

Eradication of Microplastics in Wastewater Treatment: Overview

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Abstract: Microplastics are small plastic with a size of less than 5mm in length. These microplastics are used in many types of products in different forms. In cosmetic and personal care products, they are present in microbeads forms. These microplastics enter the water systems through the products and create water pollution. Their presence in water is harmful to both terrestrial and aquatic organisms. An increase in microplastic production has been observed in recent decades, so there is a need for reliable and precise techniques for remediation of these microplastics because if remediation is not implemented, then there will be an accumulation of microplastic in water and thus harm the ecosystem. In this review article, different remediation strategies have been reviewed, such as technological methods, density-based approach, Wastewater Treatment Plants (WWTPs), Hydrophobicity based approach has been reviewed, biotechnological methods, bioremediation, photodegradation, thermo oxidative degradation, Fenton Like system has been reviewed. These techniques help in solving the microplastic accumulation problems in the water, thus decreasing the microplastic pollution in water. The efficiency of removing the different types of microplastic has also been reviewed in this article.

Keywords: microplastic; remediation; wastewater treatment plants; Bioremediation.

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1. Introduction

Plastic is formed when a single monomer unit extracted from glasses and oil is polymerized, and due to this, they are also denoted as synthetic organic polymers [1-4]. Plastics' massive production began in 1940, but with more use, the global production of plastic reached 230 million tonnes in 2009 [4,5], and it is expected till the time we reach 2050, the production of plastic will cross 33 billion tonnes. [6,7]. Plastic in today's time has become an essential item. Its enormous use by people has led to improper disposal; plastic pollution has become a global issue due to mismanagement in the discarding of plastic. [8,9]. Major plastic producing countries are Asia, USA, and Europe. This plastic gets degraded into smaller particles, the plastic with a size of less than 5 mm in its length is considered microplastic, and this microplastic has impacted the environment badly [10] was the first one who gave the term microplastic in the year 2004, but it did not provide any size-based criteria to differentiate microplastic from small macroplastics, which have low physical dimensions [11,12]. They

warned of these plastic releases into the water paths as a serious environmental problem. Since plastic in water is mentioned by different scientists and in the media, plastic in the water got major attention [13]. Pollution of the environment is through multiple factors. Still, one of the major factors is plastic pollution. This plastic can remain in the environment for a very long duration, and due to this pollution, the well-being of organisms living in this environment is affected badly. Many different studies have been done on the consumption of microplastic by animals. And through that, problems related to immunotoxicity and disruptive intestinal impacts such as the oxidative and inflammatory intestinal imbalance, dysbiosis, and disruption of the gut's epithelial permeability are known [14,15]. Figure 1 shows the different types of plastic-based on their size.

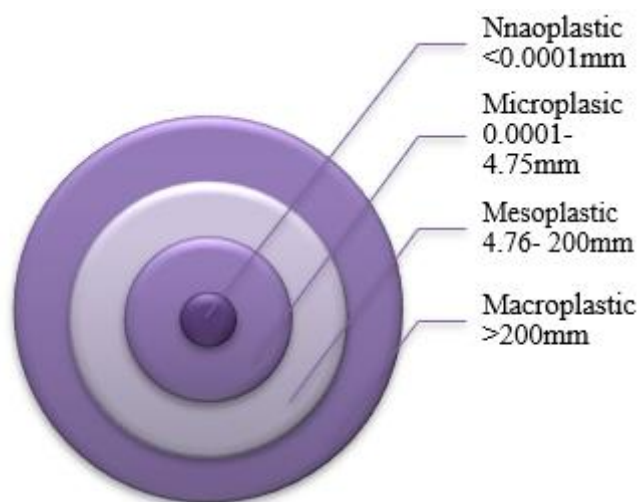


Figure 1. Plastics distinguished based on their sizes [14,15].

In the aquatic environment, the pollution of around 60-80% is due to the disposal of plastic [7,16]. These microplastics with a size of less than 5mm in length can be found in all types of the environment, be that be artic region [17] to the seawater in the Antarctic region [18,19], from rivers [19-22] to the sediments [19,23,24]. It is also found in the air that we breathe [19,25]; it can be said the whole ecosystem is covered with these microplastics. Polythene products are widely used by people nowadays, but if we talk about their degradation, it is very slow and takes a lot of time. Microplastic usually gets in water through plastic products daily, agriculture, or the packing industry [26,27]. The small particles of this plastic are added to the water from different sources such as waste materials from industries, everyday wastage of plastic, and other sources. The effect of these microplastics on the water and soil is very severe. With the pollution of these plastics, one can see possible effects on human beings such as metabolism disturbances, neurotoxicity, and increases in the chances of cancer [28,29]. MPs in the environment take decades to degrade; by the time the MPs are removed, they would have already left a negative impact on the surroundings. These microplastic's small size can be easily found in the drinkable water or tap water in houses, in household needs such as sugar, salts, honey, or in beer [30-35]. Consuming this small-sized plastic is harmful, and thus one needs a proper method to remove these microplastics from the environment. China and South-East Asian countries are responsible for the world's most plastic pollution in water or soil [36-39]. These small size plastic can absorb mainly persistent organic pollutants (POPs), and living organisms come into its contact when they get introduced into the food web. This microplastic has the ability to absorb pathogens also. These microplastic are small in size, and due to that, they are present in the air, and through them, they enter the respiratory system. 27% of the whole plastic production in China [40]. Around 8 million tonnes of this plastic were miss

