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Mini Review on Physical Microplastic Separation Methods in the Marine Ecosystem

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Abstract

Microplastics (size <5 mm) are a major source of human contamination in the seas, oceans, and other aquatic environments as they may act as carriers for the release of antimicrobial resistant genes. It is also possible for pathogenic bacteria to be spread by microplastics in new areas, which can have uncontrollable effects if not properly controlled. Due to their small size, removing or isolating them from aquatic environments is a difficult task that requires advanced technologies. Methods of separation of these microparticles from aqueous media are divided into three categories: chemical, biological and physical. In this article, we review the physical methods of extracting microplastics. Membrane technologies were effectively employed to eliminate MPs from contaminated aquatic environments. The removal efficiency of the membranes is based on its durability, influential flux, size, and quantity of MPs. Integrating of penetrable membranes with biological steps could improve the removal efficiency up to 99.9%. To enhance understanding about environmental consequences of MPs, future investigations should concentrate on the development of new modelling techniques to evaluate transport route of MPs in soil, sediments, and water. In conclusion, appropriate remedy can be identification and removal of MPs origin and route to monitor inventories of materials or employing novel devices and methods.

Abbreviations

Table1. Microplastic Abbreviations

MPs	Microplastics
Conventional activated sludge process	CASP
anaerobic/ anoxic/oxic Santos and São Vicente Estuarine System	AAO (SSES,Brazil)
coagulation/flocculation integrated with sedimentation	(CFS)
water treatment plants	(WTPs)
microliter	(ML)
Wastewater Treatment Plant	WWTP
vacuum suction	VS
sediment-MPs isolation Dissolved air Induced (dispersed) air	(SMI) (DAF) (IAF)
disc filter	(DF)
rapid sand filtration	(RSF)
oil extraction protocol	(OEP)
U.S. National Oceanic and Atmospheric Administration	(NOAA)
microplastic particles of 1 mm or less	(S-MPPs)

1. Introduction

During the last decade, MPs particles have entered directly into marine and fresh water environments, affecting habitats and animals negatively. Despite raised questions and concerns by this issue, there is no good understanding about environmental interactions of MPs [1-2]. Accordance with the U.S. National Oceanic and Atmospheric Administration (NOAA), MPs are defined as plastic particles smaller than 5mm in length. MPs can be categorized two major classifications as primary and secondary MPs, depending on their source [3].

Primary MPs consist of industrial products such as cosmetics as well as different kinds of textiles. [1-2], [4]. Also Secondary MPs form by the fragmentation of larger plastic items, caused by weathering (e.g.,UV light) and during consumption or fabrication [1], [5-6].

A recent research reveals that >100 billion MP particles can be released by a single WWTP yearly; hence WWTPs are substantial contributors to the issue of MP pollution of surface waters [7]. Additionally, MPs as a by-pass product of the WWTP penetrate into the water bodies and pile up in the environment eventually, taking into account WWTPs may remove some of MPs in light of used treatment units [8-9].

Rivers and systems leading to river ecosystems are environments and areas that provide favorable conditions for microplastic identification, so this topic should be further investigated [10]. This often includes studies and assessments of microplastics, including coastal sediments [11].

Simultaneous detection of microplastics in the water and sediment bay allows for a better description and more accurate assessment of the environment, so simultaneous detection of microplastics in water and sediment is well accepted [12-13]. In addition, there is the challenge that different results occur in the assessment of small microplastics depending on the characteristics and conditions of the sampling and sampling instruments [14].

Conley et al., reported MPs loads and removal efficiencies of three wastewater treatment plants (WWTPs) with various treatment sizes, operations and service arrangement in USA during one year [15]. The major wastewater treatment plant in investigation, by using the primary clarification, demonstrated highest MP removal efficiency (97.6 ± 1.2%). The major removal efficiency found in this study at the WWTP involving primary clarification proposed that upgrading secondary plants by primary clarifiers could enhance MPs removal.

Sieving procedure separates MPs from water sample by using only one sieve or with a series of sieves. This factor is determined by the sieving purpose, such as choosing of MP size range, removal of a particular fragment of MPs, and as well as dividing of the MPs into size categories [16].

