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A comparative study of microfiltration and ultrafiltration for algae harvesting

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ABSTRACT

The present work deals with the filtration and concentration of algae (*Chlorella*) from a diluted culture medium using six commercial microfiltration membranes (MFP2, MFP5 and MFP8 with different pore sizes) and ultrafiltration membranes (FS40PP, FS61PP and ETNA10PP with different Molecular Weight Cut-Off (MWCO)). The effects of the operating conditions, e.g. feed solution temperature, TMP (transmembrane pressure), VCF (volume concentration factor) and cross-flow velocity on the filtration performance were investigated. The results showed that permeate fluxes increased with the increase in feed solution temperature, and the fluxes were probably limited by released extracellular polymeric substances (EPS) at higher temperatures. The permeate fluxes increased slowly with increasing TMP up to a certain limit, and after that the fluxes were stable or even decreased. The higher cross-flow velocity can significantly decrease particles accumulating on the surface of membrane, and thus leading to higher permeate flux. Although ETNA10PP exhibited much less fouling than other membranes, the permeate flux of this membrane was not higher than other membranes most likely due to the fact that this membrane is the 'tightest' membrane with MWCO 10,000. The performance of UF and MF membranes was compared for this application. The interesting finding of our work is that microfiltration and ultrafiltration showed very similar performance in terms of permeate flux under the same operation conditions at low TMP.

1. Introduction

In recent years, there has been increasing interest for the production of biofuels recognizing algae biomass as the raw material [1,2]. The production of biofuels through microalgae has not only attended to the quest for renewable energy source, it also has enormous commercial potential due to the growth rates of microalgae [3]. Microalgae can be cultivated in seawater [4], saline–alkali water [5], agricultural sewage [6] and industrial wastewater [7–9]. More recently, sources of woody material (Lignocellulose hydrolysates) have been considered to be an attractive feedstock for microalgae cultivation, which are the most widespread sources of carbon in nature. However, the harvest of microalgae biomass is still a major problem because of the small size of algae cells and low biomass concentration.

Although conventional methods, such as flocculation, flotation and centrifugation have been used as processes for effective removal of microalgae biomass from culture medium, there are still some problems remaining during practical operations. For example, chemical flocculents like alum and ferric chloride were used to harvest microalgae. However, chemical flocculation has not been used for large operations [10]. Usually, flotation was used in combination with flocculation for algae harvesting, but the cost of front flotation was estimated to be too high for commercial use [11]. Centrifugation and drying are currently considered too expensive due to low content biomass of the culture media.

Membrane technologies have been used for the removal of bacteria, viruses and other microorganisms [12]. As manufacturing techniques improve and the range of applications expands, the cost of membranes and membrane systems have steadily decreased, which may make it possible to use membrane technology for microalgae harvesting. Most importantly, membrane filtration can achieve complete removal of algae from the culture media [12]. Different membrane filtration technologies have been used for the removal or concentration of microalgae. Zhang [13] evaluated the feasibility of using a cross-flow membrane ultrafiltration process to harvest and dewater algae suspension, and the microalgae was concentrated 150 times and final algae concentration reached 154.85 g/L. Hung [14] studied how operating parameters affect microfiltration and examined the effect of preozonation on flux behavior when using hydrophobic and hydrophilic membranes. Zou [15] investigated the effect of physical and chemical parameters on forward osmosis (FO) fouling during algae separation. In addition, the effect of solute reverse diffusion on FO fouling was systematically studied. Pressure-driven microfiltration (MF) and ultrafiltration (UF) membrane processes are prone to fouling and are relatively energy intensive,

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Table 1
Membrane type and characteristics.

Membrane process	Type	Pore size	pH	Pressure, (bar)	Temperature (°C)	Material
MF	MFP2	0.2	1–12	1–10	0–75	Fluoro polymer
	MFP5	0.45	1–12	1–10	0–75	Fluoro polymer
	MFP8	0.8	1–12	1–10	0–75	Fluoro polymer
UF	FS40PP	MWCO = 100,000	1–11	1–10	0–75	Fluoro polymer
	FS61PP	MWCO = 20,000	1–11	1–10	0–75	Fluoro polymer
	ETNA10PP	MWCO = 10,000	1–11	1–10	0–75	Composite Fluoro polymer

while the FO membrane process showed a very low permeate flux [16]. There were a few reports concerning comparison of MF and UF for microalgae filtration. Chow et al. [16]. compared microfiltration and ultrafiltration methods and found both techniques attractive for removal of cyanobacterial cells. Rossignol [17] compared MF and UF technologies for continuous filtration of microalgae. The results showed that, although the pure water fluxes of microfiltration membrane were higher, during separation of microorganisms, fluxes of the ultrafiltration membrane became higher than microfiltration membrane.

