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Preventing Microplastic Release into Oceans through Wastewater Treatment Technologies

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Abstract:

As the use of plastics in daily life and industrial manufacturing skyrocketed with technological advances, the problem of plastics and manmade microbeads entering the oceans and breaking down into microplastics that can harm humans and marine animals is becoming a rising concern due to improper disposal and treatment of plastic waste. There are currently no technology specifically aiming for capturing and collecting microplastics that existed in the ocean; therefore, it is essential to reduce and eventually prevent further input of plastics from land into the ocean via wastewater discharge. Based on an analysis of two wastewater treatments from their mechanisms, effectiveness, costs, and applications, research found that while Immersed and Sidestream membrane bioreactors are more efficient than other technologies at capturing and reducing plastics, they run the risk of missing or even generating secondary microplastics in the wastewater treatment processes, so there are emergent needs for improvements on the technologies as well as increasing awareness globally.

Keywords: Microplastics, Microbeads, Synthetic polymers, Hydroxyl radicals, Activated sludge.

1. Introduction

Microplastics (MPs) is a broad term used to describe any little fragments of plastic less than 5mm in length [1] that are either manufactured products or synthetic polymer breakdowns. MPs are categorized as primary microplastics if they were made to be small intentionally at the industrial level and secondary microplastics if they are broken down from macroplastics (larger plastic objects). Microbeads (ranging from 60 to 800 micrometers) [2], an example of primary MPs, are largely added into cosmetics and personal care products such as facial scrubs, eyeshadow, and toothpaste, which usually function as exfoliating [3], physical abrasion agents, and binders [4]. Microplastics often get washed down the drain and into the wastewater systems and might be released into the ocean directly or escape from wastewater treatment plants due to the incompletion of the removal [5].

Plastic pollution has become a rising concern due to plastics' persistence. They hardly get collected, reprocessed, and repurposed once they are in nature, especially in aquatic environments. Synthetic polymers, or man-made polymers derived from petrochemicals, are the type of plastics that break down into microplastics and have characteristics like high durability, hydrophobia, and non-biodegradability. In the pelagic zone of the ocean, studies found that microbeads account for 9.7% of all microplastics where they were collected in the upper ocean (within 0.75 meters of the sea surface) [6]. There are few studies focused on the amount of microbeads released into the ocean through sewage or wastewater since the majority (over 90%) of microplastics floating on the surface of the sea are a result of fragmentation - secondary microplastics [7]. A comprehensive market survey conducted in Europe has made it possible to accurately estimate the emissions of microbeads from thirty European countries. In 2012, the estimated emissions ranged from 20 to 300 tonnes, representing 0.1% to 1.5% (w/w) of the total amount of plastic debris discharged in the North Sea [8]. Even though microbeads are a small portion of the total input of plastic debris, when considered from a global perspective, the amount of plastic released will be astounding. Meanwhile, it reflects the enormous scale of the emission of other plastics and microplastics. Between 4.8 and 12.7 million tonnes of plastic are estimated to have been disposed of in the ocean, and this number is rising daily [7].

Microplastics in the ocean are bringing potential harm to marine ecosystems and posing threats to human health as they are chemically addictive and have the risk of accumulating in organisms. Microplastics in the ocean are very likely to be ingested by marine life. Studies have found that in 150 studied fish from Portuguese coastal waters (NE Atlantic Ocean), MPs were found in 49% (73) of them [9]. The microplastic consumption of wild fish has shown evidence of neurotoxicity and oxidative damage. As being at the top of the food chain, adults may consume up to 842 MP items annually from fish consumption. MPs can also enter human bodies through inhalation and skin contact [10]. MPs have the potential to seriously harm human health, causing oxidative stress, inflammation, necrosis, apoptosis, and immune responses.

Numerous studies examine the origins and distribution of microplastics (MPs), but there doesn't seem to be much research on practical ways to collect MPs that are already released into the ocean. Since promising solutions to solve this problem haven't been found, people should focus on the regulations of the elimination of primary microplastics and effective wastewater treatment to reduce and prevent further accumulation of microplastics in marine environments and eventually in human bodies.

The purpose of this paper is to (a) knowledge of the impact of microplastics on marine organisms and human health, (b) investigate current wastewater treatment technologies for microplastic removal, and (c) propose possible areas to investigate in the future.

