

Application of algae in wastewater treatment

Zhouyan Zhang *

International school of engineering, Tianjin Chengjian University, Tianjin, China

* Corresponding Author Email: 84936@student.pb.edu.pl

Abstract. Nowadays, water contamination has become one of the most significant environmental issues. The creation and use of algal biotechnology with less investment, good effect and low operating cost has garnered a lot of attention. With the ongoing development of numerous new water treatment technologies, low-cost and effective ecological governance systems have been created quickly. Its purpose is to improve the sewage purification process by improving the inorganic process of organic matter, accelerating the expansion and multiplication of microorganisms, enhancing the metabolic function of microorganisms, and promoting the proliferation of microorganisms. In this article, the removal of nitrogen, phosphorus, heavy metals, antibiotics, pathogens and pesticides by algae was introduced. Additionally, typical algae systems including immobilized algae systems, algal-bacterial symbiotic systems and combination high-rate algae pond systems used in sewage treatment and the limitations and prospects of algae technology were discussed. Algal wastewater treatment is more effective in removing nitrogen and phosphorus than conventional activated sludge processes. Aquaculture wastewater, industrial drainage, municipal sewage, and other distinct forms of water treatment processes can all benefit from the simultaneous transformation and removal of nitrogen, phosphorus, sulfur, refractory organic matter, and heavy metals in sewage that is made possible by algae technology. Engineering techniques and technological advancement will be used to create high-efficiency microalgae wastewater treatment reactors, optimize conditions, increase the utilization efficiency of microalgae biological resources, and apply microalgae to wastewater treatment, which will have a significant impact on water quality and economy.

Keywords: Algae technology; microalgae; sewage treatment.

1. Introduction

The ability of the aquatic environment to transport pollutants is severely hampered by the social economy's fast growth and the ongoing rise in diverse pollutant emissions. Relevant statistics show that as of 2020, the total amount of sewage discharged nationwide, chemical oxygen demand (COD) emissions were 25,647,600 tons, ammonia nitrogen emissions were 984,000 tons, total nitrogen emissions were 3,223,400 tons, and total phosphorus emissions were 336,700 tons [1]. At the same time, there are many problems in China's water pollution control process, such as high energy consumption and cost, heavy secondary pollution and so on, From 2012 to 2016, investment in drainage in environmental pollution control increased year by year, from 93.41 billion yuan in 2012 to 148.55 billion yuan in 2016 [1]. How to reduce energy consumption and cost in the process of water pollution control, and break through the technical bottleneck of related processes, has become one of the key tasks in the environmental field.

Ecological treatment technology and bio-ecological composite technology have received a lot of attention due to their advantages in terms of reduced building costs, low energy consumption, high ecological value and strong processing capacity. To sustain the communities of bacteria that break down pollutants and remove nutrients from the wastewater, various kinds of environments and animals can be made use of by biological treatment plants for wastewater, such as some animals like worms and mollusks, aquatic plants and algae. Among them, the algae system benefits from the abundance of algae, their rapid development, their excellent environmental adaptation and low system cost, and plays a great role in the application of cheap wastewater treatment [2].

Algae have efficient nitrogen and phosphorus removal capabilities, and they rely on functional groups on their cell surfaces to adsorb heavy metals [3, 4]. Oswald and colleagues proposed using the microalgae biological system as an alternative to activated sludge in sewage treatment in 1957. Since

then, algal sewage biological treatment technology has been built on its base and the use of mixing bacteria with algae has drawn increasing interest [3]. The “Active Algae” method was proposed by M cgriff in 1971, and this method combined algae with activated sludge thus making algae have the same function of flocculation and sedimentation performance as activated sludge, and then sewage water is treated in a process similar to activated sludge. Thus, 92% and 94%, respectively, of nitrogen and phosphorus are removed from sewage. [3]. Along with the aforementioned physiological traits, microalgae may also produce microalgae biomass and realize the resource utilization of sewage in addition to removing contaminants from sewage.