In a study carried out by Olivatto et al., the MPs found in samples of the Guanabara Bay (Rio Janeiro, Brazil) which was obtained via sieving process and manual sorting, it was indicated that Guanabara Bay is one of the most contaminated reported location in the studies. Accordingly, due to potential environmental hazards in this site, it should be taken steps drastically by responsible [17].

Flotation is the most widely used method for separation from soil or sediment in dense liquid in regard to low density of plastic particles [18]. Also due to the wonderful performance of selective flotation in microplastic separation processes, it attracts much attention recently [19].

Li et.al., provided possible separation method for MPs in soil and sludge , using pre-digestion step, floatation process with NaI solution, filtration by nylon membrane, and additional oxidation [20].

Coppock et al., proposed a novel, portable technique to separate MPs from sediments based on density floatation, experiencing mean efficiency of 95.8%. Additionally, Zinc chloride, proved as an effective and cost-effective floatation media, providing fine sediment to settle and facilitating floatation of dense particles [21].

Kalčíková et al., estimated the amount of microbeads released from cosmetic products every day and carried out lab-scale investigation by a series of batch biological WWTP, demonstrating about52% of microbeads are trapped in activated sludge [22].

In the recent past, Lares et al., investigated the efficiency of an urban WWTP on the base of a pilot-design, integrating membrane bioreactor (MBR)–CAS techniques to eliminate MPs during 3 months. This study indicated more efficient removal of MPs by applying membrane bioreactor rather than to the CAS method (99.4% vs98.3%) [23].

Some types of microplastics have a lower density than seawater (e.g. polypropylene) and some have a higher density than seawater (e.g. acrylic). These characteristics cause several problems in the aquatic ecosystem. Low-density microplastics can float and spread widely in areas such as waterways, while higher-density microplastics can accumulate deep in the sea or ocean. For this reason, density separation is a practical method for separating microplastics [24-25].
Konechnaya et al., also reported that ZnCl2-based density separation is appropriate method to separate polymer particles from a sandy samples [26]. Besides that, Bayo et al., investigated the quantity, concentration and forms of (MP) in an municipal wastewater treatment plant (WWTP), based on various environmental factors, and removal efficiency by density separation (salt-saturated solution of NaCl), showing substantial removal of MP (90.3%) in the effluent of WWTP located in Spain [15].

Recently, studies related to occurrence and removal of MPs have attracted attentions of researchers, mainly about the removal of MPs by applying different treatment techniques. This paper also reviews conventional technologies which are used to MPs removal from drinking and waste water and addresses to the perspectives for the future on development of new technologies.

2. Sedimentation Technology

In relation to MPs, sedimentation technique which is based on gravitational settling, removes suspended contaminants from liquid. This method is used not only in primary treatment but also in secondary treatment. Furthermore, this process can be used prior to other treatment techniques because of not removing pollutants completely in this stage [17], [29].

According to studies which have been carried out at WWTP of some countries, the removal rate of this technology is different and relatively high (57%–64% [27] and 91.7% [28]). Comparing, these studied revealed the MPs removal efficiency by sedimentation process is affected by two crucial factors: density and shape [27-28]. For instance: at the WWTP in Vancouver, Canada, efficiency of MPs removal by sedimentation technique reached 91.7% which this achieved high efficiency in this study might be thanks to being more fibrous MPs rather than other shapes [17], [23], [27-28].

The major drawback of sedimentation technology in related to MPs removal is that the contaminants are not completely removed, needing to select other appropriate technologies. In a study by Pivokonský et al., 88% of MPs were removed by the several steps such as Coagulation-flocculation with sedimentation which Coagulation-flocculation with sedimentation were quite effective for elimination of MPs and additional MP removal was obtained by filtration and GAC (granular activated carbon) processes [30]. Zhang et al., studied the removal efficiency of MPs and nanoplastics (180 nm–125 µm) while drinking water treatment, in particular coagulation/flocculation integrated with sedimentation (CFS) and granular filtration in the conventional working conditions at water treatment plants (WTPs) [30]. Totally, CFS was not acceptable to remove MPs and nanoplastics. The sedimentation rate of clean plastics was below 2.0% for all various sizes of plastic particles by using coagulant Al2(SO4)3. On the other hand, granular filtration was significantly more efficient at filtering MPs and nanoplastics, from 86.9% to around complete elimination (99.9% for particles >100 µm).

