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The characteristics and influencing factors of the attached microalgae cultivation: A review

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ABSTRACT

Attached microalgae cultivation could simplify the microalgae harvest process and reduce its associated cost, which has attracted much attention recently. In this paper, the reactor patterns, advantages, microalgae biomass productivity, influencing factors and the microalgae physicochemical properties in the attached microalgae cultivation was summarized to show the sketch of this novel microalgae cultivation. It was concluded that the attached microalgae cultivation is advantageous in achieving less water and space consumption, higher water treatment potential and higher biomass productivity compared with the traditional suspended microalgae cultivation. The accumulation of the attached microalgae biomass showed a linear increase with culture time with the largest productivity up to 20.7 $g\,m^{-2}\,d^{-1}$. *Chlorella* and *Scenedesmus* were the top two species that have been studied in attached culture system. Cellulose acetate/nitrate membrane, polycarbonate membrane and cotton were the most popular materials used owing to their high hydrophilicity and wide availability. Flow rate, nutrients, light, CO_2 and other factors could affect the attached microalgae productivity and the physicochemical property in a way different from the suspended microalgae, which were described in detail in this review. At last, some technical bottlenecks and the corresponding solvents in the attached microalgae were suggested.

1. Introduction

Microalgae cultivation for biomass/bioenergy production has been studied extensively in the past few decades. This is due largely to the fact that lipid from microalgae has been considered as a raw material for biodiesel production in many countries [1,2]. In addition, microalgae with high protein content is a perfect feed for fish and other animals. Some microalgae could produce valuable molecules, e.g. the polyunsaturated fatty acid oils for infants and pigment as nutritional supplements for human [3–5].

It was found that the small size (several micrometer) and the low scattered density (less than 1%)of microalgae in the culture media made the harvest process difficult and energy-intensive during the traditional suspended microalgae cultivation [6,7]. Attached microalgae cultivation i.e. microalgae growing in the form of biofilm on the surface of substrates (Fig. 1a), therefore was proposed and studied extensively in the past decade, aiming at improving the harvest process. By attached cultivation, the microalgae density can be highly concentrated and the microalgae biomass could be easily scraped from substrate surface to achieve the low-cost microalgae harvest process [8–10]. Then the concentrated microalgae biomass could be used as raw material for biodiesel refining.

In this review, the reactors for the attached microalgae cultivation, some other additional advantages of attached cultivation, the influencing factors of attached growth of microalgae, the kinetics of attached microalgae growth and the suggestions for future study are proposed.

2. The concept of attached microalgae cultivation and its reactor form

Attached microalgae cultivation is a process in which microalgae grow as a biofilm by attaching on the surface of support media (Fig. 1a), which is formed initially by the hydrophobic interactions, acid-base interactions or some other interactions between microalgae and the

