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Technologies for the Removal of Microplastics from Wastewater: A Short Review

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Abstract

One of the major routes of microplastics (MPs) to the environment is through the wastewater treatment plants' (WWTPs) discharge to water bodies. Due to their dimensions (< 5mm), MPs tend to be ingested by aquatic species, and eventually, may cause adverse impacts to the environment and to human health. This paper aims to compare different existing and potential technologies for the removal of MPs from wastewater, in terms of removal mechanisms, removal efficiencies, and the current scale of application. In addition, the effects of the presence and accumulation of microplastics in different wastewater treatment systems are reviewed. The MPs that accumulate in the wastewater sludge may also enter the environment through the disposal or reuse of biosolids. However, most of the recent reviews of the removal of MPs in wastewater focused on technologies for the removal from the liquid phase. This paper also seeks to review proposed technologies for the removal of microplastics from wastewater sludge. Finally, the challenges in the application of these strategies for removal are also highlighted in this brief review.

Keywords: microplastics removal, wastewater treatment, wastewater sludge, microplastics accumulation

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1. Introduction

Microplastics (MPs) are tiny fragments of synthetic polymer particles that are commonly of size < 5mm (Thompson, 2015). They enter the environment through several pathways, such as the wastewater treatment plant (WWTP) discharges. MPs accumulate in water bodies, and act as vectors for other pollutants, such as pathogens and persistent organic pollutants (POPs) (Yi et al., 2022). This paper aims to review the current and emerging technologies for removal and degradation of MPs in wastewater and wastewater sludge.

2. Current Technologies for Removal of Microplastics from Wastewater

A few studies evaluated the performance of existing WWTP facilities in the removal of MPs. Results showed that the removals occur throughout the wastewater treatment train. In the preliminary treatment, the MPs reduction has been observed to range from 14% to 17% (Asadi et al., 2023; Koyuncuoğlu and Erden, 2023). Primary treatment, provided 25 to 64% removal (Koyuncuoğlu and Erden, 2023; Zhang et al., 2023). Secondary treatment provided MPs removal from 16 to 93% (Asadi et al., 2023). The study of Liu et al. (2019) showed that the disinfection stage contributes a removal by 7% through partial oxidation by chlorine. Despite the significant removals of MPs by WWTPs, the amount of these emerging contaminants released to the environment remains high due to the large discharge volumes of WWTPs.

3. Emerging Technologies for Removal of Microplastics from Wastewater

3.1 Air Flotation

Flotation using air bubbles is investigated to separate and remove MPs from aqueous matrices, in which microbubbles may collide and intercept suspended particles in a solution (Swart et al., 2022). Combined with a coagulation process, dissolved air flotation was able to achieve 70 to 96% polyethylene removal from synthetic greywater (Esfandiari and Mowla, 2021).

3.2 Electrocoagulation

Electrocoagulation (EC) has been tested as a tertiary treatment to further remove MPs from WWTPs prior discharge. A laboratory-scale EC/ electro-flotation system was proposed by (Akarsu et al., 2021) to remove polyethylene (PE) and polyvinyl chloride (PVC) from municipal wastewater effluent, with 100% efficiency. EC was also shown to remove 96.5% of MPs from a real wastewater effluent sample (Elkhatib et al., 2021). In the latter study, the removal of MPs was associated with the generation of hydrogen microbubbles, which were formed at the cathode during water electrolysis.

3.3. Membrane Technologies

Previously reported surveys of MPs in full-scale wastewater treatment revealed that membrane bioreactors (MBRs), as tertiary treatment stage, exhibited high removal efficiencies, from 79% to 93% (Bayo et al., 2020; Cai et al., 2022). The concentration of fouling precursors, were shown to increase by the accumulation of MPs such as polyethylene terephthalate (PET) and polypropylene (PP) in MBRs (Wang et al., 2022; Yi et al., 2022). Recent studies showed that MPs increase the rate of membrane fouling (Enfrin et al., 2021). However, a few studies also showed that the MPs provide a scouring effect, mitigating membrane fouling (Yi et al., 2022). These contrasting findings still must be validated by further studies using different MP types and concentrations and using real wastewater. A limitation in using MBRs to retain MPs in reactors is the potential breaking down of the MPs due to high transmembrane pressures (TMP), in which MPs break down into smaller dimensions, resulting in the production of nano-plastics. One of the MBRs to be further explored for MPs removal is the self-forming dynamic membrane (SFDM), with lower TMPs. A dynamic membrane was investigated by Li et al. (2018) to remove microparticles from an aqueous matrix. However, the study only utilized tap water with diatomite particles instead of MPs. The use of SFDM for the removal of MPs from wastewater is yet to be investigated.

