Research progress and application of photobioreactor in wastewater treatment

Yingtian Xiao [1, 2, 3, *] , Yuhu Luo [1, 2, 3]

[1] Shaanxi Provincial Land Engineering Construction Group Co., Ltd. Xi'an 710075, China
[2] Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd. Xi'an 710075, China
[3] Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an 710075, China.

Abstract. The first photobioreactors were born in the 1950s, and photobioreactors based on microalgae have potential applications in the pharmaceutical industry, food and feed production, environmental engineering, wastewater treatment, and renewable energy. Photobioreactors were first used in pollutant treatment for carbon dioxide sequestration in 1953 at the Carnegie Institute in Washington. Photobioreactors use stable and efficient algae cultivation technology to create an artificial environment that provides all necessary conditions for algae growth such as (light, temperature, nutrients), and these conditions can be controlled and monitored, especially for microalgae cultivation, It is convenient for the rapid, stable and controllable growth of microalgae. Currently, there are many types of microalgae-based photobioreactors in terms of configuration, fabrication materials, and operating modes. It can optimize biomass production, improve the efficiency of pollutant removal, reduce cost and improve space advantage. The most common structures for photobioreactors are flat, columnar and tubular, followed by hoses and hybrid photobioreactors, taking their flexibility and efficacy to a higher level. Each photobioreactor type has its own advantages and disadvantages in terms of operation, biomass production, pollutant removal efficiency, and level of upgrade.

key word: Reactor; sewage treatment; photoreaction

1. Types of Photobioreactors

Photobioreactor is an emerging bioreactor for large-scale microalgae cultivation and sewage treatment based on the photosynthesis and growth and proliferation ability of microalgae using light, carbon dioxide and nutrients in water. The photobioreactor provides an environment suitable for the growth and proliferation of microalgae in it, and in practical applications, it has the advantages of simple equipment management and operation, low input cost, and large and rapid production of microalgae [1].
The types of photobioreactors, which have been applied at present, include flat plate photobioreactors, tubular photobioreactors, column photobioreactors, and bag photobioreactors. Among them, flat-plate photobioreactors are generally open-type reactors, and other types of photobioreactors are generally closed-type reactors.
Flat-plate photobioreactors are similar in shape to rectangular flat-plate containers, generally larger in area and lower in height. They have the advantages of short optical path, large illumination area, and fast gas-liquid mass transfer. Currently, they are mostly used for continuous wastewater treatment.
Tubular photobioreactors are generally tubular containers placed horizontally or vertically. The tube cross-sectional area is small, the tube length is generally long, and multiple sets of tubes are placed in parallel to improve light utilization. The aeration disturbance of the microalgae in the tube is mainly realized by the aeration pump. Due to its vertical liquid layout, the dissolved CO2 in the water will be unbalanced. In addition, the increase of the aeration stroke will also cause the water flow disturbance to be too large. The shearing of the microalgae force increases. At the same time, the narrowness of its structure also makes it difficult to clean the inside of the tube.
The column type photobioreactor is similar to the tubular type, generally placed vertically, the bottom area is relatively large, the length is shorter than the tubular type reactor, and it is a vertical cylindrical reactor.
The bag-type photobioreactor is generally used as a microalgae culture and recovery reactor.
Mixed photobioreactor in this paper refers to the above four kinds of photobioreactor or with other technologies (such as membrane technology) combined or integrated, so as to reduce the volume of the photobioreactor, higher biomass yield, better removal of pollutants. Hybrid photobioreactor was developed by using the advantages

* Corresponding author: 602885434@qq.com

of traditional photobioreactor. Soman and Shastri have come up with a new design that combines the advantages of a flat-plate and tubular photobioreactor. The tubular area is operated within a cylindrical core of a rectangular tube, while two surrounding baffles are connected to the tube and act as a flat plate structure. This type has a 7% surface-volume ratio and premium flow regime. The light/dark frequency is 0.14 Hz, which is superior to conventional light/dark frequency and reduces the operation and material cost for further optimization. Xu et al. proposed a capillary-driven photobioreactor, which could transport nutrients and water to polyester microfiber medium through capillary action, to overcome the limitation of biological harvest in traditional suspension culture, in view of the advantages of attachment culture over suspension culture in biomass harvest. Therefore, the reactor can obtain higher lipid and carbohydrate content, which is suitable for the production of biofuel.