This article will discuss the limitations and future of algae technology as well as the removal of nitrogen, phosphorus, heavy metals, antibiotics, pathogens, and pesticides by algae. It will also introduce some algae systems, such as the immobilized algae system, the algal-bacterial symbiotic system, and the combination high-rate algae pond system.

2. Removal of Pollutants in Sewage by Algae

The most common pollutants in sewage are nitrogen, phosphorus, heavy metals, pathogens and pesticides, these pollutants can be removed by algae effectively.

2.1. Removal of Nitrogen and Phosphorus

Nitrogen and phosphorus molecules that contribute to eutrophication can be effectively removed by algae. Wang [5] found *Monoraphidium* sp. HDMA-01 has the potential to be applied to the treatment of high ammonium wastewater. Through photosynthesis, algae may join inorganic ions like H_2PO_4^- , NH_4^+ and NO_2^- in sewage with nutrients like N and P found in organic materials like urea to create algal cells [5]. Additionally, it can link exogenous compounds like heavy metals, which not only remove nutrients from sewage but also encourage the circulation of N, P, and other elements, boost biomass, and provide greater economic value [5]. Zhou et al. [6] used a two-stage approach to investigate the treatment effect of *auxenochlorella prototheoridis* UMN280 on municipal sewage, the rates of elimination of UMN280 for total nitrogen and total phosphorus were 90.60% and 98.48%, respectively.

2.2. Removal of Heavy Metals

The processes of biosorption, bioaccumulation, and biotransformation can be used by microalgae to get rid of heavy metals from water, for example Fe, Zn and Mn [4]. These heavy metals can be viewed as trace components for the metabolism of cells and the enzyme function of microalgae [4].

Groupings of functions on the cell wall enable the biological adsorption of heavy metals by live microalgal cells [5]. It is possible to build coordination complexes with heavy metal cations by combining macromolecular components of microalgae's cell wall, which carry a range of charged groups and give their surfaces a negative charge. According to research by Blanco-Vieites et al. [5], *Arthrospira maxima* may remove up to 97.9% of the total iron in wastewater.

2.3. Removal of Antibiotics

Hospitals, living wastewater, and pharmaceutical wastewater are the main sources of antibiotics in urban wastewater [7]. Wang et al. [5] considered that it is anticipated that microalgae will be used to treat antibiotics in wastewater since they have been found to have a removal impact on the majority of antibiotic kinds. The types of algae are a major factor in the rate of antibiotic removal and *chlorella* is particularly efficient in removing a variety of antibiotics [7]. Leng et al. [7] indicated that microalgae respond in a variety of ways when exposed to antibiotics to live and eliminate the harmful drugs. Antibiotics may be removed by accumulation, adsorption, and some other methods, which are shown in Figure 1 [7]. After 24 hours of treatment with *C. pyrenoidosa*, Xiao et al. [5] discovered that the clearance rate of cefaladine had increased to 41.47%.

