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Review of Advances in Microalgae Cultivation Technology

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Abstract: The research results of many previous authors were summarized, and two types of microalgae culture methods were reviewed: suspension culture technology and attachment culture technology. On this basis, the future development direction of microalgae culture is prospected in order to provide a reference basis for the future large-scale production of microalgae.

Keywords: Microalgae; Cultivation; Advances.

1. Introduction

Microalgae are tiny unicellular or multicellular organisms that require a microscope to see and identify their individual forms; they contain chloroplasts and can efficiently use solar energy for photosynthesis and fix CO_2 in the air through autotrophy; they can also use organic matter to convert pollutants into their own biomass through heterotrophy; they have the advantage of high efficiency of light energy use and fast growth rate compared with traditional plants. It has the advantage of high light energy utilization efficiency and fast growth rate compared with traditional plants. In order to obtain more microalgae for biomass preparation, it is necessary to understand how microalgae are cultured and to cultivate them on a large scale, which is currently the only way and very important [1].

2. Microalgae Cultivation Technology

2.1. Microalgae Suspension Culture Technology

2.1.1. Open Type

Generally speaking, there are two types of microalgal suspension cultures: open pond systems and closed reactors. Open pond systems can be subdivided into natural ponds (lakes, lagoons) and artificial ponds (raceway ponds). The cultivation of microalgae in natural ponds or lagoons has been documented since 1950; later, runway ponds were developed and utilized to simulate the cultivation of microalgae under natural conditions [2]. Most of these systems are shallow concrete trenches or thick plastic sheets lined with different lengths and depths. Slurry wheels are installed in the runway pond system to promote nutrient circulation in the medium and uniform distribution of algal biomass. The main advantages of open raceway ponds are their scalability, simplicity of design, and low maintenance and operation costs [3]. However, open-runway ponds also have disadvantages such as vulnerability to microbial contamination (growth of bacteria, parasites, zooplankton and harmful algae), rapid evaporation of nutrient solution, low atmospheric CO_2 diffusion, large land requirement area, poor productivity and significant climatic influence [4]. Therefore, the biological production of microalgae in open runway ponds is usually low, less than 1 g/L.

2.1.2. Closed Type

Compared to open pond systems, closed systems can ensure maximum purity of algal species, facilitate control of culture conditions and allow better removal of contaminants from water [5].

The flat plate type photobioreactor consists of a flat surface (transparent polycarbonate) that supports the growth of microalgae and a culture medium, the effectiveness of which is influenced by the illumination height and illumination surface area [6]. The simple design of flat plate photobioreactors consumes less energy and can increase biological production by 5-20 times compared to other photobioreactors while reducing biomass clogging, settling or leakage [7]. However, a major problem facing such systems is the large footprint, complex design, susceptibility to contamination, and the fact that microalgal cells can shade each other from light after reaching a certain concentration [8].

Column photobioreactors are usually composed of multiple columns arranged vertically to promote the contact and mixing of nutrients and microalgae by aeration (air or CO2) into the culture system so that the microalgae can be better suspended and dispersed in the reactor; and the light/dark cycle and gas-liquid transfer process can be adjusted to improve the biological production [9]. The yield of columnar photobioreactors can be significantly improved by changing the light source position and illumination pattern. One study found that the internal lighting pattern mitigated the effect of dark areas and shadow formation in the reactor on suspension culture compared to external lighting, which could increase the biomass by a factor of 5 [10]

Tubular photobioreactors are generally composed of curved, horizontal, vertical, or spiral glass or plastic tubes arranged in overlapping or adjacent layers/array that circulate and mix the culture medium through a pump, providing sufficient contact time for mass transfer [11]. Compared to other types of reactors, tubular photobioreactors have a large illuminated area and are more suitable for industrial and outdoor culture applications. However, many design parameters (e.g., pipe arrangement, dissolved oxygen,

illumination, nutrient partitioning, and energy consumption) need to be optimized to improve the biomass yield of this reactor, thus making the reactor design process complex; and the system has poor mass transfer capacity and high energy consumption (100-500 W/m3) when continuous long pipes are used [12].

In contrast to photobioreactors permanently installed with rigid materials, software-frame photobioreactors consist of ethylene vinyl acetate, low-density polyethylene, or polytetrafluoroethylene, which can be flexibly moved, folded, and also suspended on a shelf or floated on water, saving space and suitable for a wide range of environmental conditions. Therefore, soft-frame photobioreactors have a broader application and industrial production potential. However, the lack of light efficiency, short material lifetime, high cost and inadequate internal mixing, and easy formation of dead zones are affected by their arrangement.