managed, and 3 million tonnes of this plastic were discharged into the aquatic system; all these were reported in China's Journal Pre-Proof. In India, the disposal of plastic into the ocean annually is around 1 million tonnes [41]. More and more developers are being done to get the appropriate result in modern plastic, such as increasing the durability, increasing transparency, less weight, and more strength. [42]. With such properties, the enormous production took place for plastic. In 2018 the annual production of plastic was around 359 Mt. by the end of 2050, the production is expected to be 12000 Mt of plastic found in the natural environment [9,29,43,44]. The effect of large size of the plastic referred to as macroplastics, has many severe effects on aquatic organisms. Some of the effects are the problems in the gas exchange, injury-causing, death of the aquatic organisms, and suffocation in the aquatic marine organisms. These effects are usually seen when the aquatic organisms are exposed to these macroplastics. As these are bigger in size so they can get stuck inside the body of the marine organisms. [4,45]. With the data, 250 species of these aquatic environments are affected by this plastic due to its ingestion [46]. The increased deposition of this plastic is due to the shifting of people to the coastal regions and more fishing and maritime or recreational use of the oceans [42,47]. These microplastic cannot be degraded by bio or photodegradation in the presence of the natural environment, and due to this reason, the quantity of microplastic in the water will increase gradually, and by the study [48-51] it was found that out of all debris floating on the surface of the ocean, 60% of the floating debris were of plastic. Figure 2 below shows the year when microplastic took major attention.

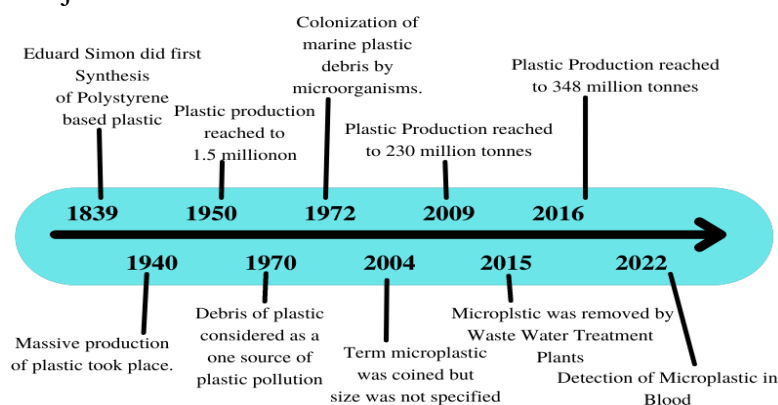


Figure 2. Representing the time period in which plastic received major attention [5,10,52-56].

2. Remediation Strategies

Sine 2004, when microplastic was first discovered in water, the remediation strategies and plastic degradation have been studied. If the production of plastic decreases, then automatically, the usage and pollution of plastic will decrease. To remove existing microplastic from water, various techniques are being adopted; the remediation process of microplastic can be categorized into technological methods and biotechnological methods used for remediation of microplastic [57-63].

2.1. Technological methods.

2.1.1. Density-based approaches.

Another method of microplastic separation from water is based on density. If the solution density is more than the microplastic density, then those microplastic will float, while if the density of microplastic is more as compared to the solution, then those microplastic will

sink into the solution [64]. If the microplastic density and solution both will be the same, there will be partial flotation of microplastic inside the solution. Several methods are proposed to separate microplastic due to their low density; most of the methods are those proposed by [10]. He used NaCl solution for the separation of microplastic. After that, modification to this was done, and many different salt solutions were used for the density separation of microplastic. In case of the density separation, the salt solution used gives the buoyant to the microplastic. The salt solution (discussed in Table 1) selected for density separation is selected based on different reasons, the ability to recover the microplastic, the processing cost needed for separation, and the environmental impact of the salt solution used. Solvents such as ethanol can damage some particular small-sized microplastic. Floatation has the ability to separate the particles to the range of millimeter size, so it is good for the separation of microplastic. Also, this floatation technique is best for separating microplastic, which is small in size and difficult to manually separate because it is also difficult to separate that small-sized microplastic from the air-liquid interface. But from this floatation, it is difficult to separate microplastic in tiny fragments, as the buoyant force acting will be low, and there are chances of surface fouling which can make it difficult for separation. And sometimes, the bubbles can capture the non-plastic material with more density and carry them to the surface, so it is also a concern. The different salt solution used to eliminate different microplastic types has been discussed in Table 1.

