Impact of algae type and cell condition on fouling and cleanability of capillary ultrafiltration membranes

S. Laksono*, A.K. Shalmani*, J. Jansen*, C. Staaks, S. Panglisch***

* Chair of Mechanical and Process Engineering / Water Technology, University of Duisburg-Essen, 47057 Duisburg, Germany; ** inge GmbH, Germany

Keywords: ultrafiltration, fouling, capillary membranes, algae, cell lysis, chemical cleaning

Abstract

Ultrafiltration membranes have a great potential to retain different types of algae with high efficiency. Nevertheless, the membrane fouling propensity, the cleanability, and consequently, the membrane lifespan are revealed to be significantly influenced by the algae type, cell condition and the operating parameters. Therefore, the fouling mechanisms of commercial ultrafiltration (UF) capillary membranes during dead-end filtration of various fresh water and marine algae types, in different cell condition, i.e., “intact” or “lysed”, are analyzed. Moreover, the potential of chemical enhanced backwashing approach and the permeability recovery are investigated. According to the results, the membranes showed different fouling behavior depending on the algae cell condition, which was also interestingly limited to the algae type. Furthermore, the fouled membranes by marine algae types exhibited better cleanability than those fouled by fresh water algae types. The differences in the fouling mechanisms and the cleanability were successfully correlated to the algae’s characteristics that were found to differ, for the same algae type, according to the cell condition.

Introduction

Algae-rich waters have undesirable influences on the water treatment process, especially during algal blooms. Pressure-driven membrane technologies, in particular UF, have been emphasized to exhibit high retention efficiency for all algae cells [1]. However, this is always accompanied by severe membrane fouling. This is mainly due to the intensive accumulation of the algae-rich and other algae-derived substances, known as algal organic matter (AOM), on the membrane surface [2]. In the current work, the fouling mechanisms of polyethersulfone (PES) capillary membranes by different types of fresh water and seawater algae are studied, in relation with cell condition, characteristics of algae feed, and operating conditions. Accordingly, a series of sequential filtration and backwashing cycles were performed using four different algae types. In each case, the fouling potential and hydraulic backwash-ability were investigated. Further on, the ability to restore the initial permeability was also investigated using different chemical cleaning protocols.

Material and Methods

Four types of algae, in either intact or lysed condition, were used as models for algae-rich water: *Chlorella Sorokiniana* “CS” (a spherical single cell green microalga) and *Arthrospira Platensis* “AP” (a filamentous helical blue-green microalga), as examples for fresh water algae, *Thalassiosira Rotula* “TR” (a cylinder diatom), and and *Chaetoceros Calcitrans* “CC” (a flat rectangular shape diatom), as examples for seawater algae. The disruption process of algae to form lysed cells was conducted using ultrasound device with 24 kHz and 250 W for 2 h.

Chlorophyll-a concentration and particle size analysis, including total particle number and total particle volume, were measured, using algae lab analyzer (bbe Moeldaenke, Germany) and Multisizer 4 particle size analyzer (Beckman Coulter Counter, USA), respectively, as control parameters for the model feed water. Moreover, the particle size analysis was also employed to define the algae morphology in both intact and lysed conditions. Algae-rich feed solutions were prepared with a high concentration of chlorophyll-a and high total particle volume in order to accelerate fouling process (cf. **Table 1)**.

UF capillary PES Multibore® membranes (inge GmbH, Greifenberg, Germany) with average pore diameter of 0.02 µm and active membrane surface area of 0.051 m^2 per module were employed in this study. The filtration experiments were performed in an inside/out dead-end mode using lab-scale membrane filtration equipment (Poseidon convergence Inspector, The Netherlands). The experiments were conducted 5 times, at least, for each algae type and cell condition. The filtration experiments were ended when either the permeability reached 100 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$ or 20 filtration cycles were performed.

