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Harvesting of microalgae *Scenedesmus sp.* using polyvinylidene fluoride microfiltration membrane

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ABSTRACT

In this paper, polyvinylidene fluoride (PVDF) microfiltration membrane was used for harvesting microalgae *Scenedesmus sp.* The changes of permeation flux and OD_{750} of the algae medium during membrane filtration process were investigated. In order to reduce membrane fouling, both ventilation into algae medium and backwashing were adopted. The results showed that backwashing was better than ventilation to control membrane fouling. The optimized procedure was backwashing for 1 min every 20 min of continuing filtration. When the volume reduction factor (VRF) was up to 10, the recovery rate of the algae cells could reach above 90%. In addition, this paper showed that VRF and the initial concentrations of algae broth significantly affected the recovery rate. Higher VRF and higher initial concentrations of algae could make the recovery rate lower. Therefore, in order to obtain the needed recovery rate, these above factors needed to be considered. Generally, these results provided the feasible way to harvest microaglae efficiently and safely.

Keywords: Scenedesmus sp.; Harvesting; Microfiltration membrane; Flux; Ventilation; Backwashing

1. Introduction

In the past few decades, there has been growing interest in the use of photosynthetic microalgae as dietetics, cosmetics, feedstock and even bioenergy [1]. However, recovery of algal biomass is a significant problem because of algal cells small size (3–30 μm diameter) and very dilute concentration in culture broths (<1 kg m^{-3} dry biomass in some commercial production system). It was estimated that only the harvesting of algal biomass from the broth would contribute 20–30% to the total cost of biomass production [2]. At present, conventional algae harvesting methods includes centrifugation, filtration, flocculation, flocculation-flotation and gravity sedimentation. However, all of these methods faced commercial problems in capital investment, efficiency and cost [3–7].

Membrane separation as a new and efficient enrichment technology has been already widely used in many fields. The advantages of this technology lay in not only the simplicity and continuity of the operation, but also the friendly and safety to human and environment due to the free of chemical addition during the whole procedure which was very important for the application of algal product as food and feedstocks. The progress of membrane manufacturing techniques made the cost

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of membranes steadily decreasing, so that application of membrane filtration in industrial level such as microalgae harvesting becomes possible [8]. Nevertheless, a well-known drawback of membrane filtration is the permeation flux decline with time owing to the fouling deposition on membrane surface (membrance pollution), mainly due to adsorption, concentration polarization and eventually pore clogging. Fouling control or recovery of permeation flux of membrane is critical for its application. There are different techniques to limit the fouling phenomenon, among which are (1) using of cross flow rather than frontal filtration, (2) working with large flow velocity, (3) choosing a design which induces instabilities in the vicinity of the membrane surface and (4) If optimization of the operating conditions is a determinant, another crucial aspect concerns the selection of the membrane itself [1,9]. However, for the system of the microalgae culture medium, these above techniques can not increase the harvesting yield. Therefore, it is decisive how to reduce membrane pollution and increase the recovery rate for harvesting process.

In this paper, polyvinylidene fluoride (PVDF) microfiltration membrane was used to harvest *Scenedesmus sp.*, one kind of oleaginous green algae. Different methods including ventilation into algae medium and backwashing was investigated to reduce membrane fouling. The results will provide a method and operation parameters of membrane filtration for microalgae harvesting.

2. Materials and methods

2.1. Algae culture

The green microalgae, *Scenedesmus sp.*, used in the study was chosen as a test organism because it is ubiquitous in the water environment, fast growing, easy culture, and often used for algae-based water treatment [10–14]. Fresh algae suspensions were obtained from outdoor panel photobioreactors. BG11 culture medium was used to grow the algae [15]. The pH value of the culture was controlled ranging 7.0–9.0 during the cultivation period by aeration of air with CO_2/air (1.5%V/V). Daily maximum temperature was 30°C and minimum temperature was 15°C. Daily maximum solar intensity was 2000 μmol $(m^2\ s)^{-1}$.

2.2. Membrane system and algae concentration process

Harvesting experiments in laboratory scale was carried out with a hollow fiber PVDF microfiltration membrane module provided by Motimo Co. (Tianjin, China). The average pore size of the PVDF membrane was 0.2 μm, and the filtration area was 0.4 m^2. The batch experiment was run under a constant transmembrane pressure of 0.05 MPa. The cross-flow mode was used with a cross-flow velocity of 4 m s^{-1}. The concentrated algae medium was returned to the initial medium tank, and the algae medium was recycled. The permeate was collected to another tank in order to backwash the membrane. After each test, the membrane module was cleaned with deionized water or 1% NaOH, depending on the fouling of the membrane.

