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Microplastics Removal in Wastewater Treatment Plants

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ABSTRACT

The research article on the disposal of microplastics in wastewater treatment plants provides a comprehensive overview of current research and technologies for the management of microplastic pollution in water. The study highlights the effectiveness of tertiary chemical treatments, especially disk filter membranes with large-pore fiber membranes (10-20 μm) to improve the removal of microplastics, with a rejection rate of about 41 % means Coagulation, membrane separation. Various other processes such as adsorption, magnetic separation and biodegradation are investigated and challenges such as membrane fouling and secondary pollution. It emphasizes the importance of interdisciplinary collaboration between stakeholders, researchers and the public in system design and industry to effectively address microplastic pollution. The study highlights the need for further studies to evaluate the performance of microplastic removal technologies under different conditions and to fill existing knowledge gaps in order to develop effective pollution control strategies. The article emphasizes the crucial role of advanced medical technology and collaborative efforts.

1. Introduction

The usage and disposal of plastic in an unsustainable manner is contributing to widespread and persistent environmental contamination (Thompson et al., 2009). Microplastics are purposefully made polymers that are smaller than 5 mm (primary) (Browne et al., 2011), or come from bigger plastics weathering down (secondary) (Andrady, 2011), which could have a negative impact on ecosystems and creatures (Van Cauwenberghe et al., 2015). Wastewater contains microplastics (Browne et al., 2011). These particles may become more hazardous when they adsorb toxic substances, such as medications and infectious organisms (Ziajahromi et al., 2017).

Despite the fact that wastewater is a significant source of microplastics, little is known about it in the literature. The goal of this focus review is to outline what is currently known about the sources, destinations, and potential solutions of microplastics in wastewater while also suggesting future research directions.

1.1. Why Might Wastewater Contain Microplastics?

Between 0.5 and 5 % of primary microplastics, or micro-beads, with an average size of 250 μm (Zitko and Hanlon, 1991), can be found in cosmetics. In exfoliant washes, micro-beads have taken the place of natural exfoliants (for example, ground walnut husks), resulting in less skin irritation and damage (Chang, 2015). Because of their abrasive nature, micro-beads in toothpaste help to eliminate stains and plaque (Vieira et al., 2016). Exfoliant washes can discharge anywhere from 4,500 to 94,500 micro-beads in a single use, compared to toothpaste's around 4,000 micro-beads (Napper et al.,

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2015). The present estimations for micro-bead release (Table 1) are limited to one polymer (polyethylene) in two types of hygiene products and do not take into account real retention efficiency in wastewater treatment plants. According to (Boucher and Friot, 2017), fibers from synthetic textiles that are discharged during laundry are estimated to account for 35 % of the microplastics found in the ocean. Research indicates that a single garment can release up to 1,000,000 fibers, 110,000 fibers, and more than 1,900 fibers (Browne et al., 2011). Similar washloads (5-6 kg) result in the release of over 6,000,000 fibers from polyester fabrics (De Falco et al., 2018) and 700,000 fibers from acrylic fabrics (Napper and Thompson, 2016). According to Sillanpää and Sainio, 2017, Finland's washing machines release between 154,000 and 411,000 kg of cotton and polyester microfibers (with a thickness of 10-20 µm and a length of 100 – 1,000 µm) every year. Apart from variations in research methodologies, these figures are significantly influenced by textile characteristics (knit, polymer), washing circumstances (temperature, friction, speed, and length of washing), detergent and softener type and usage, and the weathering of clothing (Cocca et al., 2017; Carney Almroth et al., 2018). Other consumer goods that could leak microplastics into waste water systems include jewelry, tiny buttons, contact lens cleaners, and glitter (Napper et al., 2015). Examples of non-domestic sources of microplastics in wastewater include the following: (a) plastic fragments used in air-blasting paint and engine cleaning (Gregory, 1996); (b) pre-production pellets misplaced in the course of production or transit (Sheavly and Register, 2007); (c) fibers from the synthetic textile industry; (d) dust from drilling and cutting plastics; and (e) lost Styrofoam used in shipping or fillers. When these particles become misplaced, they may unintentionally enter drain or sewage systems. Developing measures to reduce their losses and better quantifying these sources' contributions while accounting for all product and polymer types is essential.

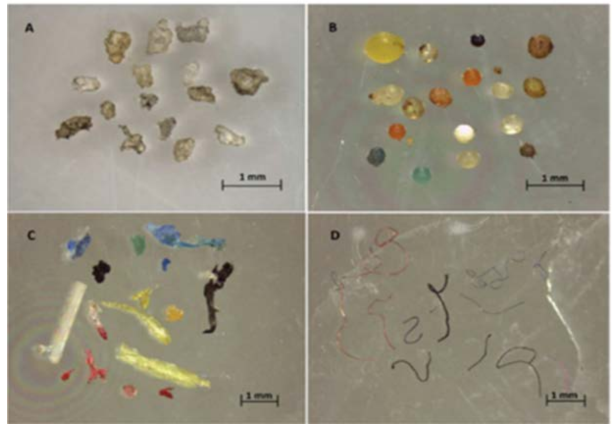

Figure 1. Microplastics retrieved from WWTP include primary microplastics (derived from personal care products) and secondary microplastics (fragments from bigger plastics and synthetic fibers) (Talvitie et al., 2017a)

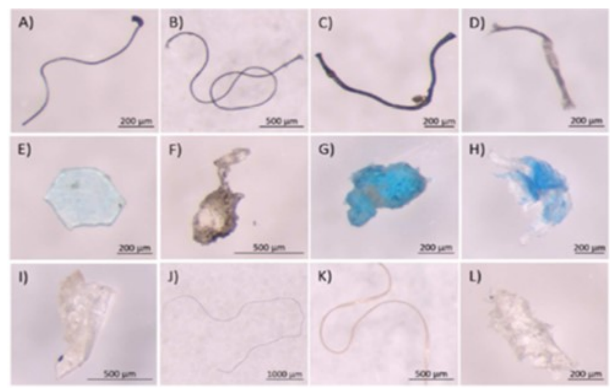

Figure 2. Polymer detection at various phases of WWTP and recipient lake using micro-FTIR and/or micro-Raman techniques (Lares et al., 2018)

