Korean J. Chem. Eng., 32(7), 1377-1380 (2015)
DOI: 10.1007/s11814-014-0343-5

pISSN: 0256-1115
eISSN: 1975-7220

Optimization of cross flow filtration system for *Dunaliella tertiolecta* and *Tetraselmis* sp. microalgae harvest

Seongkyun Kang[‡], Sangwoo Kim[‡], and Jinwon Lee[†]

Department of Chemical and Biomolecular Engineering, Sogang University, Seoul 121-742, Korea

(*Received 2 June 2014 • accepted 23 November 2014*)

Abstract−We compared *Dunaliella tertiolecta LB999* and *Tetraselmis* sp. KCTC12236BP harvesting efficiency using cross flow filtration (CFF) method. Filtration membranes with pore size of 0.45 μm and 0.2 μm were selected to determine the efficiency of membrane for harvesting. Cross flow filtration using *Dunaliella tertiolecta LB999* with 0.45 μm membrane under transmembrane pressure 0.25 bar was the optimal condition for the laboratory system and the harvesting efficiency was 84.7%.

Keywords: Microalgae, Cross Flow Filtration, Transmembrane Pressure, Flux Recovery Rate, Harvesting Efficiency

INTRODUCTION

The world's main source of energy is being depleted, so research concerning the creation of alternative fuels from biomass is of great importance [1,2]. To meet the growing energy demands, biofuels are being developed. Some microalgae species contain high levels of lipids which can be extracted and converted into biofuels. The extracted lipids can be trans-esterified into biodiesel [3]. Biodiesel can come from a variety of oil crops: sunflower and soybean oil as well as microalgae. Microalgae for biodiesel are beneficial because they have higher oil yields than land plants [4,5]. Microalgae are also autotrophic, meaning that they take carbon dioxide [6]. Microalgae can fix carbon dioxide released from power plants by photosynthesis and produce nutrients efficiently at a minimal cost [7]. Although there are many advantages of algae biofuel, many difficulties are faced in production of this form of alternative energy which is estimated to constitute at least 20-30% of the total cost [8]. Harvesting technology is an important factor in the production of biodiesel; however, an effective and economical method of microalgae harvesting has not yet been developed [9].

Filtration has been regarded as superior to conventional harvesting methods, because of its treatment of large quantities of microalgal culture [10]. Filtration is used to separate particulate or solute components in a fluid suspension according to their size exclusion under pressure differential through pore. Microfiltration (MF) involves the removal of solids ranging from 0.1-10 μm, while ultrafiltration (UF) involves the removal of solids ranging from 0.001 to 0.01 μm. Algae harvesting is commonly used in the MF range because of algal cells range from 5 to 15 μm.

In this study, two different membranes were selected to determine the optimal performance of CFF that include a 0.45 μm and 0.2 μm membrane using *Dunaliella tertiolecta LB999* and *Tetraselmis* sp. KCTC12236BP. The transmembrane pressure (TMP) studied during this experiment was 0.5 bar.

An additional experiment with *Dunaliella tertiolecta LB999* was conducted under TMP 0.25 bar to evaluate pressure difference that has an effect on harvesting efficiency. The membrane was cleaned with 5.0 liters deionized (DI) water after each test completion and then flux rate was checked to assess how well a membrane was cleaned. It was used for checking the possibility of DI water for cleaning agent to recover reusability of a membrane. These results provide a useful way that membrane technology for harvesting microalgae can be one a promising method for production of biodiesel in the future.

