Bioresource Technology 129 (2013) 582–591

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Benchmark study on algae harvesting with backwashable submerged flat panel membranes

Tom De Baerdemaeker [a,*], Bert Lemmens [a], Chris Dotremont [a], Jorien Fret [b], Luc Roef [b], Koen Goiris [c], Ludo Diels [a,d]

[a] Flemish Institute for Technological Research, VITO, Boeretang 200, 2400 Mol, Belgium
[b] Proviron, G. Gilliotstraat 60, 2620 Hemiksem, Belgium
[c] Kaho Sint Lieven, Gebroeders De Smetstraat 1, 9000 Gent, Belgium
[d] University of Antwerp, Department of Bioscience Engineering, Groenenborgerlaan 171, 2020 Antwerp, Belgium

HIGHLIGHTS

- Membrane performance on algae harvesting and water polishing was examined.
- Backwashable membranes were compared to a commercial non-backwashable membrane.
- Influences on critical flux for backwashable and benchmark membranes were examined.
- Backwashing showed significant advantage compared to relaxation.
- Membranes combined with centrifugation uses less energy than centrifugation alone.

ARTICLE INFO

Article history:
Received 26 June 2012
Received in revised form 25 October 2012
Accepted 29 October 2012
Available online 8 November 2012

Keywords:
Algae harvesting
Submerged membrane filtration
IPC
Water recycle
Polishing

ABSTRACT

The feasibility of algae harvesting with submerged flat panel membranes was investigated as pre-concentration step prior to centrifugation. Polishing of the supernatant coming from the centrifuge was evaluated as well. The effect of membrane polymer (polyvinyl chloride [PVC], polyethersulfone polyvinyl-pyrollidone [PES–PVP], poly vinylidene fluoride [PVDF]), pore size (microfiltration [MF], ultrafiltration [UF]), algae cell concentrations and species were investigated at lab-scale. In addition, backwashing as fouling control was compared to standard relaxation. PVDF was the superior polymer, and UF showed better fouling resistance. Backwashing outperformed relaxation in fouling control. The backwashable membranes allowed up to 300% higher fluxes compared to commercial flat panel benchmark (PVC) membranes. Estimations on energy consumption for membrane filtration followed by centrifugation revealed relatively low values of 0.169 kW h/kg of dry weight of algae compared to 0.5 kW h/kg for algae harvesting via classical centrifuge alone.

1. Introduction

Microalgae represent a vast potential of high value chemicals, such as poly unsaturated fatty acids, carotenoids, and pigments. They are currently considered as a strong and emerging market for feed and food as well as for renewable chemicals production (Grima et al., 2003; Dragone et al., 2010; Wolkers et al., 2011; Mata et al., 2010; Becker, 2007; Singh and Gu, 2010). Since each species of microalgae contains different amounts of compounds, a careful selection of the algae species is necessary. After cultivation the microalgae have to be harvested in an intact state. Several harvesting techniques are already commercially available such as centrifugation, flocculation, flotation, coarse filtration and sedimentation (Borowitzka, 2005; Grima et al., 2003; Spolaore et al., 2006). A novel technique for microalgae harvesting is the use of membrane filtration (Rossignol et al., 1999; Greenwell et al., 2010; Ladner et al., 2010). Grima et al. (2003) reported cross-flow microfiltration (MF) and ultrafiltration (UF) as possible alternative techniques for microalgae harvesting. Membrane filtration was suitable to completely remove debris and microalgal cells from the culture medium. The removal of debris and bacterial loads is considered advantageous towards water recycling. Using tangential cross flow filtration for the recovery of microalgae over a membrane with pore size of

Abbreviations: CFM, critical flux measurement; CF, critical flux; CWP, clean water permeability (l/m^2 h bar); DCW, dry cell weight of algae (g/l); E_W, estimated energy consumption based on dry weight of harvested biomass (kW h/kg); E_v, Estimated energy consumption based on biomass volume (kW h/m^3); MTC, mass transfer coefficient or permeability (l/m^2 h bar); PES–PVP, polyether sulfone polyvinylpyrrolidone; PVC, polyvinyl chloride; PVDF, polyvinylidene fluoride; TMP, trans-membrane pressure (bar); VCF, volume concentration factor.