To reduce membrane fouling, different methods including periodic ventilation compressed air into the algae medium and periodic backwashing were investigated. Air was pumped together with algae broth for 1 min periodically. And backwashing was continued for 1 min, too. Both the volumetric reduction factor [VRF, Eq. (1)] and concentrated factor [CF, Eq. (2)] were calculated to evaluate the harvesting efficiency according to Eqs. (1) and (2):

$$\mathrm{VRF} = \frac{V_0}{V_\mathrm{f}} \tag{1}$$

$$\mathrm{CF} = \frac{C_\mathrm{f}}{C_0} \tag{2}$$

where V_0 and C_0 are the initial volume (l) and initial algal concentration (g l^{-1}) respectively. While V_f and C_f are the final volume (l) and final algal concentration (g l^{-1}).

To evaluate the harvesting efficiency, the recovery rate (Re) of the algae medium (dry weight) was calculated as:

$$\mathrm{Re} = \frac{C_\mathrm{f} V_\mathrm{f}}{C_0 V_0} \times 100\% \tag{3}$$

2.3. Analytical methods

Cell concentration was determined both by dry weight (microfibre filters, 0.45 μm and dried at 105°C for 4 h) and by optical density at 750 nm (Unico 2600 spectrophotometer).

3. Results and discussions

3.1. The effect of different ventilation frequencies on flux and OD_{750} of the algae

Fig. 1 presented the flux decline curves and the OD_{750} increase curves of the control and ventilation every 10 min for the 10 VRF. The flux of the control and the ventilation every 10 min both declined rapidly for the beginning 10 min, but the flux increased when compressed air was ventilated every 10 min. This is due to the compressed air in conjunction with the algae fluid produced shear force on the membrane surface, which tended to loose the formatted cake of the algae on the membrane surface, so that membrane fouling was alleviated and a

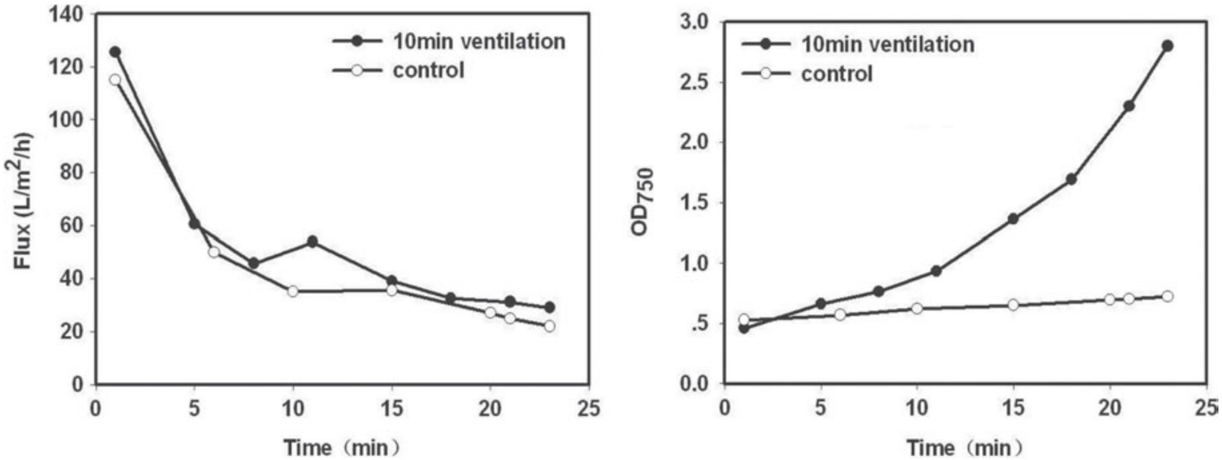

Fig. 1. Effects of ventilation every 10 min on flux and OD_{750} of *Scenedesmus sp.*

certain degree of flux was recovered. The OD_{750} of the ventilation every 10 min increased during the concentration process, while that of the control was basically unchanged due to many algae cells as algae cake formation on the membrane. Finally, if VRF was controlled 10, OD_{750} of the broth increased for 5.4 times than the initial algae broth, but that of the control increased slightly due to membrane fouling. And the recovery rate of VRF 10 was about 62% which was higher than that of the control (about 14%).

Fig. 2 presented the flux decline curves and the OD_{750} increase curves of the control and ventilation every 20 min for the 10 VRF. For the whole concentration process, the averaged flux of the ventilation every 20 min and OD_{750} was less than that of the ventilation every 10 min. This may be because the algae cake formatted on the membrane surface was compressed during the 20 min so that ventilation removed the cake slightly. At last, the recovery rate was about 45% for 10 VRF. However, the consuming time was shorter than that of ventilation every 10 min.

From the above results, although ventilation compressed air into the algae solution periodically alleviated the membrane fouling to some extent, the recovery ratio of the algae was low yet, which made membrane used for harvesting microalgae unefficient based on these results. Therefore, it is necessary to find other methods to alleviate membrane fouling.

