Microplastics and Microfibres Treatment

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Microplastics (MPs), and specifically microfibres (MPFs), are ubiquitous in water bodies, including wastewater and drinking water. In this work, a thorough literature review on the occurrence and removal of MPs, and specifically MPFs in WWTPs and DWTPs, has been carried out. When the water is treated, an average microfiber removal efficiency over 70% is achieved in WWTPs and DWTPs.

Keywords: microfibres ; technologies ; WWTPs ; DWTPs

1. Introduction

Nowadays, Microplastics (MPs) can be considered ubiquitous in the environment. These microcontaminants can be originated from different sources. Certainly, these pollutants can be emitted as 'primary MPs' (i.e., tiny particles designed for commercial use intentionally included in cosmetics, personal care products, paints, shower gel, washing textiles, etc.) or 'secondary MPs', which result from the breakdown of larger plastic items, such as those coming from industrial and agricultural activities, fishing activities, tyre wear or mismanagement of plastics [1][2][3]. Most of these MPs end up in water masses [4][5][6][7].

Microfibres can be found in different aquatic environments—namely, oceans [8][9], lakes [10][11], wastewater [12][13], sea ice [14][15], the deep sea [16][17], rivers [18][19][20], drinking water [21][22][23], surface water [24], bays [25] and marine sediments [26][27][28]. This ubiquity notably contributes to the pollution of the environment, being a risk for fauna and flora [29][30], and for even humans. Additionally, it is known that fibres are present in everyday foods, such as common salt, sugar, honey, beer, bottled water, tap water, fish, lobster, mussels and oysters, which favours human ingestion of MPs [31][32]. A recent study reported that a person may ingest between 39,000–52,000 MPs per year via food and beverages, values that depend on age and sex. In addition, this value could be increased by another 90,000 MPs annually with the ingestion of bottled water and by 4000 MPs if tap water is also consumed [33]. Additionally, MPs are not only potentially harmful to humans via ingestion; the inhalation of airborne MPs (including fibres) and dermal contact also have to be considered [34]. Specifically, the presence of these microparticles in the atmosphere increase their entry into the human body by 74,000–121,000 MPs per year [33]. Moreover, it has been suggested that nanoplastics could cross the epidermal barrier, although it is not the major entry route of these particles [35]. The potential risk of MPs is enhanced by their hydrophobic character; thus, they have the capacity to adsorb chemical additives and toxic pollutants, such as metals, PCBs, pesticides, etc., on their surface [34][36][37][38].

In order to reduce the dispersion of microfibres and other MPs in the environment, wastewater treatment plants (WWTPs) and drinking water treatment plants (DWTPs) should be considered as hotspots in which to tackle this environmental problem.

2. Microplastics and Microfibres in WWTPs

MPs originated in industrial and urban activities can be driven into the sewage system, arriving to wastewater treatment plants (WWTPs). Even though these facilities can remove even more than 90% of MPs from wastewater, still millions of MPs are discharged to the environment in treated water each day [12][39][40]. Although great variability of data has been reported, the MP concentration usually ranges between 6.10 × 10^2 and 3.14 × 10^4 particles/L in influent and 0.01 and 2.97 × 10^2 particles/L in effluent [39][41].

At the household level, microfibres can be originated in items of clothing and furnishing, whereas at the industrial level, microfibres come from the automotive sector and the construction and clothing industries, amongst others [42]. It is remarkable that the clothing industry generates around 42 million tonnes of microfibres annually [43]. Microfibres originated in laundry contributes 35% of the global release of primary MPs to the environment, and the vast majority of these microparticles found in wastewater come from household chores [2]. For example, between 1.1 × 10^5 and 1.3 × 10^7

polyester and cotton fibres can be emitted in only one wash [44][45]. Additionally, the use of garments also contributes to the emission of microfibres to the atmosphere due to wear and tear [46][47]. Most of these microfibres are introduced into the sewage system by means of surface runoff, and they subsequently arrive at WWTPs [48]. For instance, in Paris it was reported that fallout deposits an average value of 106.2 microfibres·m^{-2} per day [49][50].

