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Microplastic- An Imposing Commination to the Aquatic Ecosystem and its Removal Strategies in Wastewater Treatment Plants: A Systematic Review

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Abstract: Plastic is broadly used for various human interests (technological devices, food packaging, medical products, etc.) and there is an increasing concern about the risks for our surrounding environment and health. In particular, microplastics (MPs), both primary and secondary, occur in all environmental pockets and constitute a potential warning, since they easily enter into the food chain. Moreover, microplastics have the ability to absorb diverse pollutants, which thereby get accumulated inside human body via processes of bioaccumulation and biomagnification. A systematic review was conducted to determine the effectiveness of wastewater treatment facilities (WWTPs) in removing microplastics. Published research on the effectiveness of wastewater treatment plants (WWTPs) for microplastic removal were searched using international databases (PubMed, Science Direct, and Scopus). Contamination of MPs in aquatic environment has presently been recorded as a transpiring environmental threat because of their fatalistic impact on the ecosystem. Their sources are numerous, but, undoubtedly, all are from synthetic matters. The sources of MPs are cosmetics and products of personal care, textile and tyre, abrasion processes of some other plastic products, bitumen and paints for road marking. Due to their low density and tiny particle size, MPs get easily extravasated into the wastewater drainage systems. Therefore, the municipal wastewater treatment plants (WWTPs) are designated to be the foremost recipients of MPs prior to getting excreted into the natural water reservoirs. The focus of this article is to put forward an all-inclusive review in order to preferably understand the channels of MPs into the environment, their characteristics in wastewater, and most importantly, the removal efficiency of MPs of the subsisting wastewater treatment technologies, as arrogated by the WWTPs. This review also encompasses the expansion of budding microplastics treatment technologies that have been investigated till date. Then, in the not-too-distant future, effective and standardised techniques for measuring MPs should be developed, as well as a greater understanding of sources and strategies for reducing microplastics contamination of treated effluent.

Keywords: *Bioaccumulation, Environmental health, Food chain, Plastic, Removal efficiency*

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1. Introduction

Contamination via microplastics (MPs) in aquatic environment is an emerging environmental threat owing to the negative impact that they have on the ecosystem. Many sources of microplastics are there, but all are from synthetic components, like bitumen and road marking paints, cosmetics and personal care products, textile and tyre, abrasion or breakdown of other plastic products. Due to their small particle size and low density, they easily get discharged into wastewater drainage systems (Phuong Linh Ngoa, et al. 2019). Microplastics (MPs), the tiny plastic debris which is smaller than 5 mm in size (Eerkes-Medrano and Thompson, 2018; Lares et al., 2018; Zhang et al., 2018), have recently been documented as emerging dangerous contaminants. They are present in every type of environment worldwide from water to sediments (Van

Cauwenberghe et al., 2013; Li et al., 2019), from urban to remote areas (Cole et al., 2011) and from continent to the ocean (Hirai et al., 2011; Cole et al., 2011; Jambeck et al., 2015). Microplastic impacts have also been well identified in many environments including air (Liu et al., 2019a) soil (He et al., 2019; Li et al., 2019), ocean (Hidalgo-Ruz et al., 2012; Rochman et al., 2015; Clark et al., 2016; Hammer et al., 2016; Li, 2018) and freshwater (Lechner et al., 2014; Eerkes-Medrano et al., 2015). Microplastics can be ingested by aquatic animals which may cause choke or starvation because of pseudo satiety or physical harms such as abrasion and blockages (Clark et al., 2016). They can also poison aquatic biota by leaching out theirs contaminated monomers and toxins (Sussarellu et al., 2016). For example, MPs can transport various other toxic chemicals, namely poly-brominated diphenyl ethers, polycyclic aromatic hydrocarbons, and heavy metals which can poison aquatic species in many ways (Teuten et al., 2009; Wardrop et al., 2016; Hermabessiere et al., 2017; Li et al., 2019). The main sources of microplastic contaminants are the wastewater treatment plants (WWTPs), in aquatic environment, and an in-depth understanding of the behaviour of microplastics among the critical treatment technologies in WWTPs is urgently needed. (Weiyi Liu et al., 2021). Microplastics always cause chronic toxicity due to their accumulation in organisms (Li et al., 2018). WWTPs are the major recipients of terrestrial microplastics before entering natural aquatic systems (Sun et al., 2018), which convert primary microplastics into secondary microplastics. The microplastics that occur in municipal wastewater usually originate from day to day human activities. For example, polyester and polyamide components are commonly shed from clothing during the laundry process (Napper et al., 2016), and personal care products such as toothpaste, cleanser and shower gel enter WWTPs resulting from our daily use (Magni et al., 2019). Plastics in garbage are decomposed by microorganisms in the leachate and then are discharged into WWTPs (Durenkamp et al., 2016). In addition, the microplastics floating in the atmosphere, which have been emitted by plastics industries and vehicles, also converge in WWTPs via atmospheric deposition (Mintenig et al., 2017; Liu et al., 2019; Wright et al., 2020). It has been proven that untreated microplastics are commonly discharged from WWTPs, enter water bodies, and eventually accumulate in the environment (Carr et al., 2016). Therefore, it is urgent to study the performance of microplastic by different treatment technologies in WWTPs and understand the mechanism of removing microplastics to reduce the amount of microplastics entering the natural aquatic system. However, few pieces of research have been found to summarize the microplastics removal mechanisms of the critical treatment technologies in the WWTPs.