Table 1
Estimated micro-bead release depending on hygiene product consumption

Area	Population	Product	Polymer	Consumption ($g\ person^{-1}\ year^{-1}$)	Release ($tonnes\ year^{-1}$)	Reference
Unites States of America	308 million	Liquid soap	PE	0.88	260	Gouin et al., 2011
United Kingdom	64.1 million	Facial exfoliants	PE	14.6 - 80.3 0.04 - 0.22g $person^{-1}\ day^{-1}$	16 - 86[a]	Napper et al., 2015
European Union[b]	508 million	Liquid soap	PE	0.88	450	Gouin et al., 2011

PE: polyethylene

[a] Undescribed adjustments for retention

[b] Admitting a similar consumption to the USA and based on the polution of 2017 reported by Eurostat

Table 1 estimates micro-bead release from hygiene products in the USA, UK, and EU, showing higher release in regions with larger populations or heavier product use. Polyethylene-based products are the main source.

1.2. How do Microplastics get into Wastewater Treatment Plants?

Every day, wastewater treatment plants (WTP) receive large amounts of microplastics (Dris et al., 2015). Unlike previously thought (Browne et al., 2011), WTP are quite good at holding onto microplastics (Table 2). The primary treatment removes the majority of microplastics (78-98 %) (Murphy et al., 2016). The secondary treatment reduces concentration slightly (7-20 %) (Talvitie et al., 2017b). Therefore the concentration of microplastics is unaffected by the tertiary treatment. Microplastics are mostly captured during the skimming and sedimentation processes used to remove wastewater solids because of their own settling or trapping (Murphy et al., 2016). While fibers are more readily retained, smaller microplastics may escape WTP. The huge amount of effluents produced every day causes significant contamination of aquatic ecosystems, even when treated effluent only include a few microplastics per liter (Ziajahromi et al., 2017). In fact, reports of elevated microplastic concentrations downstream of WTP have been made (McCormick et al., 2014). Higher levels of contamination are observed in countries with insufficient wastewater treatment. Up to 45 % of microplastics can be captured by grit and oil (Murphy et al., 2016), while sedimentation can hold up to 34 % (Talvitie et al., 2017b). The majority of microplastics are found in the solid waste water components. Because of this, more than 80 % of the micro-litter ends up in the sludge portion, which can be used as fertilizer in fields and cause alien pollution (Zubris and Richards, 2005). In order to re-evaluate WTP's retention efficiency for smaller microplastics (less than 50 µm), researchers need to develop more sensitive detection methods, examine changes in the concentrations of microplastics released over time, examine the role of sludge and WTP as sources of microplastics, and examine how microplastics in wastewater absorb contaminants from the head.

1.3. How might the Contamination of Wastewater by Microplastics be reduced?

Because there are no rules, micro-beads are often used carelessly in products. Given that several countries have shown a desire to prohibit micro-beads (Pettipas et al., 2016), some businesses, including Crest, Johnson & Johnson, and L'Oréal have phased out micro-beads in their products. These nations include Canada, Ireland, the United Kingdom, and the United States (Venus, 2020). Although banning products is the most effective approach, educating customers and labeling goods that

Table 2
Wastewater Treatment's Effect on Microplastic Concentrations

Reference	Location	Wastewater treatment	Retention efficiency (%)	Untreated waste	Effluent ($MP.m^{-3}$)	Solid fraction ($MP.kg^{-1}$ d.w.)	Minimum mesh size (µm)
(Browne et al., 2011)	New South Wales, Australia	T	N.A.	N.A.	$1{\cdot}10^3$	N.A.	N.A.
(Talvitie and Heinonen, 2014)	Helsinki, Finland	N.A.	95.6	$1.6{\cdot}10^5$p	$7{\cdot}10^3$p	N.A.	20
(Magnusson and Norén, 2014)	Lysekil, Sweden	T	99.9	$1.5{\cdot}10^4$	8.3	$1.7{\cdot}10^4$	300
(Dris et al., 2015)	Paris, France	S	83.0 - 95.0	$2.6 - 3.2{\cdot}10^5$	$1.4 - 5.0{\cdot}10^4$	N.A.	100
(Browne et al., 2011)	California, USA	T	99.9	$1.0{\cdot}10^3$	0.88	$1.0{\cdot}10^3$	20
(Murphy et al., 2016)	Glasgow, Scotland	S	98.4	$1.5{\cdot}10^4$	$2.5{\cdot}10^2$	N.A.	11
(Sutton et al., 2016)	California, USA	S,T	N.A.	N.A.	$0.2 - 1.9{\cdot}10^2$	N.A.	125
(Mintenig et al., 2017)	Lower Saxony, Germany	S,T	97.0	N.A.	$0 - 9{\cdot}10^2$	$0.1 - 2.4{\cdot}10^4$	20
(Talvitie et al., 2017a)	Helsinki, Finland	S	N.A.	$1.8 - 4.3{\cdot}10^5$	$4.9 - 8.6{\cdot}10^3$	N.A.	20
(Ziajahromi et al., 2017)	Sydney, Australia	P,S,T	90.0	N.A.	$0.3 - 1.5{\cdot}10^3$	N.A.	25

Table 2 illustrates that advanced treatment processes can significantly reduce microplastic loads, but removal efficiency depends on treatment type, local conditions, and detection methods.

