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A comparison of new and age-old approaches treating microplastics in the marine environment

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Abstract. In recent years, microplastic pollution in the ocean has become a new environmental threat, posing a serious potential threat to marine ecology. Due to its high degradation resistance and bioaccumulation, it is an urgent and critical issue for the environment. Unfortunately, current technologies for removing, recycling, or degrading microplastics are not sufficient to eliminate them. The main sources of microplastics (MPs) in the ocean are ocean drift inputs, river inputs, fishing and shipping activities, microplastic emissions from human settlements, and atmospheric migration. Microplastics may pose a threat to marine life and affect the stability of marine ecosystems. Therefore, it is urgent to further study governance methods and analysis processes, and strengthen the source control of marine microplastic pollution. This study aims to analyze and discuss different methods for treating marine microplastics, analyze their respective advantages and limitations, and evaluate their feasibility and effectiveness in practical applications. The study ultimately emphasized the importance of effective management of marine microplastics, which is crucial for protecting marine ecosystems and human health. Through a comprehensive analysis of physical, chemical, and biological methods, this study provides valuable insights for marine environmental management and research institutions, thereby promoting the development and application of effective management technologies to achieve sustainable environmental outcomes.

Keywords: Marine Microplastics, Effective Environmental Management, Marine Ecosystems.

1. Introduction

Marine microplastic pollution has become a significant environmental concern worldwide in recent years. Microplastics are defined as plastic particles with a diameter of less than 5 millimeters [1]. Once in the marine ecosystem, they pose serious threats to marine organisms and ecosystems. This study aims to explore the physical, chemical, and biological methods for mitigating marine microplastic pollution, and analyze their respective advantages and disadvantages, as well as their feasibility and practical applications. The research employs a combination of literature review and empirical studies, collecting and analyzing relevant research articles and experimental data. By comparing and summarizing the principles, operability, and cost-effectiveness of different treatment methods, their feasibility and effectiveness are assessed. Physical methods mainly include techniques such as filtration, adsorption, and trapping, which offer advantages such as simplicity and high efficiency. However, they may face challenges in handling smaller particles and large-scale pollution. Chemical methods primarily involve techniques such as oxidation, degradation, and polymerization, which

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exhibit the advantages of processing larger quantities of microplastics and yielding significant results [2]. Nevertheless, further research is required to address potential environmental side effects. Biological methods mainly involve the utilization of microorganisms and biological adsorption, highlighting their environmentally-friendly and sustainable characteristics. However, more research is needed to improve efficiency and stability. Addressing marine microplastic pollution is a crucial task for safeguarding marine ecosystems and human health. Through comprehensive analysis of physical, chemical, and biological methods, this study provides a valuable reference for marine environmental management agencies and research institutions, promoting the advancement and application of mitigation technologies, and achieving sustainable development of ecological environments. In summary, dealing with marine microplastic pollution is a complex and pressing issue that necessitates adopting an integrated approach. Physical, chemical, and biological methods each have their own advantages and disadvantages, and the selection of appropriate technological combinations should be based on specific circumstances.

2. Production of plastics and effects of MPs in the ocean

The annual global production of plastic resins currently stands at approximately 300 million metric tons (MMT), with Asia accounting for nearly half of this production. Plastic litter tends to be more prevalent in areas where products are manufactured and in densely populated urban centers. These locations are more likely to have a high incidence of litter, and if they are coastal or near rivers, they are also probable sources of marine litter [3].

The increase in global plastics production, driven by population growth, has followed a non-linear trend, indicating a rise in per-capita consumption of plastics. Packaging, which has a relatively short lifespan, accounts for the majority of common plastic resin production. Consequently, a significant amount of plastic waste ends up as litter and municipal solid waste. The production of polyethylene (PE) and polypropylene (PP), the most commonly found plastics in marine microplastics (MPs), has grown at an annual rate of 8.7% from 1950 to 2012 [4]. This growth has increased the fraction of these plastics that ultimately become marine litter.

In recent years, concerns about plastic debris in oceans have expanded to include the distress caused by ingestion in organisms. These concerns are also focused on the presence of low-molecular-weight chemical species in plastics that may be bioavailable to ingesting organisms and pose a toxic hazard. Three categories of such compounds are known in plastics.

