Performance of Electrified MXene Membranes in Real Wastewater Applications

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Abstract. Nanoplastic (NP) contamination in wastewater is a growing environmental concern, requiring innovative and scalable treatment. Electrified membranes have emerged as a promising approach for NP removal by leveraging electrostatic repulsion and electrocoagulation mechanisms. In this study, we investigate the performance of a MXene-based membrane for NP filtration, focusing on the effects of real wastewater conditions. Results show that the applied electric field significantly improved NP rejection, achieving high removal efficiency, while increasing water flux compared to non-electrified conditions. Intermittent ON/OFF operation effectively mitigated fouling and maintained a stable flux over 30 h. This study provides critical insights into the scalability and practical deployment of MXene-based electrified membranes for advanced water treatment. The findings highlight the membrane's potential for efficient Multi-contaminant removal, antifouling performance, and energy-efficient operation.

Keywords: Nanoplastics; MXene; electrified membranes; electrocoagulation; wastewater treatment

1. Introduction

Nanoplastics (NPs) pose a growing environmental threat due to their ability to accumulate in water bodies, impact aquatic ecosystems, and enter the human food chain. Their small size makes them difficult to remove using conventional filtration technologies, which often suffer from membrane fouling, reduced flux, and separation efficiencies. Electrified membrane filtration (EMF) has emerged as a promising solution by leveraging electrostatic interactions and electrocoagulation effects to enhance separation performance. While previous studies have demonstrated the proof of concept for MXene-based EMF systems, their scalability and real-world applicability remain largely unexplored (Ouda et al., 2023). One critical challenge is understanding how membrane area influences NP removal efficiency and flux stability. Additionally, the impact of complex wastewater matrices on membrane performance has not been systematically assessed. This study aims to address these gaps by investigating the performance of MXene-based EMF membranes at varying scales and evaluating their effectiveness in treating real wastewater spiked with NPs..

2. Methodology

MXene-based composite membranes were fabricated by incorporating $Ti_3C_2T_x$ nanosheets into a sulfonated polyethersulfone (SPES) matrix to enhance conductivity and hydrophilicity. Membranes were prepared with varying surface areas to assess scalability (Figure 1). The membranes were tested under different applied voltages and operational modes to evaluate their impact on NP removal and flux stability. Real wastewater samples were spiked with NPs to simulate practical conditions, and additional water quality parameters, such as organic matter and nutrient content were measured. Filtration performance was quantified in terms of NP rejection efficiency, flux, and fouling resistance.

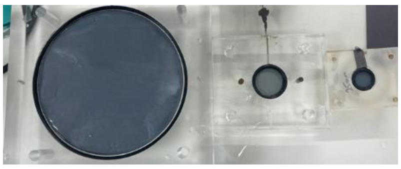

Figure 1. Real-life images of the membrane cathode at different membrane areas, A, 5 A, and 100 A.

3. Results

To evaluate scalability and practical applicability, the electrified membrane was tested with real wastewater spiked with NPs. Normalized flux measurements over 60 min demonstrated that applied voltage significantly improved membrane performance, with the ON mode maintaining consistently higher flux compared to the OFF mode. Over time, as shown in Figure 2, fouling was more severe in the OFF mode, confirming that the electric field effectively mitigates membrane clogging. Contaminant removal efficiencies (Figure 3) were assessed for ammonium, nitrate, chemical oxygen demand (COD), phosphate, and NPs. While NP removal was already high in the OFF mode (>90%), applying voltage further enhanced it to ~96%. More substantial improvements were observed for ammonium and phosphate, with ammonium removal to >50% in the extended ON/OFF cycle. Phosphate removal rose from ~40% (OFF) to nearly 99% under the same conditions, attributed to in situ electrocoagulation from the aluminum anode, which facilitated floc formation and improved pollutant capture. Extended operation over 30 h demonstrated the stability of the system, with only a gradual decline in flux. This indicated that applied voltage helped maintain permeability by preventing severe fouling, making the process more sustainable for long-term filtration applications.

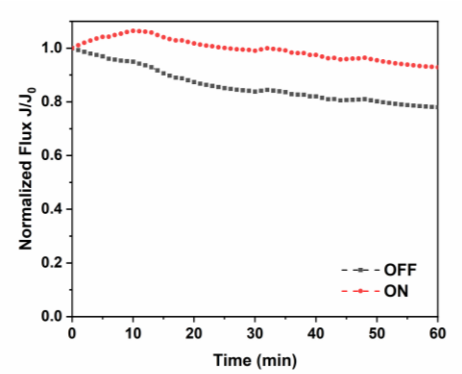

Figure 2. Comparison of system performance in ON vs. OFF mode.

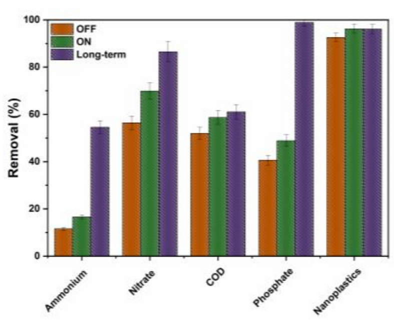

Figure 3. Removal efficiencies of NP and other contaminants using real wastewater.

4. Conclusions

This study demonstrates that MXene-based EMF membranes can be effectively scaled up while maintaining high NP removal efficiency. The application of an electric field plays a crucial role in sustaining flux and mitigating fouling under intermittent operation. The system also exhibited robust performance in real wastewater conditions, confirming its practical applicability. These findings contribute to the development of scalable, high-performance membrane technologies for advanced water treatment applications.

5. References

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