Proceedings of CONF-MCEE 2027 Symposium: Innovative Environmental Engineering Strategies for a Sustainable Future
DOI: 10.54254/2755-2721/2027.MA39150

Study on the Coupling Mechanism of Organic Matter Degradation and Microplastic Capture by Algal-Bacterial Symbiosis in Low-Concentration Organic Wastewater Systems

Yiyang Hao

School of Resources and Environmental Engineering, HeFei University of Technology, Hefei, China
2815304096@qq.com

Abstract. Algal-bacterial symbiosis (ABS), as an emerging wastewater biological treatment technology, shows unique advantages in the treatment of low-concentration organic wastewater. At the same time, the aggravation of microplastic pollution in water bodies has put forward new challenges to traditional treatment processes. Studies in recent years have shown that algal-bacterial symbiosis can not only efficiently degrade the organic matter in low-concentration organic wastewater, but also has the potential to capture and transform microplastics, and there may be a deep coupling mechanism between the two. This paper systematically reviews the mechanism of algal-bacterial symbiosis degrading organic matter in low-concentration organic wastewater, the main pathways of capturing microplastics, and the coupling relationship and interaction mechanism between the two, and elucidates the bidirectional coupling pathway of "organic matter degradation-microplastic removal" at three levels: organic matter metabolism drive, microplastic stress feedback, and quorum sensing molecule regulation. On this basis, the influence of microplastics on the performance of the algal-bacterial symbiosis system and the key influencing factors are analyzed, in order to provide a reference for the theoretical improvement and application promotion of algal-bacterial symbiosis technology in the treatment of compound polluted water bodies.

Keywords: algal-bacterial symbiosis, low-concentration organic wastewater, organic matter degradation, microplastic capture, coupling mechanism

1. Research background and significance

With the continuous increase of urban non-point source pollution, rural decentralized sewage and tailwater discharge in China, low-concentration organic wastewater has become an object that cannot be ignored in water environment governance. This type of wastewater has a low organic matter concentration and large nutrient fluctuations; the traditional activated sludge process has practical governance difficulties such as insufficient carbon source, large sludge production and unstable treatment efficiency; conventional biochemical processes find it difficult to achieve deep

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2027.MA39150

purification of water bodies; the development of in-situ biological treatment technology with low carbon consumption and low cost is of practical significance for improving the water quality of receiving water bodies [1, 2].

Microplastics (plastic particles with a particle size smaller than 5 mm) are widely present in surface water, groundwater and various wastewaters, and wastewater treatment plants are an important pathway for their entry from point sources into the natural water environment [3-5]. On the one hand, microplastics in wastewater cause toxic damage to aquatic organisms; on the other hand, they can serve as carriers to adsorb heavy metals and organic pollutants, forming compound pollution and amplifying environmental risks [6]. Low-concentration organic wastewater is often accompanied by the coexistence of microplastics, forming "organic matter-microplastic" compound pollution, while the removal of microplastics by existing processes mainly relies on sedimentation and interception, and the removal effect of biochemical units is limited [3]; the compound pollution problem brings new challenges to water treatment technology.

The algal-bacterial symbiosis system relies on the synergistic effect of oxygen production by microalgal photosynthesis and heterotrophic bacterial metabolism; it does not require a large amount of aeration energy, and can still achieve the simultaneous removal of organic matter and nutrients under low-substrate conditions [1, 2]; at the same time, extracellular polymeric substances can mediate the interception and transformation of microplastics [7], and the system has outstanding technical advantages in the treatment of compound polluted water bodies. Therefore, clarifying the coupling interaction mechanism between organic matter degradation and microplastic capture in the algal-bacterial symbiosis system is of important theoretical value for promoting the practical engineering application of this technology.

2. Characteristics of low-concentration organic wastewater and fundamentals of algal-bacterial symbiosis

2.1. Water quality and pollution characteristics of low-concentration organic wastewater

Low-concentration organic wastewater mainly includes wastewater treatment plant tailwater, rural decentralized domestic sewage and agricultural non-point source runoff; its COD concentration is usually at a low level, the carbon-nitrogen ratio is generally low, available organic carbon sources are scarce, and nitrogen and phosphorus nutrients account for a relatively high proportion [8, 9]. The wastewater quality fluctuates markedly under the influence of season, rainfall and discharge sources; the organic components are mostly refractory dissolved organic matter, which tends to accumulate in water bodies and induce eutrophication. Unlike high-concentration industrial wastewater, low-concentration organic wastewater can supply only limited carbon sources for microbial growth; microorganisms are in a carbon-source-stressed environment for a long time, and the proliferation of ordinary heterotrophic microorganisms is inhibited; traditional activated sludge systems are prone to sludge disintegration and declining treatment efficiency, and find it difficult to achieve the goal of deep pollutant removal, which is also the main technical bottleneck in the treatment of low-concentration organic wastewater [2].

