Assessing and reducing energy requirements for membrane-based algal biomass harvesting

Muriel M. Steele, Dan Carey, Pooja Mistry, David A. Ladner*

Department of Environmental Engineering and Earth Sciences, Clemson University

Abstract

Algal harvesting is a key bottleneck in the sustainability of algal biofuels, especially for the smallest microalgal and cyanobacterial strains (~3 µm) that tend to be the best biomass producers. This project seeks to determine which algal cell and culture characteristics are most important for decreasing energy requirements. *Synechocystis* sp. cyanobacteria were cultured in the laboratory and harvested with membranes to assess energy requirements during a series of filtrations at different points in the culture's growth and decline. Bound and free extracellular organic matter (EOM), total suspended solids (TSS), and optical density measurements were used to determine that an intermediate size fraction (between ~0.2 and 5 µm) of organic material was responsible for most of the membrane flux decline. Applying osmotic upshock with 0.5-M NaCl reduced the energy needed for filtration by about a third during early exponential-phase growth, but was less effective during stationary and death phases due to the overwhelming influence of cell debris. Using a novel polypropylene nanofiber membrane resulted in better sustained flux and reduced energy consumption due to its depth-filtration mechanism and more porous structure. Future work is planned to further explore the details of foulant character, osmotic upshock, and novel filter materials.

Materials and Methods

Algal Culture

- *Synechocystis* sp. (Figure 2a) grown in BG11 media with a 12-hr light-dark cycle in 1-L aerated bottles.
- Ten-day monitoring period encompassed growth, stationary, and decline phase for these experiements.
- *Haematococcus pluvialis*. (Figure 2b,c) cultured in DY-V media for visual comparison.

Membrane Setup

- Dead-end filtration apparatus (Amicon 8050, Millipore; Figure 1) used with 43-mm diameter circular membrane coupons with 125 rpm stirring.
- Pressure held at 15 psi with a nitrogen cylinder connected to a pressure vessel (feed tank).
- Water flux determined by recording the mass of permeate collected over time on a top-loading balance (Model PB3002-S, Mettler-Toledo) using data acquisition software (Labview, National Instruments).

Filtration and Osmotic Upshock

- 1-L *Synechocystis* sample harvested every two days for a ten-day growth and decline period.
- Samples adjusted to 40-mg/L (determined through optical density measurements) by diluting with growth media.
- Half of the sample diluted with NaCl added to the growth media for 0.5-M final concentration. This induces osmotic upshock of algal cells.
- Two filtration runs performed for each sample (upshocked and normal) with 0.22-µm celluose acetate (CA) membranes.

Nanofiber Nonwoven Experiments

- Milliken Eminus polypropylene nanofiber material (Figure 6) used as a potential energy-saving alternative to microfiltration membranes.
- Filtrations performed in same manner as membrane experiments.

Analytical Methods

- Free extracellular organic matter (EOM) determined with total organic carbon (TOC) measurements (Shimadzu TOC-V) after filtration through 0.2-µm PVDF membranes.
- Bound EOM determined after resuspending centrifuged cultures in 33 mM NaOH, filtering with 0.2-µm, and measuring TOC.
- Optical density measured at 656 nm using UV-Vis spectrophotometer.
- Scanning electron microscopy (SEM) performed with Hitachi SU-6600 after Au coating.

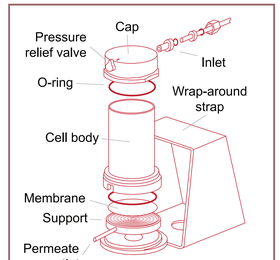

Figure 1. Filtration apparatus (Amicon).

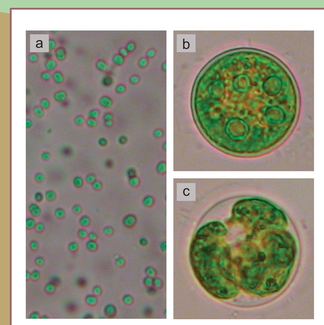

Figure 2. (a) *Synechocystis* sp. (cell diameter ~3 µm) (b) *H. pluvialis* (cell diameter ~40 µm. (c) *H. pluvialis* undergoing cell division.

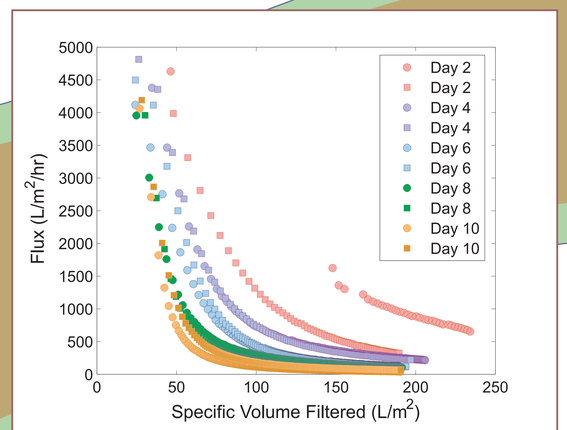

Figure 3. Flux data for algal harvesting experiments with 0.22 µm cellulose acetate membranes over a ten-day culture that encompased grown and decline phases. The initial algal concentration for each run was adjusted to 40 mg/L by dilution with growth media .

