msc

by Shweta Shweta

Submission date: 22-May-2026 09:59PM (UTC+0530)
Submission ID: 2967218459
File name: Shweta_24MSCBIO45.docx (461.47K)
Word count: 9210
Character count: 59203

ABSTRACT

Microplastic contamination has emerged as a major environmental concern because synthetic polymers continue to accumulate in aquatic ecosystems at an alarming rate. Conventional wastewater treatment methods are capable of removing only a fraction of these particles and are generally ineffective in achieving complete degradation. As a result, microplastics persist in rivers, lakes, sewage systems, and marine environments, where they may affect both ecological and human health.

The present study evaluated the potential of a biofilm-based rotating reactor system for the biodegradation of polyethylene (PE), polypropylene (PP), and polystyrene (PS) microplastics under aerobic conditions. A mixed microbial consortium isolated from wastewater sludge and plastic-contaminated environments was used for biofilm formation on rotating carrier discs. Reactor performance was examined under different operational conditions, including variations in rotational speed, oxygen availability, hydraulic retention time, and biofilm thickness.

Different analytical techniques such as weight loss analysis, Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and Total Organic Carbon (TOC) analysis were employed to evaluate the degradation process. The rotating biofilm reactor demonstrated improved degradation efficiency compared with conventional suspended microbial systems. Among the tested polymers, polyethylene showed the highest degradation, whereas polystyrene exhibited relatively slower breakdown because of its chemically stable aromatic structure.

SEM analysis revealed visible surface damage including pits, cracks, and erosion on treated polymer particles, while FTIR analysis confirmed oxidative changes through the appearance of carbonyl and hydroxyl groups. The findings suggest that rotating biofilm reactor systems may provide a sustainable and environmentally safer approach for reducing microplastic pollution in wastewater environments. The study also highlights the importance of optimizing reactor operating conditions to improve large-scale biodegradation efficiency.

LIST OF ABBREVIATIONS

Abbreviation	Full Form
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
MP	Microplastics
EPS	Extracellular Polymeric Substance
SEM	Scanning Electron Microscope
FTIR	Fourier Transform Infrared Spectroscopy
TOC	Total Organic Carbon
WWTP	Wastewater Treatment Plant

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background

Plastic materials are extensively used in modern society because they are lightweight, inexpensive, durable, and easy to manufacture. Their applications range from domestic packaging to agriculture, medicine, construction, and industrial processing (1). Although plastics have improved convenience in many sectors, the continuous increase in plastic consumption has also created a serious waste management problem across the world. One of the major environmental concerns associated with plastic waste is the formation of microplastics. These are extremely small plastic particles, generally less than 5 mm in size, that originate either from the direct production of microscopic plastic materials or from the gradual fragmentation of larger plastic products. Environmental factors such as ultraviolet radiation, temperature fluctuations, and mechanical abrasion contribute significantly to this fragmentation process (2). Depending on where they come from, microplastic particles can be categorized as either primary particles made for different technological uses or secondary particles that come from weathering processes in the environment, mechanical friction, and the photodegradation of larger plastics. These particles may arise from the breakdown of big plastic pieces in the environment or from the production of small plastic particles (8). Continuous fragmentation of larger plastics under environmental stress conditions results in the formation of secondary microplastics that persist for decades because of their resistant polymeric structure.

Studies conducted recently have shown that microplastics are found almost everywhere, ranging from river beds to oceans, from underground water to the soil, even in dust in the air and drinking water sources. This is due to the fact that they occur ubiquitously. Thus, at present, they are becoming a global environmental issue. Their widespread distribution has raised concerns because these particles can persist for long periods and may enter biological food chains. Microplastics can enter food webs and bioaccumulate in creatures because they are so tiny and not susceptible to breakdown.

Polymers such as polyethylene (PE), polypropylene (PP), and polystyrene (PS) are particularly difficult to degrade because of their strong and stable carbon-carbon backbone and hydrophobic nature, thus making microplastics hardly decomposable under environmental conditions (12). Both humans and marine organisms may be at risk from the buildup of microplastics. In several studies, it was found that microplastics can be carriers of toxic substances like pathogens, heavy metals, and persistent organic pollutants. They will be accumulated on the hydrophobic surface of the plastic materials and eventually reach biological systems via ingestion and inhalation. Thus, plastic fragments have emerged as a significant menace to human health apart from the environmental challenge.

Among different sources of microplastics in aquatic environments, one can distinguish sewage treatment plants that cannot provide complete degradation of plastics. Physical treatment approaches such as sedimentation and filtration are not effective enough. Conventional wastewater treatment plants were not originally designed to remove these microscopic contaminants completely. Physical treatment processes mainly separate particles from water instead of degrading them, while chemical treatment methods may require high energy input and can generate secondary pollutants.

Because of these limitations, biological approaches for microplastic degradation are receiving increasing attention. Polymer chains can be broken down by certain microorganisms using enzymes. However, this procedure has issues with biomass washing and ineffective microorganism-microplastic particle interaction (19). Among them, biofilm-based systems appear promising because they provide prolonged microbial retention and stronger interaction between microorganisms and polymer surfaces. In rotating biofilm reactors, microbial communities remain attached to carrier surfaces and continuously interact with oxygen and wastewater, creating favourable conditions for enzymatic degradation. The colonies of microbes that are attached to solid surfaces by EPS are referred to as biofilms. Enhanced bonding between microbial cells and plastic fragments can be achieved because of this matrix, and the cells are protected against outside pressure and retain enzymes better, enhancing the efficiency of degradation (10).

Among other features of biofilms, it is worth noting increased oxygen transport, nutrient distribution, and enhanced contact with the biofilm. Therefore, biofilm-based rotating reactors can effectively break down microplastics. It promotes better contact between the particle and biofilm and allows for higher levels of aeration efficiency (20). It can be operated continuously, provides high retention of microbial biomass, and minimizes sludge production. The evaluation of such reactors is the purpose of this study. This thesis focuses on the application of rotating biofilm reactor technology for improving microplastic degradation under aerobic wastewater conditions.

The present study is based on the principle that microbial biofilms provide enhanced surface attachment, enzyme retention, and metabolic cooperation compared to suspended microbial systems. The rotating reactor mechanism further improves oxygen diffusion and nutrient transport, thereby promoting enzymatic degradation of resistant polymer structures under aerobic conditions. This investigates the influence of microbial colonization, oxygen transfer, and operational parameters on the degradation efficiency of selected plastic polymers.

1.2 Problem Statement

Presently available technology for wastewater treatment is not able to achieve complete removal of microplastics. While physical treatments will ensure that plastics are removed from the wastewater, they will never ensure that they are completely gone, while, on the other hand, chemical treatment procedures are likely to result in the formation of dangerous chemicals that are extremely toxic to the environment.

Biological treatment methods are eco-friendly; however, the effectiveness of suspended microbial treatment systems is quite low due to microbial loss and poor contact between microplastics and microbes. Therefore, the creation of an extremely effective rotating biological system is required. In addition, conventional wastewater treatment plants were originally designed to remove organic matter and nutrients rather than microscopic plastic contaminants. That is why there is a significant amount of microplastics that finds its way into natural water bodies irrespective of the purification process. This is because there are no cheap and efficient means of getting rid of microplastics in wastewater.

1.3 Aim of the Study

The primary aim is to design and evaluate the performance of a biofilm-based rotating reactor system for sustainable degradation of microplastics in wastewater environments.