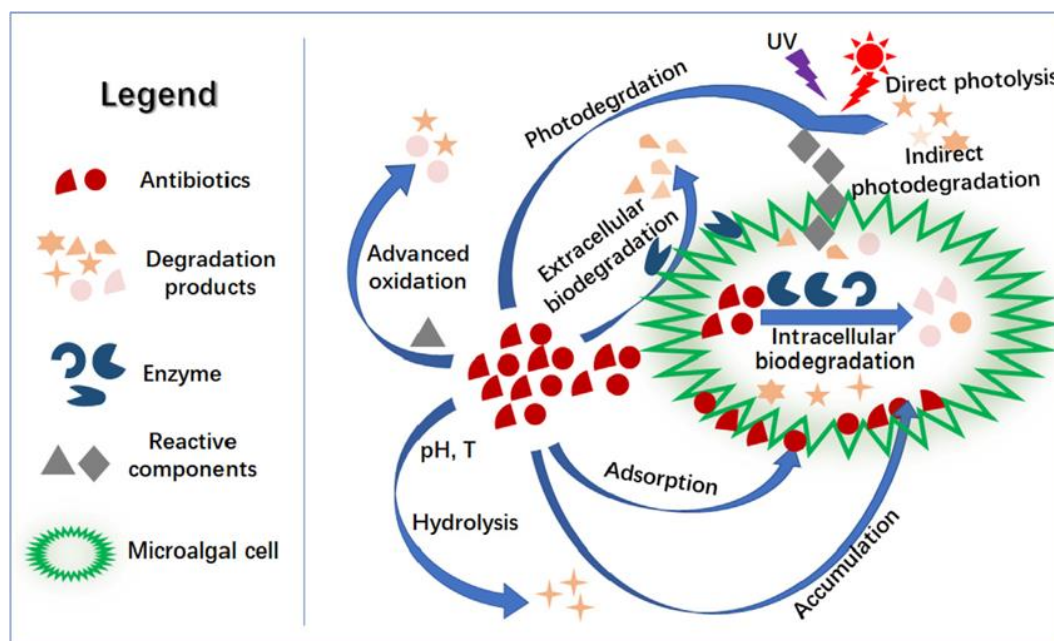


Fig 1. Antibiotic degradation and detoxification mechanisms by microalgae [7].

2.4. Removal of Pathogens

Microalgae develop by ingesting the nutrients and carbon sources that are the main sources of energy for bacterial cells. Bacterial cells will starve and eventually die off as a result of the fight for resources between microalgae and bacteria [8]. Mezzari et al. [9] indicated that a microalgae species called *Scenedesmus* sp. was discovered to be able to eradicate *Salmonella enterica* in his experiment. In the presence of microalgae, *S. enterica* was shown to be completely eradicated within 48 hours of treatment, while in the absence of microalgae, its concentration increased to 1.5 log CFU mL⁻¹ in 96 hours [9].

2.5. Removal of Pesticides

Microalgae offer huge economic and safety advantages in pesticides removal. Through biosorption and biodegradation, microalgae can use a variety of organic contaminants, including pesticides, as a source of energy for their development in wastewater. Biosorption encompasses the processes of absorption, adsorption, surface complexation, ion exchange, and precipitation in the cell walls of both living and dead cells. Biodegradation occurs when microalgae create enzymes that break down the bonds between the pesticide molecules [9]. By the research by Chai [8], *Chlorella vulgaris* was subjected to cyprodinil in two experiments: a short-term biosorption assay lasting 60 minutes, and a long-term biodegradation experiment lasting four days. The experiment's results show the levels of pesticides that persisted even after coming into touch with *Chlorella vulgaris*. Successful elimination is indicated by the cyprodinil insecticide's lowest levels, both in the short and long term.

3. Algal Systems

For the removal of several kinds of pollutants using alga, three of the most popular algal systems, including immobilized algae system, algal-bacterial symbiotic system, and combination high-rate algae pond system will be introduced. Those systems can not only significantly increase the removal efficiency of some pollutants like ammonium, nitrate, phosphorus and specific bacteria but also make the treatment of algae treatment more functional.

3.1. Immobilized Algae System

Immobilization technology is an emerging bioengineering technology that is extensively employed in the field of microbiology. The ecological benefits of biofilms can be duplicated by artificial microalgal immobilization, which can also remove nutrients (such as ammonium) from wastewater [10]. However, without immobilization, it is difficult to extract microalgal cells from treated wastewater, which severely restricts the purification of effluent using microalgae.