MATERIALS AND METHODS

1. Microalgae Culture Medium and Membrane Characteristics

The microalgae species used in this study were *Dunaliella tertiolecta LB999* and *Tetraselmis* sp. KCTC12236BP provided by In-ha Univer-

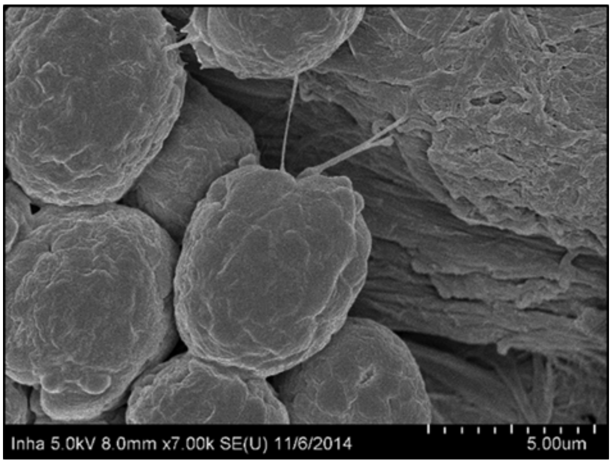

Fig. 1. Scanning electron micrograph of *Dunaliella tertiolecta LB999*. Bar, 5.0 μm.

[†] To whom correspondence should be addressed.
E-mail: jinwonlee@sogang.ac.kr
[‡] These authors contributed equally to this work.
[#] This article is dedicated to Prof. Hwayong Kim on the occasion of his retirement from Seoul National Univerisity.

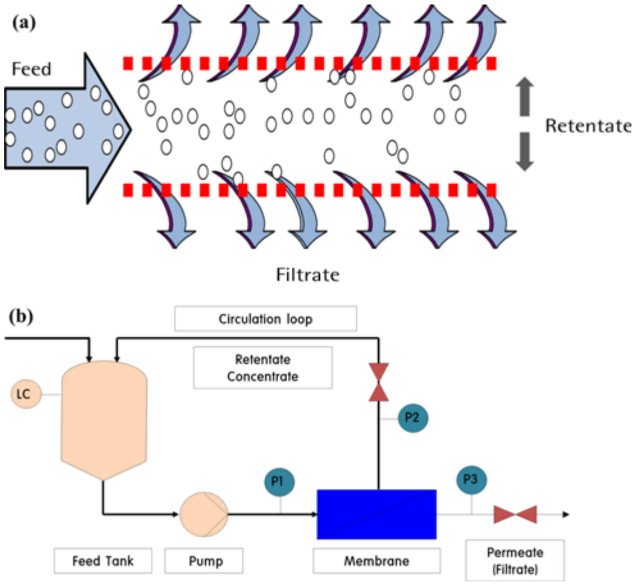

Fig. 2. Schematic diagram of cross flow filtration for microalgae harvest, (a) crossflow filter, (b) cross flow filtration system.

sity. *Dunaliella tertiolecta LB999* has 7-8 µm cell size and 16.0 g/L of fresh cell weight in Fig. 1. Otherwise *Tetraselmis* sp. KCTC12236BP has 9-10 µm cell size and 16.0 g/L of fresh cell weight. 500 mL of algal suspension was the test sample volume for CFF experiment. 0.45 µm and 0.2 µm membranes (Sartorius, Germany) were selected to determine the optimal performance for CFF.

2. Cross Flow Filtration System

Cross flow filtration (CFF), also known as tangential flow filtration, is different from dead-end filtration in which the feed is passed through a membrane or bed, the solids being trapped in the filter and the filtrate being released at the other end in Fig. 2(a). The CFF system was established to use for harvest of microalgae in Fig. 2(b).

Trice repeated CFF trials were respectively conducted by 0.45 µm and 0.2 µm membranes using two different microalgae species under TMP 0.5 bar. The membrane physical specification is described in Table 1. In addition, fifth repeated CFF trials with 0.45 µm and 0.2 µm membrane for *Dunaliella tertiolecta LB999* under low TMP 0.25 bar. Every CFF trial run of permeate flux rate was determined to compare decreased flux rate from initial to final CFF trial runs. To evaluate the results of each CFF trial runs, the flux was determined as in Eq. (1):

Table 1. Specifications of the crossflow filters used in the cross flow filtration system

Econity PF - 90M	
Material	Hydrosart
Effective membrane area (m^2)	0.02
Pore size (µm)	0.2 & 0.45
Max pressure (bar)	4
Operation temp. (C)	1-50
pH range	2-14

$$F=V/S/T \tag{1}$$

where F is the flux ($L/m^2 \cdot hr$), S is the effective membrane area (m^2) and T is the time of the concentration process (hr).