(1) MPs effectively sorb persistent organic pollutants (POPs), which are found in saltwater. In water-plastic systems, the equilibrium distribution coefficient (K) for typical POPs varies from 103 to 105 in favor of the plastic. This shows that sorbed POPs might legitimately infiltrate the marine food system by ingestion of MPs. The possible hazardous consequences of swallowing POPs depend on their bioavailability, body mass of the consuming organism, concentration in the MP, and propensity to bioaccumulate in the organism [5].

(2) Chemicals added to plastics during production or processing are known as additives. Stabilizers, plasticizers, and flame retardants are some of these additions. For instance, plasticizers might be bio-available to consuming creatures and are utilized at quite high doses (10%-50%) to assure product performance. Such additives could be included in MPs made from compounded polymers.

(3) Plastics' residual monomers. Polyethylenes (PE) and polypropylenes (PP), two popular plastics used in marine MPs, don't contain any leftover monomers [6]. The amount of styrene monomers and oligomers in polystyrene (PS), which is also present in large amounts in debris, can range from 0.1 to 0.6 weight percent.

3. Methods

Microplastics pollution has emerged as a significant global environmental issue, particularly in marine ecosystems. These tiny plastic fragments, measuring less than 5 mm in diameter, have been found in various natural environments such as oceans and the atmosphere. Only recently, however, has the potential impact of microplastic pollution on the marine environment gained recognition. Researchers

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have demonstrated the detrimental effects of microplastics on marine wildlife, and concerns about the presence of microplastics in seafood consumed by humans, given the high intake of fish and shellfish in some countries. The ingestion of microplastics by marine organisms, due to their small size, can lead to their accumulation in the food web, along with associated toxins and microorganisms that adhere to the plastic surfaces. Moreover, recent studies have revealed that plastic biofilms are diverse and influenced by several factors, including spatial and seasonal, as well as polymer type, texture, and substrate size. Understanding these complex factors is crucial for comprehending the potential consequences of microplastics on marine ecosystems and human health.

3.1. Physical methods

Physical methods focus on removing or collecting marine microplastics through physical means. Here are some commonly used physical methods:

Water filtration: Use filters or mesh devices to capture and collect microplastic particles. The coagulants utilized in this procedure, such as iron or aluminum sulfate, cause the precipitation of flocs of suspended particulate matter that are simple to separate from water. The key to achieving adequate separation efficiency during this procedure is the hydrogen bonding and/or electrostatic interactions between coagulants and suspended particles. To increase the removal effectiveness of MPs during the solidification process, it is essential to create new green additives to stabilize the flocs as well as extra oxidation stages (such ultraviolet and ozone to stimulate the interaction between the flocs and MP).

(1) Membrane filtration and absorption methods: The membrane filtration method utilizes membrane materials with microporous structures to physically separate microplastic particles from water. These members typically have specific pore sizes that selectively filter target microscopic particles Common membrane materials include ceramic membranes, polyethersulfone membranes, and nanofiltration membranes. The membrane filtration method can effectively remove microplastic particles while retaining other useful inclusions in the water. In addition, the absorption method utilizes the characteristics of adsorbent materials to adsorbent microparticles from water onto the surface of the material Common adsorbent materials include activated carbon, polymer resins, and nanomaterials. These materials have large specific surface areas and absorption capacities, enabling effective absorption of microparticles. The adsorption method can achieve selective adsorption and effective removal of microplastics by adjusting the properties of adsorbent materials and processing conditions [7]. Both membership filtration and absorption methods have their advantages and application ranges The membrane filtration method is characterized by high efficiency and strong controllability, making it suitable for treating large volumes of water. The absorption method, on the other hand, has higher absorption capacity and selectivity, making it suitable for treating low concentrations of microbial pollutants. Additionally, these two methods can also be combined to improve treatment effectiveness and remove effectiveness.

(2) Magnetic separation: Utilizing magnetism, magnetic separation devices are used to attract and separate water bodies containing microplastic particles from magnetic materials.

(3) Ultrasound: Ultrasonic technology is used to destroy the structure of microplastic particles, making them easy to capture and remove.

The advantages of physical methods are relatively simple operation, minimal environmental impact, and the ability to directly remove microplastics from the water column. However, the disadvantage is that it cannot handle the microparticles of microplastics, and there are still some efficiency and cost issues.

