Bioresource Technology 158 (2014) 388–391

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Short Communication

A magnetic separator for efficient microalgae harvesting

Yi-Ru Hu [a,c], Chen Guo [a], Xu Ling [b], Feng Wang [a], Shi-Kai Wang [a,c], Zanmin Hu [b], Chun-Zhao Liu [a,*]

[a] National Key Laboratory of Biochemical Engineering & Key Laboratory of Green Process and Engineering, Institute of Process Engineering, Chinese Academy of Sciences, Beijing 100190, PR China
[b] Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Beijing 100101, PR China
[c] University of Chinese Academy of Sciences, Beijing 100049, PR China

HIGHLIGHTS

- A magnetic separator was developed for microalgae harvesting.
- 95% of harvesting efficiency was achieved in both batch and continuous operation.
- Microalgae harvesting performance was stable in optimized operation conditions.

ARTICLE INFO

Article history:
Received 20 January 2014
Received in revised form 24 February 2014
Accepted 26 February 2014
Available online 7 March 2014

Keywords:
Chlorella ellipsoidea
Magnetic nanoparticles
Magnetic separator
Microalgae harvesting

ABSTRACT

A magnetic separator, which consisted of permanent magnet drum, separation chamber and scraper blade, was manufactured for efficient microalgae harvesting. The harvesting efficiency of *Chlorella ellipsoidea* cells reached more than 95% within forty seconds in each batch operation of microalgae harvesting. In the continuous operation of microalgae harvesting, the harvesting efficiency decreased with increasing the liquid flow rate through the separation chamber and remained more than 95% at the liquid flow rate less than 100 mL/min. The developed magnetic separator together with functional magnetic nanoparticles provided a promising method for efficient microalgae harvesting in practice.

1. Introduction

Microalgae are recognized as a promising resource to produce biofuel that is capable of meeting the increasing global demand for renewable and environmentally friendly energy (Parmar et al., 2011). Microalgae harvesting remains a challenge for the biofuel production due to small cell size, low cell density in water, and large amount of water to remove (Uduman et al., 2012; Chen et al., 2011; Chisti, 2013). Among recent techniques for microalgae harvesting, magnetic separation with functional magnetic nanoparticles provides a promising method for economically harvesting microalgal cells. Naked Fe_3O_4 nanoparticles were used to harvest both freshwater microalgal species and marine microalgal species (Xu et al., 2011; Hu et al., 2013), and some functional magnetic particles coated with diallyldimethylammonium chloride, chitosan or silica were also used for improving microalgae harvesting (Lee et al., 2013; Lim et al., 2012; Cerff et al., 2012). Therefore, there is considerable interest in the development of simple and highly efficient magnetic separator for microalgae harvesting together with these magnetic nanoparticles.

Magnetic separator can separate magnetic particles based on the physical capture of these particles by a magnetic field with high process capacity (Arab-Tehrani et al., 2010; Wang et al., 2011; Brown et al., 2013). Effective magnetophoretic removal of microalgae was achieved by a high gradient magnetic separation system at a flow rate of 1.25 mL/min (Toh et al., 2012). In order to match the industrial application of microalgae harvesting by magnetic particles, the development of efficient scale-up magnetic separators together with process optimization continues to be of interest.

The objective of this current study is to develop an efficient magnetic separator for harvesting microalgal cells by magnetic nanoparticles. The aggregates resulted from the interaction between the microalgal cells and the nanoparticles were captured from the liquid culture medium by the permanent magnet drum through the magnetic force, and the key operation parameters of the magnetic separation process were optimized.

* Corresponding author. Tel./fax: +86 10 82622280.
E-mail address: czliu@ipe.ac.cn (C.-Z. Liu).

http://dx.doi.org/10.1016/j.biortech.2014.02.120
0960-8524/

2. Methods

2.1. Synthesis of Fe_3O_4 nanoparticles

0.99 g $FeCl_2{\cdot}4H_2O$ and 2.76 g $FeCl_3{\cdot}6H_2O$ were dissolved in 100 mL deionized water in a 500 mL four-neck flask under nitrogen gas with mechanical stirring at 80 °C. 10 mL 25 wt.% NH_4OH was added quickly into the suspension and stirring continually for 30 min. The resulted Fe_3O_4 nanoparticles were precipitated by a hand-held magnet and washed several times using deionized water before use. These nanoparticles were 10 nm in diameter with a spherical shape.

2.2. Microalgae cultivation

Chlorella ellipsoidea (UTEX 20) strain was kindly provided by Prof. Zan-Min Hu (Institute of Genetics and Developmental Biology, Chinese Academy of Sciences). The cells were pre-cultivated in 100 mL liquid medium in a 250 mL Erlenmeyer flask with BG-11 medium on a shaking platform at a rotation speed of 100 rpm. The pre-cultivated microalgal cells were used as inoculum for 40 L bioreactor cultivation. All cultivations were illuminated under a light intensity of 35 μmol/m^2/s at a cycle of 16 h light/dark cycle at 25 ± 1 °C for 20 days.

