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Application of Microalgae in Environmental Field

Wen Sun[1,2,3,4,5], Yang Zhang[1,2,3,4,5, *]

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

[2] Shaanxi Key Laboratory of Land Consolidation, Chang'an University, Xi'an, Shaanxi, China

[3] Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi'an, Shaanxi, China

[4] Key Laboratory of Degraded and Unused Land Consolidation Engineering, Ministry of Natural Resources, Xi'an, Shaanxi, China

[5] Land Engineering Quality Testing of Shaanxi Land Engineering Construction Group Co,, Ltd. , Xi'an, Shaanxi, China

Abstract

Microalgae have attracted extensive attention in biodiesel, wastewater treatment, food health care, medicine and other fields due to their advantages of short generation cycle, no competition with crops for cultivated land and rich in lipid, protein and polysaccharide.Especially in the current situation of accelerating urbanization and deepening industrialization, the combination of microalgae cultivation and pollution control can not only deal with wastewater and waste gas generated by human activities, but also accumulate lipid, protein and polysaccharide by microalgae themselves, so as to realize the purose of recycling waste resources.

Keywords

Microalgae; Environmental; Application.

1. Introduction

Microalgae are a diverse group of microorganisms that can survive in water, soil, air, bark and even some animals. Their growth capacity is vigorous and their generation cycle is short. Microalgal cells contain different types of cell walls, which are usually one or more layers of cellulose. The cells contain various organelles including nucleus, mitochondria, chloroplasts, Golgi apparatus, plasma membrane, contractile vesicles, endoplasmic reticulum, ribosomes, plastids, lipid globules, flagella and microtubules [1-3]. Microalgae are usually photosynthetic and require CO2, light, water, and essential nutrients to accumulate their own nutrients [4], and the synthesis pathways of the main intracellular components of microalgae. At the same time, different types of photosynthetic pigments (chlorophyll, carotenoids, and phycocyanin) can promote photosynthesis and mitigate the environmental impact of microalgae cells. Unlike plants, the growth of microalgae is not limited to arable and fresh water, but can grow on poor, arid, semi-arid, and polluted soils that cannot be used for conventional agricultural production [5]. In addition, they can be cultivated in brackish water and nutrient-rich wastewater; and their growth is not limited by seasons and can be harvested throughout the year [6].

2. Potential Applications of Microalgae

Due to the above characteristics of microalgae, research on microalgae ranges from wastewater treatment to genomic research, from agricultural production to aquaculture, from CO2 bioreduction to biofertilizer production, involving various fields such as environmental science, biology, genetics, chemistry, chemical industry, agronomy and aquaculture. The

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industrialization of microalgae mainly includes upstream, midstream and downstream processes. Upstream processing focuses on efficient cultivation of microalgae. Midstream processing aims at harvesting and drying microalgae biomass from the culture medium and destroying the cell walls of microalgae prior to the extraction process. Downstream processing aims at extracting and purifying the bioproducts from the microalgal biomass. Through upstream and midstream processing, the aim is to utilize the microalgae products for downstream production. Microalgae cells are of interest in the bioenergy sector due to their richness in oils and fats; in addition, some algae cells are rich in proteins, which can be used in fish and animal feeds; also, microalgae products can be used in the production of nutritional supplements and cosmetics due to their richness in polyunsaturated fatty acids and active ingredients.

2.1. Biodiesel

Currently, 80% of human energy demand is provided by fossil fuels. However, excessive use of fossil fuels releases large amounts of greenhouse gases, creating a greenhouse effect. However, given the current high rate of industrial development, it is clearly not feasible to slow down the use of fuels. Therefore, there is a need to find more environmentally friendly and green energy sources to replace fossil fuels and reduce the burden on the environment. Among the choices of environmentally friendly fuels, biofuels have received wide attention from both academia and industry. According to the raw materials used, biofuel production can be divided into four generations: the first generation of biofuels is represented by sugarcane for bioethanol production through sugar fermentation, or soybean or rapeseed for biodiesel production through ester exchange; the second generation of biofuels is mainly made from lignocellulose and agricultural waste; the third generation of biofuels is mainly made from microalgal biomass; in the fourth generation of biofuels, microalgae, yeast, and In the fourth generation biofuels, microorganisms such as microalgae, yeast and fungi have been genetically modified to improve photosynthetic efficiency, reduce photoinhibition, enable rapid growth, increase oil content, reduce the complexity of biological structure, and have wide commercial application value. However, first-generation biofuels are gradually withdrawn from the biofuel field due to food shortage and rising prices, while second-generation biofuels require large-scale investment in equipment and limited production, and do not completely replace fossil fuels. Fourth-generation biofuels are still in the early stages of development, and GMOs may also leak into the environment, posing the risk of environmental pollution [7].