Wang et al., investigated the occurrence and MPs removal at an advanced WTP for each treatment process, consisting coagulation integrated with sedimentation, sand filtration, ozonation, and GAC filtration. The removal efficiency of coagulation integrated with sedimentation was reported 40.5–54.5%. Additionally, the coagulation/sedimentation techniques eliminated larger MPs efficiently removing MPs > 10 µm, near completely. Related to MPs shapes, fibers showed highest removal rate due to coagulation/sedimentation technology (around 50.7–60.6%) [31-32].

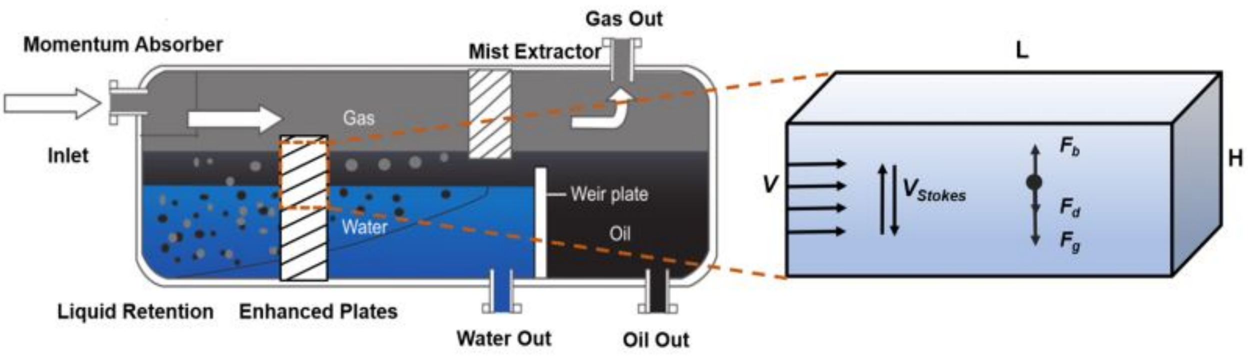

Figure 1: Mechanism of gravity sedimentation technology [16], [33].

Totally, in this investigation, conventional treatment technique (integrating coagulation/ flocculation, sedimentation and sand filtration) had a removal efficiency of near 58.9–70.5% [32].

Ma et al., examined MPs removal in coagulation/sedimentation and ultrafiltration in controlled tests by using Al- and Fe-based salts, observing a removal efficiency lower than 40% [34]. Generally, the coagulation integrated with sedimentation is an appropriate choice to the contaminant removal [35].

3. Clarification

The aim of primary clarification is to provide solid settling prior to biological treatment. Primary clarifiers are also supported with by surface skimmers to skim floating solids off the surface of the supernatant water before secondary treatment. Accordingly, MPs can be eliminated by sedimentation or flotation within primary clarification. Michielssen et al., observed that 84-88% of microliter (ML) was eliminated due to primary screening and primary clarification [36]. Murphy et al., showed that primary treatment removed up to 78% of MPs at a WWTP in the UK [9].

Frehland et al., used the marked materials to a pilot WWTP, simulating the activated sludge procedure (nitrification, de-nitrification and secondary clarification) [37]. They investigated the manner of particulate plastic in terms of the organic substance removal.

Wang et al., concurrently studied occurrence of phthalate esters (PAEs) and (MPs) at four wastewater treatment plants (WWTPs), receiving water bodies and reclaimed water treatment processes (RWTPs) in winter and spring seasons. The four WWTP effluents were substantial sources of PAEs to the receiving waterways in spring, although not possible to be the MPs origin. The total removal rates of PAEs and MPs in the four RWTPs were 47.7%−81.6% and 63.5%−95.4%. In this effort, the major techniques employed were clarification, filtration (except ultrafiltration) and reverse osmosis, helping the MP removal in the RWTPs 42.7%−69.2%, 25.3%−59.3%, and 22.6%−51.0%, respectively. Additionally, the results revealed that the amount of PAEs and MPs in surface waters could be affected by the surrounding environment considerably [38].