The advantages of physical methods are relatively simple operation, minimal environmental impact, and the ability to directly remove some large microplastics from water. However, no matter how much development has been made, the disadvantage is that it cannot handle the microparticles of microplastics, and there are still some efficiency and cost issues. The strategies mentioned above based on simple physical separation cannot permanently solve the pollution of MPs in seawater, as there is a lack of reasonable treatment to recover or completely eliminate the separated and collected MPs fragments and particles.

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3.2. Chemical methods

The re-introduction of physically separated microplastics into the environment has prompted the development of chemical strategies for degrading and permanently removing MPs. Catalysts play a crucial role in this process by generating reactive oxygen species (ROS) that trigger MP degradation.

Photocatalytic method: The photocatalytic method employs photocatalysts to degrade and decompose microplastics under light conditions. This environmentally-friendly technology utilizes solar energy, which is free and renewable. Semiconductor photocatalysts, such as titanium dioxide (TiO_2), are commonly used in this method to absorb light energy and excite electrons, resulting in the production of active oxides like hydroxyl and superoxide radicals [8]. These radicals degrade microplastic particles. The photocatalytic method boasts high efficiency, no secondary pollution, and renewability. It also offers advantages such as low toxicity, affordability, and excellent acid and alkaline resistance. However, challenges remain in applying photocatalysis in the marine environment due to limitations in lighting conditions and the complexity of microplastic particles.

(1) High-temperature pyrolysis: High-temperature pyrolysis involves decomposing microplastic particles into low molecular weight compounds under high-temperature conditions. The polymer structure of microplastic particles is disrupted at high temperatures, leading to their decomposition into smaller organic compounds. By adjusting parameters like temperature, reaction time, and reaction environment, high-temperature pyrolysis achieves effective decomposition of microplastics. However, this method requires high-temperature conditions and consumes significant energy. It also generates harmful gases and waste, necessitating subsequent treatment [9].

(2) Solvent treatment method: The solvent treatment method extracts microplastic particles from water using solvents. Organic solvents such as chloroform and dichloromethane are typically employed to dissolve microplastic particles and separate them from the solvent. By adjusting parameters like solvent type, concentration, and treatment time, the solvent treatment method achieves effective extraction of microplastics. However, this method requires a substantial amount of organic solvents, leading to environmental pollution and resource consumption. Additionally, solvent treatment methods have limitations regarding the size, shape, and chemical properties of microplastic particles.

3.3. Biological methods

Due to the numerous potential pathways for removing MPs, it is crucial to accurately evaluate the advantages and disadvantages of each method. Especially in these aspects: cost, safety, flexibility, and sustainability. The cost depends on the manufacturing of key materials (i.e. membranes, absorbents, and catalysts) and the energy consumption throughout the entire process [10]. Safety depends on the use of toxic chemicals and the production of toxic intermediate products. Flexibility is the stability of performance in practical applications under various environmental factors, including pH, temperature, and the presence of other anionic and organic pollutants. Sustainability is estimated from two aspects: (1) The structural and performance stability and recyclability of key materials in long-term applications; (2) Processing time and experimental conditions (i.e. high temperature, high voltage, electricity, ultraviolet light). Both physical and chemical methods have their advantages and disadvantages, and in recent years, biotechnology has emerged to treat marine microplastic waste [11]. Biotechnology is a very important technology for repairing the environment, whether it is in water or soil. The ingestion and metabolism of pollutants by microorganisms or the direct interaction between pollutants and extracellular enzymes of microorganisms lead to the mineralization or conversion of harmful pollutants into CO_2, H_2O, or other non-toxic small organic molecules. With the advantages of good efficiency, low operating costs, and no secondary pollution, the use of biotechnology to control pollutants in the environment is undoubtedly the future development trend.

Biomass filtration: This method utilizes biological adsorbents, such as algae or sponges, to adsorb and collect microplastics. Algae and sponges have a large surface area and porous structure, which can effectively adsorb microplastic particles. By placing these biosorbents in water, microplastic particles can be adsorbed onto their surfaces and subsequently collected and treated.