In summary, the conventional suspension culture suffers from high water demand, high energy consumption, difficulty in large-scale production, and vulnerability to pollution. In addition, the volume of water exceeds more than 95% of the total volume of suspension, and the biomass concentration is low, up to about 0.5 g/L and 2-6 g/L in open runway pools and closed photobioreactors, respectively. due to the tiny size and density of microalgae cells close to water, additional harvesting and dewatering processes are required to obtain the desired biomass in such a low concentration culture process. According to a study, the cost of microalgae harvesting accounts for about 30% of the total cost in the industrialization of microalgae based on suspension culture [13]. Therefore, a rational harvesting process is a decisive factor in the cost of microalgae culture. Currently, commonly used harvesting techniques include centrifugation, flocculation, flotation, sedimentation, and filtration [14]. However, there is no single harvesting process that can be widely used for the industrial production of different algal species due to the differences in algal cell size, biomass concentration, salt ion content, pH, and application [15].

2.2. Microalgae Attachment Culture Technology

To solve the problem of microalgal biomass harvesting in suspension systems, the attachment culture system was proposed. In this system, microalgae are immobilized in the surface or inner layer of the carrier and grown in aggregates. Compared to suspension culture, the biomass density of attached culture microalgae is higher and the process of dehydration and harvesting is easier, as only the carrier containing microalgae needs to be separated from the culture medium to harvest the biomass. It has been found that the biomass yield of attached cultures of microalgae is 2.8 times higher than that of suspended systems. From a wastewater treatment perspective, attached cultures are more likely to harvest microalgal biomass from wastewater, are less likely to contaminate effluent water quality, and can withstand relatively high pollutant loads. During the attachment process, the microalgae's own extracellular organic matter or the encapsulated polymer (sodium alginate) can protect the microalgae cells from foreign toxic pollutants or bacteria, and resist the effects of high light intensity or high nutrient loads on microalgae growth.

Microalgal attachment culture can usually be divided into immobilization culture, where microalgal cells are immobilized in a gel (e.g., chitosan or sodium alginate), and biofilm culture, where microalgae are grown attached to the surface of a solid material in the form of a biofilm. In immobilized culture systems, the biomass can be harvested by simply separating the microbeads containing the microalgae from the culture medium, and contamination can be effectively avoided. However, the gel around the microalgae inhibits nutrient transfer and light transport between the microalgae and the culture medium; resulting in a significant lag phase in the immobilization culture of microalgae cells and low biomass yields. Although the application of polymer gel materials can improve the above problems, they can also be toxic to microalgal cells and affect the downstream application of microalgal biomass. In order to solve a series of problems caused by gel-encapsulated biomass in immobilized culture, biofilm culture method was proposed. Although microalgal biofilm cultures have been proposed for a relatively short period of time, biofilms are not a new phenomenon. Based on fossils, it can be assumed that the appearance of biofilms dates back to 3.5 billion years ago and consists of protozoa, bacteria, larvae, and microalgae. In aquatic environments, biofilms cover most of the lower solid layers, such as ships, rocks, and marine animals.

Usually, biofilms are present on almost any kind of solid-liquid contact surfaces and are usually considered as a kind of surface fouling, their presence causes corrosion of metal surfaces and changes the physicochemical properties of metal substance surfaces. At the same time, biofilms play a very important role in nature, as their presence helps to facilitate the exchange of nutrients and the flow of energy. In recent years, it has been discovered through research that biofilms can be used in wastewater treatment, bioconversion and fermentation engineering.

Microalgal biofilms consist of microalgal cells, extracellular organic matter and bacteria. In recent years, many scholars have started to focus on the field of microalgal biofilm culture. Compared with suspension culture, biofilm culture has the following advantages:

1) low water consumption: In suspension culture, 1 ton of microalgae biomass requires 200 tons of water, while for the same amount of biomass, only 17 tons of water are required, of which 4 tons are used to keep the biofilm surface wet.

2) low construction cost: compared to the construction cost of runway ponds and photobioreactors in suspension systems, the carrier materials to support the cells in biofilm culture are relatively cheap, readily available and reusable.

3) According to Gross and Wen's study, the biofilm yield is 302% of that of suspension system;

4) easy to harvest: the biomass can be harvested by simple scraping;

5) low moisture content of biomass, no additional dewatering treatment is needed, and the water content of harvested biomass is similar to that of centrifugal harvesting in suspension culture;

6) better light utilization efficiency and more uniform light.

3. Conclusion

Based on local resource conditions, screening out industrial algae species with high growth efficiency and resistance is another research hotspot to realize the industrialization of microalgae, which can effectively improve the production efficiency and reduce the cost of microalgae cultivation. It is believed that with the deepening and integration of the two research fields mentioned above, the problems restricting the large-scale cultivation of microalgae will be gradually solved,

and the microalgae bio-industry will surely usher in a splendid tomorrow.

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