4. Sieving

The sieving method of water samples is used to separate in terms of MPs studies plentifully. The sieve physically traps the MPs, enabling water to get lost from the sample [39].

The method which widely use to sieve MPs in water and sediment samples is multi-step sieving, separating material of different sizes by passing the sample through a series of sieves with a mesh size reduction. Furthermore, to help in the separation of smaller MPs from smaller grains, several processes can be employed, such as density separation [40].

For example, a study discussed by Gimiliani et al., which presents an effective method for separating and quantifying MPs in the Santos and São Vicente Estuarine System (SSES,Brazil), involving sieving (2.0, 1.0, 0.5 and 0.25 mm mesh sizes), sediment collection, drying, and stereomicroscopic evaluation of the samples maintained in each sieve [41]. Additionally, this technique was introduced as cost-effective with less environmental footprint rather than other available methods. Sieving also allows MPs to be removed from the samples, resulting divided into different size sorts. The choice of sieve mesh sizes specifies the size range of MPs to be measured [42].

Turner et al., extracted MPs from sediment sampled water body in the United Kingdom by sieving and density separation techniques, providing an important contribution to information about sources, path and fate of MPs particles in freshwater systems [43].

5. Flotation

Flotation is a separation technique which applied in the waste water treatment and mineral processing, based on four steps: 1. Bubble generation in the wastewater 2. Contact between the gas bubble and oil droplet suspended in the water 3. Attachment of the particle or oil droplet to the bubble 4. Rise air-solid mixture where the floated materials are skimmed off [44].

According to used method of bubble generation, there are five types of flotation technique [45]:

1) Dissolved air (DAF); the gas is released from a supersaturated due to reducing the pressure.
2) Induced (dispersed) air (IAF); mixing of gas and liquid mechanically to induce bubble generation in the liquid.
3) Gas is directly introduced into the fluid by a sparger.
4) Electrolytic; the bubbles are generated by water electrolysis.
5) Vacuum, the air is released from a saturated solution release the air by a negative pressure.

DAF is a solid-liquid separation process for the removal of suspended material from an aqueous suspension. DAF is an efficient choice to sedimentation. DAF allows to remove of low density particles and algae effectively. However, DAF processes are more expensive to operate and maintain than sedimentation processes [46]. A study which at Paroinen WWTP aimed to examine the efficiency of different modern final-stage treatment technologies to MPs removal from effluent, using DAF as a technology with of disc filter (DF), rapid sand filtration (RSF). This method removed 95% MPs during the treatment [47].

Han et al., presented an optimized process for extraction of MPs particles by amending the floatation technology and floatation solution, proposing standardized setup [15]. This configuration was based on air mixing and flotation, consisting of a flotation solution storage section (A), air floatation section (B), and a vacuum filtration unit (C). Totally, the optimized approach demonstrated more accurate and efficient, contributing to obtain a more correct knowledge of the quantity of MPs particles present in soils and sediments. In this study, in order to achieve a density greater than the most common a NaCl-NaI mix is proposed instead of commonly used NaCl as floatation solution.

6. Activated Sludge

Conventional activated sludge process (CASP) is a common wastewater treatment method, relying on biodegradation by activated sludge isolated by a sedimentation tank. During this method, MPs could attach to suspended matter separating by the subsequent settling step [27]. Markedly, Lares et al., reported significant removal efficiency (98%) of MPs which obtained in CASP technology. Other studied conducted by, Murphy et al., and Edo et al., also revealed that this process has high ability to eliminate MPs, 92.6% and 93.7% respectively [9], [20], [48]. However, Hidayaturrahman and Lee reported that MPs removal efficiency are different from 42 to 77% [29]. Furthermore, this technology removed 62% of MPs in the municipal WWTP in Spain [27]. Magni et al., experienced removal rate of MPs about 64% using grid chamber and the CASP at municipal WWT systems in Italy [49]. Nevertheless, anaerobic/ anoxic/oxic (AAO) method, removed about. 17% of MPs from wastewater and forwarded into excess sludge [50]. Totally, the MPs removal efficiency of CASP was unstable and different relatively broadly [27]. Additionally, with regard to the ability to decompose MPs in CASP, many studies have been not carried out. The main drawbacks of CASP are to need the space and producing a lot of the excessive sludge, the extensive retention times and sedimentation surface, the huge cost of energy and dumping. However, this process is cost-effective, flexible appropriate for wide-scale treatment [15], [27], [51-52].

