Separation and Purification Technology 123 (2014) 153–163

Contents lists available at ScienceDirect

Separation and Purification Technology

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

Pulse bubble sparging for the control of hydraulically reversible fouling in submerged hollow fiber membrane systems

D. Ye [a], S. Saadat-Sanei [b], P.R. Bérubé [b,*]

[a] GE Water and Process Technologies, Singapore Water Technology Centre at National University of Singapore, Singapore
[b] Department of Civil Engineering, The University of British Columbia, Vancouver V6T 1Z4, Canada

ARTICLE INFO

Article history:
Received 7 October 2013
Received in revised form 12 December 2013
Accepted 14 December 2013
Available online 20 December 2013

Keywords:
Gas sparging
Submerged hollow fiber membranes
Coarse bubble diffuser
Pulse bubble diffuser
Induced surface shear stress
Hydraulically reversible fouling control

ABSTRACT

Previous studies have demonstrated that pulse bubble sparging is more effective at the control of hydraulically reversible fouling than coarse bubble sparging in submerged hollow fiber membrane systems. However, some of the optimal operating set points for pulse bubble sparging control have not yet been identified. The present study was conducted to further quantify the potential benefits associated with pulse bubble sparging for the control of hydraulically reversible fouling. In particular, the effect of pulse bubble release frequency and size on the shear stress induced onto membranes and the resulting effect on the control of hydraulically reversible fouling was assessed. The shear stress and fouling control resulting from continuous and intermittent coarse bubble sparging was also considered so that the performance of these conventionally used sparging approaches could be compared directly to those for pulse bubble sparging.

The shear stress resulting from pulse bubble sparging was significantly greater than that induced by continuous coarse bubble sparging, and similar to that induced by intermittent coarse bubble sparging. However, for pulse bubble sparging, the rate of fouling was significantly lower than for either continuous or intermittent coarse bubble sparging, indicating that the magnitude of the shear stress on its own cannot be used to assess the efficacy of different sparging approaches for the control of hydraulically reversible fouling.

The pulse bubble release frequency had a significant effect on the rate of fouling. At lower sparging flows (i.e. lower pulse bubble release frequencies), the fouling rate decreased as the sparging flow increased. However, at the highest sparging flow considered, the rate of fouling was greater than that observed at the lower sparging flows, indicating that an optimal bubble release frequency likely exists, below which an increase in frequency decreases the extent of hydraulically reversible fouling, and above which the control of hydraulically reversible fouling is inhibited. For the conditions investigated, a pulse bubble release frequency of approximately 0.5–0.6 Hz was optimal. In addition, the results suggest that the optimal pulse bubble size for the control of hydraulically reversible fouling is likely in the 150–250 mL range. Sparging into stagnant water also resulted in better hydraulically reversible fouling control than sparging when liquid upflow was promoted.

1. Introduction

Because of their ability to effectively remove particulate contaminants, ultrafiltration membranes are increasingly being used in water and wastewater treatment applications. However, over time, retained material can accumulate, fouling the membrane surface and increasing the resistance to the permeate flow. A number of approaches exist which can minimize and/or remove the fouling material. Of these, gas sparging is commonly used in submerged membrane systems to remove material that contributes to surface fouling [1]. The sparged bubbles induce shear stresses onto nearby membrane surfaces as they rise through the submerged membrane system [2–5], likely promoting several mechanisms that transport foulants away from a membrane surface [6].

Fulton and Bérubé [7] characterized shear stresses induced onto membrane surfaces by gas sparging in a full-scale membrane module. Operating parameters, such as gas flow rate and cyclic aeration, as well as system configurations, such as module spacing and fiber location relative to the position of the spargers, affected the magnitude as well as spatial and temporal distribution of the shear stress in the system. To identity the type of shear stress distribution that is most effective at controlling hydraulically reversible fouling, Chan et al. [2] subjected hollow fiber membranes to mechanically generated shear stress patterns that

* Corresponding author. Tel.: +1 604 822 5665.
E-mail address: berube@civil.ubc.ca (P.R. Bérubé).

1383-5866/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.seppur.2013.12.011

mimicked those observed in full-scale gas sparged membrane modules. Conditions representative of coarse bubble sparging were better than those representative of single phase liquid flow. Also, conditions representative of intermittent coarse bubble sparging were more effective at fouling control than those representative of continuous coarse bubble sparging. Greater fouling control under fluctuating hydrodynamic conditions has also been reported by others [8–10]. These results are consistent with those observed in full-scale systems, where intermittent coarse bubble sparging (also commonly called cyclic sparging), is more effective at fouling control than continuous sparging for a given cumulative volume of sparged gas added to the system [11].