In a conventional WWTP, wastewater treatment is carried out in different stages that can be classified as follows: pretreatment, primary treatment, secondary treatment and tertiary treatment. The pretreatment is a physical process that aims to remove large debris and/or residues contained in the wastewater, such as oil, grease, sand and solid wastes, in order to avoid clogging and other problems that would affect the correct performance of the facility [40]. This stage includes screening systems and grit and grease removal systems. Different works analysed the presence of MPs throughout WWTP operations. It has been reported that 45% of MPs are removed during the pretreatment process [48][51]. After that, a primary clarifier is commonly used to eliminate suspended solids [40]. Different parameters, such as the structure of suspended solids, the concentration, the retention time and shape of the settling tanks, affect the sedimentation capacity of the solid particles [40][52][53][54][55]. It has been found that primary treatment together with pretreatment could reduce the concentration of MPs with respect to raw wastewater by 78–98% [40][56]. Primary treatment can achieve different removal efficiencies with respect to pretreatment, depending on the specific characteristics of the settling tank, varying from 22% to 99% [48][51][52][57]. Once primary sludge is separated from the wastewater, the effluent from the primary treatment undergoes a secondary treatment consisting of a biological treatment that usually takes place under aerobic conditions [40]. Therefore, the aeration system used to supply the necessary oxygen for the process may make some MPs pass into the atmosphere. After the biological treatment, a settler is employed to separate the treated water from the secondary sludge [40]. For example, a study developed in Spain reported a MP removal efficiency of 67% in secondary treatment relative to primary treatment [48], whereas there was a 28% removal efficiency in a study from China [57]. Finally, a tertiary treatment is sometimes employed. The processes carried out in this stage depend on different factors, such as legal requirements, water reuse, etc. A coagulation–flocculation process followed by disinfection by chlorination or UV irradiation are the most common processes [40][58]. It has been reported that chlorination only reduces the MP concentration by 7%. However, other tertiary treatments such as rapid sand filtration (RSF) allow removals between 45% and 97%. The best results are obtained with membrane systems that remove more than 99% of the MP concentration [12][40]. In addition, photocatalytic degradation could be an effective method for MP elimination in wastewater; however, further research should be carried out in order to improve this technology's performance [59][60].

3. Microplastics and Microfibres in DWTPs

Drinking water sources are subject to pollution and require appropriate treatment to assure the accomplishment of chemicals standards and the absence of pathogenic agents. Drinking water treatment plants (DWTPs) employ several different water treatment processes to provide safe drinking water for consumers through tap water systems. The most common processes used in these facilities include coagulation–flocculation, followed by sedimentation, filtration and disinfection [61][62].

The coagulation–flocculation process consists of the addition of chemicals that favour the aggregation of particles that subsequently settle in a clarifier (sedimentation process) [12][62][63][64]. After that, the purification of water continues by means of a filtration process. Pore size and filter material (sand, activated carbon, gravel, etc.) vary depending on the treatment process. Microorganism removal and turbidity reduction occurs during the filtration step [62][63][64]. Finally, a disinfection process has to be carried out in order to ensure the absence of pathogenic agents in the drinking water. The disinfecting techniques most frequently employed are chlorination, ozonation and ultraviolet irradiation [65][66].

MP occurrence in DWTPs has not received as much attention as MPs in WWTPs [65][66]. However, this is a topic of increasing interest since MPs contained in drinking water could be potentially risky for human health [62][65][66][67]. For example, Cox et al. [33] reported that an American citizen could ingest around 4000 MPs per year by consumption of tap water.

Table 1 summarises the incidence of MPs, and particularly microfibres, in DWTPs. As can be observed, there is a wide variety in the concentration MPs, with values that go from absence to 6614 MPs/L in the influent and from absence to 930 MPs/L in the effluent, with an average value of 739 MPFs/L and 236 MPFs/L, respectively. MP concentrations found in influents and effluents of DWTPs are similar or even higher than those reported for WWTPs. It must be considered that water for human consumption is exposed to the possible entry of more MPs through several routes, such as environmental degradation of plastics and physical wear of plastic items, industrial discharges, deposition from airborne MPs, etc. [65]. It is remarkable that the abundance of microfibres in most cases is much lower in the influents of DWTPs than those obtained in the influents of WWTPs. This is probably due to the origin of the water—i.e., in DWTPs the influent is obtained from different water sources (aquifers, reservoirs, etc.), whereas in WWTPs the influents correspond to wastewater (mainly of urban origin) coming from the sewage system.

Table 1. Overview of the incidence of MPs and microfibres in DWTPs. "D" followed by a number refers to different DWTPs analysed in the cited reference.