Nevertheless there is not understanding accurately about interaction between the plastic fragments with the micro-organisms and also about MPs trapping extension. Considering, AAO removed 28.1% and 54.47% at WWTP in Wuhan, China and at WWTP in Beijing, China respectively [50], [53]. According to these investigations, the affecting factors of efficiency of activated sludge method concerning to MPs removal, consist of the retention time and nutrient extent in wastewater [8], [54].

The longer retention time causes, more possibility of surface biofilm covering on the plastic particles, changing surface, size and relative densities of the pollutants [8]. These modifications might result in a substantial influence on the buoyant MPs to enhance the possibility of MPs removal through skimming or settling procedures, increasing the removal efficiency of the method. Even though, the retention time and nutrient amount in sewage require more examination to improve the MP removal rate of this method [28].

7. Density separation

Density separation of MPs from samples is based on their different densities, adding brine solutions which allow to separate lower density particles density from denser matrices after settlement. Samples may be undergone two separation steps, including a reduction process that provide to reduce sample volume (e.g., via using nets during collection), separation step commonly by filtration and/or density separation by employing of NaCl (1.2 g cm-3) which explained by Thompson et al., due to being low-cost, easy availability and eco-friendly [1]. There are various types of separation methods to extract of MPs from sediments, including elutriation column, pressurized fluid extraction, sediment-MPs isolation (SMI) and density separation by various types of salt solutions [21], [55-56].

Nevertheless, using brine solutions with very high densities to improve the separation, effectively is increasing, considering these higher density solutions are often very expensive and harmful to the environment [42], [56]. However, newly, National oceanic and atmospheric administration NOAA has suggested the use of lithium metatungstate (LMT) (1.62 g/cm3) for density separation technology [57]. On the one hand, the separation of small MPs can be challenging process, especially from finer sediments with MP shape affecting the separation capacity. On the other hand, techniques such as elutriation and flotation) have been developed, employing for the separation of MPs from sediments

[58-59]. Regardless, density separation is the most reliable and conventional method for the separation of MPs from sediment or sand [56].

Genarally, in elutriation, a liquid such as water is inserted into the bottom of a column, leading to separation of buoyant MPs from the settling organic matter and sediment [59]. MPs are accumulated in a mesh of column, subsequently are separated using dense solutions [55], [60]. This technique is inexpensive and effective to separation of MPs from large quantities of sediment, allowing higher ecological representativeness, and reduction of sample volume subjecting density separation [61].

Preliminary tests propose adding a centrifugation step after density separation in saline solutions enhances the plastic-sediment separation ability [62].

Centrifugation allows a simple equipment to separate low-density particles from higher-density sediments. Centrifugation has been suggested by Claessens et al., as a following step after floatation to improve the extraction capacity of MP fibres and granules from sediments [55], [59].

Vianello et al., observed the presence of MPs in all sediment samples obtained from, Lagoon of Venice.This investigation revealed MP particles of 1 mm or less S-MPPs separated by density separation technique are distributed in the sediment of whole Lagoon, accumulation of S-MPPs on bottom sediments are influenced by local hydrodynamics related to their sources [63].

Similarly, Tata et al., investigated MPs sampled from the sediments of the Gulf of Annaba, Algeria. MPs were extracted by the density separation process from reporting perceptive findings about amount and types of MPs in the surface sediment [64].

