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Comparison of axial vibration membrane and submerged aeration membrane in microalgae harvesting

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HIGHLIGHTS

- Compared with SAM system AVM had a better filtrating performance.
- AVM had a low membrane fouling, especially reversible fouling.
- After filtration it was found that SAM had more irreversible EOM on membrane.
- AVM had more low-MW irreversible EOM while SAM had more high-MW irreversible EOM.

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ABSTRACT

The submerged aeration membrane (SAM) system and axial vibration membrane (AVM) system can mitigate membrane fouling. In this study, both systems were investigated to compare the performance of filtration and the membrane fouling in algae filtration. In 5-h filtration, the transmembrane pressure (TMP) of SAM reached to 70.0 kPa, while there was almost no increase in TMP for AVM. After continuous filtration, it could be found that there was hardly any algae cells on the membrane of AVM (0.11 g/m^2), which was about 32.4 times less than that of SAM (3.56 g/m^2). Compared with the SAM system, AVM had a lesser membrane fouling, regardless of the reversible fouling or irreversible fouling. By SEM, FTIR and EEM, it could be found there was less irreversible extracellular organic matter (EOM) on the membrane of AVM. By MW distribution, it could be observed that less EOM with high-MW adhered to membrane of AVM.

1. Introduction

Recently, energy and environmental concerns, such as greenhouse gas emissions, energy security and fossil fuel depletion have aroused people's attention. Microalgae can be a good renewable fuel (biofuel) source, which has been investigated for many years (Lan et al., 2015; Miao and Wu, 2006; Zhao et al., 2015a). The use of biofuel produces almost no net carbon dioxide and releases fewer gaseous pollutants than does the use of fossil fuels. However, there are lots of challenges in efficient algae harvesting for commercial use. Harvesting has been shown to be an energy intensive step and considered to be a major obstacle for algal biofuel production (Udom et al., 2013; Weschler et al., 2014).

Membrane separation processes can recover microorganisms and yield stable and clean effluent water. Thus, a growing number of researchers have studied how to make better use of the membrane to harvest microalgae (Ahmad et al., 2013; Rossignol et al., 1999a). However, this technique presents some obstacles to be overcome, and the primal problem is membrane fouling (Drews et al., 2006; Rickman et al., 2012). The deposition of algae cells on membrane mainly caused reversible fouling that could be removed by physical methods, while the adhesion of EOM to membrane would result in serious irreversible fouling (Zhao et al., 2015b). High membrane fouling rate and flux decline rate will cause frequent membrane cleaning, which will reduce filtration efficiency and increase harvesting cost. Therefore, during algae harvesting, reducing membrane fouling and enhancing membrane flux is very significant.

Cross-flow is an available method to control membrane fouling in filtrating algae. Cross-flow configuration can offer a high membrane flux because of the high cross-flow velocity and shear rates acting on the membrane surface (Rossignol et al., 1999b; Kang et al., 2015a,b). But it consumes considerable energy, on account of high driving pressures and liquid velocities (Le-Clech et al., 2006). The application of submerged membrane utilizing low pres-

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sures in absence of pressure resistant membrane housings is expected to be cheaper and more efficient. In the submerged aeration membrane system, the shearing action is generally produced by coarse air bubbles to mitigate membrane fouling and sustain the filtration operation. Another technique is producing shear on membrane surface by moving the membrane relative to the solution to reduce membrane fouling, which is commonly known as dynamic or vibration filtration. Compared with the submerged membrane system, vibration membrane system can produce very high shear rate, which can better reduce membrane fouling. Furthermore, it is difficult for aeration to provide a homogeneous bubble distribution. Producing shear rate by vibrating the membrane has been considered to be one of the most efficient methods to reduce membrane fouling. Vibration membrane has been demonstrated to have a very promising prospect (Anusha et al., 2012; Li et al., 2014).

There was literature showing submerged aeration membrane could harvest algae with a lower membrane fouling compared with conventional submerged MBRs, but it still had a fast TPM increase in filtrating algae (Bilad et al., 2012b). In the previous study, it has found that vibration membrane system not only could enhance the flux but also had a very slow TMP increase. In addition, there were also literatures showing that vibration membrane consumed less energy than the submerged membrane system in filtrating algae (Bilad et al., 2013, 2012a). Although vibration membrane system has many advantages compared with aeration membrane system, there is little study on the systematic comparison between both systems in algae harvesting. In this study, a novel axial vibration membrane (AVM) system and submerged aeration membrane (SAM) system were devised to systematically compare the effect of both systems on filtrating performance and migrating membrane fouling. First, continuous filtration experiments were conducted to compare the performance of filtrating algae. After the continuous filtration, the reversible and irreversible fouling of both systems was investigated. Finally, to further compare and analyze the irreversible membrane fouling of both systems, the irreversible EOM on membrane was characterized by scanning electron microscope (SEM), Fourier transform infrared spectroscopy (FTIR), fluorescence excitation–emission matrix (EEM) and molecular weight (MW) distribution. By this study, it is hoped to offer valuable information for algae harvesting using membrane technology.