Table 1. Comparison of the density of different microplastic with the solution used for density separation of microplastic. (Abbreviations used are: LDPE (Low-density polyethylene), PET (Polythene terephthalate), HDPE (High-density polyethylene), PE (Polyester), PPE (Polypropylene), PS (Polystyrene), PVC (Polyvinyl chloride), PA (Polyamide), ABS (Acrylonitrile-butadiene-styrene), PTFE (Polytetrafluoroethylene), PP (Polypropylene), CaCl₂ (Calcium chloride) NaI (Sodium iodide), ZnCl₂ (Zinc chloride), NaBr (Sodium bromide), ZnBr (Sodium bromide) and NaCl (Sodium chloride). Sign + Shows that the microplastic density is more than that of the solution used for density separation. Sign – shows that the density of microplastic type is less than that of solution.).

Sr. No.	Microplastic Type	Density (g/ml)	Products	CaCl ₂ -1.3 g/ml	NaI-1.8 g/ml	ZnCl ₂ -1.6-1.7 g/ml	NaBr-1.55 g/ml	ZnBr-1.7 g/ml	NaCl-1.2 g/ml	Reference
1.	LDPE	0.917–0.93	Plastic bags, drinking straws	-	-	-	-	-	-	[65]
2.	PET	1.37–1.45	Water bottles.	+	-	-	-	-	+	[42]
3.	HDPE	0.93–0.97	Milk and Juice jugs.	-	-	-	-	-	-	[65]
4.	PE	1.39	Polyester cloths.	+	-	-	-	-	+	[65]
5.	PPE	0.89–0.94	Plastic utensils, food containers.	-	-	-	-	-	-	[65]
6.	PS	1.04–1.11	Floats, bait boxes, foam cups.	-	-	-	-	-	-	[42]
7.	PVC	1.38	Pipes, electrical cables, clothing.	+	-	-	-	-	+	[65]
8.	PA	1.3	Textiles(nylon), tooth brush	-	-	-	-	-	-	[65]
9.	ABS	1.04–1.06	Pipe system, musical instruments.	-	-	-	-	-	-	[66]
10.	PTFE	2.10–2.30	Plain bearings, gears, slide plates, seals, bushing.	+	+	+	+	+	+	[66]
11.	PP	0.89–0.94	Foam, films.	-	-	-	-	-	-	[42]

2.1.2. Wastewater treatment plants (WWTPs).

Wastewater treatment plants, or WWTPs, from this plant, there are chances to control microplastic pollution to some extent. Many conventional and innovative technologies are implemented to remove microplastic from water with the help of these WWTPs plants [67-69]. All of these studies conclude that the conventional WWTPs have high efficiency in removing microplastic from water (between 90 and 98%) [67,70]. A large amount of effluent is discharged continuously into the water, which contains a microliter and microplastic [68]. There is advancement in wastewater technologies such as electrodeposition and coagulation. A membrane bioreactor (MBR) [71] has the combination of a membrane process like microfiltration or ultrafiltration with biological wastewater treatment is one of the most promising. The membrane bioreactor has a removal efficiency of 99.4% for microplastic. The MBR system provides the highest removal rate (99.4%), discharging 0.5 MP_s L⁻¹. And if we talk about conventional activated sludge-based microplastic removal, the efficiency rate is 98.3% [69]. [72] from their study of remediation of microplastic using Nano Fe₃O₄. The efficiency of different Polythene was observed. From their result, it was observed that removal efficiency depends on the size and type of microplastic. With the small size of microplastic remediation, efficiency was more as the small quantity of microplastic gets coagulated in high dosage, it was resulted from [73]. Water remediation is also affected by the condition of water, such as turbidity and ionic strength [74,75]. The polyethylene particles can be rejected completely as little membrane fouling can be observed due to the large size compared to the Ultra Filtration (UF) Membrane pores. This membrane fouling for polyethylene particles was eliminated once they underwent coagulation. Also, Fe-based flocs membrane fouling was less severe when compared with [76] findings. From [77] study, it was concluded that the operational technique for removing kaolin could also help in microplastic and microfibers remediation. Hidayaturrahman and Lee tested three types of concentration 4200 MP_s/L, 5840 MP_s/L, and 31400 MP_s/L; for them, the removal efficiency was 53.8%, 47.1% and 81.6%, respectively [28]. Several studies revealed that polyacrylamide helps in MP removal [78-80]. [79] showed that removal efficiency was 26 ± 3% to 61 ± 4%, but with the addition of 15 mg L⁻¹ anionic PAM (Polyacrylamide) and cationic PAM the efficiency rate was about 61 ± 4%, and 45 ± 4% of PE, respectively for polyethylene. The efficiency of removal of microplastic using different techniques has been discussed in Table 2.

