Wastewater Removal Strategies of Microplastic Pollution

Subjects: Environmental Sciences

Contributor: Sílvia Martinho, Virgínia Cruz Fernandes, Sónia Figueiredo, Cristina Delerue-Matos

Plastics have been one of the most useful materials in the world, due to their distinguishing characteristics: light weight, strength, flexibility, and good durability. In recent years, the growing consumption of plastics in industries and domestic applications has revealed a serious problem in plastic waste treatments. Pollution by microplastics has been recognized as a serious threat since it may contaminate all ecosystems, including oceans, terrestrial compartments, and the atmosphere. This micropollutant is spread in all types of environments and is serving as a "minor but efficient" vector for carrier contaminants such as pesticides, pharmaceuticals, metals, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). The need to deeply study and update the evolution of microplastic sources, toxicology, extraction and analysis, behavior and removal strategies is imperative.

Keywords: microplastics ; water ; wastewater ; analytical methods ; adsorption

1. Introduction

Plastics have been one of the most used materials in the world. Over the last century, humanity has learned how to create different types of plastics that are stronger, lighter, and more flexible than previous materials. Synthetic polymers, currently known as plastics, can be produced either from natural substances, such as cellulose, or, more often, from petroleum and other fossil fuels [1]. Due to the uncountable applications of plastics and their widespread use, they have become a source of pollution all over the world.

For a better understanding of this emergent problem, there is a need to identify the sources of plastics, the quantity that is spread, the effects that they may provoke on living organisms and humans' health. A reduction of the microplastic entrance in the environment must be done to prevent their dispersion, therefore removal strategies should be implemented.

In 2019, global plastic production reached 370 million tons, and European plastic production reached almost 58 million tons. In 2020, in Europe, 39.6% of plastics were used for packing and 20.4% were used for building and construction, these being the areas that consume the most. In recent years, methods of recycling materials have been developed; however, only 32.5% of plastics go to recycling, 42.6% are used in energy production, and 24.9% are sent to landfills [2]. Even though recycling has been growing in recent years, it is important to know that approximately 50% of plastics have single-use disposable applications, which leads to an accumulation of plastics in the environment. Single-use plastics are used more in packing, agricultural films, and disposable consumer items. Only 20 to 25% of plastics are used in products for long-term use, such as pipes, cable coatings, and structural materials, and the remaining plastics are used for products with intermediate lifespans, such as electronic goods, furniture, and vehicles [1].

The lifetime of plastics is a concern since, on one hand, their good durability allows extended use and renders them a good material choice, but on the other hand, it has been proved that the resistance to degradation of plastic waste is problematic [3]. Currently, there is legislation in countries in order to minimize the impact of plastics; however, the environment has been suffering from the accumulation of plastic waste. It is estimated that 10% of plastics produced end up in the oceans, where they persist, accumulate, and are a way of transporting pollutants [3]. It is estimated that 95% of marine waste has plastics as the main component [4].

Due to the incomplete microplastic removal in conventional wastewater treatment plants (WWTPs), they are a source of microplastics in the aquatic and terrestrial environment. Therefore an enhancement of their removal is needed.

2. Removal Strategies

2.1. Existing Treatments

There are no legal limits for microplastics in the environment, and the experimental monitoring limitations are a problem. Researchers have found some difficulties in the experimental methods since there are no standardized methods to separate and analyze microplastics. In parallel, the sampling in wastewater treatment systems has some challenges that must be taken into consideration, such as the variability of flow rates during the day and the variation in pollutant concentrations [5].