3. Algal Concentration

OD_{640} values were measured using an UV/vis spectrophotometer and used to calculate harvesting efficiency as follows in Eq. (2) [11]:

$$\text{Harvesting efficiency (\%)}=(1-A/B) * 100\% \tag{2}$$

where A is OD_{640} before CFF sample and B is OD_{640} after CFF sample.

4. Cleaning Procedure

The membrane was cleaned after every finished CFF trial run to reuse membrane. The membrane was flushed with 5.0 liters deionized water after every CFF trial run completion and then flux rate was checked to assess how well a membrane had been cleaned before it was reused.

5. Clean Water Flux Rate

The permeate flux rate was determined under TMP 1.25 bar after cleaning with DI water was finished to compare with initial permeate flux rate. The flux recovery rate (%) was determined as follows in Eq. (3):

$$R=F_{fi}/F_{in} * 100\% \tag{3}$$

where R is flux recovery rate (%), F_{in} is the initial flux rate ($L/m^2 \cdot hr$) and F_{fi} is the final third flux rate ($L/m^2 \cdot hr$)

RESULTS AND DISCUSSION

1. Cross Flow Permeate Flux Rate

Fig. 3 shows cross flow permeate flux rate by 0.45 µm and 0.2 µm

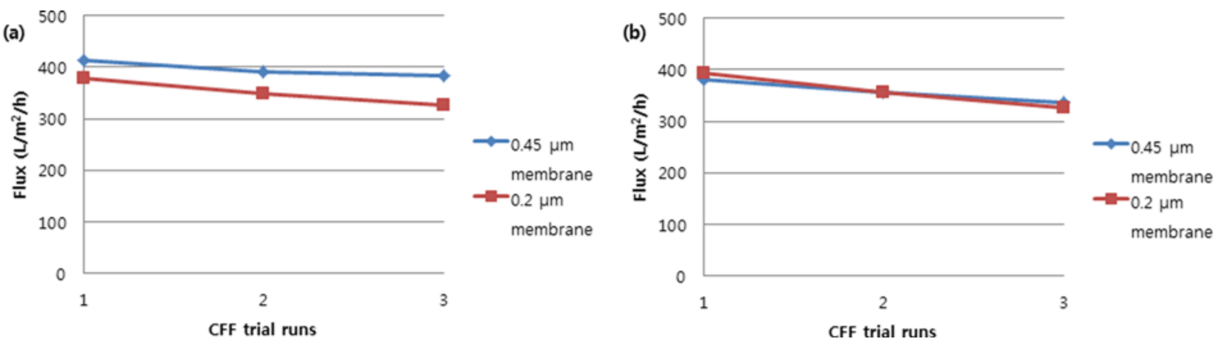

Fig. 3. Cross flow permeate flux rate during CFF trial runs (a) *Dunaliella tertiolecta LB999* with 0.45 µm and 0.2 µm membranes (b) *Tetraselmis* sp. KCTC12236BP with 0.45 µm and 0.2 µm membranes.

