A comprehensive review of microplastics in wastewater treatment plants

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Abstract. This study is a review of microplastic pollution removal methods, which are the most current pollution problems in today's world, and which have been tried to be clarified with the studies done in the recent years on their behavior, source, and removal. Used in microplastic removal; dynamic membranes have low filtration resistance low transmembrane pressure, easy to use and purification without the use of chemicals, combined use of membrane bioreactors and advanced purification methods with porous membranes, combined treatment of wastewater treatment plants by sorption-biological processes, low maintenance costs, simple use, classical coagulation and sedimentation methods, microparticles removal with a simple mechanism, and working conditions can be controlled, the flexibility of the electrocoagulation method in terms of removal of the smallest particles, minimum sludge production, energy efficiency, cost effectiveness and automation, biodegradation has advantages such as simplicity and safety in large-scale use, low operating costs, practical applicability in different environments, and flexibility to manage a wide variety of wastewater properties and flows. Key words. microplastic, treatment, coagulation, flotation, DAF system, biological treatment, flocculation.

1 Introduction

Recently, local and foreign experts have paid great attention to the purification of wastewater from microplastics, because microplastics in treated wastewater and entering water bodies are non-degradable in water bodies and cause secondary pollution of water bodies. In connection with these negative phenomena, wastewater containing dyes, surfactants and other biochemically difficult-to-oxidize organic contaminants must be subjected to local treatment at the site of their formation. Enterprises producing consumer goods are, as a rule, small, operate in one or two shifts, with significant fluctuations and interruptions in the generation of wastewater, which necessitates the creation of highly efficient, partially or fully automated periodic treatment facilities. In addition, due to the requirements to reduce freshwater consumption and reuse low-contamination streams for process purposes, separation is practiced; flows, as a result of which highly contaminated wastewater enters local treatment plants. In many cases, very deep wastewater treatment is required due to the low power of the treated wastewater.

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receiver.

The methodological sequence of work included studying the processes of electrolysis and catalysis according to domestic and foreign literature, conducting exploratory laboratory studies to select promising electrodes, structural elements of electrolyzes and catalytic materials, semi-production studies to determine optimal technological parameters and mathematical interpretation of the process, industrial testing of the developed technology, implementation results into design practice.

Despite the fact that its roots go back to the 50s of the last centuries, the scientific community fully understood the problem of plastic pollution of the biosphere relatively recently. At the same time, a definition was given to the concept of "plastic", which combines heterogeneous groups of synthetic organic polymers. Large-scale and widespread application of polymer products has led to a sharp increase in their production. According to researchers' calculations, plastic production has increased 600 times in the last 50 years. Most synthetic plastics are compounds resistant to degradation in the environment. The structure of the industrial production of these materials is dominated by disposable products and products with a limited useful life. For example, in the European Union, the packaging sector accounts for about 40% of all plastic products produced. According to environmentalists, 500-1000 billion plastic bags alone are used in the global trade network every year, which is about 150 pieces/year for every inhabitant of the planet [1].

It was determined that under the influence of environmental factors, large polymer products break down over time and form micro-sized plastic particles. The process of plastic degradation to microscopic sizes occurs especially quickly in the marine environment, where synthetic fragments are constantly exposed to sunlight and wave activity.

Microplastics are small plastic particles less than 5mm in size, originating from the breakdown of larger plastic debris or from the direct release of small plastic particles, such as microbeads in personal care products. Industrial processes, such as manufacturing and packaging, often release microplastics into wastewater, making it crucial to identify and implement effective separation methods (Figure 1) [2].

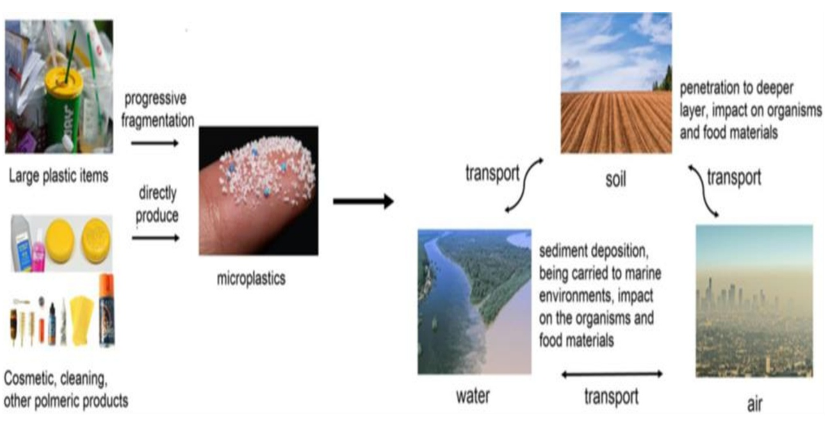

Fig. 1. The influence of microplastics on the environment

To identify effective methods to reduce the environmental impact of microplastics, it is important to understand their origins and pathways. Microplastics are primarily created by the breakdown of larger plastic items, including but not limited to bottles, bags, and packaging materials [3].