Nowadays, the three primary ways of regularly used immobilization technology are the adsorption method, embedding method, and coupling method. The two primary types of matrix currently employed for microalgal immobilization are synthetic and natural carriers [10]. The attachment of microalgal cells to these two carriers may be mediated via chemical binding, electrostatic adsorption, hydraulic impact, or natural gravity [10]. Scaffold materials made of natural biomass provide additional choices. The biomatrix, also known as the biomass-derived natural carriers, often consists of loofah, maize cobs, pine bark, sugarcane bagasse, or fragments of cotton fabric [10]. These organic materials have an open network of fibrous support that enables them to readily connect microalgal cells and subsequently create an effective immobilization system [11]. They are particularly appealing because of their large void volume, permeability, and inexpensive price. In a loofa sponge, Saeed [11] demonstrated that immobilized cells performed better in terms of growth than suspended cells. Additionally, the loofa-immobilized cell systems can treat a wide range of contaminants, including colors, inorganic/organic waste, heavy metals, and chlorinated chemicals [11]. What's more, after wastewater treatment, the immobilized biomass inside the matrix may be entirely converted into value-added products such as alcohols, organic acids, enzymes, and secondary metabolites [11].

The creation of less costly carriers, the choice of more productive algae species, the development of immobilization techniques, and the design of bioreactors appropriate for wastewater treatment will all be the focus of future studies on the purification of wastewater using immobilized algae.

3.2. Algal-bacterial Symbiotic System

Biological oxidation is the main and most basic energy supply mode for algae. Through photosynthesis, algae add oxygen to the water, raising the dissolved oxygen level so that aerobic microorganisms may continue to break down organic materials. Algae use fungi to degrade CO_2 produced by organic matter, so in the process of purifying water quality, algae and fungi are complementary to each other, called algal symbiosis. Figure 2 [12] depicts a simplified illustration of the symbiotic connection between bacteria and algae.

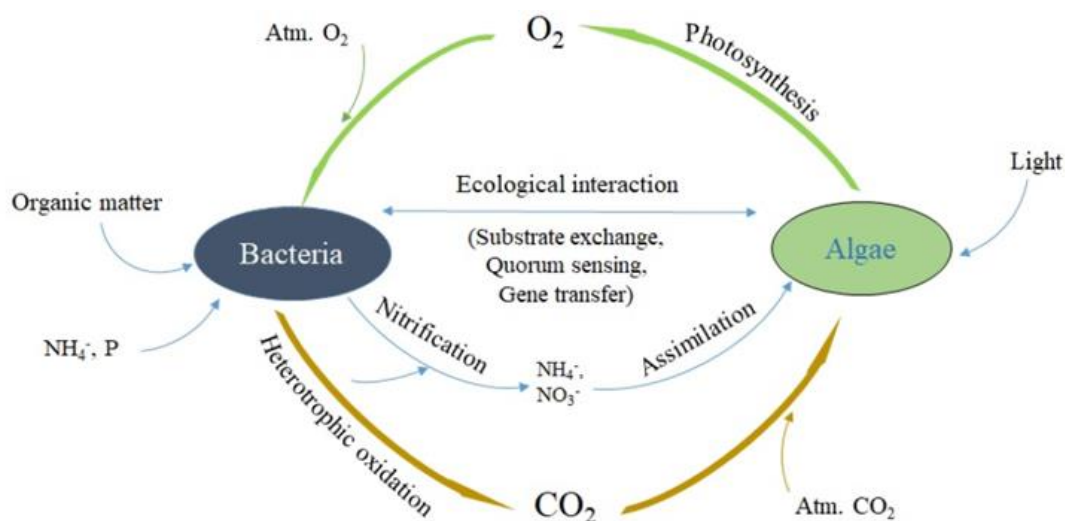


Fig 2. Schematic representation of algal-bacterial symbiosis [12].

It has been demonstrated that the symbiotic connection between bacteria and algae improves the removal efficiency. In Ca-alginate beads, researchers immobilized both *Chlorella* and *Azospirillum Brasiliense* (a kind of bacterium that supports microalgae development) [13]. This bacterium

promotes the development of immobilized algae but is unable to extract nutrients from wastewater. The removal rate of ammonium, nitrate, and phosphorus by immobilized algal cells alone were 75%, 6%, and 19%, in comparison, the share increased dramatically if a co-immobilized biological system was introduced (100% ammonium, 15% nitrate, and 36% phosphorus) [13].