2. Advanced Oxidation Processes for plastic pollution control

Advanced Oxidation Processes (AOPs) were originally used in the treatment of drinking water and now have extended their use in wastewater treatment [11]. AOPs are the processes that generate oxidizing agents through different methods with the use of chemicals, light, catalysts, or electrical energy. The oxidants generated are used to react with and mineralize the influent organics into smaller, biodegradable, and low-toxicity compounds. Methods such as Fenton oxidation, photo-catalytic oxidation, and electrochemical oxidations are very practical and adaptable in producing oxidants such as hydroxyl radicals(·OH). Hydroxyl radicals are usually in situ produced due to their short in lifetime [12]. The following lists the various steps involved in producing ·OH radicals, a potent, non-selective oxidizing agent.

$$R+\cdot HO \rightarrow OH \tag{1}$$

$$R+\cdot OH \rightarrow R+H_2O \tag{2}$$

$$R_n \cdot HO \rightarrow R_n^{-1}+OH^- \tag{3}$$

Hydroxylic radicals are effective for breaking down organic wastes [13] like synthetic polymers, which microplastics and microbeads originated from. In general, hydroxyl radicals break down chemical bonds in organics resulting in smaller particles and ultimately mineralizing them into carbon dioxide and water. Four basic processes—hydrogen abstraction, radical addition, electron transfer, and radical combination—allow hydroxyl radicals to eliminate organic pollutants [14]. Hydrogen abstraction is typically the first step in this chain of reaction. By removing hydrogen atoms from polymer chains, hydroxyl radicals (·OH) generate new radical sites on the polymer. The polymer's chemical bonds are thus weakened by this process. Conjunctionally, chain scission, the breaking of bonds happens as new radicals are created through the former process, and they can further react to break polymer chains which is known as radical addition. Followed by electron transfer, which is similar to radical addition, contributing to the further breakdown of polymers and forming new radicals by transferring electrons to other molecules. Lastly, the process ends with the radical combination when radicals combine and form stable compounds [15].

In comparison with AOPs, conventional oxidation processes (COPs) seem less efficient since they use standard oxidizing agents like chlorine. When chlorine is added to water for disinfection, it is converted to hypochlorous acid, which leads to chain breakage and chain disintegration. Chlorine is an oxidizing agent that breaks the carbon-carbon bonds in polymer chains, thus effectively disintegrating the polymer chains [16]. However, conventional oxidation processes may struggle to deal with complex pollutants since some contaminants can be resistant to standard oxidants. Chlorine byproducts as a result of chlorination from COPs may be harmful. On the other hand, AOPs generated hydroxyl radicals are extremely reactive against a broad spectrum of pollutants, including synthetic polymers, very quickly with speeds ranging from 108 to 1010 M-1 · S-1 [11]. The mineralization carried out produces less harmful byproducts: carbon dioxide and water, aiming for a complete degradation. Therefore, AOPs are very suitable for treating complex and challenging pollutants.

Although hydroxyl-based AOPs can mineralize synthetic polymers no matter the size under ideal conditions, there are always uncertainties in influent wastewater, such as the pollutant types, temperature, and pH. The impletion of mineralization contributes to the formation of secondary plastics, which can exacerbate the problem of microplastic release into the ocean.

In addition, AOPs require advanced reactors like UV and ozone generation systems, which are often associated with high costs.

3. Membrane Bioreactor for plastic pollution control

Membrane Bioreactors (MBRs) are emerging wastewater treatment systems that incorporate membrane filtration along with biological treatment procedures. MBR systems come in two general configurations: Submerged/Immersed membrane bioreactor and side-stream membrane bioreactor. These configurations differ in the possible magnitude of trans-membrane pressure (ΔP) and the direction of flow, which is reversed. The liquid is pushed across the membrane in EMBR and pumped across it in IMBR. As a result, the trans-membrane pressure for EMBR may be higher than for IMBR, which would increase the energy consumption and decrease the exchange area required for a given permeate flow for the former [17]. A crucial parameter in the membrane filtration procedure is trans-membrane pressure (TMP), which refers to the change in pressure across the membrane that drives the filtration process. The membrane can come in three different types: flat-sheet, hollow fiber, and tubular.

3.1 Submerged/Immersed Membrane Bioreactors (IMBRs)

Immersed membrane bioreactors (IMBRs) are a kind of membrane bioreactor where two principles work in conjunction to provide an optimal effect: separation and suspended growth bioreactor. The membranes in the filtration systems of IMBRs are immersed in the bioreactor plant[18]. The influent(wastewater) gets mixed with the activated sludge, a mixture of microorganisms, that performs the biological treatment. Then the biological reaction happens when the microorganisms in the activated sludge consume and degrade organic pollutants inside the wastewater through metabolic processes, which include aerobic digestion and nitrification. These two processes are performed under the presence of oxygen, in other words aerobic. Microorganisms produce carbon dioxide, water, and new microbial biomass when breaking down organics into simpler compounds. Meanwhile, they convert ammonia to nitrite and then nitrate.

Simultaneously, membrane filtration takes place. The characteristic of IMBs is that the membrane is directly immersed in the bioreactor tank with the mixed liquor and in contact with the contaminants. As driven by the trans-membrane pressure, water is able to pass through the membrane while suspended solids, microorganisms, and other contaminants are retained. The filtered water is collected, and the retained substances are left on the other side of the membrane for further circulation.