2. Methods

2.1. Cultivation of microalgae

Chlorella pyrenoidosa (*C. pyrenoidosa*, FACHB-9) was provided by the Institute of Hydrobiology at the Chinese Academy of Sciences. *C. pyrenoidosa* was cultured in Basal medium with 1 g/L glucose. The algae was inoculated in 3 L-Erlenmeyer flasks and placed in an incubator (GZX-300BS-III, CIMO Medical Instrument, China) at a temperature of 30 ± 0.5 °C with light intensity of 127 μmol/m^2 s provided for 12 h every day. After 50 days of cultivation, the algae concentration achieved about 2.0 g/L. In the filtration experiment, the concentration was adjusted to 0.3 g/L by adding distilled water.

2.2. Experimental setup

An axial vibratory membrane (AVM) system was devised to investigate the effect of vibration on filtration performance. The schematic diagram and photograph of AVM are illustrated in Fig. 1. The membrane module installed on a cassette could be vibrated by a servo motor (60FSM-04030, USA) at the frequency of 10 Hz with amplitude of 1 cm. The frequency was controlled by a digital servo drive (FDS15A-400X, USA). The tank has a working volume of 50 L. In submerged aeration membrane system, the tank is equipped with a microporous aerator pipe located on the bottom and air is provided by electromagnetic air pump (ACO-002, China). The aeration of 30 m^3 h^{-1} m^{-2} was produced to both mix the culture and reduce membrane fouling during the experiment. The membrane that was made of PVDF with a nominal pore size of 0.1 μm had a total membrane area of 0.02 m^2. PVDF membrane was purchased from a company (Minglie, China) while the membrane module is homemade. The filtrate was pumped by a variable speed peristaltic pump (BT100-LJ, China). The flux was automatically recorded by an electronic balance connecting to a computer. A vacuum meter was installed on the module measured the TMP. In the continuous filtration, 40 L/m^2 h was selected to be the initial flux.

2.3. Measurement of fouling rate

After 5-h continuous filtration, two pieces of fouled membranes were cut by a cutter knife. One membrane was applied to evaluating the total membrane fouling by measuring the water flux before rinse using a 300 ml cup-type filtration vessel under the pressure of 0.05 MPa (Qu et al., 2012a), and then the membrane was rinsed with pressurized tap water to be used for SEM and FTIR. The other membrane was flushed using 250 ml water and the algae on membrane were collected to measure the content of algae; then the membrane was also utilized for determining the water flux after rinse to measure the irreversible fouling; finally, the irreversible EOM was separated out from membrane by which was soaked in a 0.5 g/L NaOH solution for 2 h (Zhang et al., 2011).

In the present study, the membrane fouling was distributed into reversible fouling (RF), irreversible fouling (IF) and total fouling (TF). The water flux of new membrane was named as J_n, the water flux of fouled membrane before rinse was named as J_b, and the water flux of fouled membrane after rinse was named as J_a. Therefore, the reversible fouling, irreversible fouling and total fouling could be calculated as follows

$$TF = 1 - \frac{J_b}{J_n} \quad (1)$$

$$IF = 1 - \frac{J_a}{J_n} \quad (2)$$

$$RF = TF - IR \quad (3)$$

2.4. Analytical methods

The irreversible EOM solution was filtered using a 0.45 μm filter to measure the contents of TOC, proteins and polysaccharides. TOC was measured using the total organic carbon analyzer (TOC-V_{CPH}, Shimadzu, Japan). The modified Lowry method was used for determining the concentration of proteins, and the content of polysaccharides was determined using the anthrone–sulfuric acid method (Zhang et al., 1999). The concentration of *C. pyrenoidosa* was measured using OD_{680} method. EEM spectra were determined using a Fluorescence Spectrophotometer (F-4500, Hitachi, Japan). Before EEM analysis began, the pH of irreversible EOM solution was adjusted to about 7.0 (Qu et al., 2012a). The MW distribution was analyzed using a high performance size exclusion chromatography (LC-10AD, Shimadzu, Japan).