2.2. Fundamental metabolic mechanism of the algal-bacterial symbiosis system

The algal-bacterial symbiosis system is a mutually beneficial symbiotic microecosystem constructed by microalgae and bacteria. Microalgae fix carbon dioxide and release oxygen through photosynthesis, providing oxygen for the metabolism of aerobic bacteria; heterotrophic bacteria

DOI: 10.54254/2755-2721/2027.MA39150

decompose the organic matter in water, producing CO2, ammonium salts, phosphates and other substances, which in turn provide carbon sources and nutrients for microalgal growth; the two form a mutually beneficial material cycle [1, 8]. The oxygen produced by microalgal photosynthesis replaces part of the artificial aeration and reduces the energy consumption of the system; bacteria complete the mineralization and decomposition of organic matter, and microalgae achieve the assimilation and absorption of nutrients. Extracellular polymeric substances (EPS) are important metabolites of the algal-bacterial symbiosis system; they are composed of polysaccharides, proteins, nucleic acids and other macromolecular substances, constitute a biofilm matrix with a three-dimensional network structure, participate in microbial agglomeration, interfacial adsorption and stress resistance, and are the key material basis for the formation of algal-bacterial granular sludge [10].

2.3. Adaptive response characteristics of the algal-bacterial system in a low-carbon environment

Under low-carbon substrate conditions, the algal-bacterial symbiosis system initiates a series of adaptive regulation strategies. When the external organic carbon is insufficient, microalgae can compensate for the lack of organic carbon through autotrophic carbon fixation, while bacteria adjust their metabolic pathways and use the dissolved extracellular organic matter (EOM) secreted by microalgae as a carbon source to maintain growth, realizing the internal cyclic supply of carbon between algae and bacteria [2]. Studies have shown that low-carbon stress changes the structure of the algal-bacterial community; microalgae species tolerant to oligotrophic environments and functionally degrading bacteria are enriched; at the same time, the secretion and component proportions of EPS change, enhancing the resistance of the system to environmental stress and ensuring that the system maintains a stable pollutant removal capacity in low-concentration organic wastewater [2, 9]. However, too low a carbon source will also cause a decline in microbial activity, change the interaction between microbial communities, and thereby affect the overall purification performance of the system.

3. Degradation mechanism of algal-bacterial symbiosis on low-concentration organic matter

3.1. Graded degradation pathway of organic matter

The degradation of organic matter in wastewater by algal-bacterial symbiosis presents a graded process. First, macromolecular organic matter is hydrolyzed into small-molecule organic matter under the action of extracellular enzymes; small-molecule dissolved organic matter is taken up by bacteria and oxidatively decomposed through dissimilation, part of which is converted into bacterial biomass and part of which is mineralized into CO2 and inorganic nutrients; microalgae use the inorganic carbon, nitrogen and phosphorus produced by bacterial mineralization for photosynthesis to synthesize their own biomass, completing the assimilation and fixation of nutrients [1]. Part of the organic matter is adsorbed and intercepted by EPS, enriched inside the algal-bacterial aggregates, and slowly degraded by microorganisms [10]. Refractory dissolved organic matter is difficult to be directly utilized and needs to be transformed and modified by microorganisms before participating in the metabolic cycle, realizing the stepwise removal of low-concentration complex organic matter.

DOI: 10.54254/2755-2721/2027.MA39150

3.2. Regulation of organic matter metabolism under low-concentration carbon source stress

The scarcity of carbon sources in low-concentration organic wastewater drives the metabolism of the algal-bacterial symbiosis system to undergo adaptive regulation. Bacteria preferentially use the limited external organic carbon in the environment; when the external carbon is insufficient, the EOM released by microalgae becomes an important carbon source for bacteria, building an internal carbon cycle within the system and maintaining the metabolic activity of the microbial community [2]. Multi-omics related studies have shown that carbon source stress changes the expression of functional genes related to carbon metabolism and material transport, adjusts the secretion level of extracellular enzymes, and improves the ability to capture and utilize trace organic matter. At the same time, quorum sensing (QS) signal molecules participate in the communication between microbial communities, regulate microbial agglomeration and the synthesis of extracellular polymeric substances, and indirectly affect the efficiency of organic matter degradation [11]. When the carbon source is severely insufficient, the endogenous respiration of microorganisms intensifies, sludge activity decreases, and the organic matter removal efficiency declines.