2. Materials and methods

A systematic review was conducted to determine the effectiveness of wastewater treatment facilities (WWTPs) in removing microplastics. Published research on the effectiveness of wastewater treatment plants (WWTPs) for microplastic removal were searched using international databases (PubMed, Science Direct, and Scopus). Initially, keywords were used to select over fifty entire research publications. The papers were then further sorted by English language, title, and abstract, with duplicates and non-relevant studies being removed based on eligibility criteria. Finally, five study papers were included in their entirety. The authors of each of the five full research publications selected classified the microplastics found based on their shape, size, and kind of polymer.

3. Results and discussion

3.1. About microplastics

The most prevalent marine debris present in oceans and Great Lakes is plastic. Plastic debris exists in almost all sizes and shapes, but those less than five millimetres in length are called “microplastics.”

Since it is an emerging field of study, very little is known about microplastics and their impacts as of now. Field methods that are standardized for collection of sand, sediment and surface-water microplastics have been developed for testing purpose. In due course, laboratory and field procedures will permit for worldwide comparisons of the number of microplastics released into environs, which is first and foremost step to determine final dissemination, impacts, and nemesis of this debris.

Microplastics originate from diversity of sources, inclusive of huge plastic debris which degrade into smaller pieces. Additionally, a type of microplastic, namely, microbeads, are extremely tiny slices of fabricated polyethylene plastic which are adjoined as exfoliants in health and beauty products, like cleansers and toothpastes. These small particles can easily escape water filtration systems and end up in oceans and Great Lakes, thereby presenting as a potential ultimatum to aquatic lives. As per United Nations Environment Programme, for the first time, plastic microbeads appeared around 50 years ago among personal care products; gradually plastics almost replaced the natural ingredients. In 2012, this matter was still comparatively unknown, with loads of products consisting of plastic microbeads in market and minimal awareness among consumers. President Obama on 28th December, 2015, signed the Microbead-Free Waters Act of 2015, banning plastic microbeads in cosmetics and personal care products.

3.2. Sources of microplastics

The composition and sources of MP pollutants are different among various WWTPs due to the way they collect wastewater (Chang, 2015; Ziajahromi et al., 2017). Depending on the pattern of discharge set up, WWTPs may obtain only industrial sewage or domestic wastewater and also landfill leachate, provided distinct discharge systems have been applied. On the contrary, if integrated or intercepted discharge methods are utilized, municipal WWTPs may become recipient of contaminants coming from restricted industrial sewage, domestic wastewater, and storm water flow. However, irrespective of the type of wastewater runoff which delivers MPs, they have been categorized into two groups, namely, primary and secondary MPs.