Technologies based on algae and bacteria provide a workable and sustainable ecological strategy for environmental conservation. However, the area of algal-bacterial co-culture for sustainable biotechnological applications remains understudied. To determine the economic viability and scalability of algal-bacterial consortia in environmental control and to enable wider industrial use instead of lab-scale trials, careful optimization and assessment are necessary [12].

3.3. High-rate Algae Pond System

While researching the use of algal biomass for wastewater treatment in the middle of the 20th century, high-rate algae pond systems (HRAPs) were created at the University of California [14]. Open raceway ponds are different from other pond systems, because they strive to raise their algal biomass concentration to improve wastewater treatment effectiveness, and this kind of pond is called "High-rate Ponds" [14].

HARP can eliminate bacteria and pathogens effectively. Sherif Abd-Elmaksoud et al. [15] indicated that bacterial indicators showed a decrease of 5.6 log₁₀, and viral markers showed removals of 0.88 to 1.65 log₁₀. *Giardia intestinalis* and *Cryptosporidium* spp. genes had average clearances of 2.42 log₁₀ and 0.52 log₁₀, respectively [15]. It's intriguing to notice that all parasitic helminth eggs were effectively removed by the integrated system from the treated wastewater, demonstrating that this technology may be able to reduce the exposure of pathogens for people safely.

4. Limitations and Perspective of Algae Technology

4.1. Limitation

Based on the physiological and biochemical traits of microalgae, the use of microalgae for sewage treatment can efficiently remove pollutants such as COD, nitrogen, phosphorus, sulphate and heavy metals in sewage, and at the same time obtain the improvement of microalgae biomass, which is an efficient, cheap and ecologically valuable treatment method, and is also a new direction for the development of new technologies in the field of sewage treatment in the future. However, the current study also has many problems, which are summarized below.

For one thing, the research on the removal and absorption mechanism of sulphates, antibiotics and other pollutants in sewage by microalgae is still insufficient, and there is still a certain distance from the large-scale industrial application of microalgae to treat all kinds of sewage [8].

For another, more research has been done recently on using microalgae to remediate industrial effluent, but the scope of research on the influencing factors is not enough to meet, the reality of industrial wastewater, such as the pH value of the wastewater under examination is mostly neutral, the temperature is mostly room temperature, and the more extreme environmental conditions have not been systematically investigated.

Finally, microalgae are highly effective at treating sewage with high nitrogen and phosphorus content from agriculture, aquaculture, and municipalities, and they can grow in sewage, but there is not enough research on how to use the treated microalgae, making it impossible to effectively address the challenge of utilizing microalgae as a biological resource.

4.2. Future Perspective

Firstly, aiming at the types of sewage that can be treated by microalgae technology at present, establish a microalgae treatment sewage process with low production cost and simple technical model, develop new reactor equipment, materials for microalgae cultivation, etc., to obtain stable, cheap, and highly targeted microalgae reactor.

Secondly, develop corresponding microalgae harvesting, dehydration, and resource utilization technologies to solve the current high cost of microalgae recovery, and the difficulty in waste microalgae treatment and corresponding pollutant recovery after treatment of different water quality sewage and pollutants.

Thirdly, further integration and optimization of processes and systems to make them more economically efficient and environmentally sustainable. Through technical means to continuously improve the adaptation range of microalgae sewage treatment systems to different sewage and pollutants, and use engineering methods and technological innovation to develop design and conditions optimization of high-efficiency microalgae sewage treatment reactors, improve and improve the biological resource utilization efficiency of microalgae, and apply microalgae to sewage treatment, there will be broad development space and huge economic benefits.

5. Summary

Current and available experiments have shown that the application of algae to remove nitrogen, phosphorus, heavy metals, antibiotics, pathogens, and pesticides from different types of sewage is practical and feasible, which is ecologically significant and has broad prospects. In this article, the removal of pollutants by algae and three typical algae systems were introduced. Algae can effectively remove nitrogen, phosphorus, heavy metals like Fe, Mn and Zn, pathogens, pesticides, and chlorella are particularly efficient in removing antibiotics. Algae technologies including immobilized algae systems, algal-bacterial symbiotic systems and combination high-rate algae pond systems can not only increase the removal efficiency of pollutants but also have the potential to act as a replacement for traditional wastewater treatment methods like activated sludge sedimentation techniques.