1.4 Objectives

- To create a revolving biofilm reactor for the breakdown of microplastics.
- To assess how microbial biofilms affect the improvement of polymer breakdown efficiency.
- To study the influence of operating conditions, such as rotational speed and hydraulic retention time.
- To research how microplastics are changed and broken down by biological processes.
- To calculate the system's environmental sustainability.

It is hypothesized that the biofilm-based rotating reactor system will enhance microplastic degradation efficiency compared to suspended microbial systems due to improved microbial retention, enhanced oxygen transfer, and prolonged interaction between microorganisms and polymer surfaces.

1.5 Significance

In order to remove microplastics from wastewater, our research helps develop ecological and efficient sewage treatment techniques. The proposed biofilm reactor system will retain microorganisms within the sewage water, thus promoting efficient degradation processes and decreasing secondary pollution, unlike conventional wastewater treatment systems.

The results of the study can be used to invent sustainable technology for controlling the issue of microplastic pollution. Moreover, the use of a biofilm purification system could lower the costs of using costly chemical technology systems. The biological degradation process depends mainly on the metabolism of microorganisms, which makes it environmentally sustainable and energy-saving. This study might inspire future research concerning the application of large-scale biological technologies in plastic waste management.

2. LITERATURE REVIEW

2.1 Microplastic Pollution and its sources

Numerous studies have documented rising levels of microplastic pollution in both terrestrial and marine habitats (5). These contaminants are generated either through direct industrial production of microscopic polymers or through environmental fragmentation of larger plastic waste materials. Because of their persistence and mobility, microplastics are now considered emerging pollutants of global concern; produced either from industrial and cosmetic products or resulting from decomposition of large plastic material waste via weathering (8)**.** The presence of microplastics has been recorded in water sources, rivers, soil and sewage water treatment systems. Because of their tiny particle size, they are easily carried by water currents and cause contamination even in far-off places. Furthermore, microplastics have been found in food items, agricultural soils, and airborne dust.

Major sources of microplastics include:

- Domestic wastewater
- Industrial discharge
- Synthetic clothing
- Cosmetic products
- Plastic packaging waste
- Agricultural runoff

The primary disadvantage of microplastics is their low weight and small size, which allows easy distribution across aquatic environments and accumulation within the ecosystem (12). Due to their strong resistance to biological breakdown, polymers including polyethene (PE), polypropylene (PP), and polystyrene (PS) are the primary sources of microplastics. Because of their strong carbon-carbon backbone structure and hydrophobic surfaces, these polymers are resistant to natural breakdown processes (13).

The problem of contamination by microplastics is now an important one because microplastics have the ability to absorb several toxic materials like pesticides, heavy metals, etc., in addition to inducing oxidative stress in their body tissues (6). Ingestion of microplastics will cause a lack of feeding and reproduction in marine life forms. In addition, consumption of seafood and contaminated water will adversely affect human health because of the presence of microplastics (21).

2.2 Existing Treatment Methods for Microplastic Removal

2.2.1 Conventional methods

There are several physicochemical techniques which are used for separating small particles from sewage treatment facilities. These include filtration, sedimentation, chemical oxidation, and membrane filtration. These are a few more wastewater treatments used for eliminating the particulate materials present in wastewater (3).

The performance of the filtration process depends much on the sizes of plastic particles, yet problems such as fouling and high expenses remain. The sedimentation process does not work well in filtering out the small, light plastic particles as they continue to be suspended in the water system. But although these processes perform well in modifying the polymer materials and thus accelerate their degradation, they consume too much energy and produce dangerous substances (18).

The majority of these approaches use physical separation approaches, but conventional approaches have been proven highly efficient in lowering the level of microplastics in the wastewater system. The build-up of microplastics in sludge treatment systems is likely to occur, suggesting that the microplastics will find their way into the ecosystem through the disposal of the sludge. Despite conventional wastewater treatment plants having the capability to remove high volumes of suspended solid waste, complete removal of microplastics is highly difficult because of their tiny nature.

Incomplete removal efficiencies in traditional treatment systems were observed in studies by (9)Luo et al. (2021) and (18)Zhang et al. (2022), suggesting the need for better remediation techniques.

2.2.2 Biological Degradation

Biodegradation potential of microorganisms for synthetic polymers has been demonstrated by several researchers, but there is still inconsistency in the degradation efficiencies achieved due to microbial variation, reactor type, and environmental conditions (17).Various types of bacteria and fungi exist whose potentialities for utilizing synthetic polymers as carbon sources have been observed through particular environmental conditions. Microorganisms produce enzymes externally which facilitate oxidation and degradation of synthetic polymers into smaller molecules that can be easily consumed by microorganisms. Biodegradation process involves steps including surface colonization, oxidation and degradation, and ultimately mineralization of polymer chains. Oxygenases, esterases, hydrolases, and other enzyme systems that work on high molecular weight and low molecular weight of polymers, form smaller molecules, making them easy to biodegrade (12).

While biological degradation has an upper hand over chemical treatment techniques from an environmental point of view, the degradation rate may be slow due to a lack of microbial adhesion and interaction with hydrophobic plastics. Consequently, recent research has increasingly focused on improving microbial retention through biofilm engineering approaches.

However, despite remarkable developments in technology, there has yet to emerge any wastewater treatment approach that completely removes microplastics. Currently, existing approaches have primarily been aimed at separating the microplastics instead of their decomposition, resulting in the buildup of plastics within sludge or secondary wastes. As a result, scientists are looking into biological substitutes that can accomplish sustainable degradation more and more.

Although several physicochemical treatment technologies demonstrate partial removal of microplastics, most systems fail to achieve complete polymer mineralization. As a result, biological degrading techniques are being investigated more and more as viable substitutes. Conventional methods and biological methods involving biofilms are compared in Table 1.

Table 1. Comparison of microplastic treatment methods

Treatment Method	Main Advantages	Major Limitations
Filtration / Sedimentation	Simple operation, immediate particle removal	No degradation, secondary pollution
Chemical oxidation	Rapid polymer breakdown potential	High energy demand, toxic by-products
Suspended microbial system	Biodegradation capability	Biomass washout, low microbe-plastic contact
Biofilm-based rotating reactor	High stability, sustained degradation	Requires operational optimization

From the comparison made in Table 1, it is evident that conventional methods only involve the physical elimination of microplastics from sewage, while biofilm-based methods provide an extra benefit of biodegradation of polymers.

2.3 Biofilm-Based Reactor Systems

Biofilms consist of bacterial colonies that are encased in extracellular polymeric substances (EPS) that grow on solid substrates (7). Functioning like a barrier for protection, the EPS matrix ensures microbial survival under varying environmental conditions. The EPS matrix also plays an important role in ensuring that microbes communicate effectively and nutrients move into the cells. This not only stabilizes microbial communities but also facilitates localized concentration of extracellular enzymes near polymer surfaces, thereby improving degradation efficiency. Biofilm systems are therefore considered highly suitable for treating persistent pollutants in wastewater environments. These systems are beneficial because they preserve more enzymes, improve microbial stability, and shield microbes from external stressors. Additionally, biofilms promote attachment of microorganisms to the hydrophobic surfaces of plastic particles, leading to increased degradation performance (10).