2.1.3. Hydrophobicity-based Approaches.

This is the concept where separation is done based on hydrophobic interaction. Here, the hydrophobic particles get attached to the bubble surface produced from froth floatation, and through that, the particles are carried to the air-liquid interface. But this froth floatation is not suitable for analytical plastic separation as its bubble predictability is difficult and thus results in high particle loss. [81] There recovery rate for large microplastic (1-5 mm) was 100%, but for small microplastic (<1mm) the recovery was around 55% only. The recovery rate was more efficient in [82] study for microplastic; they used oil to capture microplastic through the oleophilic interaction. Also, in this technique, ethanol, which usually destroys the small microplastic, is used to remove oil residue.

Table 2. The data of efficiency with time period and technique used for plastic removal through different studies is shown below. (Abbreviations used are: WWTPs (Waste Water Treatment Plants), UV (Ultraviolet Light), and AOP (Advanced Oxidation Process), Nb₂O₅, Niobium Pentoxide).

S.No	References	Technique	Process	Time Interval	Type of Microplastic	Efficiency
1	[72]	WWTPs 1.3 g·L ⁻¹ nano-Fe ₃ O ₄	Magnetization	150 min	Polythene	86.87 ± 6.92% efficiency.
					Polypropylene	85.05 ± 4.70% efficiency.
					Polystyrene	86.11 ± 6.21% efficiency.
					Polythene terephthalate	62.83 ± 8.34% efficiency.
2	[73]	WWTPs 0.1 FeCl ₃ .6H ₂ O mmol/L	Coagulation	-	Polythene Polythene	3.43% ± 0.96% efficiency.
		WWTPs 0.2 FeCl ₃ .6H ₂ O mmol/L				6.71% ± 1.26% efficiency.
		WWTPs 0.5 FeCl ₃ .6 H ₂ O mmol/L				4% ± 1.22% efficiency.
		WWTPs 1 FeCl ₃ .6 H ₂ O mmol/L				11.72% ± 0.96% efficiency.
		WWTPs 2 FeCl ₃ .6 H ₂ O mmol/L				13.27% ± 2.19% efficiency.
		WWTPs 5 FeCl ₃ .6 H ₂ O mmol/L				12.65% ± 1.09% efficiency.
		WWTPs 0.2 FeCl ₃ .6 H ₂ O mmol/L	Ultrafiltration	300 Seconds	0.69% efficiency.	
		2 FeCl ₃ .6 H ₂ O mmol/L	0.55% efficiency.			
3	[76]	Visible Light	Photocatalytic removal	2 Weeks	Polypropylene	Reduced average particle Volume by 65%
4	[83]	UV Light	Photo oxidation	115 Hours	Polypropylene	Oxidation of Products became considerable
5	[84]	UV Light	Photo Oxidation	50 Hours	Polypropylene	Due to change in mobility and diffusive properties in polypropylene the initial period was less
6	[77]	Alum	Coagulation	2-4 Hours	Polythene	5 ml alum decreased the turbidity from 16 Nephelometric Turbidity Units (NTU) to 1 NTU
7	[85]	Hydrothermal Coupled Fenton System	AOP (Advanced Oxidation Process)	12 Hours	Polyethylene	In 16 hour the weight loss was about 95.9% and in 12 hour the mineralisation efficiency was 75.6%
8	[86]	Fe ₂ O ₃ -MnO ₂ (Iron oxide, Manganese dioxide) micro motor	Catalytic degradation and adsorption	2 Hour	Microplastic	10% of suspended microplastic in were removed

