Functional magnetic nanoparticles for microalgal biomass harvesting

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ABSTRACT

Magnetic harvesting of Chlorella pyrenoidosa was attempted using several magnetic particles with a magnetic separation system. Compared with other particles, CPAM-Fe3O4 particles were more efficient for the harvesting of C. pyrenoidosa and a high recovery efficiency of moe than 93% was obtained at a dosage of 1500 mg/L. Using a magnetic separator, more than 90% of the C. pyrenoidosa cells can be separated at a feed rate of 100 mL/min. In addition, the protein content and amino acid composition of the algal cells were not influence by the magnetic separation and detachment process. The eficient and reliable magnetic separation procedure provides a great potential for microalgal harvesting in practice.

Keywords: Microalgal Harvesting, Magnetic nanoparticles

1 INTRODUCTION

Microalgae has been considered as promising candidates for biofuel production over the past few years due to its uncomparable advantages such as a high lipid content and growth rate, utilization of non-arable land (Christi, 2007). In addition, it can accumulates various naturally-produced compounds used in pharmaceutical industries, as food supplements and animal feed (Mata, Martins, Caetano, 2010). Chlorella pyrenoidosa is a green algae commonly used as human and animal nutrition supplement due to its ability to accumulate various high-value compounds such as fatty acids, carotenoids, pigments, xanthophylls, especially riched in protein (as high as 50–65% of its dry weight) (Su; Zhang; Zhang; Zhou; Li, 2011).

Due to the small size of algal cells and the dilute nature of microalgal cultures, the harvesting process usually costly and energy-consuming and was regarded as a bottleneck for the industrialization of microalgae-based products. Traditional microalgae harvesting methods including centrifugation, filtration, flocculation, sedimentation, and flotation have various disadvantages. In recent years, a few attempts on harvesting microalgal cells using magnetic particles have been made (Wang; Sterile; Guo; Liu, 2015). Those naked and surface functionalized magnetic particles showed good potential for the recovery of algal cells. In addition, an effective magnetic separation system was developed and achieved high recovery efficiencies using either naked Fe3O4 or surface functionalized magnetic particles (Hu, Guo, Wang, Wang, Pan, Liu, 2014; Hu, Wang, Wang, Liu, Guo, 2013).

In current study, the magnetic harvesting of C. pyrenoidosa cultivated in outdoor receway pond was investigated using several magnetic particles with a magnetic separation system. In addition, effect of magnetic particles and the detachment process on the protein content and amino acid composition of C. pyrenoidosa cells was also studied.

2 EXPERIMENTAL

The C. pyrenoidosa (FACHB 9) were cultivated in the BG-11 medium. A raceway pond with a working volume and depth of 45 L and 14 cm, respectively, was applied for the outdoor cultivation of the microalgae. CO2-enriched air (2%, v/v) was bubbled ino the culture using four plastic pipes placed at the bottom of the pond with holes at a flow rate of 0.5 v/v/m. C. pyrenoidosa grew from an inoculum of 0.3 g/L to 1.1 g/L after 4 days. The pH of the final broth was around 7.0.

Three kinds of magnetic particles was investigated for the harvesting of C. pyrenoidosa, include naked Fe3O4, polyethylenimine/Fe3O4 nanocomposites (PEI-Fe3O4), and cationic acrylamide (CPAM) surface functionalized Fe3O4 particles (CPAM- Fe3O4). The preparation of those particles was according to the methods reported by Xu et al., Hu et al., and Wang et al., respectively.6, 11, 12 Algal harvesting was firstly tested in Erlenmeyer flasks by mixing

a certain dosage of magnetic particles with algal broth on a rotary shaker at 150 rpm for 2 min, 2 min, and 10 min for Fe3O4, PEI- Fe3O4, and CPAM- Fe3O4, respectively. Then placed the flaks on a permanent magnet for 2 min and the cell concentration of the decanted supernatant was measured. The magnetic separator used in this study has been reported by Hu et al.13 The separation process was conducted in continuous mode as the procedures reported by Wang et al.14 The detachment of the collected particle-cell aggregates was operated according to the method for C. ellipsoidea reported by Xu et al. 6

The recovery efficiency was calculated based on Wang et al.12 The collected cells after detachment was lyophilized using a lyophilizer (ALPHA1–2, CHRIST, Germany) and analyzed its protein content and amino acid composition based on the methods reported by Wang et al. 15 and compared them with that from centrifugation collected cells.