* Corresponding author. Tel.: +32 14 33 56 57; fax: +32 14 32 11 86.
E-mail address: tom.debaerdemaeker@vito.be (T.D. Baerdemaeker).

0960-8524/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2012.10.153

0.45 μm, Petrusevski et al. (1995) were able to recover large amounts of microalgae with an overall intact microalgal biomass recovery between 70% and 89%. In the present study, submerged membrane filtration which is used in classical membrane bioreactors was evaluated as an alternative harvesting technique for microalgae (Xing and Wang, 2008). Bilad et al. (2012) have presented this option based on non-commercial membranes and a limited filtration setup. The Flemish Institute for Technological Research (VITO) has developed backwashable flat sheet membrane envelopes, based on the so-called integrated permeate channel (IPC) concept (Doyen et al., 2008).

An IPC (PES–PVP) membrane was compared to a commercial flat panel membrane to evaluate the ability of backwashing in microalgae filtration compared to relaxation for a standard commercial membrane. Additionally, different membrane materials and membrane pore sizes were tested for algae harvesting. Membrane performance was first evaluated on lab-scale. The critical flux was determined for the selected membranes for different operation modes (with and without backwashing) and for different microalgae species. These results were generated in preparation for long-term experiments at pilot scale.

Long-term filtration tests were performed on a single microalgae species with the most promising membrane prototype (i.e. the IPC UF membrane) and offset against the commercial flat panel PVC-MF membrane as a benchmark. Pilot tests were performed on algae suspensions as well as on the supernatant after centrifugation of the microalgae suspensions. The filtration behavior during long term tests should give an indication whether water polishing of the supernatant is technically feasible. Recycling of the polished water is essential for the sustainability of the algae production as the impact of salt inflow, water and nutrients can be reduced considerably (Pittman et al., 2010; Rodolfi et al., 2003; Uduman et al., 2010; Yang et al., 2011).

2. Methods

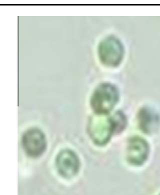
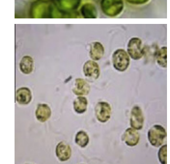
2.1. Microalgal species

Lab-scale membrane filtration tests were carried out using five different microalgal suspensions (Table 1). Fresh algae cultures were provided by Proviron and the KAHO St. Lieven College and were sampled at the end of their exponential phase (Table 1). Cell concentration was dependent on the process conditions during the cultivation cycle. Membrane filtration of the algae suspensions was started immediately after delivery to the lab. Prior to analysis the algae samples were stored at 4 °C. The influence of cell concentration on the filtration characteristics was studied at lab scale at volumetric concentration factors (VCF) of 5, 10 and 20. Pilot tests were performed with *Nannochloropsis oculata* in varying concentration dependent on growth conditions such as amount of nutrients and exposure to sunlight at the time of cultivation. A VCF is defined as the ratio of feed volume to retentate volume.

2.2. Analytical techniques

To determine dry cell weight concentration (DCW) of the algae suspensions, 100 ml of algae sample was filtered over a 0.45-μm fiber glass filter, followed by washing with 0.1 M ammonium formate to remove salt from the algae suspensions. The algae paste was dried overnight at 105 °C to remove the remaining ammonium

Table 1
Microalgae species used in filtration tests.

Algae species	Estimated size (μm)	Type	Morphology	Picture[a]
Nannochloropsis oculata	1, 5–3	Green; algae; flagellate	Spherical shape; rigid cell wall	
Phaeodactylum tricornutum	8–35	Brown; diatom	Oval, fusiform and triradiate; rigid cell wall	
Isochrysis sp.	3–5	Golden/brown; algae; flagellate	Spherical to pear shape; no rigid cell wall	
Chlorella vulgaris	2–10	Green algae	Spherical; rigid cell wall	
Pavlova lutheri	5–7	Golden/brown algae; flagellate	Spherical; no rigid cell wall	

[a] References: Algaelink, Wikipedia, Algaedepot.