Microbeads and resin pellets are the primary MPs which are utilised to manufacture plastic products like, cosmetics and also personal care products such as toothpaste, facial cleansers, and body washes (Eriksen et al., 2013; Chang et al., 2015; Gouvia et al., 2018; Magni et al., 2019; Saxena & Srivastava, 2022). In personal care and cosmetic products, a relevant number of plastic microbeads that are generally irregular or spherical in shape are employed for cleansing or exfoliation purposes. It is estimated that a single face wash using one of these products could release around 94,500 microbeads to drainage system (Napper et al., 2016). Road dust associated MP particles is another major source coming from bitumen, tyres, and paints for road marking which spread throughout highways and roads. Rubber particles generated during abrasion from the wear and tear of tyres and road wear are recognized as MPs (Kole et al., 2017). It is argued that tyre and road wear particles account for about 42 percent of the total MPs transported by freshwater system to the ocean (Max Siegfried et al., 2017). It has been estimated that average number of MPs liberated by ablation of tyres each year in UK, Japan and Germany is about 63 kilotons, 240 kilotons, 120 kilotons, respectively (Max Siegfried et al., 2017). Tiny MP dust particles are present in significant amount in the air pollution (Max Siegfried et al., 2017) that are washed off from atmosphere by wet denudation processes like snow, rain, and dew condensation, what are further transported to the WWTPs through storm water runoff.

The incidental MPs which are considered as dominant type in water environment are generated from the breakdown or abrasion process of other plastic products such as packaging and textiles (Sun et al., 2019). The foremost secondary origin is plastic products that are discarded in landfills under extreme environmental situation like acid pH, high salinity, physical stress, gas generation, temperature fluctuation, and decomposition of microorganism particle into smaller pieces which are then would be carried away by the discharge of leachates to enter the WWTPs (Pramila et al., 2011; Zettler et al., 2013; He et al., 2019). Fibre loss from textiles during laundering and discharged into domestic wastewater pipe systems is also considered as a secondary MP pollutant in WWTPs (Manson et al., 2016; Hernandez et al., 2017). It has been estimated that a single wash of one set of synthetic fibre clothing can release more than 1900 fibre debris (Browne et al., 2011). However, these materials were not the main contributor to pollution due to a low percentage in the detected contaminants in inland water sources (Zhang et al., 2018). They are mostly retained in the sludge of WWTPs (Manson et al., 2011; Murphy et al., 2016). However, these synthetic fibre materials may have been detected in a small percentage of the tested samples in land water sources, but the samples tested may not be a complete representation of the overall scenario of the presence of MPs from synthetic fiber materials in the waterbodies.

3.3. Characteristics of microplastics in WWTP

MPs are a kind of polymer mixture having various sizes and shapes. Various sizes and shapes of microplastics showed different toxicity and physicochemical properties (Lehtiniemi M. et al., 2018).

Shape

Shape is one of the chief classification factors for microplastics. The shape of microplastics affects their removal efficiency in WWTPs (McCormick, A. et al., 2014). Total nine shapes of microplastics have been perceived in effluent and influent of WWTPs namely Fibre, fragment, film, pellet, foam particle, ellipse, line, flakes. Fibres, pellets, fragments, and films were the most widely detected microplastics in wastewater, and their highest abundances were 91.32%, 70.38%, 65.43%, and 21.36%, respectively (Hidayaturrahman et al., 2019; Lehtiniemi, M. et al., 2018; Bayo et al., 2020).

Size

MPs can even end up in food chain, and size of these MPs rather than shape was a crucial factor influencing their performance and transformation in the WWTPs (Lehtiniemi, M. et al., 2018). Consequently, it is crucial to accentuate particle size of MPs. The profusion of MPs smaller than 1 mm is about 65.0–86.9% in influent and about 81.0–91.0% in effluent. With decreasing microplastic sizes, the primary microplastics were crushed (physical, chemical, and biological processes) into secondary microplastics (Magni et al., 2019). Those microplastic particles which are smaller were more probable to be ingested by plankton, filter-feeding organisms, and fishes, which can cause a series of toxicological effects in these organisms (Qiao et al., 2019). Accordingly, research regarding particle size of MPs, particularly smaller particle size (<1 mm) can be of guiding consequence for successive scrutiny of biological virulence and environmental transformation of microplastics.

Type

Twenty-nine kinds of polymers were detected in the influent and effluent of the WWTPs. Polyethene (PE), polyamide (PA), polypropylene (PP), polystyrene (PS), polyester (PES) and polyethene terephthalate (PET) were the 6 most extensively detected MPs in wastewater, and their topmost abundances were 64.07%, 32.92%, 10.34%, 75.36%, 24.17%, and 28.90%, respectively (Mintenig et al., 2017; Talvitie et al., 2017a; Ziajahromi, S. et al., 2017; Long et al., 2019).