S.No	References	Technique	Process	Time Interval	Type of Microplastic	Efficiency
9	[87]	Nb ₂ O ₅ (Niobium Pentoxide)	Photocatalytic	40 Hours	Polyethylene	100% degradation of Polyethylene
10	[28]	Polyaluminum chloride	Coagulation	-	Microplastic	For 4200 MPs/L the removal efficiency was 47.1%
		Rapid Sand Filtration	Filtration			57-64% efficiency of removing microplastic was observed.
		Membrane disc Filter	Filtration			79% of microplastic from 1444 MPs/L to 297 MPs/L
		Ozonation	Oxidation	30 Minute		90% of the Microplastic was removed.
11	[79]	Al based Coagulant	Coagulation	-	Polyethylene	Efficiency increased on addition of polyacrylamide from $26 \pm 3\%$ to $61 \pm 4\%$
12	[69]	Dissolved air Flotation	Skimming	-	Microplastic	95% of elimination
		Membrane Bio reactor	Suspension and filtration			99.9% MP were removed
		Membrane disc Filter	Filtration			Concentration was decreased from 0.5 ± 0.2 to 0.3 ± 0.1 MPs/L with the 10 μ m pore size filter.
13	[67]	Membrane Bio reactor	Ultrafiltration	-	Microplastic	99.4% of MP were eliminated
		WWTP	Conventional activated sludge			98.3% Elimination was observed
14	[88]	Granular activated Carbon Filtration	Filtration	-	Microplastic	73.7-98.5% removal efficiency was observed for microplastic ranging 1-5 μ m
15	[89]	Ozonation	Oxidation	30 Minute	Microplastic	90% of microplastic was removed
		ClO ₂		-		Degradation reached to 90% when ClO ₂ concentration was 120 mg/l.
		Ultrasonic	Degradation	20 Minute		90% degradation was observed
		Microwave	Degradation	20 Minute		Less than 40%
16	[90]	Zirconium metal-organic framework	Filtration	-	Microplastic	MPs removal efficiency of $95.5 \pm 1.2\%$ was observed
17	[91]	WWTPs	Filtration	1 Day	Microplastic	66% of small plastic and fibre got decreased from 1.44 microplastic/litre

S.No	References	Technique	Process	Time Interval	Type of Microplastic	Efficiency
						to 0.48 microplastic/ litre.
					Polystyrene	4% were detected.
					Polyethylene terephthalate	35% were detected.
					Polypropylene	10% were detected.
					Nylon	28% were detected.
					Polyethylene	23% were detected
		Reverse osmosis		-	Microplastic	90.45% of elimination was observed for microplastic
18	[92]	Activated sludge		-	Microplastic	It was founded to be efficiently removing 67% of the microplastic.
		Rapid sand filtration	Filtration			97% efficiency for removing Microplastic.
19	[93]	WWTPs	-	-	Microplastic	91.7% were removed and 31.1 ± 6.7 items/L were founded.
20	[94]	WWTPs	Sedimentation	2 Hours	Microplastic	65% of Microplastic is removed
					Nylon	61.2% were detected
					Polyethylene	14.6% were detected
					Polypropylene	10.7% were detected.
21	[95]	WWTPs	Sedimentation	-	Polyethylene terephthalate, polyether sulfone and polypropylene	71.67% efficient for remediation
					Polyethylene terephthalate	42.26% were detected
					Polyether sulfone	19.1% were detected
22	[96]	WWTPs	Filtration	-	Microplastic	79% removal rate
23	[97]	WWTPs	Filtration	-	Polypropylene , Low density Polyethylene High density Polyethylene	76.5% efficiency was observed.
24	[98]	WWTPs	Filtration	-	Polyethylene Polypropylene, Polystyrene	58% efficiency was observed
25	[99]	WWTPs	Filtration	-	Microplastic	90.3% efficiency was observed
26	[100]	WWTPs	Filtration	-	Microplastic	89.4% efficiency was observed
27	[101]	WWTPs	Filtration	-	Polyethylene Polypropylene, Polyethylene	93.7% efficiency was observed

S.No	References	Technique	Process	Time Interval	Type of Microplastic	Efficiency
28	[102]	WWTPs	Filtration	-	terephthalate Polystyrene Polyethylene Polypropylene, Polystyrene, Polyvinyl Chloride	78.5% efficiency was observed