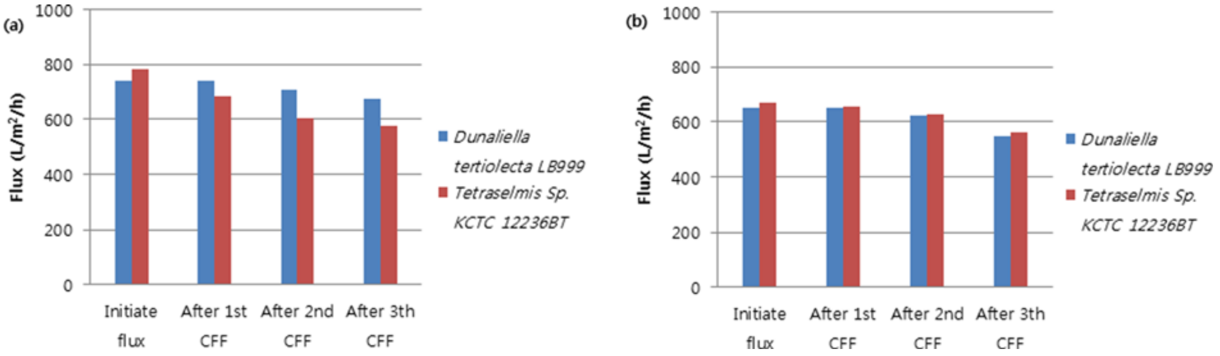

Fig. 4. Water permeate flux rate with *Dunaliella tertiolecta LB999* and *Tetraselmis* sp. KCTC12236BT after cleaning with DI water (a) 0.45 µm membrane, (b) 0.2 µm membrane.

membrane with respect to two different algae species. Each experiment was carried out in third CFF trial runs. We observed a slight decrease in permeate flux with *Dunaliella tertiolecta LB999* algae species using 0.45 µm membrane.

However, the other experiments showed that the permeate flux declined even more in the event of 0.45 µm and 0.2 µm membranes for harvesting *Tetraselmis* sp. KCTC12236BP as well as 0.2 µm membranes for *Dunaliella tertiolecta LB999* from initial until third CFF trial run. The decreased permeate flux rate compared initiate permeate flux with final permeate flux using *Dunaliella tertiolecta LB999* algae species with 0.45 µm membrane was 7.2%. On the other hand, the other experiments showed that the decreased permeate flux rates were 14.3% (0.2 µm membranes for *Dunaliella tertiolecta LB999*), 12.0% (0.45 µm membrane for *Tetraselmis* sp. KCTC12236BP) and 17.0% (0.2 µm membranes for *Tetraselmis* sp. KCTC12236BP), respectively.

2. Cleaning Water Flux Rate

The water permeate flux was recorded after every cleaning finished and shown in Fig. 4. The highest amount of declined permeate flux rate was CFF with 0.45 µm membrane using *Tetraselmis* sp. KCTC12236BP. It is assumed that even more algal cake or debris that builds on the membrane would decrease flux rate. The flux recovery rate of 0.45 µm and 0.2 µm membrane cleaning with 5.0 liters of DI water show that 73.4% and 83.6% of flux recovery rate was, respectively, accomplished in comparison to the initial water flux rate at after cleaning for third CFF run with *Tetraselmis* sp. KCTC12236BP. On the other hand, 91.3% and 84.5% flux recovery rate relevant to 0.45 µm and 0.2 µm membranes was obtained after cleaning for third CFF with *Dunaliella tertiolecta LB999*.

3. Comparison of Algae Harvesting Efficiency

The average percentage of harvesting efficiency in CFF with 0.45 µm membrane using *Dunaliella tertiolecta LB999* was 77.7%. On the other hand, *Tetraselmis* sp. KCTC12236BP was 83.7%. It shows the same trend in CFF with 0.2 µm membrane. The *Dunaliella tertiolecta LB999* was 78.4% and *Tetraselmis* sp. KCTC12236BP was 86.9%. The results showed that both 0.45 µm and 0.2 µm membrane pore sizes using the same algae species are possible to be used for microalgae harvest according to harvesting efficiency.