One of the ways to improve biodegradation using a biofilm reactor is by employing the rotating biofilm reactor. Compared to conventional biological systems, the rotating biofilm reactor offers a better operational stability due to enhanced oxygen availability and microbial-microplastic interactions (23). Advantages of biofilm systems include:

- Higher microbial retention
- Enhanced enzymatic activity
- Enhanced ability to withstand environmental stress
- Continuous treatment capability
- Reduced sludge production

There are several reports that indicate improvement in degradation effectiveness due to extended microbial activities and improved enzymatic reactions. The rotating movement of carrier surfaces continuously exposes microbial biofilms to both wastewater and atmospheric oxygen, creating favourable aerobic conditions for microbial metabolism. This system ensures better efficiency for oxygen transfer and increased enzyme oxidation in the surface layer of polymers. As such, rotating biological contactors have been developed as effective systems in treating wastewater sustainably. Despite promising laboratory-scale results, the industrial implementation of rotating biofilm reactors remains limited because of operational challenges related to oxygen diffusion, reactor fouling, and long-term microbial stability.

Several different treatment processes have been considered to effectively remove microplastics from the water cycle. The following table (Table 2) includes a selection of comparative studies along with the reactor type and results obtained.

Table 2. Comparative analysis of different microplastic treatment technologies based on degradation efficiency, operational advantages, and limitations.

Study	**Reactor Type**	**Polymer**	**Major Finding**	**Limitation**
(9), **Luo et al. (2021)**	WWTP	Mixed MPs	Partial removal	No degradation
(19), **Sun et al. (2021)**	Biofilm system	PE	Improved degradation	Lab-scale only
(20), **Patel et al. (2023)**	Rotating reactor	Mixed polymers	Enhanced oxygen transfer	High operational optimization needed

The conventional methods of treating wastewater, as highlighted in Table 2, involve physical separation of microplastics and not polymer degradation. Biofilm systems and rotating reactors help facilitate the growth of microorganisms, increase oxygen transfer, and allow sufficient contact between microorganisms and the surface of the polymers, leading to their biodegradation. Nonetheless, laboratory-scale experiments dominate the literature, and there is a need for optimization at the industrial level.

2.4 Research Gap

The majority of earlier studies have focused on the physical separation of microplastics, while the creation of biological methods for doing so has received less attention. Little work has been done on biofilm reactors that make use of rotation systems. The effect of certain operating parameters on the performance of biodegradation processes, including rotation speed, hydraulic retention time, oxygen transfer rate, and biofilm thickness, should be sustainable and effective for a rotating biological system for microplastic breakdown.

Most importantly, not enough studies have been conducted regarding the effects of biofilms on various polymers through changing operating conditions. There are many issues that need to be considered related to the optimization of reactor design, microbial stability, and degradation kinetics, which have been largely overlooked in past research. As a result, many issues arise in terms of microbial stability and degradation rate during optimization.

The present study concentrates on using the rotating biofilm reactor system for microplastic degradation in an aerobic wastewater environment. In contrast to previous studies, which concentrate mainly on the physical segregation of microplastics, the present study examines actual biodegradation using microbial biofilms formed on rotating carriers. Furthermore, the study examines the influence of operational parameters such as rotational velocity, oxygen transport, hydraulic retention time, and biofilm stability on degrading efficiency.

3. MATERIALS AND METHODS

3.1 Preparation of Microplastics

The objective of this study was to determine the potential of a biofilm-based reactor in assessing the degradation of microplastics. Because PE, PP, and PS are some of the commonly found polymers in the plastic contaminants of wastewaters and other bodies of water, these three polymer types were chosen as they are very difficult to degrade because of their stability and hydrophobicity. Among the many chemicals utilized in the experiment were ethanol, sodium chloride, nutrient broth, minimal salt media, glucose and distilled water. Samples of synthetic wastewater were prepared by the researchers to simulate a situation that would allow for the testing of the ability of various microorganisms in the biodegradation of plastics. Microbial cultures obtained from wastewater sludge containing plastics were collected to be used in biodegrading activities.

Samples of microplastic pellets ranging in diameter between 100 µm and 500 µm were used and washed in distilled water or ethanol to remove any contaminant and other unwanted particles. Drying was done in hot air oven using controlled temperature. The prepared samples were checked manually for uniformity in size and shape of microplastics. Consistency in the size and shape of the microplastics is very important during the entire process.

3.2 Microbial Consortium

Microbial consortia for the degradation of microplastics were developed using natural microbial sources. Microorganisms responsible for the degradation of microplastics were isolated from wastewater sludge and plastic-polluted soil samples taken from local wastewater treatment plants and dumping grounds. Samples were collected because these microorganisms are capable of thriving in the pollution brought about by the presence of plastics.

In the current study, the microbial consortium was isolated from samples of wastewater sludge collected from areas of plastic pollution. Repeated subculturing in a minimal salt medium with microplastics as the main carbon source ensured the isolation of microorganisms that degrade polymers. Enrichment was done under aerobic conditions in order to develop the organisms that could utilize the carbon compounds generated from plastic. Mixed microbial consortia were selected rather than single microbial strains due to their higher metabolic diversity and adaptability. Various microorganisms in the consortium could have a synergistic effect on the biodegradation of polymers by producing various enzymes.

Wastewater was prepared artificially to mimic the environmental conditions in which microplastics are found in the wastewater treatment facilities. This wastewater medium contained nutrients for the survival and proliferation of microorganisms in their biofilms. The produced wastewater was sterilized to eliminate any possible contaminants.

3.3 Reactor Design

A rotating biofilm reactor was used to degrade microplastics. The reactor was made up of a cylindrical acrylic tank that contained rotating carrier discs partially submerged in artificial wastewater. These carrier discs offered enough surface areas where microorganisms would attach and form biofilms. Rough-surfaced carrier materials were used because roughness increases the microbial adhesion ability and improves the stability of the biofilm. The design of the reactor aimed at increasing the surface area while ensuring effective wastewater circulation. Good mixing conditions were required to ensure that nutrients, oxygen, and microplastic particles would be distributed evenly throughout the reactor system.

Rotation of the carrier discs allowed for the exposure of the microbial biofilm to wastewater and atmospheric air (that is enriched with oxygen). This setup helped provide the best conditions for interaction between bacteria and microplastics, as well as access to the best oxygen supply and nutrients. The reactor had a shaft that supported the carrier discs; an electric motor, the aerating system, and a wastewater storage chamber. For controlling the rotation of the shaft and its components, the motor system was connected to the rotating shaft.

During all experiments, an aerobic environment will be maintained due to the better performance of enzymatic activity by microbes. Rotation of the carriers will prevent sedimentation of particles and provide good mixing of microplastics inside the reactor. The structural layout of the rotating biofilm reactor employed in the current research is represented in Figure 1. The setup included rotating discs partially immersed in water to support the growth of microbes and promote the interaction between biofilm and microplastics under aerobic conditions.

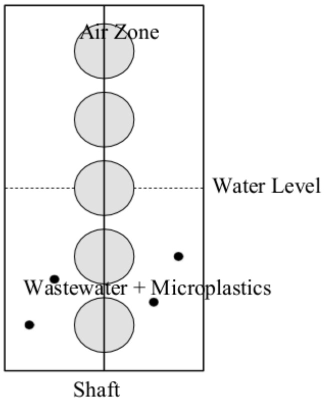

Figure 1. Biofilm-based rotating reactor showing carrier discs and microplastic integration.