3 RESULTS AND DISCUSSION

Recovery efficiencies of naked Fe3O4, PEI- Fe3O4, and CPAM- Fe3O4 on the harvesting of C. pyrenoidosa cells were illustrated in Figure 1. The results indicated that CPAM- Fe3O4 particles showed more effective for the harvesting of C. pyrenoidosa than other two kinds of magnetic particles. This was mainly due to the high flocculation capacity of CPAM. It can effectively flocculate algal cells into large flocs and the flocs can be easily separated based on the magnetic character of Fe3O4 under an external magnetic field. Compared with CPAM- Fe3O4 particles, the harvesting capacities for C. pyrenoidosa of naked Fe3O4 and PEI- Fe3O4 particles was much lower. At a CPAM- Fe3O4 dosage of 1500 mg/L, the recovery efficiency can reached more than 93%.

As shown in Figure 2, the magnetic separation pocess of C. pyrenoidosa by CPAM- Fe3O4 particles was rapid and can be effectively seperated within 2 min.Using CPAM-Fe3O4 particles, the continuous separation of C. pyrenoidosa was operated on the magnetic separation system.13 At a particle dosage and feed rate of 1500 mg/L and 100 mL/min, respectiely, a recovery efficiency of more than 90% can be achieved in this separation process.

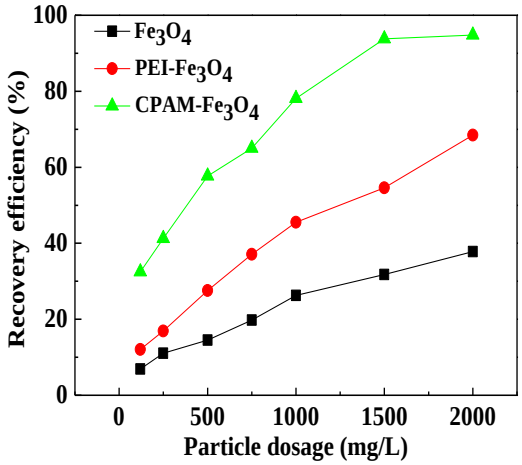

Figure 1 Recovery efficiency of C. pyrenoidosa using different magnetic particles on various dosage.

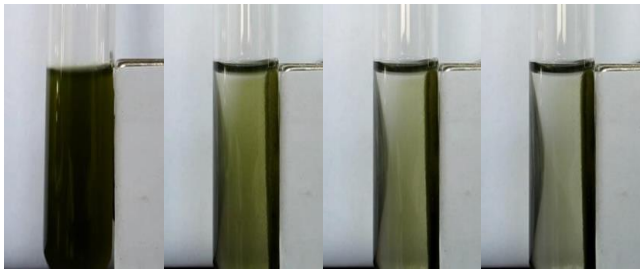

Figure 2 Photographs for the time-lapse magnetic separation process of C. pyrenoidosa using CPAM-Fe3O4 particles. From left to right: 0 s; 30 s; 60 s; 120 s.

The target product in the cultivation of C. pyrenoidosa was usually protein due to its high protein content. Therefore, it is significant to investigate the influence of the harvesting method on the protein content and composition. As shown in Table 1, the protein content and amino acid composition of C. pyrenoidosa after harvesting by CPAM-Fe3O4 particles and detachment by acid were similar with that obtained by centrifugation. The results indicated that this separation procedure has no obvious effects on the quality of the protein produced by C. pyrenoidosa. The magnetic harvesting method in this study was effective and reliable for the harvesting of C. pyrenoidosa.

TABLE 1 Amino acid and protein of the algal cells collected by magnetic separation and centrifugation.