	Treated Water (m^3/day)	Influent			Effluent			MPF Removal (%)	Number of MPFs per Day		References
		(MPs/L)	% MPFs	(MPFs/L)	(MPs/L)	% MPFs	(MPFs/L)		Influent	Effluent	
China	-	-	-	-	440 [a]	16	70.4	-	-	-	[21]
	1.2×10^8	6614	64.9	4295	930	66.7	620	85.6	5.2×10^{14}	7.4×10^{13}	[68]
	1×10^5	2753	22	605.7	351.9	50	176	70.9	6.1×10^{10}	1.8×10^{10}	[69]
Czech Republic	D1: 3.2×10^5 D2: 8.6×10^3 D3: 7.8×10^3	D1: 1473 D2: 1812 D3: 3605	D1: 11.4 D2: 6.1 D3: 36.8	D1: 168 D2: 111 D3: 1325	D1: 443 D2: 338 D3: 628	D1: 28.4 D2: 3.6 D3: 46.8	D1: 126 D2: 12 D3: 294	D1: 25 D2: 89.2 D3: 77.8	D1: 5.4×10^{10} D2: 9.6×10^8 D3: 1.0×10^{10}	D1: 4.0×10^{10} D2: 1.0×10^8 D3: 2.3×10^9	[70]
	D1: 1.6×10^4 D2: 3.5×10^4	D1: 23 D2: 1296	D1: 21.7 D2: 9.7	D1: 5 D2: 126	D1: 14 D2: 151	D1: 21.4 D2: 7.9	D1: 3 D2: 12	D1: 40 D2: 90.4	D1: 7.8×10^7 D2: 4.4×10^9	D1: 4.7×10^7 D2: 4.2×10^8	[71]
Germany	2.0×10^5	0–0.007	-	-	0–0.001	-	-	-	-	-	[72]
India	3.8×10^5	17.88	57	10.2	2.75	54.5	1.5	85.3	3.9×10^9	5.7×10^8	[73]
Spain	-	0.96	59	0.56	0.06	56	0.03	-	-	-	[74]
Thailand	-	D1: 0.94 D2: 0.55	-	-	D1: 0.68 D2: 0.62	D1: 6.4 D2: 22.5	D1: 0.04 D2: 0.14	-	-	-	[75]

The percentage of MPFs with respect to the total MPs is similar in the DWTP influents and effluents (between 6% and 67%); MPF abundance in DWTP influents is between 0.03 and 176 MPFs/L, with an average value of 110 MPFs/L, whereas in WWTP effluents this average value is 13 MPFs/L. Considering the available data, the removal efficiency of MPFs during the treatment of drinking water is between 25% and 90%.

The DWTPs analysed in this work (**Table 1**) received between 7.8×10^6 and 5.2×10^{14} MPFs per day, whereas between 1×10^8 and 7.4×10^{13} MPFs/day are emitted to the environment by DWTP effluent.

In general, DWTPs are less efficient in removing MPs and microfibres than WWTPS as a consequence of the usually simpler treatment carried out in the DWTPs [68][69][70][71][72][73][74][75]. In fact, some WWTPs achieve removal efficiencies above 99%, whereas the highest MPF removal efficiency found in literature for a DWTP was 90.4%, and it was achieved in a DWTP that included coagulation–sedimentation, deep-bed filtration, ozonation and granular activated carbon [72]. Thus, improving MP removal in DWTP is a mandatory issue for the future since this would notably reduce the ingestion of potentially hazardous MPs by humans.

As was noted in samples from WWTPs, different factors can affect the analysis and quantification of MPs and microfibres from DWTPs. The most common way of sampling is by storing the samples in containers and then filtering them through sieves of different mesh size [21][68][69][70][71][74] or sampling by direct filtration [72][73][75]. In order to isolate MPs from impurities, an oxidation of the sample (using only hydrogen peroxide or reagent of Fenton) is conducted, followed by a separation using a NaCl or $ZnCl_2$ solution [72][73][75]. Finally, a visual sorting of MPs is carried out by employing a stereomicroscope [69][72][74]; however, Sarkar et al. (2021) used a fluorescence microscope to differentiate MPs from impurities [73]. As in the case of wastewater and sludge samples, FTIR and Raman spectroscopy are employed as classical techniques for determining the chemical composition of MPs [21][68][69][70][71][72][73][74][75].

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