3.3. Analysis of the advantages of algal-bacterial symbiosis in deep purification of low-concentration organic wastewater

Compared with traditional activated sludge, the core advantages of the algal-bacterial symbiosis system for adapting to low-concentration organic wastewater are reflected in two aspects: the oxygen supply mode and the carbon source utilization mode. Microalgal photosynthetic oxygen release reduces aeration energy consumption; aerobic and anoxic micro-zones coexist in the local microenvironment, so that organic matter decomposition and nitrification-denitrification can be achieved simultaneously, realizing deep purification [2]. Under low-carbon conditions, the system can couple autotrophic-heterotrophic metabolic modes, does not rely entirely on the influent organic carbon, and can continuously remove trace pollutants with the help of the internal material cycle of algae and bacteria [8]. Experiments on the purification of wastewater treatment plant tailwater by bacterial-algal symbiosis systems showed that after optimizing the algal-bacterial combination and operating conditions, the total nitrogen removal rate could reach 93.7% or more, and the effluent could stably meet the Class V surface water quality standard [9]; combined processes such as membrane-high rate algal ponds also showed good advanced treatment performance for tailwater [12]. Algal-bacterial aggregates and the EPS matrix can capture trace colloidal and dissolved organic matter in water, prolong the contact time between pollutants and microorganisms, and realize the advanced treatment of low-concentration wastewater such as tailwater, showing good application potential.

4. Mechanism of algal-bacterial symbiosis in removing microplastics

4.1. Physical capture and interception mechanism of microplastics

Physical capture is the primary pathway for the removal of microplastics by the algal-bacterial symbiosis system. Algal-bacterial aggregates and granular sludge have loose and porous structures; at the same time, the large amount of secreted EPS contains hydroxyl, carboxyl and other functional groups; through electrostatic action, hydrogen bonding and hydrophobic interactions, microplastic particles in water are intercepted and fixed inside the algal-bacterial aggregates by means of adsorption, net capture and sweeping [7, 10]. The particle size, morphology and surface charge of

DOI: 10.54254/2755-2721/2027.MA39150

microplastics directly affect the physical interception effect: small-particle microplastics are more easily adsorbed by the EPS matrix, and the aggregated microplastics are separated from the water phase as the algal-bacterial sludge settles. Studies on pure microalgal systems have also confirmed that extracellular biopolymers secreted by algae can form hetero-aggregates with microplastics, achieving efficient removal [7, 13]; fungal-microalgal symbionts can also build aggregation structures through hypha-EPS adhesion, providing an analogy for symbiont-mediated particle capture [14]. It should be pointed out that this process is dominated by physical action; the chemical structure of the microplastics themselves is not destroyed, and only solid-liquid separation is achieved; if the sludge is not properly disposed of, there is a risk of secondary release of microplastics [4].

4.2. Mechanism of biofilm formation and aging on microplastic surfaces

After being captured by the algal-bacterial aggregates, microorganisms gradually attach and colonize on the microplastic surface, forming a biofilm. Algae and bacteria proliferate on the microplastic surface; EPS covers the microplastic surface and changes its surface physicochemical properties, and an aging process occurs, including changes such as increased surface roughness and increased oxidation groups [10, 15]. The microenvironment inside the biofilm changes accordingly, and extracellular enzymes continuously act on the microplastic surface, destroying the polymer structure. The construction of the biofilm is a prerequisite for the biodegradation of microplastics, and the community composition of the biofilm directly determines the subsequent transformation efficiency of microplastics; at the same time, microplastics also serve as a special ecological niche of the "plastisphere", enriching specific functional microbial communities and changing the community structure of the original algal-bacterial system [16].

