Application of Iron Oxide-Coated Membranes in Permeable Block Systems for Advanced Removal of Micro- and Nanoplastics

Yejin Lee[1], Sanghyun Jeong[1,2*]

[1]School of Civil and Environmental Engineering, Pusan National University, Busan 46241, Republic of Korea
[2]Institue for Environment and Energy, Pusan National University, Busan 46241, Republic of Korea

*corresponding author:
e-mail: sh.jeong@pusan.ac.kr

Abstract

The increasing prevalence of microplastics (MPs) and nanoplastics (NPs) in aquatic environments has raised significant environmental and public health concerns, necessitating the development of effective removal technologies. This study explores the application of iron oxide-coated membrane structures integrated into permeable block systems for the effective removal of MPs and NPs from aqueous media. Iron oxide nanoparticles (IONPs) were synthesized via a simple and cost-effective chemical precipitation method. In batch experiments, the synthesized IONPs achieved removal efficiencies exceeding 95% within 20 minutes. Afterward, IONPs were uniformly deposited onto membrane surfaces using a spray-coating technique. Removal efficiencies were evaluated for both MPs and NPs across a range of particle sizes and compositions. Results demonstrated that the IONPs coating significantly enhanced the capture efficiency compared to uncoated membranes. Furthermore, the coated membranes demonstrated stable performance over multiple reuse cycles with minimal decline in efficiency. These findings suggest that iron oxide-coated membranes integrated into permeable block systems offer a promising, scalable strategy for mitigating plastic pollution in water treatment and urban runoff management applications.

Keywords: Iron oxide nanoparticles, Microplastics, Nanoplastics, Permeable block systems, Membrane coating

1. Introduction

Plastic pollution has emerged as a major environmental threat, with microplastics (MPs; <5 mm) and nanoplastics (NPs; <1 μm) being detected across diverse aquatic ecosystems. Due to their small size, large specific surface area, and hydrophobicity, MPs and NPs can adsorb hazardous pollutants and readily penetrate biological barriers, posing significant risks to both ecosystems and human health. Conventional water treatment processes are often insufficient to effectively capture these fine plastic particles, highlighting the need for the development of advanced removal strategies. Among various approaches, magnetic nanoparticle-assisted separation techniques have gained increasing attention due to their tunable surface properties and high interaction affinity with plastic contaminants. In this study, iron oxide nanoparticles(IONPs) were synthesized via a facile chemical precipitation method, and those were utilized to modify membrane surfaces through a spraying technique, aiming to enhance the removal efficiency of MPs and NPs under flow conditions. The functionalized membranes were integrated into permeable block systems to simulate realistic infiltration environments. Batch tests were initially conducted using the synthesized iron oxide nanoparticles to evaluate the removal efficiency of MPs and NPs. Following this, their performance was further assessed under flow conditions by incorporating the nanoparticles into a permeable block system.

2. Materials and methods

2.1. Batch removal experiments using iron oxide nanoparticles

IONPs was synthesized by a facile chemical precipitation method. Polypropylene (PP, 50 μm) and polyethylene (PE, 12 μm) were selected as target plastics. In case of NPs, it was synthesized using the nonsolvent-induced phase separation method, yielding particles ranging from 300 nm to 2 μm. An experiment was conducted to evaluate the removal efficiency of MPs and NPs using IONPs. A 10 mL reaction solution containing 100 ppm of MPs and NPs was prepared. The MPs and NPs, and IONPs were added to a conical tube and uniformly mixed using a shaking incubator. After the reaction, MPs/NPs-IONPs complexes were magnetically separated.

The removal efficiency was calculated using the following equation:

$$Removal\ efficiency\ (\%) = \frac{M - m}{M} \times 100$$

where M is the initial weight of MPs and NPs, and m is the residual weight of MPs and NPs after magnetic separation.