3.4 Micromachines

Recent studies have suggested the use of micromotors to capture, and degrade MPs in aqueous matrices (Hermanová and Pumera, 2022). A magnetic microrobot was developed using adhesive polydopamine coated with Fe_3O_4 to trap MPs in water bodies. In addition, lipase was immobilized on the magnetic microrobot's surface to provide a mechanism for enzymatic degradation of the captured MPs (Zhou et al., 2021). A photocatalytic TiO_2 micromotor was also proposed as a technology to remove MPs from environmental water samples (Wang et al., 2019). It is to be noted that there are no reports yet of these micromachines being utilized in the field nor in WWTPs for MPs removal as of this time.

3.5 Advanced Oxidation Processes

Advanced oxidation processes (AOPs) are also explored to degrade MPs in water matrices through the generation and use of reactive oxygen species (ROS) (Piazza et al., 2022). The AOPs are aimed to remove MPs, even those with smaller dimensions, particularly microfibers. A thermal Fenton reaction achieved 95% reduction by weight of MPs, with 75% mineralization efficiency (Hu et al., 2022). However, the studies on the use of AOPs for MP degradation have mostly been examined for samples such as tap water, and river and seawater and only a few using the wastewater matrix. A UV/H_2O_2 oxidation process obtained a 52% by mass reduction of MP in deionized water, and 15% in a real hospital laundry wastewater (Easton et al., 2023). The lower MPs reduction observed in the laundry wastewater was attributed to the high content of soluble organic matter, which were also oxidized by the reactive radicals. This highlights the need for further studies on AOPs for MPs degradation in the complex real wastewater matrices.

4. Treatment of Microplastics-Polluted Sludge

Results of previous studies have revealed that a significant portion (> 90%) of MPs are accumulated in the wastewater sludge (Li et al., 2020). This underlines the need to reduce the MPs in the wastewater sludge prior disposal or reuse. Hydrothermal liquefaction (HTL) of wastewater sludge has been proposed as a treatment for the degradation of MPs present in this matrix, achieving up to 97% reduction (Chand et al., 2022). This subjects the sludge to elevated temperature and pressure, converting it to biocrude. Anaerobic digestion was also explored as a strategy to degrade MPs present in sewage sludge (Ma et al., 2022). Bioaugmentation in anaerobic digestion may also enhance MPs degradation (Tang, 2023) .

5. Challenges and Future Perspectives

A crucial aspect in the search for technologies to remove MPs from wastewater and sludge is the method used to recover and detect MPs from the said matrices. There are no agreed standard methods yet to determine the content of MPs in wastewater and sludge. Common methods employed for isolation of MPs include filtration, density-based separation methods (using saturated NaCl solution), and chemical digestion methods (Fenton reagent or H_2O_2) (Liu et al., 2022). Methods for detection and identification include the use of FTIR-Raman spectroscopy and scanning electron microscopy among others (Liu et al., 2022). The reporting of % removal efficiencies are also based on different MP dimensions. The presence of MPs in wastewater systems have also been shown to influence wastewater treatment processes. MPs in wastewater have the potential to inhibit the activity of nitrogen-removing microorganisms (T. Wu et al., 2023). MPs also tend to reduce the efficiency of removal of antibiotic resistance genes during aerobic sludge treatment (Zhang et al., 2021), and to decrease methane production during anaerobic sludge digestion (Li et al., 2020). These concerns must be taken into consideration when evaluating and designing technologies for removal of MPs from wastewater.

Conclusions

The removal of MPs from wastewater may be accomplished using existing wastewater treatment facilities. However, due to the high number of MPs still discharged to the environment, there are still needs to enhance the efficiency of existing treatment technologies, or to develop MPs-targeted technologies. As of the time of writing, most of the emerging MP removal technologies are still in the laboratory-scale state of application. Further studies are needed to realize the full-scale application of these processes. In addition, other aspects of wastewater treatment such as the effect of MPs in the efficiencies in removal of other pollutants should also be considered in the evaluation and design of new technologies.

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