4.3. Mechanism of biological enzymatic hydrolysis and complete mineralization degradation of microplastics

Functional microorganisms colonized in the microplastic biofilm secrete plastic-degrading enzymes that break the polymer long chains, decomposing macromolecular plastics into small-molecule oligomers and monomers; the small-molecule products are further absorbed and utilized by microorganisms, part of which is used for microbial growth and part of which is completely mineralized into inorganic substances such as carbon dioxide and water, achieving the true degradation and removal of microplastics [15, 17]. Since PET hydrolases were discovered, research progress on the biological enzymatic hydrolysis of degradable plastics and ester-bond-containing polymers such as PET has been significant [17]; oxidases can oxidize and activate inert carbon-chain polymers such as PE and PS [15]. Current studies have confirmed that the algal-bacterial symbiosis system can achieve enzymatic conversion of some degradable plastics and traditional petroleum-based microplastics, but for most refractory microplastics, the complete mineralization efficiency is still limited. Under algal-bacterial synergistic conditions, the combined action of multiple enzymes has improved the degradation and transformation capacity for microplastics compared with a single microalga or a single bacterium.

DOI: 10.54254/2755-2721/2027.MA39150

5. Bidirectional coupling mechanism between organic matter degradation and microplastic removal

In the algal-bacterial symbiosis system, organic matter degradation and microplastic removal are not two independent parallel pollutant removal pathways, but a coupling process deeply intertwined and mutually conditional at the levels of metabolites, functional microbial communities and signal molecules. The coupling relationship between the two is shown in Figure 1: the graded degradation of organic matter and the "capture-colonization-enzymatic hydrolysis-mineralization" process of microplastics share the same metabolic network and EPS matrix of the algal-bacterial aggregate, and form a closed loop through mineralized product feedback and signal regulation.

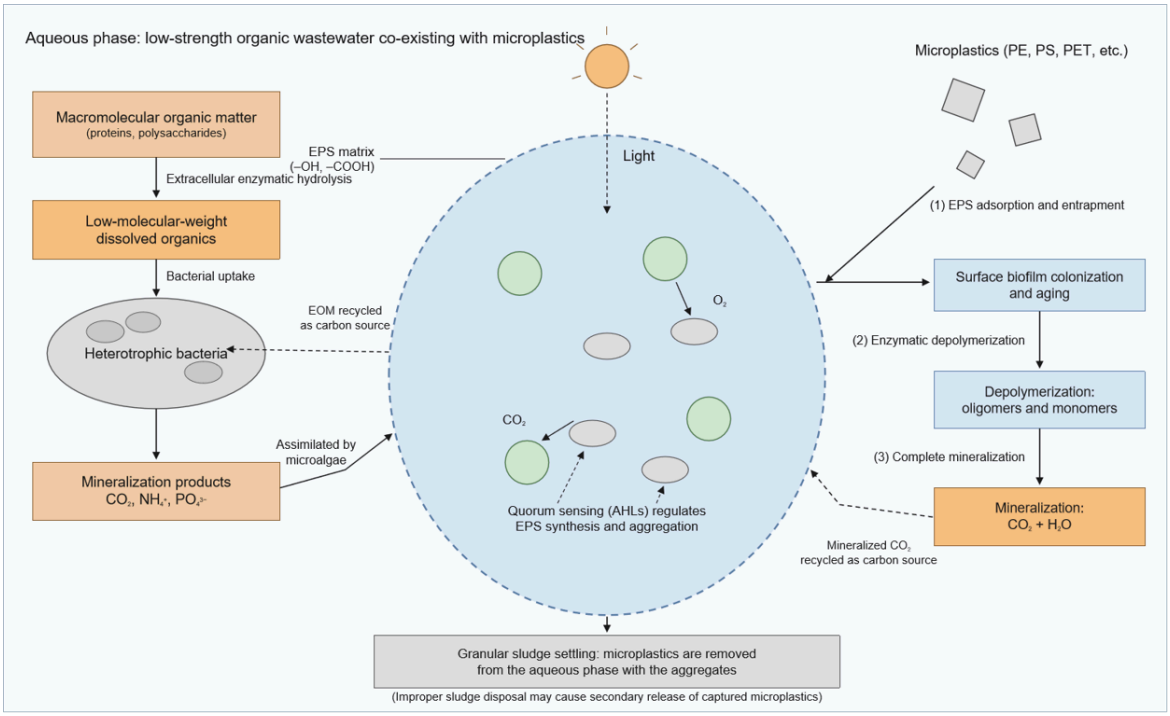


Figure 1. Coupling mechanism between organic matter degradation and microplastic capture in algal–bacterial symbiosis