2.2. Biotechnological Method.

2.2.1. Bioremediation.

The natural process involved in cleaning the environment with the help of the microbe, mostly fungi or bacteria, is called bioremediation [103,104]. Plastic materials get degraded into macro plastic and microplastic due to the different environmental factors [15]. When bioremediation comes, it is the bioengineered process in which microorganisms like bacteria or fungi are used for biologically degrading the microplastic [105,106]. And in order to achieve higher efficiency, these degradations by microbes are combined with physicochemical processes. Here degradation is the process that leads to numerous changes in polymer properties such as physical or chemical. And these physical and chemical changes occur due to environmental factors (such as light, heat, moisture, etc.), chemical conditions, or biological activity [107]. After primary degradation of the polymer, organic intermediates can be formed due to the solubility of oligomers, and these organic intermediates are aldehydes, alcohols, acids, ketones, etc. The efficiency of removal of microplastic is relatively above 20%, but this also depends upon the type of microbes one is using [108]. When discussing the disadvantages of bioremediation, sometimes it becomes difficult to find a suitable consortium, and the microplastic and sometimes microplastic is not removed completely [109]. This degradation process is slow and takes a lot of time; sometimes, it even takes years to complete. This method also has some advantages, like the process is cost-effective and demands low energy. The process is environmentally friendly, and the utilization of bacteria for remediation is highly specific. And the harmful by-product generation is lower. Biodegradation occurs in four steps, shown in Figure 3 below. The first step is biodeterioration, which involves the formation of the biofilm around the plastic polymer. Then biofragmentation occurs in these microbes particularly producing the extracellular enzymes, which act upon the polymer and convert polymer into oligomer/dimer/monomer, so the easy ingestion can occur of these polymers after that assimilation occur once these polymers are converted into the oligomer/dimer/monomer. They get assembled on the microbes, and then these are absorbed by the microbe's cells via simple or facilitated diffusion. Finally, mineralization occurs; in this step, daughter metabolites such as CO₂, H₂O, and CH₄ are produced. [110] used bacteria, *Arthrobacter* sp and *Pseudomonas* sp for remediation of High-density polyethylene; after 30 days, the weight loss for *Arthrobacter* sp. was 12.23 ± 0.6 and for *Pseudomonas* sp 15.18 ± 0.7 . They successfully degraded the polyethylene; in another study [111], they used fungus strain of *Aspergillus tubingensis* for remediation of HDPE after 30 days. Weight loss of HDPE was $6.02 \pm 0.2\%$, and in the presence of mineral oil, it was $6.88 \pm 0.1\%$. For Low-density Polyethylene remediation using the Fungus strain of *Penicillium pinophilum*, the results were that mineralization in ethanol medium was 0.64%, and without ethanol, the medium was 0.37% in the study [112]. Below in Table 3, different fungus and bacteria stain efficiency to degrade microplastic is discussed.

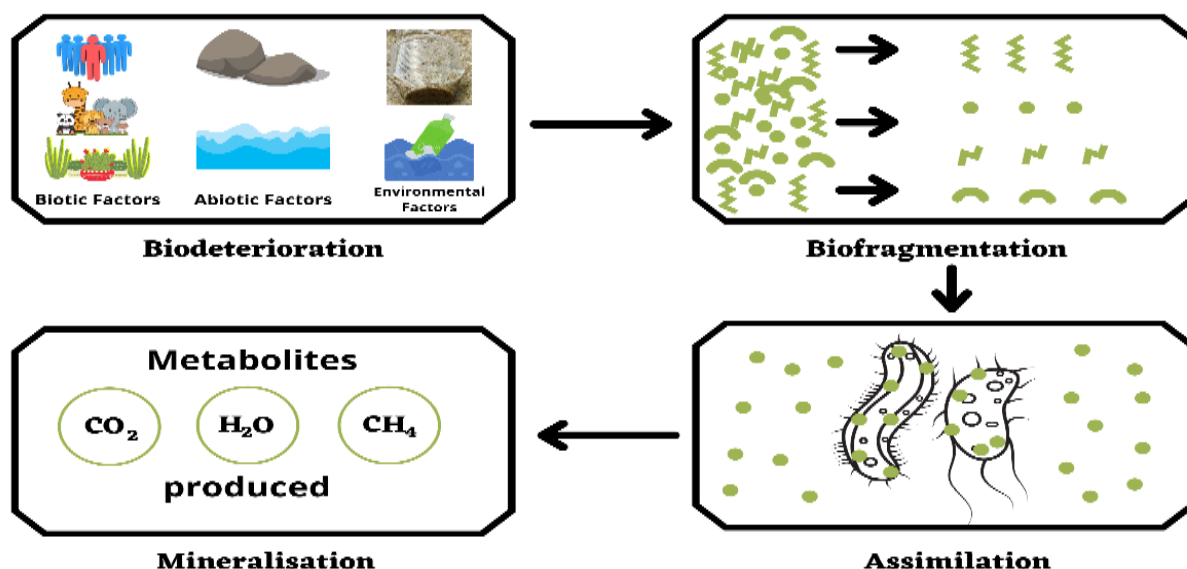


Figure 3. Shows the steps involved in the process of biodegradation of microplastic.

Table 3. Shows the time required and efficiency for degradation of different microplastic with the help of different strains of bacteria and fungus.