3.2. The effects of backwashing on the harvesting *Scenedesmus sp.*

Figs. 3 and 4 showed the effects of different backwashing intervals (10, 20 and 30 min) on flux decline and OD_{750} variation of the algae. Shorter backwashing intervals led to higher permeate flow recovery and higher initial flux for each filtration cycle, because backwashing could disturb foulants deposited on the membrane surface.

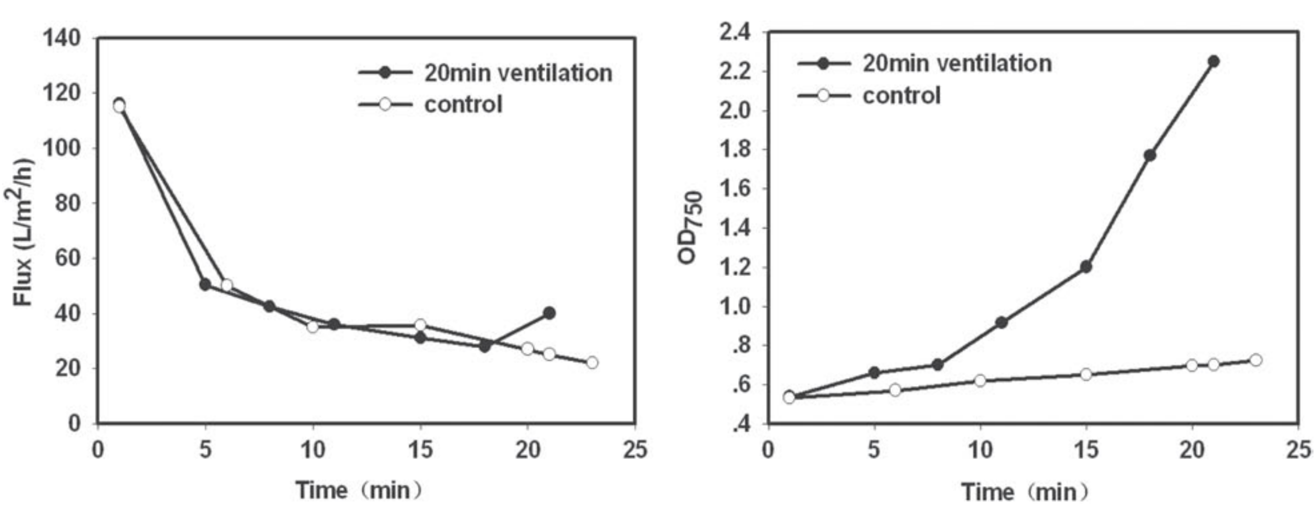

Fig. 2. Effects of ventilation every 20 min on flux and OD_{750} of *Scenedesmus sp.*

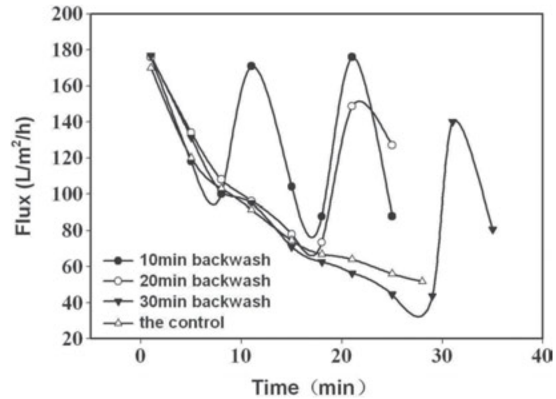

Fig. 3. Effects of backwash on flux of *Scenedesmus sp.*

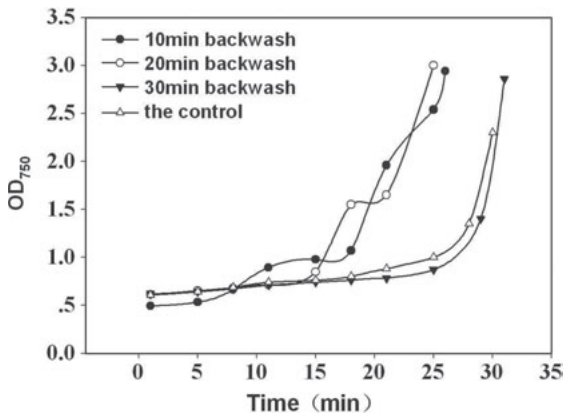

Fig. 4. Effects of backwash on OD_{750} of *Scenedesmus sp.*

Then, forward flushing algae solution could help to flush out debris which remained in the module during backwashing [16]. The OD_{750} at any backwashing frequency was higher than that of control. However, frequent backwashing also decreased online working time and thus lowered the concentration efficiency. This anti-fouling operation also obviously affected operating costs, as energy was required to achieve a pressure suitable for flow reversion [8]. Therefore, it was important to choose a suitable backwashing interval to obtain higher membrane flux and OD_{750}. Considering the flux and OD_{750} variation from Figs. 3 and 4, 20 min backwashing intervals was chosen as optimal in this paper.