5.1. Organic matter metabolism drives efficient microplastic removal

The metabolic activity of organic matter drives the efficient removal of microplastics from both the material basis and the biochemical level. First, during organic matter degradation, bacteria synthesize and secrete a large amount of EPS; the polysaccharide and protein components in EPS are rich in -OH, -COOH and other functional groups and are the main medium for adsorbing and net-capturing microplastics; the more vigorous the EPS secretion, the stronger the flocculation capture capacity of the algal-bacterial aggregate for microplastics, and the higher the formation rate of microalga-EPS-microplastic hetero-aggregates [7, 10, 13]. Second, organic matter metabolism maintains the activity of the microbial community and the yield of extracellular enzymes, providing an enzymatic reserve for the formation of biofilms on microplastic surfaces and enzymatic hydrolysis; when aerobic microorganisms oxidatively decompose the organic matter co-existing in the water phase, the related oxygenase and hydrolase systems have a synergistic effect on the oxidative activation of microplastic surfaces [15]. Third, microalgal photosynthetic oxygen release

DOI: 10.54254/2755-2721/2027.MA39150

ensures the continuous existence of the aerobic degradation microenvironment, so that the aerobic degradation enzyme systems in the microplastic biofilm can be efficiently expressed [2]. Conversely, when the influent organic matter is too low and the metabolic intensity is insufficient, EPS secretion decreases, and the physical capture and biodegradation capacities are weakened simultaneously. It can be seen that organic matter metabolism provides a "capture matrix-degrading enzyme-dissolved oxygen" triple support for microplastic removal, and is the positive main pathway of the coupling relationship.

5.2. Microplastic stress regulates organic matter degradation efficiency

The presence of microplastics in turn exerts a concentration-dependent bidirectional regulation on the efficiency of organic matter degradation. Under low-concentration stress, microplastics show a "stimulatory effect": moderate microplastics (e.g., at the level of 12 mg/L) can stimulate microorganisms to secrete more EPS, increase the compactness of algal-bacterial particles, and enrich functional microbial communities related to nitrogen and phosphorus removal, so that the pollutant removal performance of the system is instead improved [18]. When the microplastic concentration exceeds the threshold, negative effects dominate: high-concentration microplastics inhibit microalgal photosynthetic oxygen production through shading, and weaken the matrix structure through reactive oxygen species (ROS)-induced oxidative damage and the quenching of protein-like components in EPS, leading to the disintegration of algal-bacterial particles and a significant decline in settling performance and the removal efficiency of organic matter, nitrogen and phosphorus [6, 18]. In addition, microplastics enrich hydrophobic organic pollutants by virtue of their hydrophobic surfaces and change their bioavailability, and their surface biofilms may also enrich drug-resistant bacteria and resistance genes, increasing the ecological risk of the system [6]. Therefore, the regulation of organic matter degradation by microplastics shows a threshold characteristic of "promotion at low concentrations and inhibition at high concentrations", and the influent microplastic load is a boundary condition that must be controlled for the stable operation of the algal-bacterial symbiosis system.

5.3. Quorum sensing and molecular regulation coupling pathways

At the molecular level, quorum sensing and multi-omics responses constitute the "intersection hub" of the two pollutant removal pathways. On the one hand, QS signal molecules such as acyl-homoserine lactones (AHLs) secreted by bacteria accumulate with population density, regulate the expression of genes related to extracellular polysaccharide synthesis, promote microbial agglomeration and granulation, and thereby simultaneously strengthen EPS-mediated organic matter interception and microplastic adsorption [11]; the second messenger c-di-GMP regulates the transition of bacteria from a motile state to an attached state, promoting their colonization and film formation on organic matter particles and microplastic surfaces [11]. On the other hand, the plastisphere formed on microplastic surfaces has an independent microbiome structure and signal environment, and QS-mediated horizontal gene transfer can promote the enrichment and expression of plastic-degrading enzyme genes (such as PETase homologous hydrolases and alkane hydroxylase genes) in biofilm microbial communities [16, 17]. Metatranscriptomic studies have shown that under the conditions of carbon source stress and microplastic coexistence, genes related to carbon metabolism and material transport show co-upregulation with hydrolase and oxidase genes related to plastic degradation, indicating that the system has carried out coordinated resource allocation for the removal of the two types of pollutants at the transcriptional level [15, 16]. Based on this, a three-

DOI: 10.54254/2755-2721/2027.MA39150

layer coupling model of "metabolism-signal-community" can be proposed: the bottom layer is the metabolic flow (carbon source, enzymes, oxygen) shared by organic matter and microplastics, the middle layer is QS/c-di-GMP-mediated signal regulation, and the top layer is the reshaping of the algal-bacterial and plastisphere community structures; the three layers feed back on each other and jointly determine the coupled removal efficiency.