The PE, PP, and PS microplastics originated from plastic products, including food packaging bags, plastic bottles, and plastic cutlery (Mintenig et al., 2017; Talvitie et al., 2017b; Lares et al., 2018). The PA, PET, and PES microplastics mainly originated from textiles and synthetic clothing, which are the main sources of household microplastics (Hernandez E. et al., 2017; Sun et al., 2019; Wei w. et al 2019). Moreover, mechanical compressing of plastic products, textile industries, the tire and rubber molecules in road dust were also identified as potentially important sources of the PE, PP, PS and PES microplastics (Talvitie et al., 2017a; Hidayaturrahman, H.et al., 2019; Wei w. et al. 2019). Additionally, polymer kinds mentioned above, distinct polymers also were recognized in WWTPs. For example, alkyds, which are widely used in industrial coatings, exhibited the highest abundance in a Glasgow WWTP (28.67%) (Murphy F et al., 2016). Therefore, research priority should be assigned to specific polymer types in addition to common polymers.

3.4. Risks of microplastics

Microplastics and their chemical components

The constituents of MPs, like additives and monomers, may get released in course of usage and disposal of product, and some of these substances may be hazardous to the environment. Monomers are the basic units of plastic polymers, and the backbone structure derived from them is considered biochemically inert due to its large molecular size (Teuten et al., 2009).

However, studies have shown that some monomers have harmful effects. Lither et al. (2011) classified polymers depending on monomer threat categorizations and observed that the styrene monomer producing polystyrene possesses carcinogenic or mutagenic risk, so polystyrene is ranked as one of the most hazardous polymers and has been listed as a toxic substance by the US Environmental Protection Agency (Lithner, et al., 2011). Besides monomers, health hazards associated with additives must not be ignored. Some common plastic supplements include flame retardants, plasticizers, UV stabilizers and antioxidants. Many of these are recognized as hazardous, inclusive of brominated flame inhibitors (e.g., poly-brominated diphenyl ethers or PBDEs), lead heat stabilizers, and phthalate plasticizers (Halden, R.U., 2010; Lithner, et al., 2011). Bisphenol A, which is used in the production of polycarbonate, has endocrine-disrupting effects that can adversely affect human health (Halden, 2010). As a result, MPs and their chemical constituents pose health hazards.

Effects of microplastics on marine organisms

Ingestion is the highest frequent interconnection between microplastics and marine organisms. It has been evaluated that about 690 species were contrived by marine plastic pollution in 2015, and at least 10% of those species had ingested microplastics (Gall et al., 2015). Moore observed that organisms might mistake microplastics for prey and ingest them directly. Moreover, plastic debris or microplastics have been identified in the guts or tissues of many marine organisms, including fish (Lusher, A. et al, 2013a; Neves D. et al., 2015), bivalves (Van Cauwenberghe et al., 2014), zooplankton (Frias, J. et al., 2014; Desforges et al., 2015), seabirds (Blight et al., 1997), turtles (Bugoni L et al., 2001), and whales (De Stephanis, R. et al., 2013). Ingestion of MPs by several aquatic organisms (bivalves, zooplankton, and fish) have been reported in the natural environment. The uptake of microplastics by marine organisms shows that the potential for physical and toxicological harm is an emerging topic. In terms of physical harm, plastic debris has direct mechanical effects on marine organisms through entanglement and ingestion (Derraik J.G. 2002) . Specifically, plastic debris (mainly synthetic fibres) swallowed by marine organisms can lead to intestinal blockage, while hard microplastics with irregular shapes and sharp edges can penetrate the intestinal wall and damage the digestive system. All of these effects can reduce food intake, ultimately leading to starvation and death (Wright et al, 2013; Duis et al., 2016).

3.5. Microplastic removal efficiency in existing WWTPs

Removal efficiency of MPs in the existing WWTPs have been calculated depending on its congregation in effluent and influent samples. Nonetheless, since MPs are a transpiring category of pollutants present in wastewater, currently, there are no WWTP dedicated to eradicate them. As for example, post preliminary, primary, secondary, then tertiary treatment procedures in UK, in a WWTP, the comprehensive profusion got decreased by 6%, 68%, 92% and 96%, respectively (Blair et al., 2019). As a consequence, the removal rate of the contaminants in WWTPs is not efficient enough to prevent the MPs pollution of natural aquatic ecosystem and attained coherence of MP elution of each WWTP varies from around 60% to 99.9% worldwide, depending upon registered mechanics. WWTPs can remove overall 65% of MP in the wastewater influent such as WWTP in Wuhan, China (64.4%) (Liu X et al., 2019b) And in Sydney, Australia (66%) (Ziajahromi, et al., 2017). Whereas WWTP in Vancouver, Canada can reach to 91.7% (Gies et al., 2018) and with tertiary advanced treatment processes, WWTP in Finland can achieve 99.9% MP removal (Talvitie et al, 2017a).