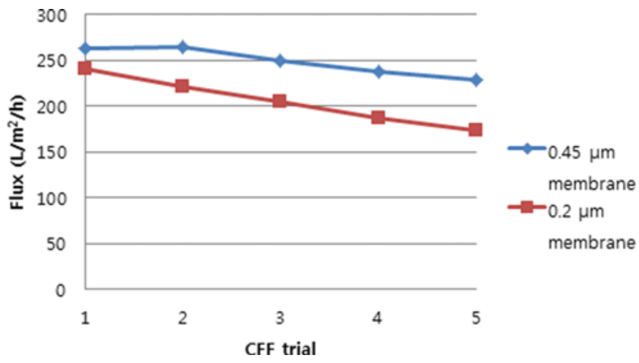

Fig. 5. Permeate flux with 0.45 µm and 0.2 µm membrane for *Dunaliella tertiolecta LB999* at low TMP 0.25 bar for the fifth CFF trial.

4. *Dunaliella tertiolecta LB999* Low TMP (0.25 bar) Results

Fig. 5 shows that the two different results of each fifth repeated CFF with 0.45 µm and 0.2 µm membrane for *Dunaliella tertiolecta LB999* at low TMP 0.25 bar. The decreased permeate flux rate compared initiate permeate flux with final permeate flux using *Dunaliella tertiolecta LB999* algae species with 0.45 µm membrane was 12.9%. On the other hand, the 0.2 µm membrane showed that the decreased permeate flux rates were 28.1%. It is concluded that the amount of declining permeate flux rate using 0.2 µm membrane was higher than 0.45 µm membrane. Also, the average percentage of harvesting efficiency in CFF with 0.45 µm membrane was 84.7%, whereas 0.2 µm membrane was 88.7% in Fig. 6. The flux recovery rates relevant to 0.45 µm and 0.2 µm membranes were 84.0% and 71.9%, respectively. That means that 0.45 µm membrane was shown as the more

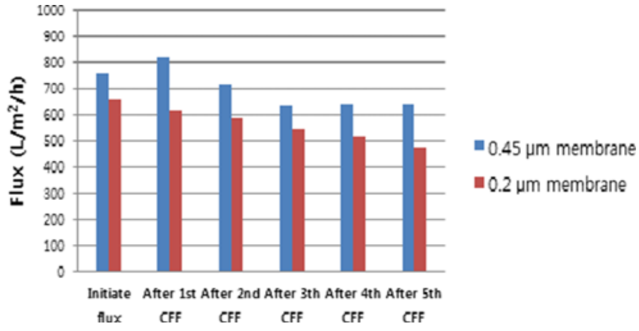

Fig. 6. Water permeate flux rate with *Dunaliella tertiolecta LB999* after cleaning with DI water.

useful one for microalgae harvest because of high recovery rates.

CONCLUSIONS

Harvesting efficiencies of CFF with 0.45 μm and 0.2 μm membranes were determined by comparing *Dunaliella tertiolecta LB999* and *Tetraselmis* sp. KCTC12236BP. The highest harvesting efficiency was filtration for *Tetraselmis* sp. KCTC12236BP using 0.2 μm membrane. However, on the problem with decreasing flux, it shows both 0.45 μm and 0.2 μm membranes for *Tetraselmis* sp. KCTC12236BP during CFF.

Although the harvesting efficiency of CFF for *Tetraselmis* sp. KCTC12236BP using 0.2 μm membrane was the highest during separation of algae, the performance of CFF for *Dunaliella tertiolecta LB999* would be more suitable than *Tetraselmis* sp. KCTC12236BP when using long-term operation in large scale algal medium. Furthermore, low TMP 0.25 bar during CFF for *Dunaliella tertiolecta LB999* indicated that it improves harvesting efficiency up to 10% compared with TMP 0.5 bar. Considering the balance of all these factors, the overall optimum condition for harvesting between two types of algae species was CFF with 0.45 μm membrane at TMP 0.25 bar using *Dunaliella tertiolecta LB999.*

ACKNOWLEDGEMENTS

This research was supported by a grant from the Marine Biotechnology Program funded by Ministry of Oceans and Fisheries, Korea. This work is also supported by Sartorius Korea Biotech.

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