S.No.	Fungus/ Bacteria	Type	Microplastic Type	Time Span	References
1	Fungus*	<i>Zalerion maritimum</i>	Polyethylene pellets	14 Day	[113]
2	Fungi	<i>Penicillium pinophilum</i>	Low density Polyethylene	31 Months	[112]
3	Fungi	<i>Aspergillus niger</i>	Low density Polyethylene		
4	fungus	<i>Aspergillus flavus</i>	High density Polyethylene		
6	Fungi	<i>Aspergillus tubingensis</i>	High density Polyethylene	30 Days	[111]
7	Fungus	<i>Aspergillus niger</i>	Polyethylene	30 Day	[114]
8	Fungus	<i>Aspergillus oryzae</i>	Polyethylene	16 Day	[115]
9	Bacteria	<i>Bacillus cereus</i>	Polyethylene terephthalate	40 Day	[116]
10	Bacteria	<i>Ideonella sakaiensis</i>	Polyethylene terephthalate	6 Weeks	[117]
11	Fungus	<i>Aspergillus tubingensis</i>	Polyethylene	30 Day	[111]
12	Bacteria	<i>Bacillus gottheilii</i>	Polyethylene	40 Day	[116]
13	Bacteria	<i>Bacillus mycoides</i>	Polyethylene	60 Day	[118]
14	Fungus	<i>Chaetomium sp.</i>	Polyethylene	6 Months	[119]
15	Bacteria	<i>Desulfotomaculum nigrificans</i>	Polyethylene	30 Day	[120]
16	Bacteria	<i>Arthrobacter sp. and Streptomyces sp.</i>	Polyethylene	90 Day	[121]
17	Bacteria	<i>Bacillus tropicus</i>	Low density Polyethylene	40 Day	[122]
18	Bacteria	<i>Stenotrophomonas sp. and Achromobacter sp.</i>	Low density Polyethylene	100 Day	[123]
19	Bacteria	<i>Stenotrophomonas sp., Comamonas sp. and Delftia sp.</i>	Polyethylene	90 Day	[124]
20	Bacteria	<i>Stenotrophomonas pavanii</i>	Modified Low density Polyethylene	56 Day	[125]
21	Bacteria	<i>Achromobacter xylosoxidans</i>	High density Polyethylene	150 Day	[126]
22	Fungus	<i>Fusarium sp.</i>	Polyethylene	60 Day	[127]
23	Bacteria	<i>Pseudomonas aeruginosa</i>	Polyethylene	60 Day	[128]
24	Bacteria	<i>Rhodococcus ruber</i>	Polyethylene	30 days	[129]
25	Fungus	<i>Penicillium simplicissimum</i>	Polyethylene	1 Weeks	[130]
26	Fungus	<i>Penicillium chrysogenum</i>	Polyethylene	90 Day	[131]
27	Bacteria	<i>Actinobacteria and Bacillus strain</i>	Polyethylene	30 days to 1 year	[132]
28	Bacteria	<i>Ideonella sakaiensis</i> 201-F6,	Polyethylene terephthalate	6 weeks	[117]
29	Bacteria	<i>Arthrobacter sp and Pseudomonas sp</i>	High density Polyethylene	30 days	[110]
30	Fungi	<i>Pestalotiopsis</i>	Polyurethane	2 Weeks	[133]
31	Bacteria	<i>Bacillus sp. and Paenibacillus sp.</i>	Polypropylene	60 Days	[134]

S.No.	Fungus/ Bacteria	Type	Microplastic Type	Time Spam	References
32	Bacteria	<i>Bacillus cereus</i>	Polypropylene	40 Day	[135]
33	Bacteria	<i>Bacillus sp</i>	Polypropylene	40 Day	[116]
34	Bacteria	<i>Sporosarcina globispora</i>	Polypropylene	40 Days	[136]
35	Fungus	<i>Aureobasidium pullulans</i>	Polyvinyl chloride	95 Weeks	[137]
36	Fungus	<i>Phanerochaete chrysosporium</i>	Polyvinyl chloride	90 Days	[138]
37	Fungus	<i>Poliporus versicolor</i>	Polyvinyl chloride	30 Days	[139]
38	Bacteria	<i>Bacillus cereus</i>	Polyethylene terephthalate	40 Day	[116]
39	Bacteria	<i>Ideonella sakaiensis</i>	Polyethylene terephthalate	6 Weeks	[117]
40	Bacteria	<i>Pseudomonas sp.</i>	Polystyrene	60 Day	[140]
41	Bacteria	<i>Brevibacillus sp. & Aneu-rinibacillus sp</i>	Polypropylene	140 Day	[141]
42	Fungus	<i>Penicillium variable</i>	Polystyrene	16 Weeks	[142]
43	Bacteria	<i>Rhodococcus ruber</i>	Polystyrene	8 Weeks	[143]
44	Fungus	<i>Curvularia sp.</i>	Polystyrene	9 Weeks	[144]