3.4 Biofilm Formation

The microbial consortia were added to the system to initiate biofilm development on the carrier surfaces prior to the addition of microplastics to the reactor. Dense layers of connected bacteria and their EPS matrices will form if the reactor is further incubated and shaken. It is simple to follow the biofilm generation process under a microscope. Dense microbial layers attached firmly to the carrier surfaces, indicating successful biofilm development. It is crucial to remember that biofilm formation ensures that microbial enzymatic systems function effectively. A well- developed biofilm structure improves microbial resistance to hydraulic stress and prevents excessive biomass loss during reactor operation.

Additionally, the EPS matrix improves adhesion with hydrophobic microplastics and guarantees microbial stabilization within the reactor. Due to increased enzymatic activity and improved microbe retention within the reactor, stable biofilm growth is essential.

The development of the biofilm generally occurs through sequential stages which are as follows:

1. Initial reversible microbial attachment
2. Irreversible adhesion through EPS secretion
3. Microcolony formation
4. Biofilm maturation
5. Partial detachment and dispersion

The mature biofilm stage is particularly important because it supports stable microbial activity and prolonged interaction with polymer surfaces.

3.5 Experimental Procedure

After stable biofilm formation, prepared microplastics were added to the reactor containing wastewater at predetermined concentrations. A variety of operating parameters, including rotating speed, hydraulic retention time, oxygen availability, and biofilm thickness, were varied while the reactor was continually run under aerobic conditions.

Samples were taken from at different times during the experiment in order to perform the analyses. To measure changes in microplastic content and surface shape, the degradation studies were carried out for a specific period. There was also a non-biological analysis without microbial inoculation that was used in comparative analysis to establish differences in biological and non-biological situations. The use of the control systems was necessary in order to establish the effectiveness of the biofilm reactor system.

3.6 Operational Parameters and Analytical Techniques

- **Temperature:** The reactor was kept at room temperature between 25 and 30°C to promote microbial growth and enzyme production.
- **pH:** The pH of the wastewater was kept constant between 6.8 and 7.2 during the experimental study since microbes work best at neutral pH levels.
- **Rotational speed:** The effects of various rotational speeds on oxygen transport, biofilm formation, and polymer breakdown performance were investigated.
- **Hydraulic retention time:** It was adjusted to maximize the interaction between microorganisms and microplastic particles.

The operational parameters were carefully optimized due to their strong impact on the behaviour of microbes and enzymes involved in degradation reactions. Any change in oxygen availability, hydraulic retention time, and rotational speed can have a major impact on biofilm formation and degradation efficiency.

Different analysis methods were employed to study the degradation process. The few techniques are as follows:

- FTIR → chemical changes
- SEM → surface morphology
- TOC → mineralization
- Particle size analysis
- Weight loss measurement

Weight Loss Analysis: The reduction in microplastic mass following biological treatment was assessed by weight loss analysis. After being extracted from the reactor, the microplastic particles were properly cleaned, dried, and weighed using a precision balance. Degradation effectiveness was computed using the difference between the beginning and final weight.

Fourier Transform Infrared Spectroscopy (FTIR): FTIR analysis was utilized to identify chemical changes in polymer structures during degradation. The formation of oxygen-containing functional groups indicated oxidative degradation of polymers.

Scanning Electron Microscopy (SEM): SEM analysis was used to look at the surface morphology of microplastic particles before and after treatment.

Total Organic Carbon (TOC): The degree of mineralization and organic carbon release during degradation was assessed using TOC analysis. Microbial use of damaged polymer molecules was indicated by a decrease in the concentration of total organic carbon.

Degradation of microplastics follows several interrelated steps that include microbial adherence, enzymatic oxidation, cleavage of polymer chains, and finally assimilation of microplastics into the microbial metabolic pathway. This entire process is briefly shown in Figure 2.

Wastewater Sludge Collection
↓
Microbial Enrichment
↓
Biofilm Development
↓
Reactor Inoculation
↓
Microplastic Addition
↓
Sampling & Analysis
↓
SEM / FTIR / TOC Analysis

Figure 2. Schematic representation of the experimental procedure followed for biofilm-mediated microplastic degradation.

The flowchart illustrates the sequential stages involved in the study, including microbial isolation, biofilm development, reactor inoculation, microplastic exposure, and analytical characterization using SEM, FTIR, TOC, and weight loss analysis.

4. MECHANISM OF MICROPLASTIC DEGRADATION

The process of breaking down microplastics involves biological and physicochemical activities, such as the presence of microbes, enzymes, oxygen, the environment, and polymers. Decomposition of plastics occurs at a very slow pace in nature because synthetic polymers possess high molecular weight, hydrophobicity, crystallinity, and stable carbon–carbon backbone structures, all of which significantly reduce microbial accessibility and enzymatic susceptibility under natural environmental conditions. Therefore, to improve degrading performance, more sophisticated biological mechanisms should be employed.

Biofilm-based rotating reactors facilitate effective microplastics degradation through enhanced biological residence time, aeration efficiency, and microbial-particle contact rate (25). In rotating reactors, bacteria grow and produce biofilms in the carriers while continually coming into contact with microplastics in the wastewater. The process of degradation usually entails microbial attachment, biofilm formation, enzyme oxidation, chain cleavage, and mineralization.

Characteristics of microplastics affecting degradation:

The physical and chemical characteristics of the polymers influence significantly the degradation process of the microplastics. Because they have hydrophobic surfaces and stable molecular structures, plastics like PE, PP, and PS are extremely resistant to deterioration.

The following properties of the polymers influence the rate of biodegradation:

Molecular structure: In general, highly branched or aromatic polymers are more difficult to break down than polymers with simple linear carbon chains. Long hydrocarbon chains found in polyethylene and polypropylene are susceptible to oxidation and fragmentation when exposed to bacterial activity. Because of this difference, polystyrene generally degrades more slowly under biological conditions.

Hydrophobic nature: Because most plastics are hydrophobic, water cannot penetrate polymer structures, and microorganisms cannot bind to them. By generating extracellular polymeric substances (EPS) that enhance microbe attachment to plastic surfaces, biofilms aid in overcoming this restriction.

Crystallinity: Because of their densely packed molecular structure, which prevents enzyme penetration, highly crystalline polymers are more resistant to breakdown. In general, amorphous areas of plastics are more vulnerable to biological invasion.

Surface Area & Particle Size: Microscopic microplastics have higher surface areas than larger ones. Smaller microplastic particles possess larger surface area-to-volume ratios, which facilitate greater microbial attachment & improve enzymatic accessibility during degradation.

Microplastics degradation is a process that happens sequentially:

1. **Adhesion** of plastic particles to biofilm
2. **Enzymatic oxidation** of polymer surface
3. **Fragmentation** into smaller molecules
4. **Assimilation** into microbial metabolism

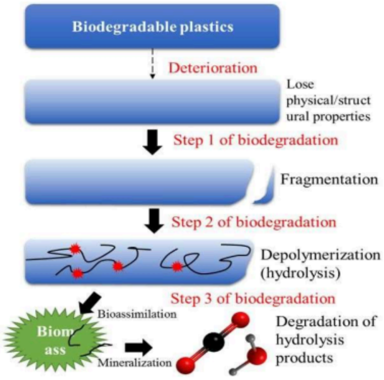

Figure 3. The evolution of microplastic breakdown from microbial adhesion to polymer mineralization is shown by sequential steps.

Figure 3 describes the entire mechanism of degradation that was taking place within the rotating biofilm reactor system.