2.2. Coating of membrane surfaces with iron oxide nanoparticles

To coat the membrane surface with IONPs the nanoparticles were dispersed in ethanol. Specifically, 0.2 g of IONPs was added to 20 mL of ethanol in a 20 mL vial and sonicated for 24 hours to achieve a uniform dispersion. The resulting suspension was then uniformly sprayed onto the surface of the nonwoven fabric and subsequently dried for 1 hour at room temperature.

3. Results and discussion

Figure 1 shows the image of the IONPs-MPs/NPs complex removal using the magnet, and the removal efficiency of MPs and NPs for both PP and PE. It can be observed that the removal of IONPs–MPs/NPs complexes using a magnet takes less than two minutes. When the removal efficiencies of MPs and NPs were evaluated separately, for PP, NPs exhibited higher removal efficiency than MPs, even with a smaller amount of iron oxide, and a similar trend was observed for PE. When sufficient IONPs were applied, removal efficiencies exceeding 90% were achieved for all tested particle types.

Figure 2 shows SEM images of the membrane surface after spraying with IONPs. Compared to the virgin nonwoven fabric, it can be observed that the IONPs were successfully attached to the fiber surfaces. As the number of coating cycles increased from one to two and three, a greater amount of IONPs was deposited on the fibers. However, after three coating cycles, although the nanoparticles were uniformly distributed, some aggregation of IONPs was observed. Therefore, two coating cycles were determined to be the optimal condition for subsequent membrane preparation aimed at MPs/NPs removal.

4. Conclusions

In batch tests, the removal efficiency of MPs and NPs using IONPs reached up to 95%. Afterall, IONPs was sprayed onto nonwoven fabric, and it allowed water to permeate without any detachment of the IONPs. The IONPs-coated nonwoven fabric is expected to rapidly and efficiently remove MPs and NPs, and further experiments will be conducted to evaluate the performance.

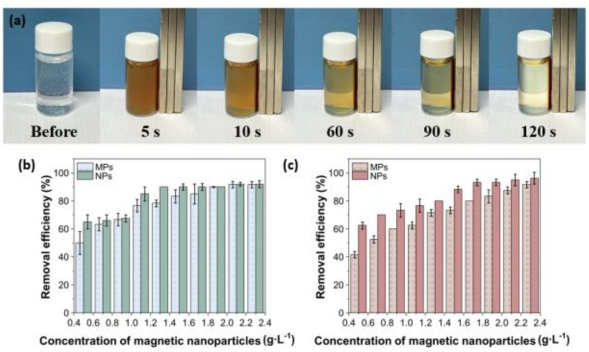

Figure 1. (a) Image showing the removal of MPs and NPs after the iron oxide reaction using a magnet. And removal efficiencies of different types and sizes of MPs and NPs: (a) PP and (b) PE.

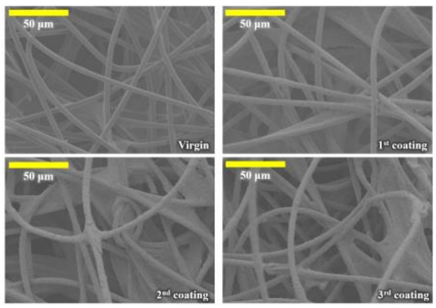

Figure 2. SEM analysis of membrane surfaces after multiple cycles of iron oxide nanoparticle coating.

References

Chazovachii, P. T., Rieland, J. M. et al., Using Adhesives to Capture Microplastics from Water. ACS ES&T Engineering, 1(12), 1698-1704, 2021

Feng, X., Gu, X. et al., Efficient microplastic removal in aquatic environments using iron–nitrogen co-doped layered biocarbon materials. Chemical Engineering Journal, 506, 160095, 2025.

Martin, L. M. A., Sheng, J. et al., Testing an Iron Oxide Nanoparticle-Based Method for Magnetic Separation of Nanoplastics and Microplastics from Water. Nanomaterials, 12(14), 2348, 2022.

Vohl, S., Kristl, M. et al., Harnessing Magnetic Nanoparticles for the Effective Removal of Micro- and Nanoplastics: A Critical Review. Nanomaterials (Basel), 14(14), 2024.