contain micro-beads is a useful backup plan (Chang, 2015). Improvements in knitting techniques (Carney Almroth et al., 2018); the combination of synthetic and natural textiles, the application of textile coatings (e.g., silicone emulsions; (Cocca et al., 2017) and the removal of loose fibers during the manufacturing process are a few techniques to enhance production and lower the amount of microfibers released into fabrics. For instance, materials that are tightly knitted release more fibers during washing since they contain more fiber strands per region. Additionally, a combination of natural and synthetic textiles may cut fiber loss by 80 % (Napper and Thompson, 2016). By installing filters (such as Wexco's Filtron 160) in the washing machine drain and improving the filtering mechanisms in washing machines, microfiber discharge can be reduced at home (Browne et al., 2011), as well as using certain fabric softeners. These actions might lessen wastewater pipeline blockages as well. Simple preventive actions, like the voluntary "Operation Clean Sweep" (Sheavly and Register, 2007) and the industry - specific rules outlined in the California Code, can assist companies in minimizing plastic waste. Both provide strategies, such as immediately covering spilled pellets or installing filters in drains, to reduce the quantity of pre - production pellets wasted. To reduce microplastic losses, industries need to take both mandated and discretionary actions (Prata, 2018b). Certain writers in WTP suggest creating novel treatments to hold on to microplastics (Browne et al., 2011). According to (Phillips, 2016), the decrease in particle size can be attributed to inefficient sand filters, while membrane bioreactors - which employ micro - and ultrafiltration membranes - are more expensive (Beljanski et al., 2016). According to (Beljanski et al., 2016), filters in low - flux tubes cleaned by back - flushing appear to be an effective low-cost alternative. On the other hand, source reduction, where the polluter pays principle is applied by holding manufacturers accountable - is less expensive and requires less public investment. Examples of this include outlawing micro-beads, enhancing textiles, and cutting down on the loss of plastics. The goal of research should be to create tools or strategies that reduce the amount of microplastics in wastewater at its source. In order to increase "retention efficiency" in WTP, plastic - degrading species that are capable of eliminating microplastics from wastewater or sludge could potentially be employed. For example, the concentration of microplastics in sludge treated by anaerobic digestion appears to be decreasing (Mahon et al., 2017), and novel species that degrade plastic are being found (Paço et al., 2017). Storm water discharge may contain a significant amount of plastic debris. For instance, New Orleans declared that storm drains had been freed of 46 tons of plastic Mardi Gras beads. Although it happens seldom, runoff can get to WTP and increase the total plastic load. Utilizing more biodegradable materials, improving urban cleaning services, and installing drain meshes, booms, or separators are necessary for reduction in these circumstances. Even though the majority of international initiatives to minimize marine litter do not name waste water as a source of microplastics specifically, they could still be beneficial. (Walker, 2018) One example is the EPA's Marine Debris Prevention Program statement at the Honolulu Strategy, which discusses the part wastewater plays in marine litter (Prata, 2018a). These conferences ought to establish goals, plans, and monitoring in the future to lessen the amount of microplastics released into wastewater effluents.

2. Technologies for Removing Microplastics

The efficiency of current treatments in eliminating MPs was analyzed using a range of factors in this article. Table 3 (provided in Appendix) also highlights the advantages and disadvantages of each technique, including skimming and sedimentation, coagulation, ozonation, fast sand filter, dissolved air flotation, conventional activated sludge, and membrane bioreactor (MBR).

2.1. Primary Sedimentation and Grit Chamber

The main sedimentation and grit chamber are the first stages of the wastewater treatment plant. MPs can mostly be eliminated by surface skimming and sedimentation at this initial stage of treatment thanks to the aeration process at the back of the grit chamber. In actuality, 41 % of MPs are eliminated during this time (Liu et al., 2019b). The MP concentrations in the influent and effluent of this study were 47.4 and 79.9 MPs/L, respectively. Likewise, it was demonstrated that relatively high efficiency, 54-64 % (Hidayaturrahman and Lee, 2019) and 66 % in (Ziajahromi et al., 2017). Additionally, the researchers looked into the first stage performance at Glasgow, Scotland's municipal wastewater treatment facility. Following this phase, average MPs dropped from 15.7 MPs/L to 3.4 MPs/L, with an approximate 78 % removal efficiency. According to the findings (Bayo et al., 2020), over 74 % of MPs were removed from the urban wastewater treatment plant in Spain during the initial stage. On the other hand, the primary stage of a big wastewater treatment plant in Canada achieved great efficiency (92 %) of MPs removal. The majority of MPs were fibrous in nature (Gies et al., 2018). At this initial step, the majority of MPs (especially those in the form of fiber) were removed (99 %), with an input concentration of 57.6 MPs/L. The great efficiency of this investigation may have resulted from the fibrous nature of over 96 % of the MPs. From the outcomes of (Hidayaturrahman and Lee, 2019), more fibrous MPs (76-92 %) were retained in the first treatment stage compared to other kinds such as micro-bead, sheets, and fragments. The majority of MPs were removed in this pretreatment phase, and the remaining microplastic was removed in the subsequent stage. Nevertheless, it is vital to take into account suitable technologies in the secondary or tertiary therapy stage in order to completely eradicate MPs.

2.2. Dissolved air Flotation

Oils, greases, and suspended particles are among the soluble materials that are intended to be extracted from water using dissolved air flotation, or DAF. During the DAF process, air is dissolved into water under high pressure, creating tiny bubbles. The suspended solids separate and can be skimmed off the surface as a result of these bubbles sticking to it. DAF has recently offered MPs great removal efficiency. Researches showed that DAF eliminated almost 95 % of MPs. However, the influent MPs concentrations in the study were quite modest, at 2 ± 0.07 MPs/L. There haven't been any studies done evaluating how well DAF removes MPs in different situations, such as those involving MP density, size, shape, and composition. Because of this, it is now difficult to offer detailed and accurate feedback regarding the removal of this technology from MPs. There has to be more research done in this interesting field (Talvitie et al., 2017a).

