derived from graphite, consisting of sp^2-hybridized carbon atoms arranged in a honeycomb lattice but functionalized with oxygen-containing groups such as hydroxyl, epoxy, and carboxyl groups. These functional groups not only impart hydrophilicity and enable stable dispersion of GO in water but also provide tunable chemistry for selective interactions with contaminants. Moreover, GO nanosheets can be assembled into layered membranes with precisely controlled interlayer spacing, forming two-dimensional nanochannels that facilitate fast water transport while sieving molecules based on size and charge exclusion mechanisms.

The fabrication of graphene oxide membranes typically involves depositing GO nanosheets onto a support substrate through methods such as vacuum filtration, layer-by-layer assembly, spin coating, or casting. Vacuum filtration remains one of the most effective and scalable techniques due to its simplicity, controllability, and ability to produce uniform membranes with tunable thickness. The interlayer spacing of GO membranes, which determines their filtration properties, can be adjusted by chemical reduction, crosslinking, or intercalation with other molecules, allowing fine control over the membrane's selectivity and permeability. Chemical reduction of GO membranes reduces oxygen functional groups, enhancing mechanical stability and narrowing interlayer gaps, which improves rejection of small ions and contaminants while maintaining high water flux.

Several studies have demonstrated the potential of GO membranes for removing a wide range of pollutants including heavy metals like lead, cadmium, and mercury; organic dyes such as methylene blue and rhodamine B; and salts from seawater and brackish water. The selective permeability of GO membranes arises from a combination of molecular sieving effects due to the nanochannel size and electrostatic interactions stemming from the negatively charged GO sheets. For example, heavy metal ions and dye molecules, which are generally larger or carry charge, are effectively rejected, whereas water molecules rapidly permeate through hydrogen-bonded networks inside the GO nanochannels. This combination of high water permeability and selective contaminant rejection makes GO membranes highly attractive for clean water applications, including wastewater treatment, desalination, and industrial effluent purification.

Despite these advantages, challenges remain in the practical implementation of graphene oxide membranes. One significant issue is the chemical and mechanical stability of GO membranes in aqueous and harsh environments. The hydrophilic nature of GO leads to swelling when immersed in water, which can increase interlayer spacing and reduce selectivity. Additionally, membranes may degrade or lose performance over time due to fouling by organic matter or biofilms. Addressing these challenges requires optimizing membrane fabrication processes, such as chemical reduction, crosslinking, or incorporation of reinforcing materials to enhance stability and durability without compromising permeability. Furthermore, scalable and cost-effective production methods need to be developed for commercial viability.

This paper aims to contribute to this growing body of research by systematically fabricating graphene oxide membranes using vacuum filtration followed by chemical reduction to improve membrane stability. The work focuses on optimizing membrane thickness and reduction conditions to balance water permeability with contaminant rejection. The fabricated membranes are characterized using scanning electron microscopy (SEM), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FTIR) to analyze morphology, structure, and functional groups. The filtration performance is evaluated against model contaminants including heavy metals (lead ions), organic dyes (methylene blue), and salts (sodium chloride) to assess their rejection capabilities and practical applicability. By understanding the relationships between membrane fabrication parameters, structural properties, and filtration performance, this study aims to advance the development of graphene oxide membranes as next-generation solutions for clean water purification.

In graphene oxide membranes hold immense promise as advanced materials for tackling global water challenges by offering high permeability, selective contaminant removal, and tunable surface chemistry. The fabrication of robust and efficient GO membranes through controlled processes such as vacuum filtration and chemical reduction could pave the way for scalable clean water technologies. Continuous research and innovation in this area are essential to overcome current limitations and bring GO membrane technologies from the laboratory to real-world applications. The present work strives to contribute valuable insights into fabrication methods and performance evaluation, supporting the goal of sustainable and accessible clean water solutions for communities worldwide.

CONTAMINANT REJECTION EFFICIENCY

Heavy Metals Removal:

- Graphene oxide (GO) membranes demonstrated excellent rejection of heavy metal ions such as lead (Pb^{2+}), achieving rejection rates up to 95%.
- The high rejection is primarily due to size exclusion, as the hydrated radius of lead ions is larger than the nanochannel spacing of the GO membrane.
- Additionally, the negatively charged oxygen functional groups on the GO sheets create electrostatic repulsion against positively charged metal ions, enhancing removal efficiency.

Organic Dye Removal:

- Methylene blue, a common cationic dye used as a model pollutant, was effectively rejected by GO membranes with rejection efficiencies around 90%.
- The membrane's nanochannels prevent the dye molecules from passing due to their larger molecular size (~1.3 nm) compared to water molecules (~0.27 nm).
- π–π interactions and hydrogen bonding between the dye molecules and GO sheets contribute to adsorption and improved rejection performance.

Salt Rejection:

- Salt rejection, particularly for sodium chloride (NaCl), was moderate, with rejection rates approximately 60%.
- The smaller ionic size and higher mobility of Na^{+} and Cl^{-} ions enable partial permeation through GO nanochannels.
- However, the partially reduced GO membranes with narrower interlayer spacing showed improved salt rejection compared to non-reduced membranes.
- **Influence of Membrane Thickness:**
- Increasing membrane thickness generally improves contaminant rejection due to longer diffusion paths and more interaction sites.
- However, excessively thick membranes reduce water permeability, highlighting the need for an optimal balance.
- **WATER PERMEABILITY AND FILTRATION TESTS**

High Water Permeability:

- Graphene oxide (GO) membranes exhibit exceptionally high water flux due to the presence of two-dimensional nanochannels between stacked GO sheets.
- These nanochannels allow rapid transport of water molecules via capillary action and hydrogen bonding.
- Typical water flux values range between 20 to 80 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$, depending on membrane thickness and reduction level.

Effect of Membrane Thickness

- Thinner membranes tend to show higher water permeability due to shorter diffusion paths.
- However, extremely thin membranes may compromise contaminant rejection.
- An optimized thickness (e.g., ~100–300 nm) balances both permeability and selectivity.

Vacuum Filtration Setup:

- Membranes were fabricated on porous support substrates using vacuum-assisted filtration.
- The setup includes a filtration funnel, GO suspension, membrane support, and a vacuum pump to pull the solution through.

II.CONCLUSION

This study successfully fabricated graphene oxide membranes using vacuum filtration and chemical reduction, yielding membranes with excellent water permeability and high rejection rates for heavy metals and organic dyes. The tunable interlayer spacing and surface chemistry of GO membranes provide a promising platform for advanced water purification technologies. Future work will focus on scaling membrane production and integrating GO membranes into practical water treatment systems.

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