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Short Communication

A novel suspended-solid phase photobioreactor to improve biomass production and separation of microalgae

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HIGHLIGHTS

- Solid carriers were added and kept suspended by aeration in this ssPBR.
- Microalgae could attach and grow on the carriers.
- By catching carriers, microalgae could easily be separated from liquid phase.
- Biomass production in ssPBR was increased by adding solid carriers.

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ABSTRACT

A novel suspended-solid phase photobioreactor (ssPBR) was proposed in this paper to solve the problem of microalgal expensive and complex harvest system for biomass/biofuel production. In this ssPBR, solid carriers were added and kept suspended by aeration. Part of microalgae could attach and grow on the carriers. By catching carriers, microalgae could easily be separated from liquid phase. Three kinds of Carriers A, B, C made of cotton, mohair and linen, respectively, were used in this study. Compared with the reactor without carriers, the biomass production in each ssPBR was increased by adding these three kinds of carriers at a dosage of 2 g/L, and the maximum increments of biomass were 2.2×10^5 (10.3%), 7.8×10^4 (3.9%) and 4.4×10^5 (20.5%)cells/mL, respectively. By increasing the dosage of Carriers-C to 4 g/L, the maximum increment of microalgal biomass could reach up to about 30% in the ssPBR compared with control group.

1. Introduction

With the shortage of fossil fuels, microalgal biofuel as a renewable resource has attracted worldwide attention this decade (Li et al., 2010; Rawat et al., 2012; Yu et al., 2012). Microalgae have many advantages as a feedstock of biofuel, such as short cultivation period, high photosynthesis efficiency and high lipid content. The energy independence and security act (EISA) passed by USA in 2007 requires microalgae-derived biofuels as a kind of fossil fuels substitute (Yang et al., 2011). In the meantime, many challenges have impeded the production and utilization commercially of micro-algal biofuel, which includes large-scale cultivation, high energy consumption for recovery of microalgae, evaporation reduction of water and so on (Brennan and Owende, 2010).

Microalgae biomass can be harvested by centrifugation, coagulation and filtration in the traditional cultivation systems. Centrifugation is rapid but energy intensive, so it is preferred to recover biomass for the production of high-value chemicals. Coagulation may be a pretreatment of centrifugation to improve recovery of cells but coagulant may influence the quality of product. When the microalgae are fragile, microfiltration can be a suitable alternative. The high cost of membrane replacement and pumping restricts the application of filtration in a large scale (Brennan and Owende, 2010; Molina Grima et al., 2003). The methods mentioned above are, in general, either expensive or unpractical in the large scale. Therefore, some new methods for microalgal biomass recovery are required.

Some novel cultivation systems integrating microalgal cultivation and harvest have been studied recently. In Liu's research, microalgae cells attached on the surface of vertical artificial supporting material. CO_2 and nutrient solution were provided by perforated nylon tubes (Liu et al., 2013). A rotating algal biofilm reactor (RABR) was designed by Christenson, which consisted of

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a cylinder provided with a growth surface partially submerged in wastewater (Christenson and Sims, 2012). In Johnson's research, substrate materials were fixed on the bottom of a growth chamber, and then the biomass attached on the substrate surface was harvested by scraping (Johnson and Wen, 2010). All the attach cultivation systems mentioned above demanded stable environment and the structure of these bioreactors were too complex, which were difficult to apply in a large scale microalgal production. In this paper, a novel suspended-solid phase microalgae photobioreactor (ssPBR) for microalgae cultivation was proposed. The ssPBR ran similarly as aeration tank in activated sludge biological wastewater treatment process of wastewater with a simple reactor construction and the biomass could be easily recovered, which has a potential to be used in a large scale.

2. Methods

2.1. Algal cultures

The *Scenedesmus* sp. LX1 (Collection No. CGMCC 3036 in China General Microbiological Culture Collection Center) isolated from fresh water by Li et al. (2010) was used in this study.

2.2. Design of the suspended-solid phase photobioreactor (ssPBR)

The conception of the ssPBR is shown in Fig. 1. The appearance of ssPBR was a flat cuboid made of organic glass, and the flat cuboid was divided by an organic glass pane into two parts. The shape of the major part was a reverse trapezoid used for algal cultivation. Solid carriers were put into the reactor for microalgae to attach on. A perforated pipe was settled in the bottom of the reactor, and the pipe was connected with an air pump outside the reactor. A hole was set in the bottom of the side wall to drain after experiment.