5.4. Factors influencing the pollutant removal efficiency of the algal-bacterial coupling system

The efficiency of the simultaneous removal of organic matter and microplastics by the algal-bacterial symbiosis system is jointly constrained by biological factors, pollutant characteristics and environmental conditions; the main influencing factors and regulation directions are shown in Table 1.

Table 1. Factors influencing pollutant removal efficiency of the algal-bacterial coupling system

Factor category	Key elements	Effect on organic matter degradation	Effect on microplastic removal	Regulation direction
Algal-bacterial combination and ratio	Algal species (Chlorella, Scenedesmus, etc.), functionally degrading bacteria, inoculation ratio	Determines the oxygen production-consumption balance and mineralization efficiency	Affects EPS yield, flocculability and plastisphere community composition	Select algal-bacterial combinations according to water quality and optimize the inoculation ratio [1, 2, 9]
Physicochemical properties of microplastics	Polymer type, particle size, shape, surface charge, aging degree	Stimulation at low concentrations and inhibition at high concentrations of EPS and algal activity	Small particle sizes and hydrophobic polymers are more easily adsorbed and captured by EPS	Control the influent microplastic load below the threshold concentration [4, 13, 18]
Influent substrate characteristics	COD level, carbon-nitrogen ratio, organic matter composition, hydraulic retention time	Low carbon sources drive the internal cycle; too low leads to decreased activity	Determines EPS secretion and the abundance of the capture matrix	Maintain an appropriate carbon source and ensure the stable synthesis of EPS [2, 9]
Environmental conditions	Light intensity and photoperiod, temperature, pH, dissolved oxygen, shear force	Affects photosynthetic oxygen production and microbial metabolic rates	Changes biofilm aging and enzymatic hydrolysis rates	Optimize light and temperature conditions and avoid strong shear destroying particles [2, 9, 18]
Operation and disposal methods	Granular sludge retention time, sludge discharge method, sludge disposal	Affects the granulation process and system stability	Determines the final fate of captured microplastics	Discharge sludge reasonably and standardize sludge disposal to prevent secondary release [3, 4]

6. Conclusions and prospects

In the treatment of low-concentration organic wastewater, algal-bacterial symbiosis relies on the material cycle of "oxygen production by algal photosynthesis-carbon mineralization by bacteria" to achieve deep purification under low-carbon source conditions; the removal of microplastics is advanced step by step through EPS physical capture, surface biofilm colonization and aging, and

DOI: 10.54254/2755-2721/2027.MA39150

extracellular enzymatic hydrolysis and mineralization. The core conclusions of this paper are as follows:

(1) Organic matter degradation and microplastic removal achieve positive coupling through the shared EPS matrix, extracellular enzyme systems and the photosynthetic oxygen supply system: organic matter metabolism provides a "capture matrix-degrading enzyme-dissolved oxygen" triple support for microplastic capture and degradation.

(2) The effect of microplastics on organic matter degradation efficiency shows a threshold regulation characteristic of "promotion at low concentrations and inhibition at high concentrations": moderate microplastics stimulate EPS secretion and functional microbial enrichment, while exceeding the threshold leads to particle disintegration and performance decline through shading, oxidative damage and the quenching of EPS components.

(3) AHLs/c-di-GMP-mediated quorum sensing and plastisphere microbiome reshaping constitute the molecular regulation hub of the two removal pathways, and the three-layer coupling model of "metabolism-signal-community" can provide a theoretical framework for the targeted enhancement of the system.

Future research should be deepened in the following directions: first, develop in-situ quantitative characterization methods for microplastic-organic matter coexistence systems, analyze the dynamic coupling relationship between the removal of the two pollutants in the aggregate micro-zones, and make up for the shortcomings of existing "dosing-detection" style research in spatiotemporal resolution; second, based on omics and QS signal regulation, directionally strengthen functional microbial communities and EPS component synthesis, and at the same time keep the influent microplastic load below the threshold through operating parameter optimization, realizing the active regulation of coupled removal efficiency; third, pay attention to the secondary release of microplastics and the risk of resistance gene transmission in the sludge disposal stage of granular sludge, and establish a full-chain technical specification of "water phase purification-safe sludge disposal"; fourth, promote the pilot verification and engineering application of algal-bacterial granular sludge technology in the advanced treatment of tailwater and the remediation of compound polluted water bodies, forming replicable design parameters and evaluation standards.