4.1 Initial Attachment and Biofilm Formation

The first step in the breakdown process is bacterial attachment to the surface of microplastic particles. When microplastics enter the reactor system, microorganisms suspended in wastewater approach the polymer surface through diffusion and fluid movement. Van der Waals forces, hydrophobic interactions, electrostatic attraction, and the roughness of plastic surfaces all contribute to bacterial adhesion.

Attachment is first feeble and reversible. Interestingly, microorganisms gradually begin to produce extracellular polymeric substances (EPS), leading to irreversible attachment and stable colonisation. Hydrophobic interactions between microbial cell surfaces and polymer particles play an important role during the initial attachment stage of biofilm-mediated degradation. The roughness and porosity developed on weathered plastic surfaces further enhance microbial adhesion. Microorganisms quickly multiply and create structured microbial communities on the plastic surface once they are attached (14).

One of the most important stages in the degrading process is the formation of biofilms. In reactors, the microbial attachment to the carriers starts producing extracellular polymeric substances (EPS), which leads to the attachment and biofilm formation. Once this matrix develops, microbial cells will be firmly attached to the plastic surface (27). Biofilm formation results in better biological stability and prolongs the time of contact between bacteria and microplastics. Surface roughness and the weathering of plastic particles may further enhance microbial colonization by increasing more favourable attachment sites.

The EPS matrix performs several important functions in the degradation process. It helps the microbial population to be attached to hydrophobic plastics, improve enzyme retention near the surface of the polymers, and protect microbial cells against environmental stress. Also, the biofilms enable microorganisms to stay near the plastic particles for longer periods.

Biofilm formation facilitates the decomposition of microplastics through several mechanisms:

- Shields microbes from environmental stress
- Enhances microbial retention
- Concentrates extracellular enzymes near polymer surfaces
- Improves adhesion between microorganisms and hydrophobic plastics
- Traps nutrients and microplastic particles

Within the biofilm structure, microorganisms remain in prolonged contact with plastic surfaces, thereby increasing degradation efficiency.

4.2 Enzymatic Degradation of Polymers

After the stable biofilms are established, microbes start releasing extracellular enzymes that initiate oxidative reactions on polymer surfaces, capable of weakening the structural integrity of plastics. During this stage, oxygen-containing functional groups such as hydroxyl and carbonyl groups are added to the polymer structure. Along with this modification, the polymer chain size is reduced means the chains are broken down into smaller fragments, and the structure of the plastic is weakened and becomes visible in the form of cracks, pits, erosion, etc (15). The biodegradation process includes:

- Oxidation of polymer surfaces
- Formation of oxygen-containing functional groups
- Cleavage of long polymer chains
- Reduction in molecular weight

4.3 Fragmentation of Microplastics

Large polymer molecules are broken down into small substances as a result of enzymatic degradation. Mechanical stress, hydrolysis, oxidation, and enzymatic cleavage may lead to fragmentation. The agitation caused by the rotating motion of the reactor enhances fragmentation because it increases the interaction between biofilms and microplastic particles. Constant mixing enhances the exposure of plastic surfaces to microbial enzymes and prevents particles from settling. Large molecular weight polymers cannot be directly absorbed by microbes; that's why the fragmentation stage is very important.

4.4 Assimilation and Microbial Metabolism

Disintegrated small molecules are carried inside the bacterial cells, where they serve as the sources of carbon and energy. Metabolism of degraded polymer molecules takes place in cellular pathways such as the β-oxidation pathways, the Tricarboxylic acid (TCA) cycle, Glycolytic pathways. The carbon in polymers is converted into microbial biomass, carbon dioxide, water, and energy through metabolism. Under aerobic circumstances, carbon dioxide and water are the end products after mineralization. This represents a true biodegradation stage because the polymer carbon is incorporated into the microbial metabolism rather than simple fragmentation.

4.5 Role of the Rotating Biofilm Reactor

The rotating biofilm reactor improves the degradation performance by maintaining favourable conditions for bacterial activity. The rotating process of the reactor provides:

- Improved oxygen transfer
- Better nutrient distribution
- Increased interaction between biofilms and microplastics
- Reduced biomass washout
- Stable reactor performance

Compared with suspended microbial systems, rotating biofilm reactors are likely to have more stable microbial populations and lower biomass washout rates. One additional advantage of the rotating system is better nutrient distribution within the environment of the bioreactor. This is due to proper oxygen availability and stable microbial retention, which together support higher enzymatic activity.

4.5 Factors Influencing the Degradation Process

There are many factors that determine the efficiency of the degradation of microplastics within the reactor system.

- The chemical nature of the polymer is one of the most important factors that makes some plastics more prone to degradation by the enzymes due to their less stable chemical structure (26).
- Biofilm thickness is another factor that influences the working of the reactor system. Moderate thickness increases efficiency, but excessive thickness may restrict oxygen diffusion and lead to low efficiency.
- Oxygen is another parameter because aerobic microbial degradation heavily depends on oxygen. The efficiency of deterioration is greatly decreased by inadequate oxygen.
- Rotation rate also determines the behaviour of microplastics within the reactor, as it influences factors like shear stress and oxygen transfer from the medium. Very low rotational speed limits mixing, while excessively high speed may damage biofilm stability.

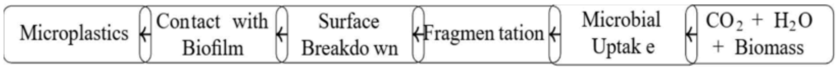

Figure 4. Microplastic degradation in a biofilm-based rotating reactor: a step-by-step process

5. RESULTS

In this study, the performance of a rotating biofilm reactor was investigated on the biodegradation of PE, PP, and PS microplastics under controlled aerobic conditions. It was observed that during the experimental period, there was noticeable microbial growth and gradual biodegradation of polymer particles by the rotating biofilm reactor system.

It was found that the rotating biofilm reactor showed improved performance for biodegradation compared to conventional suspended microbial systems. Continuous rotation maintained in the reactor ensured better oxygen transfer and enhanced contact between microbial biofilms and suspended microplastics. Consequently, there was relative stability of the microbial population during the operation of the reactor.

5.1 Biofilm Formation and Microbial Growth

The microbial biofilm successfully developed after a few days of reactor operation, as dense layers of microbial growth were observed attached to the discs. Microscopic observation revealed that the microorganisms were organized into a microbial community within the EPS matrix.

The EPS matrix appeared to improve microbial retention and facilitated closer interaction between microorganisms and hydrophobic plastic particles. Since the synthetic polymers do not easily allow microbial cell attachment, the biofilm formation played an important role in prolonging the contact between the microbial cells and the substrate.

The continuous rotation of the reactor enhanced oxygen diffusion and nutrient distribution, which was favourable for microbial growth. When compared to suspended culture systems, biofilm reactors experience high microbial retention and less biomass washout due to the rotation of the reactor.

5.2 Degradation Performance

There was a gradual decrease in the concentration of the microplastics over time due to the degradation process taking place in the reactor. The degradation rates of the polymers differed based on their different structures and chemical stabilities.

Among the tested polymers, polyethylene had the highest degradation rate, polypropylene came second, while polystyrene showed relatively low degradation rates. This could be attributed to the benzene rings in polystyrene, which offer additional chemical stability, hence limiting access to enzymatic activities. This result is consistent with the findings of Urbanek et al. (2020), who found that aromatic polymers biodegrade 40–60% more slowly than their aliphatic counterparts.