Regardless of these difficulties, it is important to understand how wastewater treatments can help to decrease the presence of microplastics, because of the small size of the particles that may pass throw the different treatment steps and consequently be discharged into rivers [6][7]. Iyare et al. [8] reported several studies about the impact of WWTPs on the concentration of microplastics in the treated wastewater, considering the sampling method, identification, and concentration of microplastics in the influent and effluent of WWTPs in different locations. With the information collected from 21 studies, it was possible to conclude that with a preliminary/primary treatment, an average removal of 72% of microplastics was achieved, while with secondary and tertiary treatments, the removal stayed at an average of 88% to 94%. The activated sludge process is also responsible for the removal of 7–20% of microplastics [9]. Thus, besides studying the sedimentation of microplastics, the shapes and sizes of the particles must be considered important factors for their removal. Despite these good removal efficiencies, it is important to underline that there is a significant variation in the concentration of microplastics in the influent and effluent, which can be related to the variation in the sampling, isolation, and detection methods. Even though WWTPs are not prepared for removing microplastics, good removal efficiencies of around 98–99% have been reported; nevertheless, they may still be a considerable source of microplastics in the effluents discharged [5][10][11].

2.2. Advanced Treatments

Since microplastics are present in treated wastewaters and drinking waters [12][13], several studies have reported the importance of understanding the actual removal efficiencies of microplastics in conventional treatments and how to enhance their removal. Although actual water and wastewater treatments are not projected to remove microplastics, they present good removal efficiencies. Nevertheless, they should be complemented by advanced treatments to enhance microplastic removal. Researchers have been developing and testing different approaches that show possible routes that can be taken in the future. However, it is important to mention that most of the experiments were performed on a laboratory scale and still need to be tested on industrial scales.

WWTPs have been projected to remove contaminants from wastewater, and even though microplastics do not make up part of the list, they have started to be seen as an important focus for removal. Regardless of their efficient removal, WWTPs continue to be a source of microplastics in the aquatic and terrestrial environment. Several tertiary treatments have been tested successfully, although with variable efficiency: rapid sand filtration (55.6–95.0%), micro-screen filtration with disc filters (40.0–98.5%), dissolved air flotation (95.0%), and membrane bioreactors (33.3–99.9%) [14]. Complementing these treatments with new advanced treatments will be the way forward to enhance the removal of microplastics. Recently, different treatment approaches have been reported, namely, electrodeposition, electrocoagulation, and dynamic membranes [15].

The combination of biological wastewater treatment with microfiltration or ultrafiltration in a membrane bioreactor [14] presents a higher maximum efficiency (99.9%) than the conventional primary (95.0%) and tertiary treatments (98.5%), which makes it one of the most efficient technologies that should be explored [15]. Recent studies reported a removal percentage of 100% of commercial PS beads with a magnetic polyoxometalate-supported ionic liquid phase and total removal of PE, PET, and PA microplastics using magnetic carbon nanotubes [16][17].

Electrocoagulation is another advanced treatment that combines the benefits of coagulation, flotation, and electrochemistry. This method promotes the removal of particles, such as microplastics, by destabilizing the repulsive forces that keep the particles suspended in water. Then, the forces are neutralized, and the suspended particles start to aggregate, favoring their removal from the wastewater [18]. The reported advantages are the effective cost, compatibility with different particles, and sludge production minimization [19]. Perren et al. [20] demonstrated the effective removal (around 90%) of microbeads from the water, with pH values ranging from 3 to 10, suggesting that this can be an effective method.

The sol–gel method is a new treatment method that has been used to remove polymers by induced agglomeration of polymers in wastewater, forming big particle agglomerates. This is an economical process that presents good chemical stability, since the use of synthetic amorphous silica (SAS) is very common and successful as a catalyst, carrier, and adsorbent [21]. This process has been tested under alkaline and acidic catalytic conditions, and according to Zhang and Chen [19], the sol–gel method can promote the flocculation of microplastics. With the formation of big microplastic flocculates, the process of the isolation and separation of plastic particles from the water is achieved. The different types and sizes of particles, the concentration of trace contaminants, and external factors, such as pH, temperature, or pressure, are independent of the agglomeration process, being an advantage of the use of this method [19].