As a third-generation biofuel, microalgae have the advantages of high photosynthetic efficiency, short growth cycle and no seasonal restriction, and their oil yield can exceed that of the best oil crops. For example, a 30% oil content microalgae can produce 58,700 l/ha of oil a year, compared to 2689, 1190 and 446 l/ha for coconut, rapeseed and soybean, respectively. Microalgae can also be cultivated in domestic sewage and industrial wastewater. In addition to providing nutrients to microalgae, wastewater can also promote the accumulation of microalgal biomass for fermentation to produce bioethanol and methane.

Despite the many advantages of microalgal fuels, their level of development is far behind traditional fossil energy sources in terms of theory, technology and industrialization. Compared with cellulosic biofuels, the steps of biodiesel production from microalgae are more complicated, generally including large-scale culture, harvesting, dewatering, oil extraction and biofuel conversion. The culture and harvesting processes account for 25-70% of the total cost of industrializing microalgae, and the subsequent processing steps account for 15-30%. The costs and end products of microalgae industrialization vary depending on the algal species, technology, composition and bioconversion process. Therefore, minimizing the energy input and reducing the production cost of biofuel products remains a challenge for current technology development.

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2.2. Wastewater Treatment

As mentioned earlier, the cost of microalgal biomass production limits the application of microalgal biodiesel, so combining microalgal culture with wastewater treatment can greatly reduce the economic investment in the microalgal culture process, which provides a cost-effective and sustainable means of wastewater treatment and biomass production for its industrial application. The growth of microalgae depends on the content and type of nutrients in the medium, and in addition to N and P, trace elements are also important for the growth of microalgae. Studies have proven that wastewater contains a large amount of organic and inorganic nutrients that can be used for microalgae culture. Compared to commonly used microbial wastewater treatment methods (e.g., anaerobic-anoxic- aerobic, A2/O), microalgae do not require additional organic carbon for the nitrification/denitrification step when removing nutrients from wastewater, which reduces the investment and operating costs of microalgae-based wastewater treatment processes to some extent. Unlike traditional photosynthetic autotrophy, organic carbon in wastewater offers the possibility of heterotrophy of microalgal cells, which has given rise to a new culture model - mixed culture. It was found that the total lipid, carbohydrate and protein contents of microalgae cells could be increased to 19.29%, 41.40% and 33.06%, respectively, under mixed culture. However, the selection of suitable algal species and optimization of the treatment process are the keys to the use of microalgae for wastewater treatment because of the wide variety of wastewater species and different treatment environments.

In general, microalgae are used in the treatment of municipal, agricultural, industrial and pharmaceutical wastewater. Among them, municipal wastewater has a large annual treatment volume and is rich in organic substances such as N and P. Its uncontrolled discharge leads to an increase in pollution loads such as COD, BOD and TSS, which reduces dissolved oxygen in the water column and leads to the death of fish and aquatic animals, degrading water quality and thus damaging the aquatic environment. However, it is also because municipal wastewater is rich in N and P and has reduced levels of toxic substances that it is not a less desirable medium for microalgae, which is the reason why microalgae treatment of municipal wastewater has been widely studied in recent years [29]. Various algae such as Chlorococcum, Spirulina, Scenedesmus, Chlorella, Chlamydomonas, and Botryococcus have been shown to be useful for municipal wastewater treatment. The biomass of these algae doubled within 24 h and had a high potential for lipid or polysaccharide accumulation.