2.2.2. Photo degradation or photocatalytic degradation.

Photocatalytic comes under the AOP's (Advance oxidative processes), and this technique is said to be energy efficient technique for the degradation of microplastic in the aqueous environment. The process involves exposing light to the semiconductor through the holes, and the formation of electrons takes place; after that, those holes combine with H₂O (water) OR OH⁻ (Hydroxide) to produce OH and O₂ (oxygen). This will attack microplastic and causes rupture, crosslinking, branching, and even mineralization into CO₂ (Carbon dioxide) and H₂O. Photolysis in the natural environment happens in the C-C backbone of plastic. This whole process happens in three steps: initiation, propagation, and termination. During the whole process, the radicles are formed to produce peroxy radicals, which have an important role in photodegradation [48] addition, chemical chain scission, addition reaction (with O₂/H₂O), and formation of EPFRs (Environmentally persistent free radicals) happen to MPs after 15 days of photo-irradiation [145]. EPFRs subsequently result in Reactive Oxygen Species (e.g., •OH); once generated, they will attack microplastic and rupture the chain, resulting in molecular weight reduction and the generation of small molecular products [145]. This is further divided into a solid phase and aqueous phase photocatalysis. The plastic which is present in an aqueous environment for them, aqueous photocatalysis is used. To degrade PVC and polyvinylidene chloride copolymer, which is a 95% mixture of PVC and 5% mixture of PVLC. ZnO has more rate of Dechlorination as compared to TiO₂, but due to the presence of several catalysts, the reaction is inhibited during photo-oxidation. In photodegradation, the harmful radiation from the stratosphere, such as Ultraviolet -A radiation (~315–400 nm) and Ultraviolet-B terrestrial radiation (~295–315 nm) due to this photolysis occur, and through this photo oxidation gets initiated. The Polymer degradation is accelerated from the visible (400–760 nm) part of sunlight, and the infrared radiation (760–2500 nm) accelerates the thermal oxidation [107,146] initial rate achieved due to degradation is slow, but the propagation is fast. The photo degradation process is eco-friendly till the high-energy radiations are not used. This degradation is accepted, but the process is very costly [147,148].

2.2.3. Thermo-oxidative degradation.

In the case of thermal oxidative degradation, heat and oxygen are the main components of the degradation process that occurs in microplastic. When a high temperature is provided to the polymer of microplastic, the components of a long chain of microplastic get separated, resulting in component reactions with each other, and the properties of the microplastic polymer are changed. Because of overheating, this process is also known as molecular

deterioration. The new physical or optical properties result in chemical reactions compared to previous properties. Due to the thermal degradation change in molecular weight and molecular weight distribution, typical property changes (such as reduced ductility and embrittlement, chalking, color changes, cracking) and a general reduction in physical properties are observed [149]. Two processes are necessary for biodegradation in oxobio-reduction processes such as photodegradation (UV) and oxidation. With the help of UV light, the degradation of microplastic polymer is done, and time and heat are required to break down the microplastic in the oxidation process. These methods lead to a reduction in the molecular weight and allow the polymer to degrade. The heat which is required for this process is more than the ambient temperature, and the rate of degradation is very fast, but this method is not environment friendly. This process takes time to degrade microplastic [147,150-153].

2.2.4. Fenton/Fenton-like system.

With the help of peroxides, this system has an extraordinary capability to decompose the organic pollutant in an aqueous environment. It was particularly used for recovering specific polymers from water [154]. In this microplastic are exposed to Fenton treatment ($\text{Fe}^{2+}/\text{H}_2\text{O}_2$) and heat-activated $\text{K}_2\text{S}_2\text{O}_8$ (PDS) at 70 °C. With the help of field emission scanning electron microscopy (FESEM), the size distributions of treated MPs were analyzed. Before the AOPs, the PS and PE sizes were in-between 40–50 μm , but after 30 days of treatment, around 80.1% of PS and 97.4% of PE were less than 20 μm and the rest were smaller than 30 μm . But once the size became slow the degradation process gets slow [64,85,94,155].

2. Conclusions

We reviewed the different techniques used for microplastic remediation from the water in this account. As the production and consumption of plastic have increased, the microplastic particles enter the water, and then through there, they enter the food chain and are harmful. So there is a need to reduce the microplastic in water. Remediation papers were studied, and data from the different papers were collected for microbial degradation and different techniques used for remediation. While reviewing some papers, it was found that when one method is used with respect to another method or combined techniques, the remediation efficiency increases, and the method shows better results. When biodegradation of microplastic with fungus or bacteria strain was used, it was revealed that when mineral oil or ethanol treatment was given before degradation through biological entities, the removal efficiency was more. In the case of polyethylene, the degradation is difficult as there is no functional group and it has a long structure; for that also, degradation was done, although it took time through simple or complex microbial communities, the degradation was completed. Also, it was modulated by abiotic factors such as the use of UV light. The degradation from bacteria was efficient as it was economically friendly and cheap, but the duration biological entities took was longer. The technological method was also efficient for the removal of microplastic from water. For example, the removal of microplastic with the help of wastewater treatment plants showed 90–98% efficiency. Density separation was also helpful, along with froth floatation. Less dense microplastic usually floats over the surface of the solution density is more. Thus, they can be easily separated.

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Conflicts of Interest

None.

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