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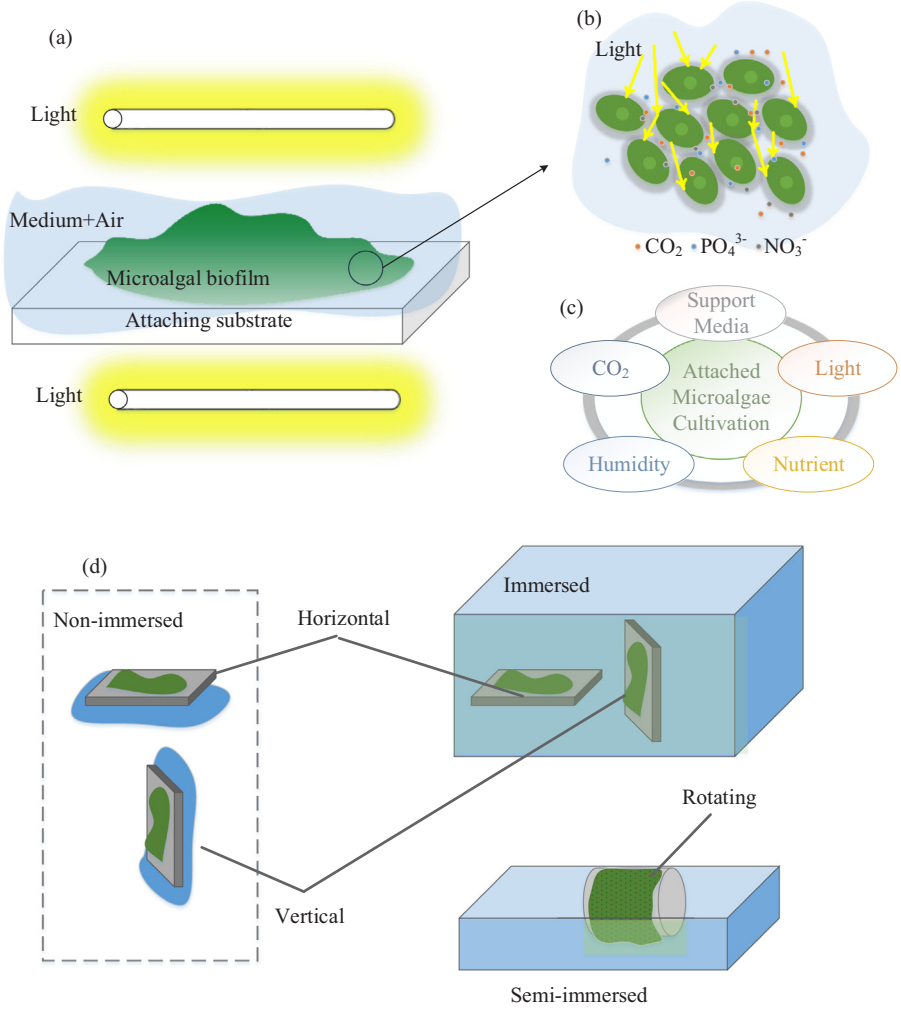

Fig. 1. sketch and elements of attached microalgae cultivation.

support media [11,12]. In this review, the definition of "attached microalgae cultivation" just means the microalgae growing on the surface of support media except the microalgae immobilized inside the alginate or other macromolecules. The essential elements for the growth of microalgae (i.e. light, nutrient, CO_2 and water) are the same for both the attached and suspended status. Comparatively, the attached microalgae culture system has an extra element of support media (Fig. 1c).

Seen from the macro scope, the structure of attached reactor for microalgae cultivation is obviously different from the suspended ones (i.e. open pend and closed photobioreactor). As shown in Fig. 1, microalgae are usually attached on a plain support media [13–15]. Light and culture broth are provided from the surfaces of the biofilm. The surface near the support media is called inner side and the one far from the support media is called outer side thereafter. Normally, culture broth and light are provided form the outer side of microalgae biofilm. However, if the support media is porous or transparent (e.g. filter paper or glass), culture broth or light could be provided from the inner side, respectively.

Papers on the attached microalgae culture systems were found by searching the key words of microalga* ("*" means fuzzy search for microalgae and microalga), attached and biofilm. Though the reactor configurations were different from each other, attached microalgae culture systems could be classified into immersed, semi-immersed and non-immersed based on the relative position of the support media to the culture broth, or classified into vertical, horizontal and rotating by the orientation of the support media (Fig. 1d). Most semi-immersed culture system are also rotating systems. This kind of reactor could get sufficient nutrient when immersed in liquid phase and absorb CO_2 when exposed in air, but the structure is relatively complex. Most non-immersed systems are vertical systems. This kind of reactor could easily absorb CO_2 but might have the risk of cell dehydration [13]. The immersed reactor could face the same problem as the suspended microalgae culture system, i.e. the efficiency of CO_2/O_2 exchange.

When examined under the microscope, all the microalgae from both attached and suspended status are surrounded by extracellular organic matters (EOMs), water and nutrients that dissolved in it (Fig. 1b). However, the concentrations of the substance above could be significantly different, especially the EOMs [16]. Since microalgae density in the attached microalgae culture system is much higher than the suspended systems and the microalgae positions are fixed, the mass transfer and light transmit are quite different from the suspended cultivation, which differentiates the further growth of attached microalgae, e.g. on the aspects of their growth rate and the release of EOMs. The different growth statuses could feed back into the mass transfer and light transmit [17]. Consequently, the same influencing factor (e.g. light intensity or nutrient concentration) could result in different response on the microalgae growth in the attached and suspended culture systems.

3. Advantages of attached microalgae cultivation

3.1. Easier harvest and energy efficiency

Low-energy cost and easy operation of harvest is the initial purpose