Recently, a new approach that involves using coated Fe nanoparticles to magnetize plastics, allowing magnetic extraction and the isolation of microplastics, was explored [22][23]. The hydrophobic surface of microplastics allows their magnetization via binding nanoparticles [23]. Shi et al. [23] reported that this approach was effectively applied to remove microplastics in environmental water bodies including river water, domestic sewage, and natural seawater, with a removal rate higher than 80%. Additionally, nanoencapsulation has been showing promising results in this area, but it needs to be further explored [24].

Dynamic membrane technology is a possible removal technique applied to the removal of microplastics. This method consists of a layer of particles deposited via permeation and pulled onto a conventional membrane, such that the deposited particles act as a secondary membrane to minimize fouling of the primary membrane to lower transmembrane pressures. It is like a cake layer on a supporting membrane. One of its major advantages is the non-existence of chemicals or the generation of by-products. This can be a widely applied method as it can be used to support membranes with a large pore mesh or other low-cost porous materials [25].

3. Conclusions

Microplastics are an emerging pollutant with standard analytical procedures still under development, which limits their accurate monitoring in the environmental compartments. The absence of standardization of the sampling and analytical methods is generating confusion about the real state of this contaminant.

Moreover, according to the reported studies, they interact and present the ability to sorb other contaminants, such as pesticides, pharmaceuticals, and metals. Studies have demonstrated the interactions between microplastics/contaminants and reinforced the idea of microplastics as a vector for the transport of contaminants into different ecosystems. Even though it was possible to confirm the important role that microplastics play, future works must proceed since there is an infinity of combinations and potential spreads into the environment.

The implementation of legislation limiting the concentration of microplastics would be a path to ensure that they start to be seen as a pollutant, with there also being a pressure to ensure that new, precise, and accurate methods are developed for the sampling and analysis of microplastics.

While standardization is not available, which can lead to the misidentification of microplastics, in further works, detailing all the steps (sampling, treatment, solution preparations, equipment required) should be a priority to allow future developments and improvement of the procedures and reach a more precise evaluation.

Several treatment processes have been exposed, such as sol–gel treatment, electrocoagulation, magnetic separation, and dynamic membrane technology; however, most of them have only been tested on a laboratory scale with a few microplastics. New treatment alternatives must continue to be explored and tested in real samples, where a mixture of microplastics and different contaminants is present. It is also important to approach both lab tests and the industrial scale to ensure the viability of strategies to be implemented in future wastewater treatments.

References

1. Hopewell, J.; Dvorak, R.; Kosior, E. Plastics recycling: Challenges and opportunities. Philos. Trans. R. Soc. Lond B Biol. Sci. 2009, 364, 2115–2126.
2. Ferdous, W.; Manalo, A.; Siddique, R.; Mendis, P.; Zhuge, Y.; Wong, H.S.; Lokuge, W.; Aravinthan, T.; Schubel, P. Recycling of landfill wastes (tyres, plastics and glass) in construction—A review on global waste generation, performance, application and future opportunities. Resour. Conserv. Recycl. 2021, 173, 105745.