The effectiveness of membrane separation is greatly affected by fouling. It can be further explained that the accumulation of microorganisms on membrane surface or in membrane pores causes decline in permeate flux [18]. Many efforts have been made to understand and reduce fouling, including membrane surface modification and new membrane material development [19,20]. Conventional polymeric materials membranes have been widely used in filtration and concentration of microalgae [13,21–23]. Rossignol [24] evaluated the performances of inorganic filtration membranes. Liu [25] utilized a thin, porous metal sheet membrane to harvest microalgae, which exhibited high properties of membrane area packing density, chemical stability, thermal stability, mechanical strength, high permeability and low cost.

The purpose of our work is to compare the performance of microfiltration and ultrafiltration for algae harvesting by using microfiltration (MF) membranes with different pore size and ultrafiltration (UF) membranes with different MWCO. All 6 types of the membranes used are Polyvinylidene Fluoride (PVDF) based, and ETNA10PP is a surface modified PVDF membrane. ETNA10PP is the only membrane with hydrophilic surface [26], which is supposed to show lower fouling tendency. Our intention is to investigate the influence of membrane materials (hydrophobic versus hydrophilic), membrane pore size, and porosity on performance. We have studied how operating parameters affect MF and UF filtration. MF and UF experiments were carried out separately including 3 kinds of membranes in each test. Then, the performance of the microfiltration membrane (MFP8) and ultrafiltration membrane (FS40PP) were compared in the same test for the filtration of *Chlorella*. The effect of VCF (Volume Concentration Factor = Total starting feed volume / retentate volume) on permeate flux was also studied during the concentration process of *Chlorella*.

2. Materials and methods

2.1. Microalgal suspensions

Chlorella pyrenoidosa FACHB-9 cells were cultivated in an open cultivation system, provided by Algae Innovation Center of Denmark. The fresh cultures were taken in the middle of the exponential growth phase. Then algae cells were placed in a refrigerator and stored under darkness at 4 °C. The pH of the culture was 9.0 ± 0.5. In order to compare the performance of the tested membranes, all comparative experiments have been carried out with the same cell concentration level, 0.68 g/L.

2.2. Membrane characteristics

Different commercial MF and UF membranes from Alfa Laval Nakskov A/S were used in the experiments, using Alfa Laval's cross-flow membrane module M10 (a small lab-scale membrane module). Performance of different membranes can be compared according to the permeate flux and cell retention. The membrane characteristics are shown in Table 1.

2.3. Experimental set-up

The schematic diagram of the membrane module is shown in Fig. 1. The membrane module consists of four plates kept together with four bolts. The module contains four flat-sheet membrane samples operating in series, with each having an effective filtration area of 0.0084 m^2. Inlet (P_{in}) and outlet pressures (P_{out}) are measured with pressure transducers (D) and (F) mounted on the inlet and outlet of the membrane module. The transmembrane pressure (TMP) was calculated as TMP = $(P_{in} + P_{out}) / 2\text{-}P_{permeate}$. A diluted *Chlorella* culture medium was kept in the feed tank (G).

The membrane filtration was performed in a batch mode operation with recycling of permeate and retentate back to the feed tank to simulate a continuous operation. The permeate flow rate was measured by measuring the collected permeate in a 500 ml cylinder over a time of 60 s. The flux data were measured 2 times to get an average value for each measurement. The total test time for each membrane test was 4.5 h. After each experiment, the M10 module was cleaned with cleaning agents Ultrasil 10 (from Ecolab) for approximately half an hour at 55 °C.

3. Results and discussion

3.1. Effect of temperature

In most microfiltration and ultrafiltration processes, permeate flux increases with increasing feed solution temperature [27]. The effect of temperature on permeate flux may be attributed not only to the effect of temperature on the physical properties (viscosity, solubility, etc.) of

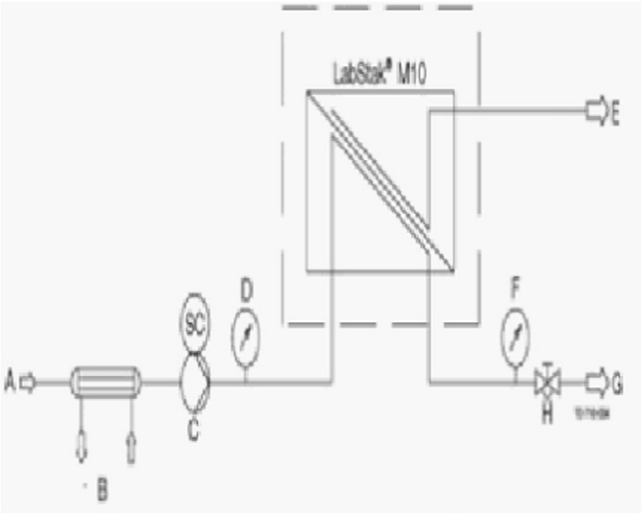

Fig. 1. Schematic diagram of experimental system, showing feed (A), cooling/healing (B), pump (C), pressure (D), permeate (E), pressure (F), retentate (G), control value (H).