2.3. Coagulation

Coagulation was used as the first step in the tertiary treatment stage, using chemical coagulants (ferric and aluminum salts or their derivatives) to destabilize surface charge and form flocs with MPs and other contaminants in wastewater. After that, these flocs were eliminated by settling or skimming. (Hidayaturrahman and Lee, 2019) investigated the use of polyaluminum chloride (PAC) to remove MPs from coagulation, varying the initial dosage of MPs (A: 4200 MPs/L, B: 5840 MPs/L, and C: 31,400 MPs/L). The removal efficiencies of MPs were 53.8 % for A, 47.1 % for B, and 81.6 % for C, according to the results. It is clear that the MPs concentration had a significant influence on the creation of MPs flocs. In fact, water with a lower MPs content would find it difficult to create flocs with a particular amount of coagulant, leading to a reduced MPs removal efficiency (Hidayaturrahman and Lee, 2019). Rezania et al. (2018) found that the ability to remove MPs was positively correlated with the coagulant dosage. However, as the flocculant dosage increased, the removal rate of MPs tended to decrease. This can be explained by the fact that as the coagulant dosage grew dramatically, the MPs' zeta potential decreased, making it impossible to produce MPs flocs. Moreover, the effectiveness of the coagulation process depends on the type of coagulant used. For example, in (Ma et al., 2019) study, polyethylene (PE), which is frequently found in different waste-waters and whose proportion was significantly higher than that of aluminum, was tested simultaneously with ferric-based coagulants and aluminum coagulants, which are seen as additional categories of MPs. Consequently, the aluminum coagulant performed better than the other in terms of PE elimination. The removal efficiency of MPs from PE with a tiny size (less than 0.5 mm) increased from 8.3 % to 36.9 % when the dosage of aluminum coagulant was raised from 13.5 mg/L Al to 405 mg/L Al. Polyacrylamide (PAM) has been shown in several studies to be useful in improving coagulation efficiency (da Luz et al., 2019; Hosseinzadeh et al., 2019). Ma et al. (2019) looked into the removal of MPs (PE less than 0.5 mm) using a pH 7 combination of cationic and anionic PAM in an Al-based coagulant at a dosage of 135 mg/L. The findings showed that with 15 mg/L of anionic PAM, the removal efficiency increased from 26 ± 3 % (without anionic PAM) to 61 ± 4 %. On the other hand, adding 15 mg/L of cationic PAM eradicated 45 ± 4 % of PE, whereas using the same dosage of anionic PAM reduced 61 ± 4 %. The results demonstrated that anionic PAM removed PE MPs more successfully than cationic PAM. Furthermore, the pH levels of the water solution affected the MPs' coagulation process efficiency (Ma et al., 2019). Examined the elimination of PE from the coagulation process using $AlCl_3 \cdot 6H_2O$ (5 mmol/L or 135 mg/L Al) at pH values of 6, 7, and 8. At lower pH conditions, a higher removal effectiveness of 27.5 % was achieved (Table 3 - provided in Appendix). Additionally, Ma et al. (2019) investigated the impact of pH conditions (6, 7, and 8 pH) on the coagulation performance using $FeCl_3 \cdot 6H_2O$ (2 mmol/L) and 0.92 - 0.97 g MPs/m^3. According to the findings, MPs had the maximum clearance (17 ± 2 %) at a pH of 8. This experiment also revealed that MPs had a relatively low density (0.92 - 0.97 g/m^3), which made it difficult for them to settle during coagulation. At this low density, $FeCl_3 \cdot 6H_2O$ of 2 mmol/L, anionic PAM of 15 mg/L, and pH of 8 were the ideal working conditions to achieve the maximum efficiency of MPs elimination (91 ± 1 %). Wang et al. (2020) evaluated the impact of polymer type and particle size of MPs on the effectiveness of the coagulation process in conjunction with sedimentation most recently. Larger particles will have a higher clearance efficiency, according to the data. In particular, 45-75 % of tiny particles (5-10 µm) and 100 % of large particles (> 10 µm) were eliminated by coagulation. Because fibrous MPs were simpler to attach to flocs, fibers could be removed at a higher rate (51-61 %) than filament and pellet forms. In addition, the data showed that PET was eliminated at the highest rate (59-69 %) when compared to PP, PS, and PAM.

Additionally, Katrivesis et al. (2019) and Lares et al. (2018) have reported on this discovery. Generally speaking, up to 90 % of MPs may be eliminated by the coagulation/flocculation process. It is evident from the literature research that the pH value, MP size, shape, and composition, as well as the kind and dosage of coagulant and flocculant aids, all had a significant impact on this procedure. There have not been many studies on this technology for MPs up to now, particularly when it comes to wastewater treatment systems. Future research must focus on identifying the best flocculant aids and coagulants, as well as the ideal conditions for eliminating colloids and MPs.

2.4. The Method of Filtering

2.4.1. Sand Filter

By attaching to the surface of the sand grains or by trapping mechanisms between the grains, sand filters can eliminate MPs. According to a study on the Italian municipal wastewater treatment system, disinfection and sand filtration removed roughly 56 % of microplastics (MPs) (Magni et al., 2019). Furthermore, Wang et al. (2020) examined the use of a sand filtration device for MP removal inside a water treatment plant in China. The authors found that only 29-44 % of MPs were effectively removed by the sand filter. The results demonstrated that there were considerably more MPs preserved in the sphere/pellet and fiber forms 31-49 % for pellets, 24-51 % for fibers, and 19-28 % for fragments - than in the fragment form. Consequently, these writers did not advocate for the use of conventional filtration technology as the main therapeutic approach for getting rid of MPs.

2.4.2. Rapid sand filter

The construction of a rapid sand filter (RSF) involves numerous media layers. Typically, there are three layers: gravel, silica sand, and anthracite granules. Sometimes the RSF consists of nothing but sand. For instance, in (Hidayaturrahman and Lee, 2019) a case study employed a 6.8 m deep sand filter with 0.8-1.2 mm sand particle size and a 1.08 h hydraulic residence duration. After going through RSF, approximately 74 % of the MPs in the wastewater were retained, with an MP concentration of 215 MPs/L at the influent. At the Finnish sewage treatment facility, Talvitie et al. (2017a) assessed efficiency of MP removal using RSF that contained 0.5 m of quartz and 1 m of gravel. A high removal efficiency of 97 % was attained, with MPs decreasing from 0.7 ± 0.1 MPs/L to 0.02 ± 0.007 MPs/L. Sand filters were therefore thought to be an appropriate technology for MPs elimination in the low MPs concentration range.