8. Challenges and new approaches

The occurrence and impacts of MPs in water bodies is progressively obvious across the world. Notably, millions of MPs from WWTPs are released per day throughout the world. Although the many attempts have been conducted towards the development of approaches of separation, quantification and identification of these rising contaminants. There is no standard protocol for performing WWTPs. These different research methodologies cause complicated comparison of the results. Accordingly, the establishment of effective and reliable protocols for the study of MPs is essential. Furthermore, the standardization of sizes (e.g., sieving), chemical digestion, density separation, visual separation, demanding to be improved and used in a standard procedure [53].

It cannot be determined exactly which technology can remove MP efficiently relative to the other, because of insufficient research [28]. However, studies of MPs have been growing, over the past decade, and methods and approaches have been proposed on account of the current studies of MPs, which will facilitate to fill research gap in the future [65]. Concerning the separating MPs from environmental samples, new techniques have been suggested which are usually combination of technological alternatives, following some of them will be reviewed. Vermeiren et al., conducted examinations to combine systematic advances, and illustrated their application to organic rich sediments with fine grain size, leading to a new density separation column. Additionally, some processes of the protocol could be accelerated such as using centrifugation as a contributing step in density separation [66]. The wide range of techniques and brine solutions currently use to separate MPs from sediment it is increasingly difficult to compare the results generated from various studies [58].

Zhang et al., introduced a simple and cost-effective technique developed to extract, and quantify MPs in soil by a floatation method using distilled water which used sodium dihydrogen phosphate (NaH_2PO_4) solution, demonstrating promising alternative in the MPs extraction [67]. Han et al., provided an improved and optimized method for extraction of MPs particles from soil and sediment samples by amending the floatation technique and solution [18].

In this study, to replace the widely used NaCl as floatation solution, a NaCl-NaI mixture suggested in order to obtain a greater density. As a result, stirring or shaking of the sample with floatation solution was altered to air floatation in the developed form.

Grbic et al., developed a method that extracts plastics magnetically, by drawing on their hydrophobic surface to magnetize the plastics. They generated hydrophobic Fe nanoparticles providing magnetic recovery, being as an effective method for different sizes, polymer types in post density separation step. Furthermore, this procedure specifically helpful for small MPs (<20 µm) [68].

A large number of extraction technologies are currently employing to separate MPs from sediment particularly density-based separations. Some of these methods are cost-effective but non-effective to completely recover all plastic types. On the other hand, other techniques may be more efficient related to most plastic types, although are more expensive or environmental -health hazard.

Crichton et al., presented a new inexpensive oil extraction protocol (OEP) that proposes a selection to density-based approaches by using oleophilic MPs characteristics. Applying of this novel method on real sediment samples collected from different sites in Canada, showed that the oil extraction protocol is cost-effective choice for environmental samples specially in field of density-based techniques [69]. Kedzierski et al., suggested new information and protocol components according to model calculations. These new elements suggest major changes in forthcoming elutriation technologies. Furthermore, other data may contribute to promote future generations of elutriation techniques [70]. Dyachenko et al., refused using of methods that consist of centrifugation and microwave because of fracturing and disfiguring of these techniques [71]. Kim & An developed a vacuum suction (VS) system as a preparation instrument for MPs films, separating films into small areas. In this study, a new, vacuum-based separating technique for low-density polyethylene films was developed and utilized. This methodology includes of two differently sized cylindrical sieves enabling film samples in special sizes to be accumulated [72].

Table 2. **Used microplastics**

	Site	Technique	Size/Shape	Type	Source	Reference	Comment
1	Chabahar Bay, Iran.	Wet sieving Digestion	100–500 µm, 500–1000 µm, 1000–3000 µm and 3000–5000 µm), 4 shape categories (fragment, pellet, fber & paint flakes	PP PE PS PET PVA	Main source for production of paint flakes was found to be boats color and vessel cleaning	[75]	Sampling
2	Seine River (Paris, France)	Filteration	5 -100 µm,	PET, PP, PA PET-PUR blend	Synthetic and non-synthetic anthropogenic fibers	[76]	Sampling
3	Yangtze River (China)	Coagulation/flocculation, Sedimentation, Sand filtration and Advanced treatment units, Ozonation combined with	1–5µm, 5–10 µm, 10–50 µm, 50–100 µm and > 100 µm	PET PE PP PAM PS PVC	-	[32]	overall removal efficiency of MPs: 82.1–88.6%