These items gradually break down into smaller fragments, eventually turning into microplastics that are easily transported by wind and water currents. Another source of

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microplastics is the removal of synthetic fibers from textiles and clothing during the washing process. Due to their tiny size, these fibers are not retained by filtration systems at wastewater treatment plants and eventually end up in rivers and oceans. Additionally, microplastics are created by the breakdown of plastic beads and microbeads used in personal care products, including toothpaste and facial cleansers [4].

2 Methods and materials

Various methods and technologies have been developed and are under investigation to address microplastic pollution. Here are some key strategies:

1. Filtration

- Description: Filtration involves passing wastewater through a physical barrier that captures
microplastics while allowing water to pass through. Filters can vary in pore size and material, including sand filters, membrane filters, and activated carbon filters.

- Efficiency: Filtration is highly effective for larger microplastics but may struggle with particles smaller than the filter’s pore size. Advances in nanofiltration and microfiltration technologies have improved the capture of smaller particles.

- Practicality: Filtration systems are relatively easy to implement and maintain. However, regular cleaning or replacement of filters is necessary to prevent clogging and maintain efficiency [5].

2. Coagulation and Flocculation

- Description: This chemical process involves adding coagulants to wastewater, causing microplastics to aggregate into larger particles (flocs) that can be more easily removed. Common coagulants include aluminum sulfate and ferric chloride.

- Efficiency: Coagulation and flocculation are effective for a wide range of microplastic sizes and types. The efficiency depends on the choice of coagulant and optimal dosing.

- Practicality: The process is widely used in water treatment facilities and can be integrated into existing systems. It requires careful monitoring of chemical dosages and may produce sludge that needs further handling [6].

3. Dissolved Air Flotation (DAF)

- Description: DAF involves injecting air into the wastewater, creating bubbles that attach to microplastic particles and floating them to the surface, where they can be skimmed off.

- Efficiency: DAF is effective for removing microplastics of various sizes and densities, especially those that are difficult to filter.

- Practicality: The method is suitable for large-scale operations and can handle high volumes of wastewater. It requires specialized equipment and can be energy-intensive [7].

4. Electrocoagulation

- Description: Electrocoagulation uses electrical currents to induce the coagulation of microplastics. Metal electrodes release ions into the water, promoting the aggregation of particles.

- Efficiency: This method is effective for a broad spectrum of microplastics and can also remove other contaminants, such as heavy metals.

- Practicality: Electrocoagulation systems are versatile and can be adjusted for different wastewater characteristics. However, they require a stable power supply and regular maintenance of electrodes [8].

5. Biological Treatment

- Description: Biological treatment involves using microorganisms to degrade or transform microplastics. While traditionally used for organic waste, some studies explore the potential of specific bacteria and fungi to break down plastics.

- Efficiency: The method is still in the experimental stage for microplastics, with varying degrees of success reported. The degradation rate is typically slow.
- Practicality: Biological treatment offers a sustainable solution with minimal chemical use. However, it requires further research and development to be viable for industrial wastewater treatment (Figure 2) [9].

Conducted a study utilizing dynamic membranes for the efficient removal of microplastics from synthetic wastewater. They investigated the effects of influent water and particle concentration on the removal efficiency of dynamic membranes formed on a diatomaceous earth platform with a 90 µm support mesh during the filtration of synthetic wastewater. They achieved excellent microplastic filtration by reducing the turbidity of the influent water from 195 NTU to below 1 in the effluent water within 20 minutes [10].

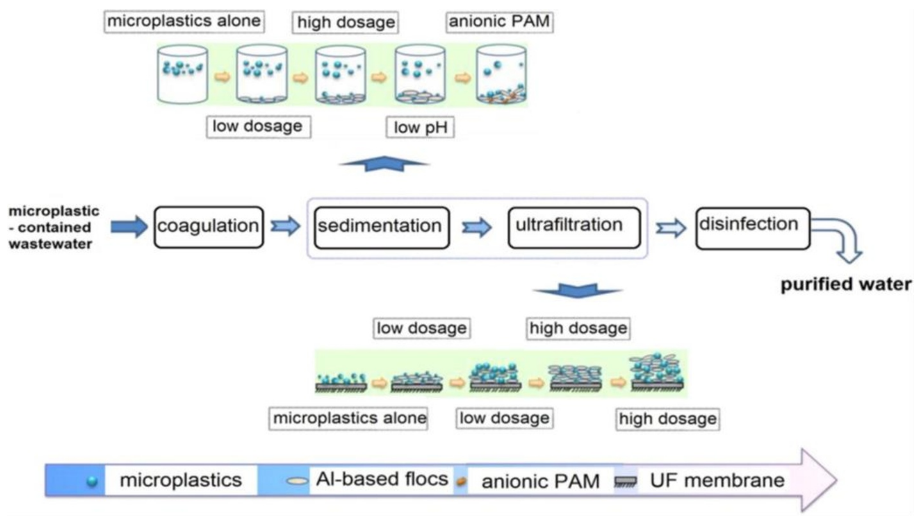

Fig 2. Treatment of Microplastics in Wastewater

Superior Capacity of Membrane Bioreactors

Membrane bioreactors demonstrate higher capacity for removing micro-sized plastics compared to simple dynamic membranes. The successful removal of a wide range of complex industrial wastewaters by membrane bioreactors confirms that this technology is suitable for treating high-strength pollutants like polymeric residues and microplastics. Explored the removal of various microplastic types from wastewater treatment plant effluents using advanced final-stage treatment technologies, including membrane bioreactors, disk filters, rapid sand filtration, and dissolved air flotation. The membrane bioreactor was found to remove 99.9% of microplastics from water, regardless of their shapes [11].