Other innovative types of photobioreactors have also been developed to reduce reactor size and maximize biomass production. These designs and techniques are suitable for different geographical locations. Dogaris et al. developed a floating horizontal photobioreactor on a plastic film in a modular configuration. It involves attaching two layers of plastic film to the upper and lower surfaces of the photobioreactor, which seal each other, and having two vertical airlifts attached to the film. Pruvost et al. realized high capacity performance of thin-film photobioreactor in fermentation process. The thin culture layer (1.5-2 mm) provides up to 500 m^2/m^3 light area by strengthening mechanism. Similarly, adding the light guide plate modified by silica chitosan medium to the photobioreactor can increase the yield of bio-hydrogen.

The combination of biofilm and photobioreactor is called membrane photobioreactor. For example, Chang et al. designed an ion-exchange membrane photobioreactor, which divided the source of wastewater and microalgae into different chambers. N^+ and P^{6+} entered the microalgae chamber through the ion-exchange membrane. The design mitigated the negative effects of pollutants in wastewater on microalgae growth. However, the high cost of ion exchange membrane is the main restriction factor of its application, and membrane fouling is the main technical problem of membrane photobioreactor. In recent years, the research on how to treat membrane fouling is more and more in-depth. For example, the fouling rate of ceramic membranes was found to be more significant at 6.5 h HRT than at 24 h and 72 h HRT, and the combination of microalgae and sludge bioremediation mitigated the fouling of hollow fiber membranes. The oxygen released by algae photosynthesis reduces the mortality rate of bacteria, thus alleviating membrane pollution. In terms of large-scale application, Viruela et al. produced a membrane photobioreactor consisting of a flat plate photobioreactor and a fiber ultrafiltration membrane. In addition, Sheng et al. also established a photobioreactor method to treat secondary effluent wastewater.

The utilization and combination of membrane and photobioreactor technology can significantly improve the efficiency of nutrient removal. The removal of TN and TP from secondary effluent by biofilm photobioreactor reached 82.5% and 85.9%, respectively, and the removal rate was higher than that of conventional photobioreactor. The membrane photobioreactor can also trap microalgae, so the concentration of suspended solids in effluent is lower. In another study, the removal rate of TN and TP in aquaculture wastewater by hollow fiber microfiltration membrane photobioreactor designed by Gao et al reached 86.1% and 82.7% respectively. Ammonia concentration in effluent water is as low as 0.002 mg/L. Then, by adjusting HRT and biomass residence time to 2 d and 21.1 d, respectively, the operation of the membrane photobioreactor was optimized, and the removal efficiency of TP was increased to 90.8%.

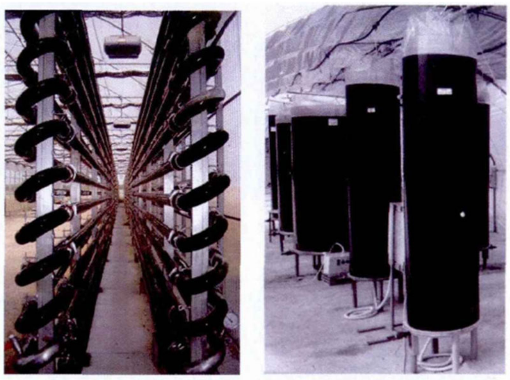

Figure 1 Tubular photobioreactor and column photobioreactor

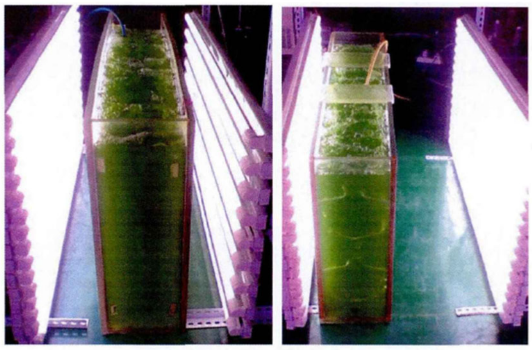

Figure 2 Flat-plate photobioreactor

2. Current Status of Photobioreactor Treatment of Wastewater

In the practical application of photobioreactors, the focus is on improving the utilization rate of light and CO2, which can easily complete the work of adding substances and recovering finished products. In the photobioreactor cultivation of microalgae, the main consideration is to avoid the adherent growth of microalgae It is necessary to adapt to the large-scale and high-density cultivation trend of microalgae. When treating wastewater in a photobioreactor, the main consideration is the aeration rate disturbance and the reduction of the treatment efficiency caused by the anaerobic dead space of the reactor.