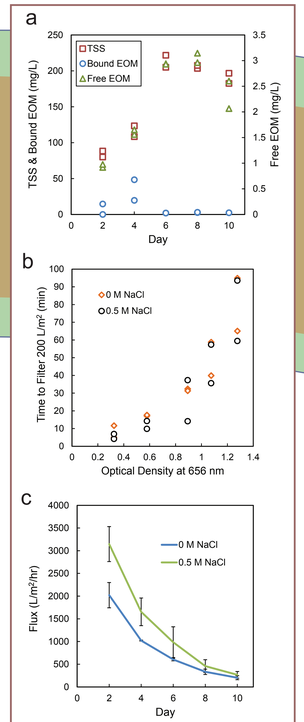

Figure 4. (a) TSS and bound and free EOM during culture. (b) Time required to filter 200 L/m² versus optical density. Optical density was linearly correlated with culture time. (c) Flux measured after filtration of 100 L/m² without (0 M) and with (0.5 M) NaCl as an upshock agent. Error bars are standard deviation of two filtrations.

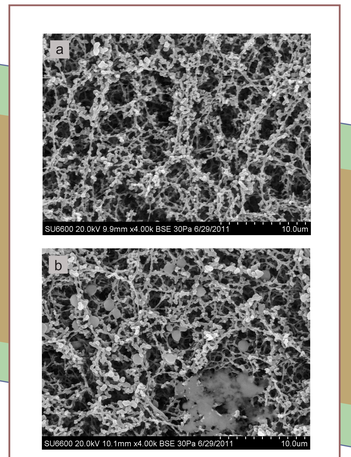

Figure 5. SEM images of (a) 0.22-µm pore size cellulose acetate (CA) membrane (b) CA membrane with *Synechocystis* sp. cells and extracellular organic matter attached. The membrane was thoroughly rinsed before SEM sample prep to remove unbound material.

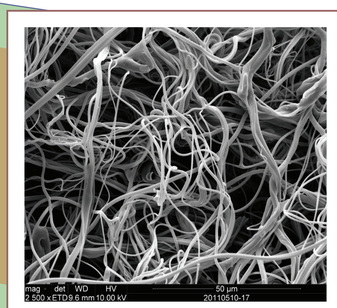

Figure 6. Milliken Eminus nanofiber nonwoven polypropylene material, 30 grams per square meter (gsm). (Image provided by Milliken).

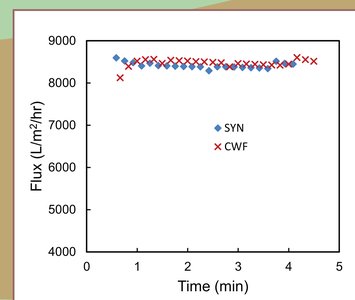

Figure 7. Filtration of *Synechocystis* sp. (SYN) on 100-gsm Eminus material compared to the material's clean-water flux (CWF).

Results and Discussion

- Flux decline (and thereby energy required for harvesting) was exacerbated as the *Synechocystis* culture aged (Figure 3), even though samples were diluted to maintain equal biomass concentration.
- Optical density (OD) was better correlated with flux decline than were TSS or EOM measurements, especially in older cultures (Figure 4a,b).
- Algal samples exposed to 0.5-M NaCl had higher fluxes than samples with no added salt. This effect was diminished in older cultures (Figure 4c).
- Whole *Synechocystis* cells as well as loose organic matter were bound to membrane materials after filtration (Figure 5).
- Milliken Eminus nanofiber filters initially retained very few *Synechocystis* cells, but performance increased to 55% retention after pretreatment of the polypropylene with monoethanolamine (data not shown).
- Nanofiber filters maintained near-constant flux while retaining 55% of the *Synechocystis* culture (Figure 7).

Conclusions and Future Work

- Based on OD, TSS, and EOM measurments, material between ~0.2 and 5 µm in size is suspected as the major foulant that increases the energy requirements for filtration. This is the fraction that passed through the TSS glass-fiber filter, but did not pass through the 0.2-µm filter used in free EOM analyses. Further characterization is needed to identify this material so that mitigation strategies can be designed.
- Osmotic upshock is a promising method for pretreating algae to reducing harvesting energy requirements. This could be performed with concentrate from desalination processes. More work is needed to verify the mechanism for flux enhancement.
- Nanofiber nonwoven material holds promise for energy-efficient algal harvesting. Instead of a complete barrier, it allows small material (like EOM) to pass and has a depth-filtration mechanism that leaves pore space open for water flow. Further work will be done to tune the pore space to an optimal size for balancing algal retention with water flux.

*Contact Information
342 Computer Court
Anderson, SC 29625
864-656-5572
ladner@clemson.edu

Ladner Research Group Web Site
http://clemson.edu/ces/ladnergroup

CLEMSON UNIVERSITY