Amino acid	Content (% of DW)	
	Magnetic	Centrifugation

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		separation	
Essential amino acids	Phe	2.11	2. 08
	Thr	1.76	1.95
	Met	0.36	0.38
	Val	2.62	2.50
	Ile	1.59	1.53
	Leu	4.13	3.96
	Trp	0.11	0.14
	Lys	2.71	2.77
	Total	15.39	15.31
Non-essential amino acids	Ala	3.60	3.77
	Gly	2.33	2.61
	Tyr	1.34	1.40
	Ser	1.48	1.69
	His	0.82	0.84
	Arg	3.20	3.22
	Glu	5.24	5.64
	Asp	3.72	3.93
	Pro	1.88	1.99
	Cys	0.30	0.39
	Total	23.91	25.48
Total amino acid (% of DW)		39.30	40.79
Total protein (% of DW)		47.00	51.40

A magnetic separator was built for continous harvesting of microalgal (Figure 3). The separator is composed of permanent magnet drum, Scraper blade and Separation chamber. Magnetic nanoparticles can adsorbed on microalgal cells, then they will attach on magnet drum, and are scraped by scraper blade.

A typical magnetic microalgal harvesting system is shown in Figure 4. At the end of microalgal culture, magnetic nanoparticles are added in the algal cultural solution. The solution then are bumped to the chamber of magnetic separator. Along with the rotate of magnet drum, magnetic particles coated cells are adsorbed on to the drum. The remained clear water then go to the collecting tank. The seperated cells with coated particles are harvested by scraping from the magnet drum.

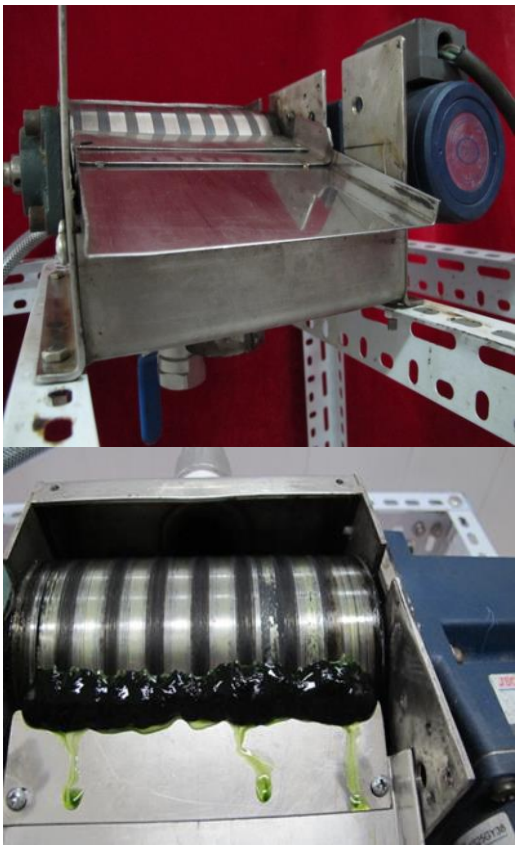

Figure 3 Photograph of magnetic seperator

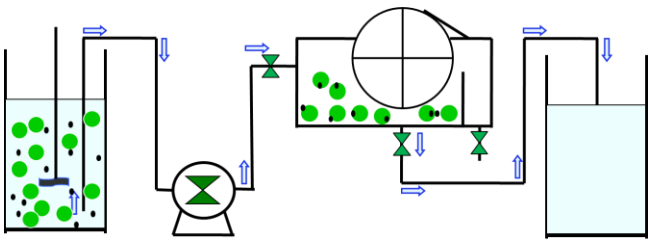

Figure 4 The schematic illustration how the magnetic separator works. From left to right: mixing tank, peristaltic pump, magnetic separator, and collecting tank

4 CONLUSION

In order to recovery of microalgal, magnetic nanoparticles are applied to microalgal harvesting process. Three kinds of magnetic nanoparticles are compared for seperating Chlorella pyrenoidosa. Among the three nanoparticles investigated, CPAM- Fe3O4 particles were more efficient for the harvesting of C. pyrenoidosa than other two kinds of magnetic particles. This may be the electrastatic interaction between cation acrylamide and microalgal cells with negative charge. A recovery efficiency of more than 93% can be reached at a dosage of 1500 mg/L. Integrated the magnetic particles with a magnetic separator, the C. pyrenoidosa cells can be effectively separated at a feed rate of 100 mL/min under continuous mode. The magnetic separation procedure has no negative influence on the production of the protein in C. pyrenoidosa cells and showed great potential for the effcient harvesting of microalgal cells.

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