2.4.3. Filtration using Granular Activated Carbon

Granular activated carbon (GAC) filtration has been utilized in recent times to address certain newly discovered pollutants in an aqueous setting (Östman et al., 2019). Wang et al. (2020) assessed the GAC filtering system's capacity to remove MPs from a drinking water treatment facility. Only 60.9 % of MPs could be eliminated by this technology, which is less effective than ozonation, sand filtration, RSF, and coagulation/flocculation, among other conventional techniques. Moreover, the data showed that PE was accountable for most of the expelled MPs in contrast to PP and PAM. To remove contaminants, the GAC technique combines physical adsorption with biodegradation. However, at this point, it is still unclear how MPs can be taken out of GAC. Therefore, the filtration procedure would be a helpful method for MPs elimination at low concentration levels. Further investigation into the cost-benefit analysis of different filtration rates and filter medium types would be intriguing.

2.4.4. Disc-Filter Membrane

The tertiary treatment disc-filter (DF) was composed of large pore fiber membranes (10-20 µm). In Daegu, South Korea, (Hidayaturrahman and Lee, 2019) used DF with a 10-µm pore size to eliminate MPs. The outcomes demonstrated that approximately 297 MPs/L, down from 1444 MPs/L, or 79 % of MPs, were eliminated under the DF system. Furthermore, Talvitie et al. (2017a) discovered that the DF decreased the MPs concentration using 10-µm pore size filters, from 0.5 ± 0.2 to 0.3 ± 0.1 MPs/L (40 %), and 20-µm pore size filters, from 2.0 ± 1.3 to 0.03 ± 0.01 MPs/L (98.5 %). Higher removal efficiency was often expected with smaller sized filters. Nevertheless, the disruption of earlier treatment phases, which had an impact on the sampling time, was the cause of the study's opposite outcome. According to the literature assessment, the DF's removal of MPs was comparatively ineffective. This might be explained by the fact that a lot of MPs stuck to the membrane surface, causing membrane fouling. In an attempt to clean the disc-filter, high-pressure backwashing was used, which unintentionally allowed the MPs to pass through the membrane. Backwashing removed the disc-filter's biofilm layer, or secondary membrane layer, which made it easier for MPs to pass through this early filtration stage.

2.4.5. The Conventional Approach of Activating Sludge

Once activated sludge has undergone biodegradation, wastewater is separated using a sedimentation tank in the commonly used conventional activated sludge process (CASP). For the treatment of nutrients and soluble/colloidal organic pollutants in a range of wastewater types, CASP has been widely used. Following a thorough investigation of the frequency of MPs in surface water and wastewater, the efficiency of CASP in getting rid of MPs was also assessed. Using this technology, MPs can serve as a moving medium for attach growth or attach themselves to suspended objects, separating by settling. Lares et al. (2018) discovered that the CASP system achieved a very high removal efficiency of MPs, specifically 98 %. Similarly, it was claimed by (Murphy et al., 2016) and (Edo et al., 2020) that up to 92.6 % and 93.7 % of MPs, respectively, could be eliminated by this method. According to (Hidayaturrahman and Lee, 2019) study, the removal efficiency of MPs ranged from 42 to 77 %. About 62 % of MPs were also eliminated by CASP in the municipal wastewater treatment facility in Spain (Bayo et al., 2020). According to a survey conducted in Italy on municipal wastewater treatment systems, the grid chamber and the CASP system eliminated roughly 64 % of MPs (Magni et al., 2019). However, approximately 17 % of MPs were extracted from wastewater and transported into excess sludge in the anaerobic/anoxic/oxic (AAO) process (Liu et al., 2019a). Overall, CASP's MPs removal efficiency varied a lot and was not consistently constant. According to (Li et al., 2015), leaching of bisphenol A (BPA) from PVC microplastics releases toxicity that inhibits the growth of heterotrophic bacteria and nitrifying bacteria of CASP. Furthermore, there is not much research that demonstrate how MPs can be broken down in CASP. According to He et al. (2017), the primary drawbacks of this technique are its increased sludge production and area use, despite its lower investment cost.

2.4.6. Bioreactor with Membrane

A membrane bioreactor (MBR) combines membrane separation technology with biological processes. This system is more efficient at treating wastewater and reusing it than the traditional activated sludge process (CASP), and it also takes up less space, produces less sludge, and is easier to scale up. As a result, MBR is well - known and has been effectively used in a variety of wastewater types, particularly those that contain developing pollutants such pesticides, medicines, personal care items, and antibiotics (Nguyen et al., 2019). The majority of studies' MPs in the surface water had sizes larger than 300 µm. It has the potential to be totally eliminated by MBR using the micro-filtration membrane modules at this size. In fact, in recent years, MBR's ability to eliminate MPs has been studied. Using MBR, Talvitie et al. (2017a) used 20 submerged flat-sheet UF membranes with 0.4 µm pore size. The MPs concentration in the influent was 6.9 ± 0.1 MPs/L. The majority of MPs were kept after going through the MBR system, according to the data. Similar to this, Lares et al. (2018) used the pilot-scale submerged MBR with flat-sheet UF and 0.4 µm pore size. Approximately 99.4 % of MPs were eliminated by MBR. The effectiveness of PVC gel removal (particle size < 5 µm) by the MBR with a 0.1-µm submerged membrane and a 0.1-m^2 surface area has been investigated most recently by (Li et al., 2020). Almost no MPs were found in the MBR system's permeate under the working parameters of 2.5 hours of high-pressure steam (HRT), temperatures of approximately 19.1 °C, and pH 7.5. After filtration, MPs typically still cause problems since the sludge needs to be treated as solid waste again, which raises the treatment costs over time. Membrane fouling is one of the main disadvantages of MBR and can be avoided with chemical or backwash cleaning. This could have a detrimental effect on membrane fibers and raise maintenance expenses. Nonetheless, in contrast to other technologies, MBR's effectiveness appears to be unaffected by the dimensions, makeup, and structure of MPs. Several studies have been considered in order to reach the conclusion that MBR is a very stable and extremely successful method of removing MPs. This implies that MBR is the most promising removal technology for getting rid of MPs. Furthermore, a future study should look into how MPs affect membrane fouling. The degradation and/or change of MPs in MBR ought to be examined in subsequent research as well.