Photobioreactor wastewater treatment is mainly for eutrophic water body remediation and industrial sewage treatment. In photobioreactor eutrophic water body restoration, it is mainly used in the treatment of aquaculture, animal husbandry and domestic wastewater Animal feed, feces and urine contained in wastewater contain high concentrations of N, P and organic pollutants. Discharge into the natural ecological environment will cause a large number of algae and other substances in the natural water body, resulting in a significant decrease in the dissolved oxygen content of the water body[2]. This in turn leads to the death of a large number of aquatic animals and affects the natural ecological environment. The use of microorganisms to treat aquaculture wastewater has matured in the current research, and the common activated sludge method is one of them.

Microalgae themselves exist widely in nature, and their diversity and strong adaptability to wastewater have become one of the basic bases for the study of microalgae in wastewater treatment. The basic biological structure of microalgae is an autotrophic and oxygen-releasing microorganism, which can utilize the organic matter in the wastewater while using light for its own light and effect. Coupled with its special growth requirements, the designed photobioreactor can provide it with sufficient light area and suitable aeration amount, so that the microalgae can perform photosynthesis more efficiently in the photobioreactor, thereby greatly improving the high concentration of organic matter. Efficiency of wastewater treatment[3 4].

In the treatment of industrial wastewater by photobioreactors, it is often used to treat toxic and harmful industrial wastewater such as coal chemical wastewater, so as to achieve the purpose of no secondary pollution in industrial wastewater treatment. Especially in the treatment of printing and dyeing industry wastewater, the use of photobioreactors can effectively degrade organic pollutants in printing and dyeing wastewater under the treatment of microorganisms in the reactor.

For example, in the research of Ying Jianguo et al., the column-and-column photobioreactor designed in the new bubbling column-type photobioreactor has the characteristics of easy enlargement, large illumination area and high culture density. The optimal ventilation volume of the designed photobioreactor is 0.2vvm. The reactor with a diameter of 10cm has a higher radial flow rate and a higher specific light rate than the reactor with a diameter of 15cm, and the cultured cell density reaches 1.56g/L[5].

In the study of Jian Enguang et al., it was found that the symbiotic system of Chlorella and bacteria and algae was used to treat the biogas slurry of the pig industry by using a laboratory plate to treat the biogas slurry of the pig industry under the light. -N and COD treatment efficiencies were 88.84%, 79.91%, 90.86% and 88.9%, respectively[6].

3. Development and Potential of Photobioreactors

Photobioreactors are widely used in the commercial production of microalgae products due to their high light utilization rate, large biomass in the container, and low water evaporation, and are important equipment for industrialized production of biotechnology products[7]. Microalgae products have received a lot of attention in the fields of animal bait, pharmaceutical production excipients, etc.

Today, as fossil fuels are the main energy source, the global greenhouse effect is becoming more and more intense. Among them, a large amount of CO2 emissions is the main culprit. However, the current treatment and absorption of CO2 rely on environmental protection catalytic treatment of emission sources on the one hand, and green environmental protection on the other hand. The photosynthesis of plants absorbs CO2 in the atmosphere, but generally speaking, it has the characteristics of high cost and slow effect. Therefore, the advantages of microalgae's photosynthetic reproduction, fast reproduction and large number have been optimized in the photobioreactor, and the application of using photobioreactor to cultivate microalgae to efficiently fix CO2 has great potential. In the study of Li Yongfu et al[8]. the use of flat-panel photobioreactors to fix high concentrations of CO2 in industrial flue gas has an obvious fixation effect.

Microalgae photobioreactors have also gradually attracted attention in research due to the cleanliness of energy use in fuel cells. Photobioreactor fuel cells convert the substances in organic wastewater through the biological metabolism of microorganisms to convert chemical energy into electrical energy, the organic wastewater releases electrons through the biological metabolic reaction in the anode chamber in the photobioreactor, and obtains a continuous current through the external circuit treatment. Its main energy products also include biodiesel, biogas and hydrogen[28].

4. Conclusion

Although the performance of photobioreactors is promising in laboratory and pilot-scale environments, industrial-scale photobioreactors still require a lot of research and improvement. Current research is carried out by research institutes and small private companies, so research for large-scale industrial applications is limited. However, as an environment- and energy-friendly strategy, the industrialization of photobioreactors has broad prospects.

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