		(Granular Activated carbon) the GAC.					
4	Wastewater Treatment plant (WWTP) in Wuhan, China	Conventional Activated Sludge process	100- 800 µm	PA PE PP PVC PC	-	[50]	removal rate of 64.4%
5	Úhlava Riverat, Drinking Water Treatment Plants (DWTP) at Plzeň and Milence Czech Republic	Coagulation-Flocculation with Sedimentation Filtration GAC	fragments and fibres (≥ 1 µm)	CA PET PVC PE PP	-	[30]	Final Removal of MPs at the DWTP Plzeň:88%, Removal of MPs at the DWTP Milence: 40%
6	Cartagena), Urban WWTP Cabezo Beaza (Spain	Grit and Grease removal(GGR), Primary Clarifier (PCL) ,Activated Sludge Process (ASP)	fragment, film, bead, fiber, and foam (400-600 µm)	ACRYLr (BPL) (HDPE) (LDPE) MF PEP, PS, PES, PETPIB, PP, PUR, PVI	-	[15]	removal of: 90.3%
7	Lake Kallavesi Eastern Finland,	Pump Filtration	synthetic fibers and fragments 20–100 100–300 µm	PE, (PP), (PMMA), (PVC), polyethylene (PET), and (PS)		[77]	(Sampling)
8	Saigon River is located (Southern Vietnam)	Density separation, Filtration	fragments and anthropogenic fibers	PP PE/PP PE PET	Textile and Plastics Industries	[78]	(Sampling)
9	Pearl River Estuary, South (China)	Digestion Density separation	0.355–5.0 mm foam; fIber, fIlm, fragment, and pellet.	PE, LDPE, MDPE, PP, PP/EPR, PS, EVA, EPDM	plastic shopping bags, tableware (i.e., cups, bowls and cutlery), food containers, packaging flms and bubble wraps in southern China	[79]	Sampling
10	China	Coagulation Sedimentation Ultrafiltration	<0.5mm 0.5mm<d<1mm 1mm<d<2mm 2mm<d<5mm	PAM PE	-	[80]	Removal efficiency< 40%)
11	Lake Michigan, USA	Wet Peroxide Oxidation Technique	0.355–0.999 mm 1.000–4.749 mm >4.75 mm Fragment Pellet Fiber/line Film Foam	PE PP	-	[81]	Sampling

12	The East of Spain The WWTPs were located near Albaida, Canet d'En Berenguer	Floatation and Filtration Method	150-250 mm Fragment, Fiber, film	High density Low density	Sewage Sludge Source	[82]	Sampling
13	North African coasts of Mediterranean Sea(Algeria)	density separation	Fibers, Fragments, Pellets, Films, Foams.	PE, PP, PET, PES Butyl branham EPR CTA	e.g., industrial harbor, …	[64]	Sampling
14	Laizhou Bay, China	density separation	fiber, film, fragment 336.2 - 4997.7 µm 28.3-4933.0 µm 60.1 - 4913.9 µm) range: 94.1 - 4842.9 µm	PET CP) PE P (PP), (PAN), (PE), polyamide (PA), polystyrene (PS),	Fishing activities, heavy marine traffic and textiles	[83]	Sampling
15	Pearl River Estuary (PRE), South China		<500 µm fiber, fragment, pellet and sheet	PP, copolymer (PP&PE), polyethylene terephthalate (PET), (PS), (LDPE), CE	Industrial sources	[84]	Sampling

Conclusion

Membrane technologies were effectively employed to eliminate MPs from contaminated aquatic environments. The removal efficiency of the membranes is based on its durability, influential flux, size, and quantity of MPs. Integrating of penetrable membranes with biological steps could improve the removal efficiency up to 99.9%. [15].

To enhance understanding about environmental consequences of MPs, future investigations should concentrate on the development of new modelling techniques to evaluate transport route of MPs in soil, sediments, and water [73].

In conclusion, appropriate remedy can be identification and removal of MPs origin and route to monitor inventories of materials or employing novel devices and methods [74].

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