2.4.7. Ozonation

The polymer that makes up MPs can be oxidized to produce oxygen-containing functional groups (Chen et al., 2018). The physiochemical characteristics of polymers can change when they are subjected to ozonation treatment. For instance, adhesion, surface tension, solubility, and hydrophobic qualities can all increase, while melting point and viscosity can decrease (Singh and Sharma, 2008). In fact, a large number of MPs were removed and organic and non-organic pollutants were oxidized using ozonation technology. After 30 minutes of processing, ozonation removed almost 90 % of MPs (Hidayaturrahman and Lee, 2019). More than 90 % of MPs degrade after 60 minutes in the presence of ozone at temperatures between 35 and 45 °C, according to another study (Chen et al., 2018). Because the ozonation treatment only reduced large-size MPs to smaller sizes, in some circumstances it was nearly ineffective and only marginally increased the concentration of MPs in the output relative to the input (Wang et al., 2020). Operating costs may be one of the issues restricting the use of ozonation for MP removal. This procedure needed a substantial dosage of ozone, even though the degradation rate rose dramatically in a shorter length of operational time. Furthermore, intermediate compounds that could be harmful to both human health and the ecology could emerge during ozonation if the treatment is not completed.

3. Challenges in Microplastics Removal

The tiny size of the particles, which makes detection challenging, is one of the difficulties in eliminating microplastics. Many techniques, including stereo-microscopy and visual analysis, are employed in the detection process. However, their ability to identify tiny particles is limited. The full removal of microplastics from wastewater appears to be achievable using hybrid treatment systems that combine membrane technology and microbiological treatment. Nonetheless, the removal rate is affected by operational factors like material, pore size, and membrane surface charge (Dey et al., 2021). One major obstacle is the expensive expense of modern treatment technology for the removal of microplastics. The effectiveness of different wastewater treatment plants in eliminating microplastics varies; some are more successful than others in this regard. For instance, the effectiveness of eliminating microplastics using various techniques varied from 54 % to 71 % in a Beijing treatment facility to as low as 0.78 % in a Shanghai plant. This variation emphasizes the necessity of a thorough evaluation of the available treatment techniques in order to enhance the removal of microplastics (Tang and Hadibarata, 2021). Depending on the treatment method and the physiochemical characteristics of the polymer, different microplastic removal efficiencies have been seen in wastewater treatment plants due to a lack of standards and norms. According to studies, primary and preliminary wastewater treatment removed 72 % of the microplastic particles on average, and secondary treatment removed an additional 16 % on average. For the removal of microplastic from wastewater, a variety of technologies have been developed, including membrane filtration, adsorption, biofiltration, magnetic extraction, and microbial degradation. However, little is known about microbial degradation in biological treatment systems (Dey et al., 2021).

3.1. Future Developments for Microplastics Removal Technologies

Numerous techniques, including coagulation, membrane separation, adsorption, magnetic separation, and biodegradation, are being investigated as part of ongoing research on novel and cutting-edge microplastics removal technologies. These techniques differ in their effectiveness and possible hazards, including membrane fouling and secondary contamination. Future developments of biodegradable plastics and zero pollutant removal technology are two more green techniques for plastic abatement that are being put forth. To increase the effectiveness and positive environmental effects of microplastics removal technology, more investigation is still necessary (Shen et al., 2020). In order to remove microplastics from wastewater, politicians, industry, and researchers must work together. Cross-sector cooperation and multi-actor talks are necessary to close knowledge gaps and provide practical policy solutions. Collaboratively, researchers, politicians, industry organizations, and the public must build evidence-based decision-making procedures and execute effective policy initiatives at different levels. In Norway, cooperation has been essential in combating plastic pollution, underscoring the need of important parties working together in concert (Lusher et al., 2021).

Stricter restrictions for the removal of microplastics from wastewater treatment plants must be based on modern final-stage treatment technologies that demonstrate high removal efficiency. Disc-filter treatments, dissolved air flotation, membrane bioreactors, and fast sand filters have all been shown to produce appreciable removal rates of between 95 % and over 99.9 %. To ensure efficient removal of microplastics, it is also essential to comprehend the chemical and physical characteristics of microplastics in STPs and to assess their removal during the treatment process. To determine which technologies, perform best for the removal of microplastics, it is crucial to take into account the various stages of treatment and their respective contributions to the overall removal rates (Khan et al., 2022).

4. Discussion and Comparison

The removal of microplastics (MPs) from wastewater treatment plants (WWTPs) is a vital concern due to possible environmental and health hazards. Various treatment methods, including primary sedimentation, dissolved air flotation (DAF), coagulation, rapid sand filtration (RSF), and conventional activated sludge processes (CASP) have been implemented to resolve this issue. Primary sedimentation shows removal efficiencies between 41 % and 99 %, effectively eliminating fibrous microplastics through skimming and sedimentation (Bayo et al., 2020). DAF has resulted in high removal rates of around 95 %, utilizing micro-bubbles to float MPs, though its efficiency may vary with particle size and density (Talvitie et al., 2017a). Coagulation, depending on coagulant type and dosage, achieves removal efficiencies between 53 % and over 90 %-for instance, polyaluminum chloride (PAC) resulted in 81.6 % removal in South Korea (Hidayaturrahman and Lee, 2019). However, smaller microplastics at low concentrations can lead to a reduction in coagulation efficiency (Ma et al., 2019). RSF has shown efficiency ranging from 74 % to 97 %, with enhanced performance using multi-layer filtration beds (Talvitie et al., 2017a; Hidayaturrahman and Lee, 2019). Removal efficiencies of CASP vary from 42 % to 98 %, with studies from Scotland showing a maximum of 92.6 % when used alongside coagulants (Murphy et al., 2016; Lares et al., 2018). Membrane bioreactors (MBRs) consistently demonstrate removal rates exceeding 99 %, with near-complete elimination of MPs reported in studies from China and Finland (Talvitie et al., 2017a; Li et al., 2020). Despite their effectiveness, MBRs are prone to fouling, requiring frequent maintenance. Table 3 (provided in Appendix) highlights the variation in MP removal efficiencies among these methods, and highlights the importance of combining treatment methods to achieve optimal removal. Coagulation and MBR show higher efficiencies consistently, when primary rainfall and RSF exhibit considerable variability, formal performance parameters need to be illuminated to improve effectiveness.