The decrease in the mass of the polymer particles proved that the microbes were able to metabolize the polymer fragments during their metabolic processes. Analysis of weight loss verified that the microbes used broken-down polymer particles as carbon sources for their metabolic processes. This is due to increased contact between the biofilm formed by the microbial consortiums and the polymer particles. The degradation efficiency for these various polymer types during reactor operation is shown in Table 3.

Table 3. Polymer Degradation Efficiency

Polymer	Initial Weight (mg)	Final Weight (mg)	% Degradation
PE	500	290	42%
PP	500	340	32%
PS	500	415	17%

The findings indicate that polymer composition strongly influences biodegradation efficiency. Plastics with relatively simpler hydrocarbon structures appeared more susceptible to microbial attack than highly stable aromatic polymers.

5.3 Effect of Operational Parameters

5.3.1 Effect of Rotational Speed

Rotational speed significantly affected reactor performance and degradation efficiency. Moderate rotational speed produced ideal conditions for microbial activity by improving oxygen transfer and maintaining continuous contact between biofilms and suspended microplastic particles.

At lower rotational speeds, not enough or inadequate mixing reduced interaction between microorganisms and polymer particles, resulted in relatively low degradation efficiency. Oxygen transfer within the reactor also decreased under these conditions. Whereas, an excessively high rotational speed generated greater shear stress within the reactor and sometimes caused partial detachment of biofilms from carrier surfaces. These observations suggest that maintaining an optimal rotational speed is important for balancing oxygen transfer and biofilm stability.

5.3.2 Effect of Hydraulic Retention Time

Hydraulic retention time also significantly influenced biodegradation performance. Longer retention periods allowed for more extended interaction between microorganisms, enzymes, and the polymer surfaces, leading to oxidation and decomposition of polymer fragments.

Shorter retention times meant that microorganisms could not form strong interactions or establish stable attachment and initiate effective enzymatic degradation. Increased retention time therefore, improved both polymer weight reduction and surface modification.

However, extremely long retention times might negatively impact the productivity of the process at full scale due to reduced capacity of the system. It is important to determine the optimal retention time.

5.3.3 Effect of Oxygen Availability

Aerobic conditions strongly supported microbial growth and biodegradation activity within the reactor system. Continuous rotation provided exposure of biofilms to atmospheric oxygen, thus improving oxygen transfer throughout reactor operation.

Good oxygen availability promoted aerobic microbial metabolism and enhanced oxidation reactions by enzymes on polymer surfaces. Under limited-oxygen conditions, microbial activity decreased noticeably, leading to poor degradation rates.

The observations made from this study indicate that oxygen transfer is one of the key factors controlling biodegradation efficiency in rotating biofilm reactors (22).

5.4 Surface Analysis of Microplastics

- **Scanning Electron Microscopy (SEM) analysis:**

Analysis using SEM has revealed major changes in the structure of the microplastic beads that had been subjected to treatment relative to those that were not. The former appeared to have rough surfaces with cracks and eroded areas, while the latter had smooth surfaces.

These structural modifications indicate microbial colonization and enzymatic attack on polymer surfaces during reactor operation. The surface damage became more obvious with prolonged treatment duration, suggesting progressive degradation of polymer structures.

- **Fourier Transform Infrared Spectroscopy (FTIR) analysis:**

FTIR analysis demonstrated noticeable chemical changes in polymer structures after biological treatment. The formation of oxygen-containing functional groups such as hydroxyl and carbonyl groups indicated that there was an oxidation process taking place.

It was further observed that there was a decrease in the peak intensity of the polymer structure. The FTIR observations corresponded closely with the structural modifications identified during SEM analysis and weight loss measurements.

5.5 Comparison with Conventional Systems

The rotating biofilm reactor demonstrated several advantages compared with conventional suspended microbial systems and physical treatment methods. Unlike filtration and sedimentation processes, which rely on physical separation, the biofilm reactor promoted actual biochemical degradation of polymer materials.

Compared with certain advanced oxidation methods, the biological reactor required lower chemical input and depended primarily on microbial metabolism and mechanical rotation and thereby reducing overall energy consumption. Continuous reactor operation also supported stable microbial activity and prolonged treatment efficiency. These findings suggest that rotating biofilm reactors may provide a more sustainable approach for microplastic remediation in wastewater treatment applications.

6. DISCUSSION

Results achieved during this study suggest that microbial biofilms have the potential to increase the degradation rates of microplastics in an aerobic environment. In comparison with the conventional suspended microbial system, the rotating biofilm reactor maintained better stability of the bacterial population and longer microbe-particle interaction.

One of the most noticeable findings is the importance of EPS in supporting microbial attachment and further colonization. Because most of the synthetic materials usually have hydrophobic surfaces, it is difficult for microbes to attach to their surfaces during the initial stage of decomposition. With stable biofilm formation on the surface of the carriers, closer interaction between microbes and plastic became possible, and the enzymatic activity improves.

The rotating motion of the reactor was also a factor that increased the efficiency of the process. The continuous movement improved the oxygen availability and ensured the uniform distribution of nutrients within the system. At the same time, the repeated interaction between suspended microplastics and microbial biofilms resulted in increased enzymatic attack on polymer surfaces.

The most effective degradation efficiency was observed in polyethylene among all the tested polymers, while polystyrene showed comparatively slower decomposition. A possible reason behind this can be the chemical structure of polystyrene because of the presence of an aromatic benzene ring in it, which provides chemical stability to the material.

SEM observation revealed several changes on the surface of the polymer materials after the experiment. Some cracks, pits, erosion, and roughness were observed after biological treatment. Similarly, FTIR analysis indicated the appearance of functional groups containing oxygen, like carbonyl and hydroxyl groups, which indicated oxidative degradation.

From these findings, it can be concluded that the degradation process in the rotating biofilm reactor actually involved biochemical reactions in the polymers rather than a simple fragmentation. In other words, only mechanical breakdown into smaller pieces may generate secondary microplastic particles that will persist in the environment in future.

Operational parameters have also played an important role in influencing degradation performance. Moderate rotational speed appeared to provide a good balance between oxygen transfer and biofilm stability. Too low rotational speeds led to poor mixing performance, while too high speeds resulted in biofilm detachment due to the increased shear stress. Another parameter that affected reactor performance is hydraulic retention time. Increased hydraulic retention time led to increased interaction time between the microbes and plastic particles and thus to increased enzymatic activity. However, too high hydraulic retention times may reduce treatment capacity in practical applications.

Despite the achievement of notable degradation results, complete mineralization of highly resistant plastic polymers was not observed during the course of the experiment. The high hydrophobicity, crystallinity, and stability of the molecular structure of synthetic plastics prevent fast biodegradation in the environment.

These current results support previous research reporting improved biodegradation rates in biofilm reactors. It shows that good microbial retention, oxygen availability, and enzymatic activity contribute significantly to the higher biodegradation performance of the rotating biofilm reactors (23), (24). Thus, the study demonstrates that biofilm reactors can be a promising approach to the reduction of microplastic pollution of wastewater systems.

7. ADVANTAGES AND LIMITATIONS

Advantages:

- Enhanced microbial stability
- Improved degradation efficiency
- Energy-efficient operation
- Reduced chemical usage
- Minimal secondary pollution
- Integration with current treatment facilities is simple.

Limitations:

- It is essential to optimize operating settings
- Biofilm separation in situations with high shear
- Slow degradation of highly resistant polymers (28)

While it is clear that the rotating biofilm reactor performed better in the degradation of polymers using aerobic conditions, some limitations are still there currently. One is that the experimental setup did not involve actual environmental conditions and actual wastewater. Throughout the period of the study, only some types of polymers were tested. Further research should be conducted on reactor stability, performance, and economic viability for implementation purposes (28). Also, the limited study period may not give a true depiction of the decomposition under actual environmental conditions.