Primary sedimentation and floatation

Primary as well as secondary treatment phases in sedimentation method brought a noteworthy contribution to MP eradication. Usually, sedimentation is a technique that extracts suspended solid fragments from liquid stream via gravitational settling, an indispensable ingredient in WWTP (Cheremisinoff, 2002). This technique may be applied for wastewater treatment procedure as either primary or secondary method, or also both. Besides showing a substantial effect in decreasing contaminants, it also imparts an optimal state for following methodologies like filtration, biological equipment, and disinfection due to an increased capacity of suspended material extraction.

Analogously, air flotation technique is one of the favoured methods for removal of solids, fibrous material and oil. This technique is the outcome of air bubbles of microscopic range that enhance the natural proclivity of contaminants to float on the surface before being collected by mechanical skimming (Cheremisinoff, 2002). The air floatation procedure can extract grease, solid particles and oil, about up to 99%, hence, it has been one of the pivotal steps in domestic sewage, food processing and laundry wastewater treatments (Cheremisinoff, 2002).

Activated sludge and sedimentation

Initialized sludge is a favoured technology pertained in municipal WWTPs post or aerated grit bower, sedimentation tank or diffused air flotation. In the aerobic panzer, sludge floccules or extracellular polymers of bacteria during the growth stage are competent of fostering the accumulation of the MP contaminants in sewage which then would get eliminated in the sedimentation process. The plastic debris may also be held into sludge flocs by the ingestion of microorganisms (Scherer et al 2018). Nevertheless, there is uncertainty yet regarding how exactly plastic debris associate with microorganisms and to what magnitude the procedure could pin down MPs. Ziajahromi et al. (2017) encountered the MP removal grade of activated sludge about at 66.7%, whereas A2O which is the combination of anaerobic, anoxic and aerobic (activated sludge) eliminated only 28.1% in WWTP in Wuhan, China (Rummel et al., 2017) and 54.47% in WWTP in Beijing, China (Yang, L. et al 2019). The outcomes from these reports manifested an unsteady MP rate of removal of this technology. The influencing factors that could affect the MP removal rate of the activated sludge process are the retention time (Carr et al., 2016) and nutrient level in wastewater (Rummel et al., 2017). Longer the contact period, higher are the probabilities of surface biofilm overlay on plastic debris that modifies the surface, size and relative densities of the contaminants (Carr et al., 2016). These changes may cause a noteworthy impact on the nonchalantly buoyant MPs to escalate the probability for extracting them by settling or skimming techniques, which then upgrade the removal frequency of the technique. Hence, the contact time and nutrient level in sewage need further investigation to enhance the MP removal efficiency of the technology.

Membrane bioreactor system

Biofilm is now gaining interest for wastewater treatment with a variety of models such as fluidized bed reactor, rotating biological contactors and membrane bioreactor (MBR) (T.W. et al., 2016). Amidst these technologies, the exceedingly approved technique is Membrane bioreactor (MBR) for peak strength treatment of wastewater due to its high removal capacities of the contaminants. This is due to membrane filtration and dual biodegradation contrivance which only permit tiny solution molecules to pass through; while on the contrary, other materials like biomass, macromolecules and solid particles are captured in the membrane and are removed with the dead sludge (Seow et al., 2016). Membrane bioreactor technology could remove MPs up to 99.9% (Talvitie et al, 2017a). The technique may eliminate MPs far the flow from 6.9 ±1.0 item/L to straight 0.005±0.004 item/L when it was tested in WWTP of Kenkaveronniemi in Finland (Talvitie et al, 2017a). Talvitie et al contended that two MPs were advancing through MBR structure in their test due to intermittent wreckage of filters or tiny leaks in between seals in structure. Likewise, Lares et al. (2018) encountered 99.4% MPs abolition by the technique which stipulated that MP removal grade of MBR is consonant and crucial. Membrane bioreactor filters have been expected to have the slightest pore size (around 0.08 µm) comparing to other currently used filters in wastewater treatment, which can prevent most microplastics to pass through. Consequently, MBR may be the most efficient technology so far among the common wastewater treatment technologies in terms of eliminating MPs from wastewater flow.