5. Conclusion

In conclusion, the study underlines the importance of combining several treatment steps to maximize the removal of microplastics. While primary treatment removes a significant portion, advanced technologies such as MBR, DAF, and coagulation are crucial to achieve near-total elimination. Adapting the operating conditions (e.g. coagulant type, filtration pore size) to the characteristics of the MP and utilizing regional expertise can further increase efficiency. The problem of removing microplastics from wastewater treatment plants is an urgent issue that can only be solved with an integrated approach. Future studies need to identify and address research gaps, develop new effective methods, and test them at central centralized level in real environments. Similarly, the use of a large-scale level in practice should be determined, as research is primarily based on a laboratory-based, controlled approach. Future research must focus on using a scientific approach to find an answer to the problem by closing the gaps.

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Appendix

Table 3
Treatment technologies' performance in removing microplastics (MPs)

Technologies/Operating conditions	Location	Influent (MPs/L)	Effluents (MPs/L)	Removal %	References
Grit chamber/primary sedimentation: NA	Spain	12.43 ± 2.70	3.21 ± 0.50	74.0	(Bayo et al., 2020)
Passing through a 6-mm screen mesh before grit chamber	China	79.9	47.4	40.7	(Liu et al., 2019b)
NA	South Korea	4200	1568	62.7	(Hidayaturrahman and Lee, 2019)
NA	South Korea	31,400	12,580	56.8	(Hidayaturrahman and Lee, 2019)
NA	South Korea	5840	2080	64.4	(Hidayaturrahman and Lee, 2019)
Passing through a 6-mm screen mesh before grit chamber	Finland	57.6 ± 12.4	0.6 ± 0.2	99.0	(Lares et al., 2018)
NA	Columbia	31.1 ± 6.7	2.6 ± 1.4	91.7	(Gies et al., 2018)
Passing through a 3-mm screen mesh or a 6-mm screen mesh before grit chamber	Australia	1.44	0.48	66.0	(Ziajahromi et al., 2017)
Polyacrylamide as coagulant added before primary sedimentation	Scotland	15.70 ± 5.23	3.40 ± 0.28	78.3	(Murphy et al., 2016)
Dissolved air flotation - DAF: Flocculant: PAC of 40 mg/L	Finland	2.0	0.1	95.0	(Talvitie et al., 2017a)
Coagulation: MPs with size > 10 µm	China	1334 ± 459	1 ± 1	> 99.0	(Wang et al., 2020)
MPs with size 5-10 µm	China	1520 ± 258	136 ± 22	44.5 - 75.0	(Wang et al., 2020)
Coagulants: PAC of avg. 32.4 mg/l	South Korea	710	164	53.8	(Hidayaturrahman and Lee, 2019)
Coagulants: PAC of avg. 30.5 mg/l	South Korea	7863	1444	81.6	(Hidayaturrahman and Lee, 2019)
Coagulants: PAC of avg. 29.3 mg/l	South Korea	433	215	47.1	(Hidayaturrahman and Lee, 2019)
$AlCl_3 \cdot 6H_2O$ of 13.5 mg/L Al; pH of 7 ; PE (size < 0.5 mm)	China	NA	NA	8.3	(Ma et al., 2019)
$AlCl_3 \cdot 6H_2O$ of 135 mg/L Al; pH of 6 ; PE (size < 0.5 mm)	China	NA	NA	27.5	(Ma et al., 2019)
$AlCl_3 \cdot 6H_2O$ of 135 mg/L Al; pH of 7 ; PE (size < 0.5 mm)	China	NA	NA	25.8	(Ma et al., 2019)
$AlCl_3 \cdot 6H_2O$ of 135 mg/L Al; pH of 7; anionic PAM of 15 mg/L; PE (size < 0.5 mm)	China	NA	NA	61.2	(Ma et al., 2019)
$AlCl_3 \cdot 6H_2O$ of 135 mg/L Al; pH of 7; cationic PAM of 15 mg/L; PE (size < 0.5 mm)	China	NA	NA	45.3	(Ma et al., 2019)
$AlCl_3 \cdot 6H_2O$ of 405 mg/L Al; pH of 8; PE (size < 0.5 mm)	China	NA	NA	22.2	(Ma et al., 2019)
$AlCl_3 \cdot 6H_2O$ of 405 mg/L Al; pH of 7; PE (size < 0.5 mm)	China	NA	NA	36.9	(Ma et al., 2019)
$FeCl_3 \cdot 6H_2O$ of 2 mmol/L; pH of 6; PE (size < 0.5 mm)	China	NA	NA	11.6	(Ma et al., 2019)
$FeCl_3 \cdot 6H_2O$ of 2 mmol/L; pH of 7; PE (size < 0.5 mm)	China	NA	NA	13.3	(Ma et al., 2019)
$FeCl_3 \cdot 6H_2O$ of 2 mmol/L; pH of 8; PE (size < 0.5 mm)	China	NA	NA	17.2	(Ma et al., 2019)

Table 3 Continued
Treatment technologies' performance in removing microplastics (MPs)