8. ENVIRONMENTAL SIGNIFICANCE

Plastic contamination is currently becoming a growing environmental problem due to the inability of existing technologies to ensure full degradation of the artificial polymer. The accumulation of plastic waste in aquatic environments may negatively impact the environmental system and its biological components for a long period of time.

According to the results of this study, it seems that biofilm reactors can be considered an effective tool that can allow for a more sustainable approach to solving the problem of microplastic pollution. Since the system primarily depends on microbial activity rather than the intense chemical treatment, it may help reduce both energy consumption and secondary pollution. A widespread use of biological reactor systems will promote better wastewater management and will help prevent the discharge of persistent pollutants.

9. FUTURE PERSPECTIVES

Although the current study provided better and promising degradation performance, further study is needed to improve the reactor operation within wastewater treatment processes. Future studies might focus on obtaining a highly specialized microbial population capable of degrading resistant polymers. This might be achieved by using advanced techniques such as metagenomics and proteomics to obtain enzymes or metabolic pathways responsible for degradation.

Improvement of reactor design, aeration systems, carrier materials, and rotational speed might enhance oxygen transfer and microbial stability. Large-scale studies are also necessary to evaluate the reactor performance and economic viability within real environmental conditions. Further research must focus on the complete mineralization of polymers degraded in order to ensure that polymer degradation does not produce secondary smaller microplastic fragments. Future studies could focus on the following:

- **In the development of advanced microbial consortia:** For tough polymers like polystyrene, the employment of highly specialized or genetically modified microbial consortia may further boost breakdown efficiency. The biodegradation efficiency may get better through isolating novel plastic-degrading microbes under the stress.
- **Development of improved reactor design:** Improvement in oxygen transfer and microbial activity by additional reactor design, carrier material types, rotational speed, and aeration. It is necessary to develop an energy-efficient reactor technology for large-scale use.
- **Combining wastewater treatment facilities**: Biofilm-based rotating reactors may be included in the existing treatment systems before the wastewater is released back into the environment to degrade microplastics.
- **Evaluation of complete mineralization**: Future research must be done to determine the extent of the breakdown process, which results in carbon dioxide, water, etc.
- **For investigating different types of environmental pollutants**: In natural sewage systems, microplastics might exist with organic pollutants, metals or other materials. That's why future research should focus on this too.
- **Molecular approach to identify microbes involved in degradation process**: Important microbial species that involved in polymer breakdown can be determined through genomics or proteomics studies.

10. CONCLUSION

This study proved that rotating biofilm reactors can be used to facilitate the biodegradation process of microplastics under aerobic conditions of wastewater treatment. The problem associated with increasing accumulation of polyethylene (PE), polypropylene (PP) and polystyrene (PS) microplastics in aquatic ecosystems has become a serious concern because of their resistance to degradation naturally.

A laboratory-scale rotating reactor has been successfully designed to examine the degradation of the chosen types of microplastics. Microbial consortia obtained from a wastewater sludge sample and the environment contaminated by plastics were able to form stable biofilms on rotating disks through EPS. Rotating biofilms provided ideal conditions for the degradation process by ensuring better oxygen supply, nutrient distribution, and increased contact between microorganisms and microplastics. It is important to note that the rotating biofilm reactor demonstrated a relatively higher degradation performance compared to traditional suspended systems.

Out of all the polymers studied in this study, it was found that PE had higher efficiency in degrading than PP, while PS was less effective due to its chemically stable nature. The weight loss study proved the reduction in weight of the polymer, showing that there was microbial action in the fragmentation of the polymers.

The result obtained from SEM showed that there were various changes in the structure of the microplastics. There were cracks, pits, eroded areas, and increased surface roughness in the sample. These indicate microbial presence and enzyme action on the polymer. Whereas, FTIR analysis results showed chemical changes in the polymer, like the addition of oxygen-containing functional groups (carbonyl and hydroxyl groups) in the samples. Operation parameters like rotational speed, oxygen level, HRT, and biofilm stability also had a great influence on the degradation performance.

Many advantages were noted in the study about the use of a rotating biofilm reactor, such as good microbial immobilization, better oxygen transfer, lower sludge washout, and continuous operation ability. It can be concluded that the use of rotating reactors in combination with biofilm can help provide a sustainable and environment-friendly method for microplastic remediation.

Few benefits of the biofilm-driven revolving reactor include:

- Improved microbial retention
- Enhanced oxygen transfer
- Better operational stability
- Reduced sludge production
- Lower energy requirement
- Continuous treatment capability

These benefits indicate that biofilm-based rotating reactors can be a long-term solution to deal with microplastics. Though complete mineralization was not achieved, this study has shown that there is indeed clear potential for the development of microbial biofilms for improving the degradation of the synthetic polymer material.

Further large-scale studies are required to improve the operational efficiency for a long-term application. The obtained result confirms that biofilm reactors have a great potential for the biological treatment of microplastics in water.

References

1. Geyer, R., Jambeck, J. R., & Law, K. L. (2017). *Production, use, and fate of all plastics ever made.* Science Advances, 3(7), e1700782.
   DOI: https://doi.org/10.1126/sciadv.1700782
2. Frias, J. P. G. L., & Nash, R. (2019). *Microplastics: Finding a consensus on the definition.* Marine Pollution Bulletin, 138, 145–147.
   DOI: https://doi.org/10.1016/j.marpolbul.2018.11.022
3. Gewert, B., Plassmann, M. M., & MacLeod, M. (2015). Pathways for degradation of plastic polymers floating in the marine environment. *Environmental Science: Processes & Impacts*, 17(9), 1513–1521
4. Auta, H. S., Emenike, C. U., & Fauziah, S. H. (2017). Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. *Environment International*, 102, 165–176.
5. Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin*, 62(8), 1596–1605.
   DOI: https://doi.org/10.1016/j.marpolbul.2011.05.030
6. Rochman, C. M., Hoh, E., Hentschel, B. T., & Kaye, S. (2013). Long-term field measurement of sorption of organic contaminants to plastic pellets. *Environmental Science & Technology*, 47(3), 1646–1654.
7. Flemming, H.-C., & Wingender, J. (2010). The biofilm matrix. *Nature Reviews Microbiology*, 8(9), 623–633. DOI: https://doi.org/10.1038/nrmicro2415
8. Wang, J., Tan, L., & Peng, H. (2022). Microplastic pollution and remediation technologies. *Journal of Cleaner Production*, 350, 131286.
9. Luo, L., Su, J., Li, X., & Zhang, D. (2021). Microplastics in wastewater treatment plants: Occurrence, removal, and environmental impacts. *Water Research*, 197, 117099.
   DOI: https://doi.org/10.1016/j.watres.2021.117099
10. Rummel, C. D., Jahnke, A., Gorokhova, E., Kühnel, D., & Schmitt-Jansen, M. (2021). Impacts of biofilm formation on microplastic degradation. *Environmental Science: Processes & Impacts*, 23(1), 45–56.
11. Li, J., Liu, H., & Chen, J. P. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. *Water Research, 137*, 362–374. DOI: https://doi.org/10.1016/j.watres.2017.12.056
12. Urbanek, A., Rymowicz, P., & Mironczuk, M. (2020). Plastic biodegradation by microorganisms. *Applied Microbiology and Biotechnology*, 104, 7669–7678.
    DOI: https://doi.org/10.1007/s00253-020-10878-4
13. Webb, H. K., Arnott, J., Crawford, R. J., & Ivanova, E. P. (2013). Plastic degradation and its environmental implications with special reference to poly(ethylene terephthalate). *Polymers*, 5(1), 1–18. DOI: https://doi.org/10.3390/polym5010001
14. Oberbeckmann, S., Osborn, A. M., & Duhaime, M. B. (2016). Microbes on a bottle: Substrate, season and geography influence community composition of microbes colonizing marine plastic debris. *PLoS ONE, 11*(8), e0159289.
    DOI: https://doi.org/10.1371/journal.pone.0159289
15. Arutchelvi, J., Sudhakar, M., Arkatkar, A., Doble, M., Bhaduri, S., & Uppara, P. V. (2008). Biodegradation of polyethylene and polypropylene. *Indian Journal of Biotechnology, 7*, 9–22.
16. Shah, A. A., Hasan, F., Hameed, A., & Ahmed, S. (2008).
    Biological degradation of plastics. Biotechnology Advances, 26(3), 246–265.
    DOI: https://doi.org/10.1016/j.biotechadv.2007.12.005