2.3. Magnetic separation

As shown in Supplementary material Fig. 1A, the magnetic separator consisted of permanent magnet drum, scraper blade, and separation chamber with two outlets. The permanent magnet drum with surface magnetic field of 2000 G (Runfine Filtra Systems Company, Yantai, China) was made up of Nd–Fe–B magnet to generate the magnetic field. The separation chamber was made up of non-magnetic stainless steel with 23 cm in length, 17 cm in broad and 13 cm in height. The baffle inside the separation chamber was 9 cm in height. Upon the separation chamber, the scraper was tightly closed to the permanent magnet drum for collecting the attached magnetic mixtures from the surface of permanent magnet drum. As shown in Fig. 1, Fe_3O_4 nanoparticles were firstly mixed with the microalgal solution to form magnetic particle-cell aggregates. The dosage of Fe_3O_4 nanoparticles was determined by pre-experiment in 25 mL Erlenmeyer flasks to get a harvesting efficiency of 95%. The peristaltic pump was used to drive the mixture into the separation chamber where the magnetic mixtures were absorbed by the permanent magnet drum. The captured mixtures onto the surface of the permanent magnet drum were collected through the scraper blade by rotating the drum, and the liquid medium after microalgal harvesting was collected through the outlet on the bottom of the separation chamber. The magnetic nanoparticles and the magnetic particle-cell aggregates in the separation chamber were captured onto the surface of the rotating permanent magnet drum (Supplementary material Fig. 1B) and then collected by the scraper blade (Supplementary material Fig. 1C).

The magnetic separation process was conducted in batch and continuous operations. For the batch operation, the separation chamber was filled with the mixture solution by a pump, and the mixture solution was kept in the separation chamber for a given time in order to capture the magnetic particle-cell aggregates by the rotating permanent magnet drum. The supernatant resulted from the batch harvesting was collected through the outlet 1. For continuous operation, the mixture solution was pumped continuously through the separation chamber at a given flow rate, and the permanent magnet drum was rotated at a speed of 10 rpm to capture the magnetic particle-cell aggregates. The supernatant resulted from the continuous operation was collected through the outlet 2. The magnetic particle-cell aggregates onto the permanent magnet drum were scraped for recovery by scraper blade, and the outlet solution was collected to determine the harvesting efficiency.

Microalgal cell concentration ranged from 0.5 to 2 g/L was used for the harvesting process. In order to obtain harvesting efficiency above 95% in the batch operation, a given resident time ranged from 10 to 60 s was tested. In the continuous operation, the flow rate of the mixture solution through the separation chamber ranged from 15 to 1200 mL/min was investigated.

2.4. Analytical methods

Cell concentration was determined by chlorophyll content of the microalgal samples. Cellular chlorophyll was calculated using a spectrophotometric method after cell extraction with 95% ethanol. 5 mL sample was centrifuged for 10 min at 4500 rpm, and the resulted residue was resuspended in 5 mL of 95% ethanol and grinded for 10 min to extract chlorophyll. After centrifugation, the absorbance at 665 and 649 nm of the supernatant was measured with a UV spectrophotometer (Unico, UV-2100). The chlorophyll content in the sample was calculated according to the following equations.

$$Ca = 13.95 \times OD_{665} - 6.88 \times OD_{649} \quad (1)$$

$$Cb = 24.96 \times OD_{649} - 7.32 \times OD_{665} \quad (2)$$

$$M(mg) = (Ca + Cb) \times 0.01 \quad (3)$$

The harvesting efficiency (R, %) was calculated as follows:

$$R = \frac{C_0 - C_t}{C_0} \times 100\% \quad (4)$$

where C_0 and C_t represent initial and final chlorophyll concentrations of microalgal cells before and after harvesting (g/L).

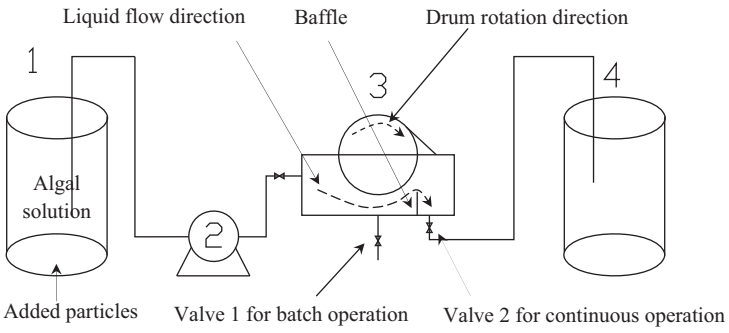

Fig. 1. Schematic illustration of magnetic separation system. (1) Mixing tank, (2) peristaltic pump, (3) magnetic separator, (4) collecting tank.