$FeCl_3{\cdot}6H_2O$ of 2 mmol/L; pH of 6; anionic PAM of 15 mg/L ; PE (size < 0.5 mm)	China	NA	NA	90.9	(Ma et al., 2019)
Sand filtration: NA	China	3472 ± 178	2230 ± 91	29.0 - 41.0	(Wang et al., 2020)
NA	Italy	0.9 ± 0.3	0.4 ± 0.1	56.0	(Magni et al., 2019)
Rapid sand filter (RSF): Diameter of sand of 0.8-1.2 mm; HRT of 1.08 h	South Korea	215	66	74.0	(Hidayaturrahman and Lee, 2019)
Filtration bed: 1 m of gravel (size of 3 - 5 mm) + 0.5 m of quartz (size of 0.1 - 0.5 mm)	Finland	0.7	0.02	97.0	(Talvitie et al., 2017a)
Granular activated carbon (GAC): Coagulants: PAC of 40 mg/L, PAM of 0.001 - 0.002 mg/L; pH of 7.70 - 7.84	China	930 ± 44	906 ± 45	56.8 - 60.9	(Wang et al., 2020)
Membrane discfilter: Filtration media: pore size of 10 µm; HRT of 2.5 min	South of Korea	1444	297	79.0	(Hidayaturrahman and Lee, 2019)
Hydrotech HSF 1702-1F, two discs with 24 filter panels for each disc; HRT of 4 min; filtration area of 5.76 m^2; iron-based coagulant (2 mg/L); cationic polymer (1 mg/L); filtration pore size of 10 µm	Finland	0.5	0.3	40.0	(Talvitie et al., 2017a)
Hydrotech HSF 1702-1F, two discs with 24 filter panels for each disc; HRT of 4 min; filtration area of 5.76 m^2; iron-based coagulant (2 mg/L); cationic polymer (1 mg/L); media (pore size of 20 µm)	Finland	2.0	0.03	98.5	(Talvitie et al., 2017a)
Conventional activated sludge/ secondary sedimentation: Anaerobic/ Anoxic/ Oxic process	Madrid	171 ± 42	10.7 ± 5.2	93.7	(Edo et al., 2020)
NA	Spain	3.21 ± 0.50	1.23 ± 0.15	62.0	(Bayo et al., 2020)
NA	South Korea	1568	710	54.7	(Hidayaturrahman and Lee, 2019)
NA	South Korea	12,580	7863	42.0	(Hidayaturrahman and Lee, 2019)
NA	South Korea	2080	433	77.3	(Hidayaturrahman and Lee, 2019)
NA	Italy	2.5 ± 0.3	0.9 ± 0.3	64.0	(Magni et al., 2019)
NA	China	34.1 ± 9.4	28.4 ± 7.0	17.0	(Liu et al., 2019b)
SRT of 28 ± 3 days; HRT of 4 - 8 h; pH of 6.3 - 7.3; MLSS of 3100 - 4200 mg/L; Temperature of 8 - 18 °C	Finland	57.6 ± 12.4	1.0 ± 0.4	98.3	(Lares et al., 2018)
Polyacrylamide as coagulant was added before secondary sedimentation	Scotland	3.40 ± 0.28	0.25 ± 0.04	92.6	(Murphy et al., 2016)
Membrane bioreactor (MBR): Submerged MBR (pore size of 0.1 µm); PVA gel (< 5 µm) of 5 %, HRT of 2.5 h; DO of 8.3 ± 0.6 mg/L, temperature of 19.1 ± 1.4 °C	China	10	0	100.0	(Li et al., 2020)

Table 3 Continued
Treatment technologies' performance in removing microplastics (MPs)

Submerged anaerobic/aerobic MBR (flat-sheet membrane, pore size of 0.4 μm, flux of 3.8 L/m^2 h, SRT of 6 days, MLSS of 14,000 ± 1800 mg/L; temperature of 21 ± 4 °C)	Finland	57.6 ± 12.4	0.4 ± 0.1	99.4	(Lares et al., 2018)
Submerged MBR (KUBOTA flat-sheet; HRT of 20 - 100 h)	Finland	6.9	0.005	100.0	(Talvitie et al., 2017a)
Ozonation: O_3 dosage of 1.5 - 2.5 mg/L, three stages (dosage ratio of 2:1:1)	China	2230 ± 91	2348 ± 103	-	(Wang et al., 2020)
O_3 contact time of 1 min; dosage of avg. 12.6 mg/L	South Korea	164	33	90.0	(Hidayaturrahman and Lee, 2019)
O_3 contact time of 60 min; temperature of 35 - 45 °C	China	NA	NA	> 90.0	(Chen et al., 2018)

Remarks: HRT - hydraulic retention time; PAC - polyaluminum chloride; PAM - polyacrylamide; PE - polyethylene; PVA - polyvinyl alcohol; Q - flow rate; MLSS - mixed liquor suspended solids; SRT - sludge retention time; NA - not available.

Uklanjanje mikroplastike u postrojenjima za preradu otpadnih voda

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Pregledni rad

Ključne reči:
Mikroplastika
Postrojenja za preradu otpadnih voda
Filter membrane u obliku diska
Međusektorska saradnja

I Z V O D

Ovaj rad o rešavanju problema prisustva mikroplastike u postrojenjima za preradu otpadnih voda pruža sveobuhvatan pregled savremenih istraživanja i tehnologija za upravljanje zagađenjem mikroplastikom u vodi. Studija ističe efikasnost tercijarnih hemijskih tretmana, posebno filter membrana u obliku diska sa vlaknastim membranama velikih pora (10–20 μm), koje poboljšavaju uklanjanje mikroplastike, sa stepenom odbacivanja od oko 41 %, uključujući procese koagulacije i membranske separacije. Istražuju se i drugi procesi poput adsorpcije, magnetske separacije i biodgradacije, kao i izazovi poput zagušenja membrana i sekundarnog zagađenja. Naglašava se značaj interdisciplinarne saradnje između relevantnih aktera, istraživača i javnosti u projektovanju sistema i industrijskoj praksi kako bi se efikasno odgovorilo na problem zagađenja mikroplastikom. Studija ukazuje na potrebu za daljim istraživanjima koja bi procenila efikasnost tehnologija za uklanjanje mikroplastike u različitim uslovima i popunila postojeće praznine u znanju radi razvoja delotvornih strategija za kontrolu zagađenja. U radu se takođe ističe ključna uloga savremenih medicinskih tehnologija i zajedničkih napora sa ostalim sektorima.