Agricultural wastewater, especially animal manure wastewater, contains a large amount of nutrients and is a good source for nutrient recovery. However, it is not suitable for direct application in microalgae culture due to chromaticity, turbidity, suspended matter and excessive ammonia concentration. For pig manure wastewater containing high concentration of nutrients, the most commonly used treatment technology is anaerobic digestion. That is, the organic matter in the wastewater is converted into biogas, thus achieving the purpose of reducing the organic matter in the wastewater. This method, however, may have certain safety hazards and make it difficult to meet safe discharge standards. By diluting and reducing the content of nutrients in the wastewater, pig manure wastewater can be used for microalgae culture to produce biomass. Zhu et al. found that pig manure wastewater diluted to 1900 mg/L had the best nutrient removal rate when used for microalgae culture. In addition, it was demonstrated that Chlorella and Scenedesmus can be cultured in pig manure wastewater due to their high tolerance to environmental stress and use inorganic nitrogen (NH4+-N, NO2--N and NO3--N), organic nitrogen (urea and amino acids), carbon and phosphorus sources for biomass and lipid accumulation.

Industrial wastewater is the wastewater or waste liquid produced in the industrial production process, which usually contains a variety of toxic and harmful substances. Common industrial wastewaters are textile industry wastewater and metallurgical industry wastewater. Generally,

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most textile industry wastewater requires treatment of the synthetic dyes in it. Chlorella vulgaris was reported to have a high tolerance to azo dyes and it could maintain growth in wastewater containing 400 mg/L of Tectilon Yellow 2G (an azo dye) and decolorized up to 63%-69%. The ability of Chlorella vulgaris to decompose azo bonds was also found by Lim et al. when using Chlorella vulgaris to treat textile industry wastewater. In addition, cyanobacteria, such as Synechocystis sp. and Phormidium sp., were also found to be effective in removing reactive dyes through biometabolism and the removal rate was improved with the addition of specific plant growth regulators (Triacontanol hormone). Metallurgical industry wastewater usually contains many metallic elements. Many studies have clearly demonstrated the potential of algal biomass for the removal of heavy metals from wastewater. Microalgal cells contain a large number of negatively charged groups (e.g., carboxyl, amino groups, etc.) due to their surface. Most of the positively charged metals can bind tightly to the negatively charged groups on the surface of microalgae cells, which is the main removal mechanism of microalgae for metal-containing wastewater. In addition to adsorption on the surface of microalgae cells, other mechanisms of metal-containing wastewater removal by microalgae include bioaccumulation, formation of chelates, and precipitation on or within the microalgae surface. The acid-tolerant microalgae Heterochlorella sp. MAS3 and Desmodesmus sp. MAS1 were reported to remove 2 mg/L Cd(II) at pH 3.5 with >58% removal efficiency and accumulate lipids rich in aliphatic long-chain hydrocarbons and triglycerides. Arora and colleagues found that Chlorella minutissima and Scenedesmussp. IITRIND2 were able to tolerate up to 500 mg/L of arsenic and remove it up to 161 μg/g. In addition, many algal species were able to tolerate and accumulate high concentrations of Cr(VI). Chlorellasorokiniana tolerated 100 ppm Cr(VI) for 3 days with a removal efficiency of 99.7% after 24 h of exposure; Naviculasubminuscula was able to remove 98% of Cr(VI) in a medium containing 20 mg/L Cr(VI).

2.3. CO2 Capture

Microalgae can use CO2 to convert to carbohydrates through photosynthesis. As a biochemical carbon capture technology, microalgae carbon sequestration technology is one of the few carbon neutral technologies with industrialization potential. Compared with traditional carbon capture methods, microalgae carbon sequestration has the following advantages:

(1) The process of microalgae carbon sequestration is environmentally friendly and there is no secondary pollution in the metabolites.

(2) Microalgae do not compete with agricultural crops for arable land. The earth has a vast ocean area and unexplored mudflats. By using the ocean and mudflats to cultivate microalgae in large quantities, we can not only reduce CO2 in the atmosphere, but also avoid wasting resources.

(3) The ability of microalgae to fix CO2 is 10-50 times higher than that of other terrestrial plants, and it has a rapid growth/proliferation rate that is much higher than that of higher plants.

(4) Microalgae biomass contains about 50% carbon, and its growth requires large amounts of CO2. microalgae carbon sequestration can achieve the dual purpose of reducing CO2and promoting biomass production.

(5) Microalgae biomass is rich in oil and polysaccharide components, which can be reused later. The fermentation of microalgae biomass to produce clean oil and gas fuel can achieve emission reduction and low carbon economy.

3. Conclusion

Microalgae are considered to be a third generation renewable biomass energy source with great potential to replace traditional fossil energy sources. The use of wastewater for microalgae

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culture can not only reduce its production cost, but also achieve effective treatment of wastewater and create conditions for resource utilization of wastewater.

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