References

[1] Lu, L., Ma, J. Y., Chu, H. Q., et al. (2023). Research progress of new technologies for wastewater treatment and resource recovery based on bacterial-algal symbiosis. *Energy Environmental Protection, 37*(2), 156-167.

[2] He, Z. M., Chen, Z. P., Yu, S., et al. (2025). Application status and technical challenges of algal-bacterial symbiosis wastewater treatment technology. *Energy Environmental Protection, 39*(1), 73-86.

[3] Xing, W., Liu, M. Y., Li, D., et al. (2021). Removal efficiency and whole-process analysis of microplastics in wastewater treatment plants: A case study of a sunk three-stage wastewater treatment plant in Beijing. *China Environmental Science, 41*(3), 1140-1147.

[4] Chai, Y. R., Xu, H. J., Gao, K. X., et al. (2024). Separation and removal of microplastics in water treatment processes and research progress. *Environmental Science, 45*(10), 6112-6128. DOI: 10.13227/j.hjkx.202309240.

[5] Ndrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin, 62*(8), 1596-1605.

[6] Yang, H. Y., He, X., Li, X. Q., et al. (2025). Microplastic pollution in wastewater treatment plants and its influence on water treatment processes. *Safety and Environmental Engineering, 32*(1), 41-51, 61.

[7] Cunha, C., Silva, L., Paulo, J., Faria, M., Nogueira, N., & Cordeiro, N. (2020). Microalgal-based biopolymer for nano- and microplastic removal: A possible biosolution for wastewater treatment. *Environmental Pollution, 263*, 114385.

[8] Hu, H. Y., Li, X., & Yang, J. (2009). Coupling technology of advanced water purification and high-value biomass production based on microalgal cell culture. *Ecology and Environmental Sciences, 18*(3), 1122-1127.

[9] Jia, X. T., He, X. J., Feng, J. M., et al. (2022). Condition exploration and optimization of purifying wastewater treatment plant tailwater by a bacterial-algal symbiosis system. *Journal of Environmental Engineering Technology,*

DOI: 10.54254/2755-2721/2027.MA39150

12(4), 1177-1184.
[10] Flemming, H. C., & Wingender, J. (2010). The biofilm matrix. *Nature Reviews Microbiology, 8*(9), 623-633.
[11] Cui, L. H., & Wan, J. F. (2021). Research progress of N-acyl homoserine lactone (AHLs)-mediated quorum sensing effect in aerobic granular sludge. *Microbiology China, 48*(2), 627-636.
[12] Xie, Y. Y., Ji, K. F., Jing, J., et al. (2016). Treatment of wastewater treatment plant tailwater by a membrane-high rate algal pond process. *Technology of Water Treatment, 42*(6), 67-70.
[13] Cheng, Y. R., & Wang, H. Y. (2022). Highly effective removal of microplastics by microalgae Scenedesmus abundans. *Chemical Engineering Journal, 435*, 135079.
[14] Mei, D. Y., Feng, X. L., Li, J., et al. (2026). Fungal-microalgal symbiont technology and its research progress in wastewater treatment. *Chinese Journal of Biotechnology, 42*(1), 1-9. DOI: 10.13345/j.cjb.250551.
[15] Ru, J., Huo, Y., & Yang, Y. (2020). Microbial degradation and valorization of plastic wastes. *Frontiers in Microbiology, 11*, 442.
[16] Fan, X., Kong, L., Wang, J., Tan, Y., Xu, X., Li, M., & Zhu, L. (2024). Surface-programmed microbiome assembly in phycosphere to microplastics contamination. *Water Research, 262*, 122064.
[17] Yoshida, S., Hirga, K., Takehana, T., et al. (2016). A bacterium that degrades and assimilates poly(ethylene terephthalate). *Science, 351*(6278), 1196-1199.
[18] Wang, Q., Huang, J., Gu, S., et al. (2025). Microplastics reshape frozen algal-bacterial granular reactivation: Decoding structural collapse and microbial drivers of nutrient removal. *Bioresource Technology, 432*, 132672.