17. Yoshida, S., Hiraga, K., Takehana, T., et al. (2016). A bacterium that degrades and assimilates poly(ethylene terephthalate). *Science*, 351(6278), 1196–1199. DOI: https://doi.org/10.1126/science.aad6359
18. Zhang, Y., Kang, S., Allen, S., et al. (2022). Atmospheric microplastics: A review on current status and perspectives. *Earth-Science Reviews*, 223, 103780.
19. Sun, Y., Zhou, Y., & Wang, X. (2021). Biofilm-driven biodegradation of polyethylene microplastics. *Journal of Hazardous Materials*, 416, 125881.
20. Patel, S., Kumar, V., & Sharma, R. (2023). Rotating biofilm reactors for wastewater remediation: Recent advances and future prospects. *Environmental Technology & Innovation*, 29, 102985.
21. Mohan, S., Singh, R. K., & Sharma, P. (2023). Recent developments in microplastic remediation technologies: A review. *Science of the Total Environment*, 857, 159123.
22. Nicolella, C., van Loosdrecht, M. C. M., & Heijnen, J. J. (2000). Wastewater treatment with particulate biofilm reactors. *Journal of Biotechnology, 80*(1), 1–33. DOI: https://doi.org/10.1016/S0168-1656(00)00274-8
23. Cortez, S., Teixeira, P., Oliveira, R., & Mota, M. (2008). Rotating biological contactors: A review on main factors affecting performance. *Reviews in Environmental Science and Biotechnology, 7*, 155–172. DOI: https://doi.org/10.1007/s11157-008-9127-7
24. Lazarova, V., & Manem, J. (1995). Biofilm characterization and activity analysis in water and wastewater treatment. *Water Research, 29*(10), 2227–2245. DOI: https://doi.org/10.1016/0043-1354(95)00054-O
25. Kumar, R., Sharma, P., & Verma, A. (2021). Biofilm reactor technologies for wastewater treatment applications. *Bioresource Technology Reports*, 15, 100774.
26. Chamas, A., Moon, H., Zheng, J., et al. (2020). Degradation rates of plastics in the environment. *ACS Sustainable Chemistry & Engineering*, 8(9), 3494–3511. DOI: https://doi.org/10.1021/acssuschemeng.9b06635
27. Hoellein, T. J., Rojas, M., Pink, A., Gasior, J., & Kelly, J. J. (2014). Anthropogenic litter in urban freshwater ecosystems: Distribution and microbial interactions. *PLoS ONE*, 9(6), e98485. DOI: https://doi.org/10.1371/journal.pone.0098485
28. Tiwari, E., Singh, N., Khandelwal, N., Monikh, F. A., & Darbha, G. K. (2022). Application of microbial technology for microplastic degradation: Opportunities and challenges. *Environmental Pollution*, 312, 120089. DOI: https://doi.org/10.1016/j.envpol.2022.120089

APPENDIX

Conference name and date: **International Conference on Environmental Chemistry of Microplastic Additives, Chennai (25th April 2026)**

Paper ID: **NC _0687531**

Title: **Performance Evaluation of Biofilm-Based Rotating Reactor for Microplastic Treatment**

Google Scholar

CERTIFICATE

OF PRESENTATION

NATIONAL CONFERENCE

International Conference on Environmental Chemistry of Microplastic Additives (ICECMPA-26)

25th April 2026 | Chennai - India

This is to certify that **Shweta Kumari** affiliated with Delhi Technological University, New Delhi, India has presented a paper titled Performance Evaluation of Biofilm-Engineered Rotating Reactor for Microplastic Treatment

at the esteemed Conference organized by the National Conference (NC) held on 25th April 2026 at Chennai

CiteFactor
Academic Scientific Journals

Dr. Tara Srivastava
Director

NC

Raj Kumar
Co-ordinator

Crossref

msc

ORIGINALITY REPORT

4%	4%	3%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	H.S. Auta, M.A. Murtadha, G. Aruwa, M.M. Wuna, D.O. Aboyeji, Awono, A.T. Edzili, E.O. Balogun. "MICROPLASTIC POLLUTION AND RISK ASSESSMENT IN SELECTED BEACHES IN LAGOS STATE, NIGERIA AND DEGRADATION USING ASSOCIATED MICROBIAL ASSEMBLAGES", Environmental Pollution and Management, 2026 Publication	<1%
2	www.mdpi.com Internet Source	<1%
3	studentsrepo.um.edu.my Internet Source	<1%
4	ebin.pub Internet Source	<1%
5	link.springer.com Internet Source	<1%
6	theses.hal.science Internet Source	<1%
7	Sesan Abiodun Aransiola, Yakubu Adekunle Alli, Kondakindi Venkateswar Reddy, Naga Raju Maddela. "Nanotechnology and Emerging Contaminants in Drinking Water - Advanced Solutions for Purification", CRC Press, 2026	<1%

	Publication	
8	dokumen.pub Internet Source	<1%
9	www.canada.ca Internet Source	<1%
10	oceandiagnostics.com Internet Source	<1%
11	pdfcookie.com Internet Source	<1%
12	Submitted to The University of Texas at Arlington Student Paper	<1%
13	"Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea", Springer Science and Business Media LLC, 2018 Publication	<1%
14	Submitted to Anna University Student Paper	<1%
15	Camur, Bilge Bahar. "Harnessing Environmental and Engineered Microbes for Polyethylene Surrogate Degradation and Sustainable Bio-Oil & Wax Production", University of Minnesota, 2025 Publication	<1%
16	Submitted to Curtin University of Technology Student Paper	<1%
17	orca.cardiff.ac.uk Internet Source	<1%
18	c.coek.info	

	Internet Source	<1 %
19	Narjes Basiri, Mehdi Zarei, Mohammad Kargar, Farshid Kafilzadeh. "Effect of plasma-activated water on the biofilm-forming ability of Salmonella enterica serovar Enteritidis and expression of the related genes", International Journal of Food Microbiology, 2023 Publication	<1 %
20	repository.ntu.edu.sg Internet Source	<1 %
21	www.biorxiv.org Internet Source	<1 %
22	www.scielo.br Internet Source	<1 %

Exclude quotes	On	Exclude matches	< 10 words
Exclude bibliography	On		