Besides, some algal systems have been proven to treat wastewater much more effectively in the laboratory. However, more research has shown that the sewage treatment technology of microalgae is still immature, temperature, water pH, light, and oxygen concentration, restrict the application of microalgae. Compared with activated sludge, its relative fragility has higher requirements for the treatment environment. Domestic technology is still in the laboratory research stage, has not made breakthroughs, and has not been in large-scale application in production. In the future, the development of cheap and stable carriers, the development of efficient and large-scale bioreactors, and the research of integrated systems combining algae sewage purification systems with other sewage treatment processes will be hot spots in this field.

References

- [1] Liu Aihua, Ye Zhihua. Yearbook of Statistics in China. Chinese People's Republic National Bureau of Data, 2020.
- [2] Chang Yayue. Selection and application demonstration of biological and ecological combination technologies for rural domestic sewage treatment. Shanghai: East China Normal University, 2018.
- [3] Wu Wei, Liu Lei, Huang Kui, et al. Research status and development trend of using algae to remove nitrogen and phosphorus from sewage at home and abroad. Jiangxi Science, 2007, 25(1): 47-50.
- [4] Leong Y K, Chang J S. Bioremediation of heavy metals using microalgae: Recent advances and mechanisms. Bioresource technology, 2020, 303: 122886.
- [5] Wang Meiqi, Ping Wenxiang, Ge Jingping, et al. Research progress of microalgae-based water remediation and biomass recycling and reuse. Journal of Microbiology, Acta Microbiologica Sinica, 2022, 62(12): 4756-4768.
- [6] Zhou W, Min M, Li Y, et al. A hetero-photoautotrophic two-stage cultivation process to improve wastewater nutrient removal and enhance algal lipid accumulation. Bioresource technology, 2012, 110: 448-455.
- [7] Leng L, Wei L, Xiong Q, et al. Use of microalgae-based technology for the removal of antibiotics from wastewater: A review. Chemosphere, 2020, 238: 124680.

- [8] Chai W S, Tan W G, Munawaroh H S H, et al. Multifaceted roles of microalgae in the application of wastewater biotreatment: a review. *Environmental Pollution*, 2021, 269: 116236.
- [9] Mezzari M P, Prandini J M, Kich J D, et al. Elimination of antibiotic multi-resistant *Salmonella typhimurium* from swine wastewater by microalgae-induced antibacterial mechanisms. *J. Bioremediat. Biodegrad*, 2017, 8: 379.
- [10] Han M, Zhang C, Ho S H. Immobilized microalgal system: An achievable idea for upgrading current microalgal wastewater treatment. *Environmental Science and Ecotechnology*, 2022, 100227.
- [11] Saeed A, Iqbal M. Loofa (*Luffa cylindrica*) sponge: Review of development of the biomatrix as a tool for biotechnological applications. *Biotechnology Progress*, 2013, 29(3): 573-600.
- [12] Oruganti R K, Katam K, Show P L, et al. A comprehensive review on the use of algal-bacterial systems for wastewater treatment with emphasis on nutrient and micropollutant removal. *Bioengineered*, 2022, 13(4): 10412-10453.
- [13] Moreno-Garrido I. Microalgae immobilization: current techniques and uses. *Bioresource technology*, 2008, 99(10): 3949-3964.
- [14] Young P, Taylor M, Fallowfield H J. Mini-review: high-rate algal ponds, flexible systems for sustainable wastewater treatment. *World journal of microbiology and biotechnology*, 2017, 33: 1-13.
- [15] Abd-Elmaksoud S, Abdo S M, Gad M, et al. Pathogens removal in a sustainable and economic high-rate algal pond wastewater treatment system. *Sustainability*, 2021, 13(23): 13232.