Fig. 5 showed the effects of VRF on the recovery of the algae. When VRF was 10, the recovery rates with different backwashing frequency were all higher than 90% which was much higher than that of the control (about 40%). However, with the VRF increasing, the recovery rate dramatically decreased even if backwashing interval was once every 10 min. As the VRF was 20, the recovery rates of every backwashing frequency were about 70%. And when VRF was 30, the recovery rate was only about 60%. In addition, for the same VRF, the

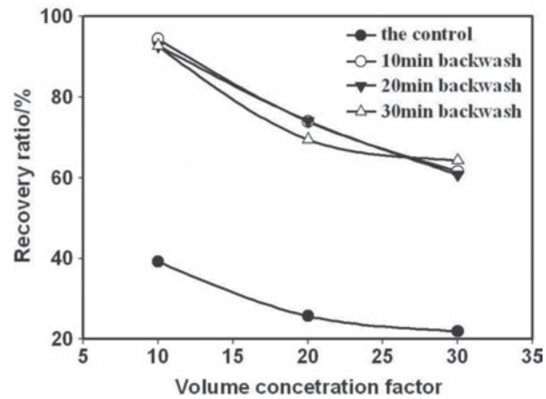

Fig. 5. Effects of volume reduction factor on the recovery ratio of the algae.

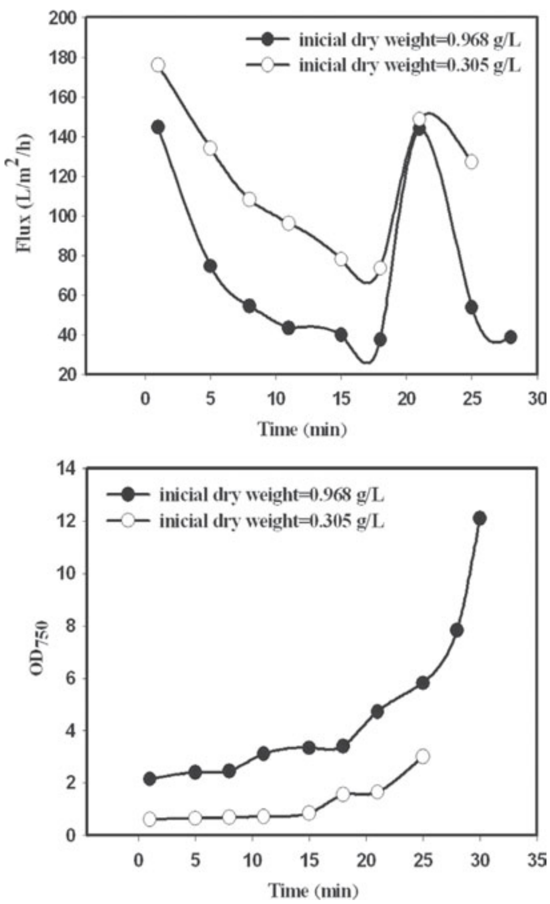

Fig. 6. Effects of initial biomass concentrations on flux and OD_{750} of the algae.

backwashing frequency seems no obvious influence on recovery rate. Thus, in order to obtain high recovery rate, it is important to choose suitable VRF.

Fig. 6 showed the effects of different initial biomass concentrations on flux decline and OD_{750} of the algae.

Initial biomass concentration presents obvious effects on membrane filtration behavior. The average flux of the initial biomass with a concentration of 0.305 g l^{-1} was higher than that of the initial biomass with a concentration of 0.968 g l^{-1}. For higher biomass concentration, the algae cake builds up faster and thus the flux declined rapidly. In addition, the steady state flux was lower for higher initial biomass concentration. However, the permeate flow recovery of the two groups was not significant difference. The final OD_{750} of the initial biomass concentration of 0.968 g l^{-1} was much higher than that of the initial concentration of 0.305 g l^{-1}, but the recovery ratio of the latter (about 60%) was lower than that of the former (about 94%). Perhaps this result was due to the fact that the initial cake and polarization layer governed the overall fouling situation.

4. Conclusions

Algae cake layer and adsorption of algogenic organic matter (AOM) cause membrane fouling. in this paper, in order to alleviate membrane fouling, different methods including ventilation into algae medium and backwashing was studied. The results showed that both two methods were efficient to recover the permeate flow, and backwashing showed higher efficiency. Backwashing for 1 min every 20 min was the best for the harvesting of *Scenedesmus sp.* In addition, the volume reduction factor was up to 10 and the recovery yield of the algae was above 90%. These results would make membrane separation a possible way for industrial micro-organisms harvesting.

Acknowledgements

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