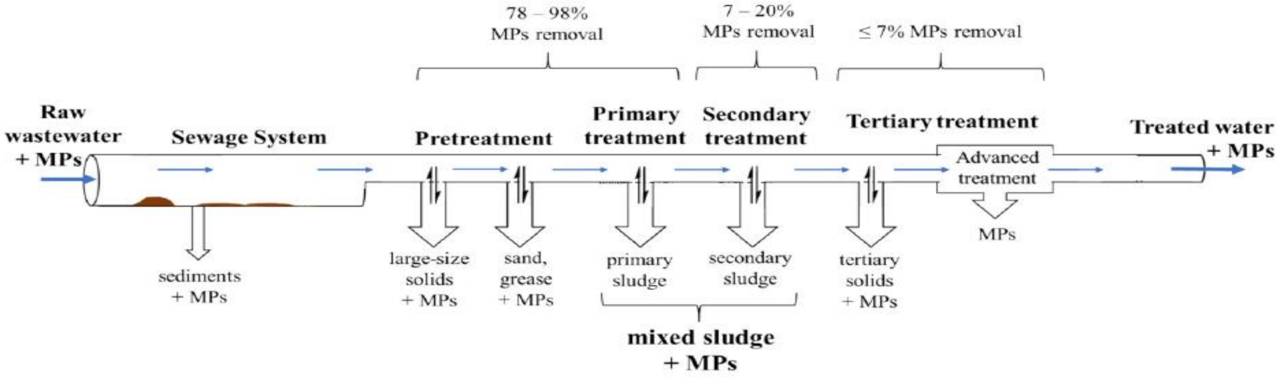

Figure 1: A Schematic Representation of WWTP processes and percentages of MPs removal during processing (Paula Masia et al., 2020)

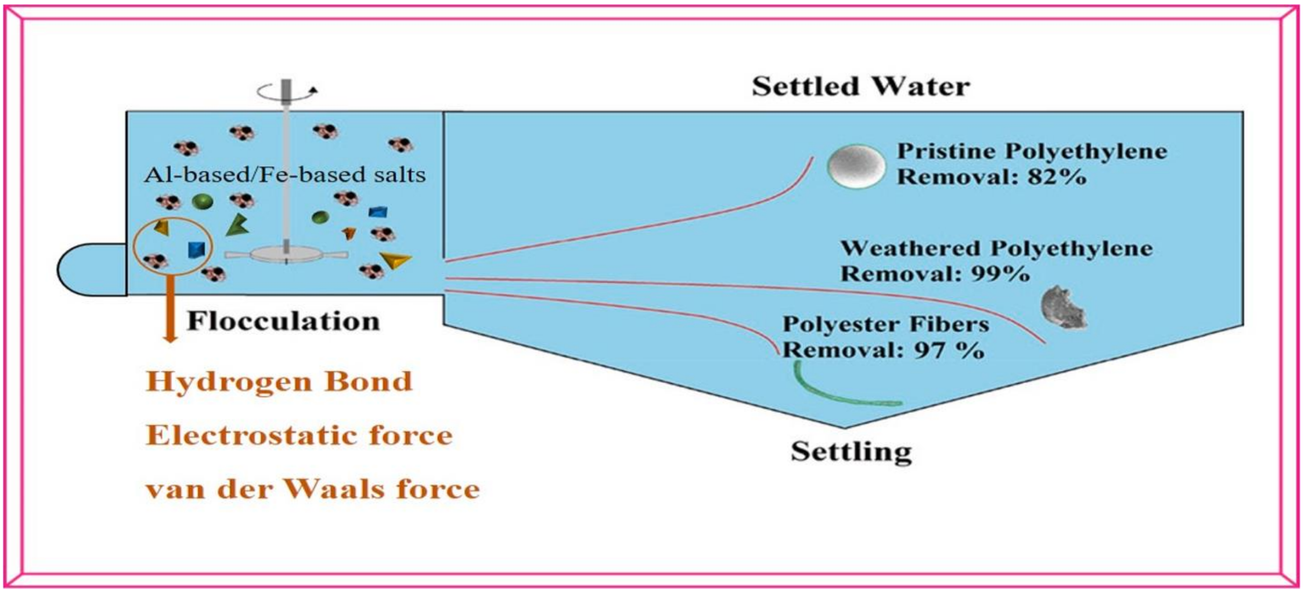

Figure 2: The schematics of primary settling with flocculation technologies in microplastics removal (Lapointe, et al., 2020)