Table 1. Chlorophyll-a concentration and total particle volume for the feed solutions

Type of algae	Chlorophyll-a in µg/L	Total Particle Volume in 10^6 µm³/mL
Chlorella Sorokiniana	197 - 225	14.00 ± 1.44
Arthrospira Platensis	25 - 50	6.11 ± 1.59
Thalassiosira Rotula	28 - 42	9.64 ± 2.80
Chaetoceros Calcitrans	50 - 72	11.20 ± 2.19

The chemical cleaning was performed in two steps. First, intensive chemical enhanced backwash (iCEB) using 50 ppm sodium hypochlorite solution at pH 12 was carried out two times at 21ºC ± 2. Thereafter, one-time intensive chemical enhanced backwash plus (iCEB+) was made using 200 ppm sodium hypochlorite solution at pH 12.5 and at 21ºC ± 2.

Results and Discussion

The normalized permeability was plotted vs. filtration time and the curves are shown in **Figure 1**. In case of *Chlorella Sorokiniana*, lysed cells were found to cause more severe fouling compared to intact cells; consequently, hydraulic backwashing was more effective in restoring the permeability in case of intact cells than lysed cells. This might be attributed to the stickness propensity of the released intracellular material after cell disruption that increase the adhesion to the membrane surface. Similarly, in case of *Thalassiosira Rotula*, more severe fouling was observed for lysed cells compared to intact cells. Nevertheless, the reduction in the membrane permeability was less pronounced compared to that in case of *Chlorella Sorokiniana*. This could be explained by the differences in the nature of the produced sticky colloids, after cell disruption, due to differences between the two algae types *Chlorella Sorokiniana* and *Thalassiosira Rotula*, i.e., single cell green algae vs. cylinder diatom algae, respectively.

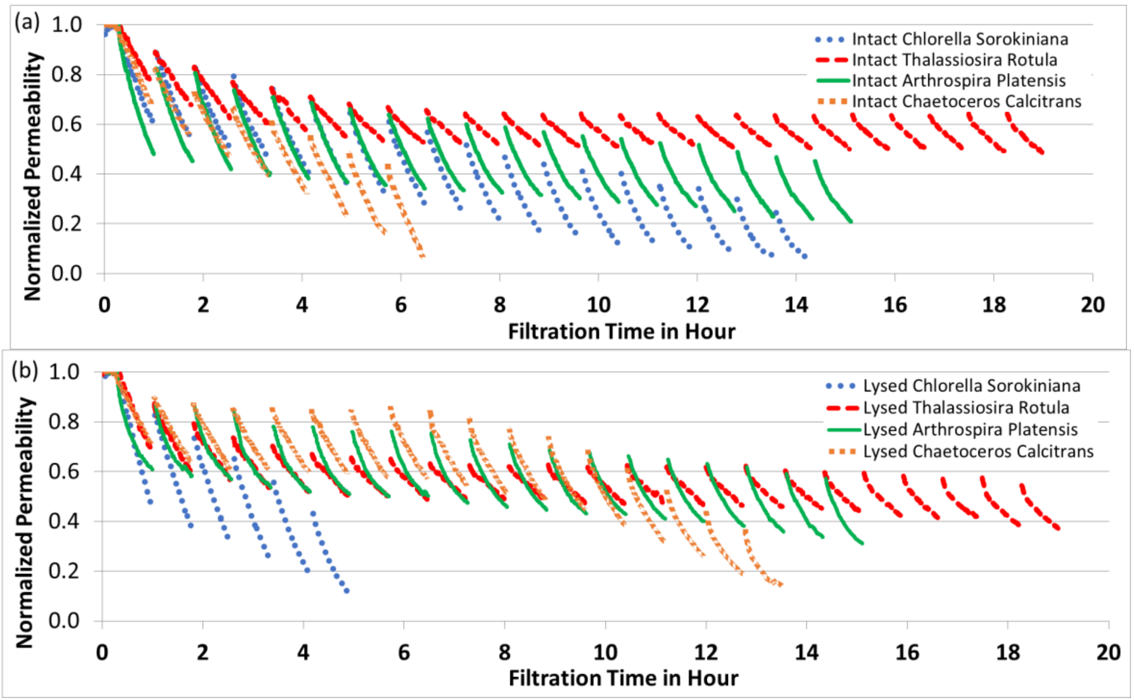

Figure 1. Normalizaed permeability vs. filtration time in intact (a) and lysed (b) condition