3.2 Sidestream/External Membrane Bioreactors (SS MBRs)

A sidestream MBR with an external membrane module set up outside the aeration tank is also known as a cross-flow membrane bioreactor (CFMBR). The invention of sidestream was at first purpose to reduce the problem of membrane fouling.

Similarly, the liquid-solids mixture(wastewater) has gone through biological treatment -bacteria in the activated sludge degrade organic pollutants into smaller molecules. The mixture is then pumped to the membrane module, where it undergoes cross-flow filtration through the membrane to filter it. The excess flow, or retentate, is circulated to the aeration tank while the permeate is released. The pore size of the membrane is ranging from 0.01 -0.45 micrometer. On the permeate side, a suction pump was added additionally to the recirculation pump to improve operation flexibility and lower energy and cross-flow rates [19].

3.3 Compare and Contrast Two Configurations of Membrane Bioreactor

The advantage and disadvantage of the two types of membrane bioreactor are summarized in table 1. In general, IMBRs are more suitable for municipal wastewater treatment application, while SS MBRs are more effective in treating industrial wastewater. Compared to other technologies, Membrane bioreactors have higher quality of water treated, smaller plant footprint and sludge production, and better operational flexibility make them beneficial [20].

Table 1. Comparison of IMBRS and SS MBRs

	IMBRS	SS MBRs
Advantages	Lower energy consumption	Lower risk
	More suitable for place-constrained applications	Easier membrane maintenance for the membrane modules installed separately
	Simper installation	Higher scalability
Disadvantages	Difficult and challenging membrane maintenance	Higher energy consumption
	Lower flux rates	Higher complexity in installation and operation
	Limited scale	Larger footprint

3.4 Concerns Related to the Membranes

In current applications, the most common membranes are made of polyethylene (PE), polyvinylidene fluoride (PVDF), polyethersulfone (PES), and polysulfone (PSF), all of them are synthetic polymers. These polymers are more widely used than other materials like metallic and inorganic because they are relatively cheaper [19]. This gives rise to a concern that secondary plastics may be produced during the processes, and are likely to escape from the side where filtered water gets collected.

Both configurations face the problem of membrane fouling [21], so there need for careful maintenance such as backwashing and chemical cleaning.

4. Possible Future Focuses

4.1 Educating the Public and Raising Awareness

People must acknowledge the global microplastic concern and understand that if plastics are managed properly, the harm brought by microplastics to the environment can be minimized. A large portion of plastic waste is either disposed inadequately or littered. The National Library of Medicine stated that proper waste management will reduce plastics in the environment and lessen the fragmentation into microplastics. Therefore, it is pressing to raise public awareness of the seriousness of microplastics, and the problems associated with them. To achieve this goal, educational institutions and social media should make a joint effort to promote the popularity in this field and carry out relevant campaigns.

4.2 On-Site Waste Segregation

Manufacturers should separate and sort waste materials as they are produced, which can reduce plastic leakage. Plastic materials are less likely to mix with other waste streams and cause contamination due to mismanagement when waste is separated, thus lowering the potential of plastics leaking into the environment and eventually being degraded into microplastics.

4.3 Policymaking

To lessen the amount of microplastics that enter the oceans from industry, governments ought to introduce policies encouraging the use of water treatment and standardizing sewage treatment in industrial settings since the industries account for the majority of plastic and microplastic emissions and leakages, especially synthetic textiles in order to determine the permissible legal amounts for the discharge of plastic wastewater, governments need to evaluate wastewater emissions regulations.

4.4 Government Incentives

Governments could offer tax breaks or subsidies to businesses that adopt new procedures or technologies to reduce plastic consumption and leakage. The installation and use of these technologies may be promoted by these financial incentives, or the initiatives could be expanded into larger systems that could be implemented in the industrial sector.

4.5 Technology Improvements

As mentioned earlier, there is plenty of room for improving existing technologies: increasing the adoption and efficacy of microplastic removal technologies. For instance, advancing the membrane antifouling technology, finding cost-effective material substitutes, and maintaining steady operational stability with high durability. All these will contribute to the reduction of microplastics ending up in the ocean.

4.6 Innovations

To author's knowledge, there is currently no technology specifically targeting the microplastics that are in the ocean. Most of the existed technologies are focusing on the collection of plastics pollution in the waterways, with limited capacity and potential to solve the plastics pollution in a vast extent, however. This should be a field that people should dive into because the problem is getting more serious day by day.

5. Conclusion

This paper discussed two technologies Immersed membrane bioreactors and Sidestream membrane bioreactors that are already in used for treating plastics, including microplastics and microbeads, which can prevent the number of plastics discharged into the ocean. Both types of membrane bioreactors efficient at removing microplastics; however, they each have limitations that limit their use in many circumstances. To overcome these obstacles and increase the adaptations and practicability of these technologies for extensive implementations, more investigation and advancement are imperative.

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