3. Cole, M.; Lindeque, P.; Halsband, C.; Galloway, T.S. Microplastics as contaminants in the marine environment: A review. Mar. Pollut. Bull. 2011, 62, 2588–2597.
4. Wang, F.; Wong, C.S.; Chen, D.; Lu, X.; Wang, F.; Zeng, E.Y. Interaction of toxic chemicals with microplastics: A critical review. Water Res. 2018, 139, 208–219.
5. Murphy, F.; Ewins, C.; Carbonnier, F.; Quinn, B. Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment. Environ. Sci. Technol. 2016, 50, 5800–5808.
6. Fendall, L.S.; Sewell, M.A. Contributing to marine pollution by washing your face: Microplastics in facial cleansers. Mar. Pollut. Bull. 2009, 58, 1225–1228.
7. Chang, M. Reducing microplastics from facial exfoliating cleansers in wastewater through treatment versus consumer product decisions. Mar. Pollut. Bull. 2015, 101, 330–333.
8. Iyare, P.U.; Ouki, S.K.; Bond, T. Microplastics removal in wastewater treatment plants: A critical review. Environ. Sci. Water Res. Technol. 2020, 6, 2664–2675.
9. Novotna, K.; Cermakova, L.; Pivokonska, L.; Cajthaml, T.; Pivokonsky, M. Microplastics in drinking water treatment—Current knowledge and research needs. Sci. Total Environ. 2019, 667, 730–740.
10. Carr, S.A.; Liu, J.; Tesoro, A.G. Transport and fate of microplastic particles in wastewater treatment plants. Water Res. 2016, 91, 174–182.
11. Lares, M.; Ncibi, M.C.; Sillanpaa, M.; Sillanpaa, M. Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. Water Res. 2018, 133, 236–246.
12. Miranda, M.N.; Silva, A.M.T.; Pereira, M.F.R. Microplastics in the environment: A DPSIR analysis with focus on the responses. Sci. Total Environ. 2020, 718, 134968.
13. Prata, J.C.; da Costa, J.P.; Lopes, I.; Duarte, A.C.; Rocha-Santos, T. Environmental status of (micro)plastics contamination in Portugal. Ecotoxicol. Environ. Saf. 2020, 200, 110753.
14. Talvitie, J.; Mikola, A.; Koistinen, A.; Setala, O. Solutions to microplastic pollution—Removal of microplastics from wastewater effluent with advanced wastewater treatment technologies. Water Res. 2017, 123, 401–407.
15. Pico, Y.; Barcelo, D. Analysis and Prevention of Microplastics Pollution in Water: Current Perspectives and Future Directions. ACS Omega. 2019, 4, 6709–6719.
16. Misra, A.; Zambrzycki, C.; Kloker, G.; Kotyrba, A.; Anjass, M.H.; Franco Castillo, I.; Mitchell, S.G.; Guttel, R.; Streb, C. Water Purification and Microplastics Removal Using Magnetic Polyoxometalate-Supported Ionic Liquid Phases (magPOM-SILPs). Angew. Chem. Int. Ed. Engl. 2020, 59, 1601–1605.
17. Tang, Y.; Zhang, S.; Su, Y.; Wu, D.; Zhao, Y.; Xie, B. Removal of microplastics from aqueous solutions by magnetic carbon nanotubes. Chem. Eng. J. 2021, 406, 126804.
18. Moussa, D.T.; El-Naas, M.H.; Nasser, M.; Al-Marri, M.J. A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. J. Environ. Manag. 2017, 186, 24–41.
19. Zhang, Z.; Chen, Y. Effects of microplastics on wastewater and sewage sludge treatment and their removal: A review. Chem. Eng. J. 2020, 382, 122955.
20. Perren, W.; Wojtasik, A.; Cai, Q. Removal of Microbeads from Wastewater Using Electrocoagulation. ACS Omega 2018, 3, 3357–3364.
21. Herbort, A.F.; Sturm, M.T.; Schuhen, K. A new approach for the agglomeration and subsequent removal of polyethylene, polypropylene, and mixtures of both from freshwater systems—A case study. Environ. Sci. Pollut. Res. Int. 2018, 25, 15226–15234.
22. Grbic, J.; Nguyen, B.; Guo, E.; You, J.B.; Sinton, D.; Rochman, C.M. Magnetic Extraction of Microplastics from Environmental Samples. Environ. Sci. Technol. Lett. 2019, 6, 68–72.
23. Shi, X.; Zhang, X.; Gao, W.; Zhang, Y.; He, D. Removal of microplastics from water by magnetic nano-Fe3O4. Sci. Total Environ. 2022, 802, 149838.
24. Garcia-Manrique, P.; Matos, M.; Gutierrez, G.; Pazos, C.; Blanco-Lopez, M.C. Therapeutic biomaterials based on extracellular vesicles: Classification of bio-engineering and mimetic preparation routes. J. Extracell. Vesicles 2018, 7, 1422676.
25. Li, L.; Xu, G.; Yu, H.; Xing, J. Dynamic membrane for micro-particle removal in wastewater treatment: Performance and influencing factors. Sci. Total Environ. 2018, 627, 332–340.