On the other hand, different fouling behaviors were found in the case of *Arthrospira Platensis* and *Chaetoceros Calcitrans.* In case of *Arthrospira Platensis*, intact and lysed cells showed comparable fouling tendencies. This might be attributed to the disintegration of the cells from a filamentous form into smaller particle size lysed cells with a more regular shape during cell disruption.While in case *Chaetoceros Calcitrans*, more severe fouling was caused by intact cells in comparison with lysed cells. Consequently, *Chaetoceros Calcitrans* showed a significant permeability reduction rather than *Arthrospira Platensis*.

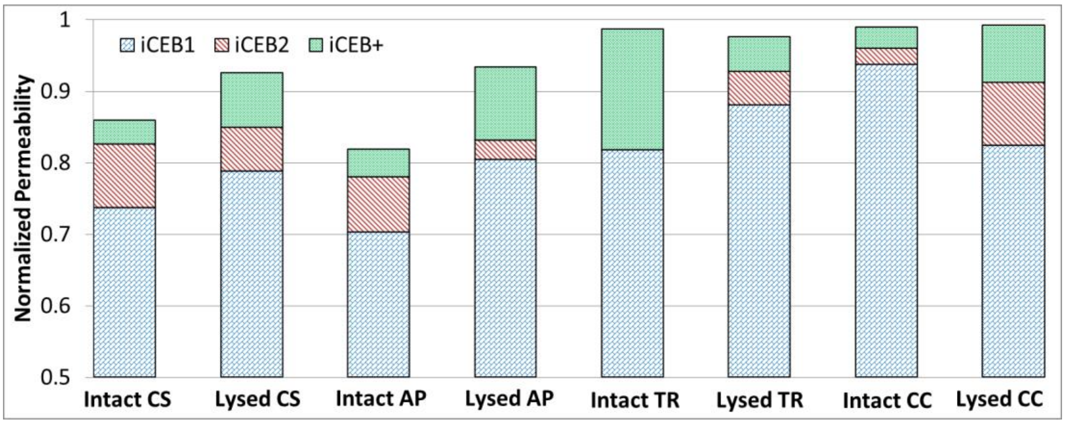

Figure 2. Normalized permeability after different chemical cleaning procedures

Moreover, the chemical cleaning protocol was, generally, revealed to be effective in cleaning and recovering the permeability for fouled membranes by intact and lysed cells, for different algae types (cf. **Figure 2**). Nevertheless, the fouled membranes by marine algae types exhibited better cleanability those fouled by fresh water algae types. This indicates the severe fouling tendency by fresh water algae types that required multiple iCEB cycles.

Conclusions

- The fouling propensity and the cleanability were found to be interestingly influenced by the algae type, cell condition, and the operating conditions.
- The different fouling tendencies were successfully correlated to the algae's characteristics that differ according to the cell condition, i.e., lysed or intact.
- The fresh water algae types were revealed to cause more severe fouling than marine algae types.

Reference

[1] B. Liu, F. Qu, H. Liang, B. Van der Bruggen, X. Cheng, H. Yu, G. Xu, G. Li, Microcystis aeruginosa-laden surface water treatment using ultrafiltration: Membrane fouling, cell integrity and extracellular organic matter rejection, Water Res, 112 (2017) 83-92.

[2] L.O. Villacorte, S.A.A. Tabatabai, D.M. Anderson, G.L. Amy, J.C. Schippers, M.D. Kennedy, Seawater reverse osmosis desalination and (harmful) algal blooms, Desalination, 360 (2015) 61-80.

Paper prepared for: *17. Aachener Membran Kolloquium (AMK); 13. - 15.11.2018; Aachen*

DOI: 10.17185/duepublico/49397
URN: urn:nbn:de:hbz:464-20201127-162150-9