Advanced Filtration Technologies in Wastewater Treatment Plants

The results of studies to date indicate that membrane technologies can be successfully used to remove microplastics from aquatic environments. Combining porous membranes with biological processes can increase removal efficiency to as high as 99.9%.

Removal in Wastewater Treatment Plants Using Advanced Filtration Technologies

Examined the performance of a pilot-scale municipal wastewater treatment plant based on a combined membrane bioreactor-conventional activated sludge methodology for microplastic removal. The results indicated that using a membrane bioreactor resulted in better removal of microplastics (99.4%) compared to the conventional activated sludge treatment system (98.3%) [12].

Effectiveness of Various Treatment Steps

Examined the effectiveness of 11 wastewater treatment plants in removing microplastics, considering parameters like quantity, color, shape, and size of the particles in the effluent. The study revealed that all plants using various treatment steps, such as flotation, sedimentation, and filtration, removed over 90% of microplastics from the water. The most significant factors causing variability in removal efficiency were daily treatment volume, raw water characteristics, and types of treatment processes used. Generally, sorption and filtration methodologies showed good efficiency in treating wastewater containing microplastics, especially when combined with biological and sedimentation processes. To achieve higher removal efficiency, membrane bioreactors should be used simultaneously with other advanced physico-chemical treatments in wastewater treatment plants [13].

Chemical Methods for Microplastic Removal

Many wastewater treatment plants worldwide use coagulation and agglomeration processes to form larger pollutant particles, making them easier to separate from water. These processes involve the use of Fe and Al-based salts and coagulants to bind small particles through complexation mechanisms, creating strong bonds between waste particles. Studied the removal of polyethylene microplastics from water using iron, aluminum salts, and ultrafiltration. Experiments conducted under different concentrations of $Al3+$ and $Fe3+$ ions showed that $Al3+$ performed better than $Fe3+$ [14].

Researchers also employed a robust and environmentally friendly electrocoagulation technique for the removal of polyethylene microplastics using a stirred batch reactor, offering benefits like sludge minimization, energy efficiency, cost-effectiveness, and automation flexibility. The in-situ formation of metal hydroxide coagulants is initiated by the reaction of metal ions such as $Fe2+$ and $Al3+$ released from electrodes with hydroxyl anions in the water. These coagulants disrupt colloids and stabilize the surface charges of suspended microparticles, allowing particles to come close enough to interact via van der Waals forces. The coagulants simultaneously form a trap to capture microplastics suspended in wastewater, achieving a reported efficiency of 90% [15].

Degradation Mechanisms of Microplastics

The mechanisms of microplastic degradation are not fully understood. Studied the chemical changes in

the structure of two types of microplastics, polypropylene and polyethylene, over three years under simulated realistic environmental conditions. FTIR (Fourier Transform Infrared Spectroscopy) analyses revealed non-linear changes in carbonyl, hydroxyl, and carbon-oxygen bonds over time, indicating a slow degradation of microplastics.

Summarizing the advantages and disadvantages of various microplastic treatment methods: (Table 1) [16].

Table 1. Comparative analysis of microplastic separation methods

Method	Efficiency	Practicality	Advantages	Disadvantages
Filtration	High for larger particles	Easy to implement and maintain	Simple, scalable	May struggle with very small particles
Coagulation & Flocculation	Effective for various sizes	Widely used, can be integrated into existing systems	Flexible, effective	Requires chemical handling, produces sludge
Dissolved Air Flotation	Effective for various densities	Suitable for large-scale operations	Handles high volumes	Energy-intensive
Electrocoagulation	Effective for broad spectrum	Versatile, adjustable for different characteristics	Removes other contaminants	Requires stable power supply, maintenance of electrodes

Biological Treatment	Experimental for microplastics	Sustainable, minimal chemical use	Eco-friendly	Slow degradation, requires further research

These processes combined with membrane bioreactors have been shown to allow the removal of high percentage of microplastics in the inlet water entering the wastewater treatment facilities, but it has been revealed that the discharge of wastewater directly into the aquatic environment is also the main source of microplastics.

3 Conclusion

According to this review, the results of microplastic removal from water are, respectively, 90% from filtration systems, 80% from classic wastewater treatment plants coagulation and flocculation, 95% from dissolved air flotation, 85% from eletrocoagulation method and 60% from biological treatment method.

The results of the studies revealed that electrocoagulation and coagulation processes are reliable techniques for the removal of microplastics, but in order to achieve high efficiency, they should be combined with extra filtration steps.

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