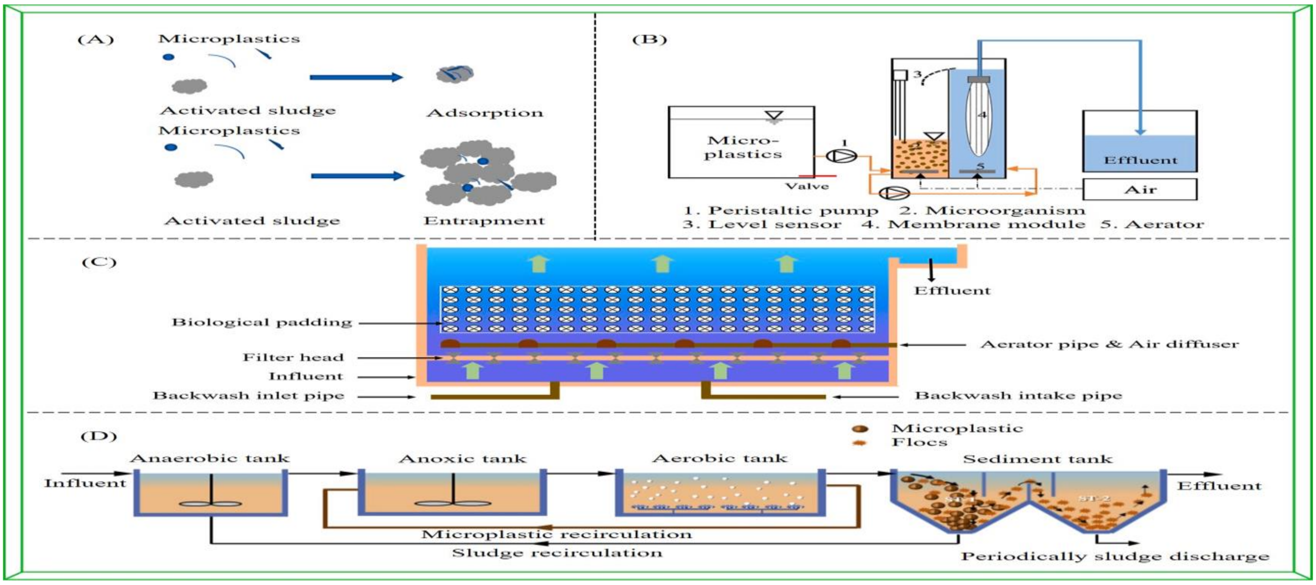

Figure 3: The schematics of the bioreactor system in microplastics removal. (a) Activated sludge process (Zhang, et al., 2020); (b) MBR (Li et al., 2018); (c) Biofilter; (d) A2O (Liu et al., 2020)

4. Conclusion

It is estimated that around 245t of MPs, whose ultimate destiny is the aquatic environment are being generated every year. The removal efficiency achieved by WWTPs was high, despite WWTPs not being designed solely for the removal of microplastics. The filter-based reception procedures procured the highest efficiency for microplastic removal. Fibres and MPs having larger particle size (0.5–5 mm) got separated easily via primary settling. PE and tiny-particle size MPs (<0.5 mm) got trapped easily in actuated sludge and by the bacteria in WWTPs. To evaluate, in a better way, the kismet of MPs in WWTPs or other environmental avenue, further study should emphasize on generation of standardized analysis and sampling procedures. Microplastic-directed treatment methodologies are also incessantly needed in order to avoid discharge into soil and aquatic environments. Furthermore, the potential effect of successive exertion of sludge on soil habitats should be scrutinized in future. To date, no standard protocol or international rules for monitoring MPs in treated wastewater are available for professionals to follow, making it difficult to compare results. Concurrently, further study should highlight the inquiry of specific MPs, particularly those in industrial areas. The regulating components of ministrations in eliminating MPs in WWTPs also needs in-depth study, like salinity, hydraulic retention time, and dissolved organic matter.

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