Microbial degradation: This method utilizes microorganisms with degradation ability, such as bacteria or fungi, to decompose microplastic particles. These microorganisms can secrete enzymes to degrade the polymer structure of microplastics, breaking them down into smaller compounds. By regulating environmental conditions and providing appropriate nutrients, the growth of microorganisms and the degradation of microplastics can be promoted.

Ecosystem restoration: This method restores the self-purification capacity of marine ecosystems by constructing artificial wetlands or improving coastal vegetation. Artificial wetlands can provide habitats and habitats, attracting various biological species, including microorganisms and biosorbents, to degrade and adsorb microplastics. Improving coastal vegetation can increase biodiversity and ecosystem stability, thereby enhancing the processing capacity of marine ecosystems for microplastics.

The advantages of biological methods are their low cost and minimal environmental impact. Compared to some chemical and physical methods, biological methods are more sustainable and environmentally friendly. Biological methods utilize existing organisms and biological processes in nature to process microplastics in the natural environment. However, biological methods also face some challenges. Different environmental conditions and types of microplastics may require different biological methods, thus requiring in-depth research and optimization. In addition, the efficiency and feasibility of biological methods also need to be verified and evaluated in practical applications.

4. Suggestions, Challenges and Prospects for the Prevention and Control of Marine Microplastic Pollution

The following suggestions can be made to prioritize the prevention and control of microplastic pollution in marine ecological protection and development:

(1) Collect comprehensive data on marine microplastic pollution and assess the pollution status. Advancements in methods for recognizing and quantifying microplastics are essential not only for detecting environmental microplastics but also for studying degradation kinetics and product selectivity [12].

(2) Enhance the traceability of microplastic pollution and incorporate it into water pollutant discharge standards across industries. While traditional microplastic removal strategies, such as absorption, ultrafiltration, and membrane technology, have shown some efficacy, exploring chemical methods for degrading or mineralizing microplastics into harmless substances like CO holds greater significance. Additionally, there is an urgent need to develop advanced technologies for removing microplastics from air and soil, as research increasingly highlights their potential risks [13].

(3) Promote the use of alternative materials that are recyclable and/or easily recyclable, particularly in plastic packaging. Support the development and promotion of green and reduced plastic packaging alternatives, invest in research and development of low-cost and degradable plastics, and contribute to the growth of the degradable plastic industry.

(4) Expand plastic degradation technologies through various approaches, including the design of PET depolymerization enzyme technology for plastic decomposition and recycling. Inspired by the application of coupling technology in detection and catalysis, exploring different combinations of technologies may advance microplastic removal methods. The synergistic effects of physical-chemical, physical-biological, or chemical-biological coupling methods could enhance the efficiency of microplastic degradation. In addition to focusing on completely harmless treatment methods, attention should also be given to the intentional degradation and recycling of bulk plastic waste. Implementing a well-designed plastic waste recycling strategy can effectively reduce the primary source of secondary microplastics.

5. Conclusion

Marine microplastic pollution is a significant environmental concern that requires urgent attention and action. This study has explored the physical, chemical, and biological methods for mitigating marine microplastic pollution and analyzed their respective advantages and disadvantages. Physical methods, such as filtration and adsorption, offer simplicity and high efficiency but may face challenges in

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handling smaller particles and large-scale pollution. Chemical methods, such as oxidation and degradation, can process larger quantities of microplastics but require further research to address potential environmental side effects. Biological methods, utilizing microorganisms and biological adsorption, highlight environmentally-friendly and sustainable characteristics but require more research to improve efficiency and stability. Addressing marine microplastic pollution is crucial for safeguarding marine ecosystems and human health. An integrated approach that combines physical, chemical, and biological methods is necessary. The selection of appropriate technological combinations should be based on specific circumstances. It is important to collect comprehensive data on marine microplastic pollution, enhance traceability, and incorporate it into water pollutant discharge standards. Promoting the use of alternative materials and investing in research and development of degradable plastics can contribute to reducing plastic pollution. Expanding plastic degradation technologies through various approaches and implementing a well-designed plastic waste recycling strategy can effectively reduce the primary source of secondary microplastics. Overall, this study provides a valuable reference for marine environmental management agencies and research institutions, promoting the advancement and application of mitigation technologies, and achieving sustainable development of ecological environments. However, further research and optimization are needed to improve the efficiency, feasibility, and stability of the different methods for mitigating marine microplastic pollution.

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