In the ssPBR, the aerator pipe in the bottom of the reactor provided the circumrotation power for cultivation of microalgae. When aerated, the suspended algae and the solid carriers would circle with the fluid circulation at different speed for the different shapes and gravities. When the suspended algae or the carriers were brought to shallow water periodically, all the algae could absorb the sunlight for the photosynthesis. A part of microalgae would attach on the suspended-solid phase carriers. When reactors were aerated, the relative movement between suspended algae and carriers can promote the enmeshment of carriers to microalgae. After the microalgae attached on the carriers, they could also get nutrients and sunlight for growth.

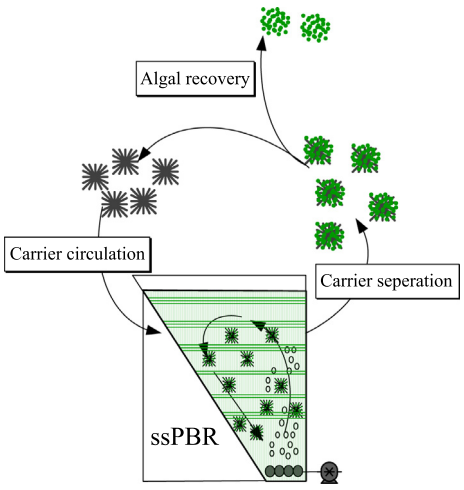

Fig. 1. Conception of the suspended-solid phase photobioreactor (ssPBR) for microalgae cultivation.

When the quantity of algae attached on the carriers gains to a certain amount, suspended carriers could be captured from cultivation solution. As the volume of these carriers were far bigger than microalgal cells, the harvest process of carriers is much easier than that of microalgal cells. So the microalgae attached on carriers could easily get recovery from liquid phase. By mechanical separation, solvent extraction or some other ways, the microalgae would be harvested and converted, and then the solid carriers could be put into reactors for reuse. The suspended microalgae could act as "seed" for attachment and recovery.

2.3. Experimental set up

Scenedesmus sp. LX1 was inoculated into four 10 L ssPBRs with BG11 culture medium. The original inoculum dose was about 5 mL solution of microalgae at logarithmic phase for 1 L culture medium to keep the original microalgae density at about 10^4 - cells/mL. The culture conditions were: light intensity 6000–7000 Lux, light/dark periods of 14/10 h, aeration rate 4–6 L/h. When the algal density reached about 10^6 cells/mL in the initial stage, three different kinds of Carriers A, B, C were put into each reactor. These carriers of A, B and C were made of cotton, linen and mohair respectively, and were added with the same weight of 2 g/L. The reactor without carriers was blank control. The properties of the carriers are listed in Table 1.

The kind of carriers which showed the best performance in microalgal attachment was chosen for investigation. The different dosages of this kind of carriers were set as experimental variable, and the other conditions were the same as the first experiment. The dosage of carriers was set at 2 g/L, 4 g/L and 6 g/L.

2.4. Analytical methods

Microalgal density was determined by hemacytometer counted under optical microscope. The microalgae attached on the carriers were dissolved in water by ultrasound and then the density of microalgae attached would be counted and transferred by counting density of liquid phase-microalgae. All tests were carried out in triplicate ($n = 3$) and *T*-test was done by SPSS to find out the consistency between different groups.

3. Results and discussion

3.1. Growth properties of suspended and attached microalgae in different reactors

The suspended algal density of *Scenedesmus* sp. LX1 is shown in Fig. 2, and all of these microalgae in the four reactors reached into stationary phase in about 6 days. Compared with the traditional algal cultivation system, the most significant difference of this reactor proposed in this study is the addition of solid carriers. The results showed that the suspended algal density in different reactors had consistency at the 95% confidence intervals with *T*-test.

Attached algal density on the carriers was tested and the results were calculated and shown in Fig. 2. The attached algal density on the three kinds of carriers increased and got a maximum at about the fourth day after carriers were added into each reactor. The maximum algal density on Carriers-C was 4.4×10^5 cells/mL, which was the highest followed by Carriers-A and Carriers-B with the algal density of 2.2×10^5 cells/mL and 7.8×10^4 cells/mL, respectively.

As the density of suspended microalgae was almost the same between the reactor with and without carriers, the microalgae