Chan et al. [2] also considered shear stress patterns that were not representative of those observed at full-scale at that time. One in particular, which was characterized by shear events of short duration and of high magnitude, was reported to be the most effective at the control of hydraulically reversible fouling compared to all other shear stress patterns considered. A more recent study by Jankhah and Bérubé [4] demonstrated that the optimal shear stress pattern for the control of hydraulically reversible fouling identified by Chan et al. [2] could be generated using pulse bubble sparging. Pulse bubble sparging releases large bubbles (i.e. greater than 100 mL in size) at a relatively low frequency, compared to coarse bubble sparging which continuously releases small bubbles that are only a few mL in size. Pulse bubble sparging was recently introduced by some membrane manufacturers as a means to improve the efficacy of sparging for fouling control (e.g. GE Water and Process Technologies, Siemens, Samsung). The improved performance was attributed to the greater power transfer efficiency for the control of hydraulically reversible fouling which, for pulse bubble sparging, was twice that which could be achieved for coarse bubble sparging [4]. Membrane manufacturers that have adopted pulse sparging have also claimed similar order of magnitude improvements in terms of fouling control at a given sparging flow when switching from coarse to pulse bubble sparging [11].

Jankhah and Bérubé [12] also observed that the extent of hydraulically reversible fouling control increased with the frequency at which pulse bubbles were released into the system during sparging. The increase in the extent of fouling control at higher sparging frequencies was attributed to the higher power induced at membrane surface when sparging with pulse bubbles at these frequencies. Similarly, Chan et al. [2] observed that the extent of hydraulically reversible fouling control increased with the frequency at which shear events were induced onto a membrane. Although the shear events considered by Chan et al. [2] were generated mechanically rather than with pulse bubbles, their results nonetheless suggest that the control of hydraulically reversible fouling could also be inhibited in a system where the sparged bubbles are released at a high frequency. Unfortunately, the study by Jankhah and Bérubé [12] did not consider pulse bubble release frequencies greater than 0.5 Hz. As a result, the optimal frequency for the control of hydraulically reversible fouling remains unknown.

The pulse bubble release frequency is dependent on both the sparging flow and the bubble size. When considering discrete pulse bubbles, Jankhah and Bérubé [12] reported that larger pulse bubbles (e.g. 500 mL) were more effective at controlling hydraulically reversible fouling than smaller ones (e.g. 150 mL). However, when multiple pulse bubbles generated by sparging at a given gas flow were considered, smaller pulse bubbles were more effective at controlling hydraulically reversible fouling than larger ones. The greater fouling control observed for smaller pulse bubbles was attributed to the higher frequency of shear events at a given gas flow.

The present study was conducted to further assess the benefits associated with using pulse bubble sparging for the control of hydraulically reversible fouling. In particular, the effect of pulse bubble release frequency and pulse bubble size on the shear stress induced onto membranes, and the resulting effect on the control of hydraulically reversible fouling, was investigated. For comparative purposes, the shear stress induced onto hollow fiber membranes, and the resulting effect on the extent of hydraulically reversible fouling control, was also determined for continuous and intermittent coarse bubble sparging, which is currently commonly used for fouling control in commercial submerged hollow fiber membrane systems.

2. Materials and methods

2.1. Experimental set-up

The experimental set-up consisted of system tanks, fiber modules and gas sparging systems. The configuration of the set-up (Fig. 1) differed depending on the type of experiment being performed as discussed below. The system tanks were vertical Plexiglas cylinders with a height of 2.6 m and a liquid depth of 2.2 m. Two tank diameters were considered: the small tank (ST) had an internal diameter of 14 cm and the large tank (LT) had an internal diameter of 20 cm. A concentric open-ended cylindrical baffle with a height of 200 cm and an internal diameter of 14 cm was placed in the large tank to promote convective flow in the system. As a result, for both tanks, the fiber module and the sparged bubbles were confined within similar cylindrical volumes. The fiber modules were potted into 15 mm ID bulkheads at both ends. The length of the fibers between the bulkheads was 1.8 m, and the distance between the bulkheads was approximately 1.76 m, allowing the fibers to sway. The fiber modules were held within the system tank using rigid plastic brackets that were designed not to impact the liquid or gas flow in the system tank.

When performing filtration experiments, the fiber modules consisted of 3 active 1.8 mm diameter hollow fiber ultrafiltration membranes (total filtration area of 0.0293 m^2) with a nominal pore size of 0.04 μm (ZW500, GE Water and Process Technologies), potted into a 2 cm long and 6.3 mm (ID) rigid Teflon tube at both ends and surrounded by 37 inactive hollow fiber membranes (Fig. 2a). 37 Hollow fiber membranes were selected because this was the maximum number of fibers that can fit into the 15 mm ID bulkheads with the 3 active fibers at the center of the module (Fig. 2a). The bottom end of the active hollow fiber membranes were sealed and potted into the bottom bulkhead, while the top end was potted into the top bulkhead without being sealed so that permeate could be extracted from the active fibers. The top bulkhead was connected to a permeate pump (Masterflex). A pressure gauge and transducer installed on the permeate line were used to monitor and record the trans-membrane pressure in the system. The permeate was returned to the system tank to maintain a constant level and solids concentration in the system. The only type of fouling considered in the filtration experiments was hydraulically reversible surface fouling. Therefore water matrix used could not result in internal or adsorptive fouling. For this reason, a solution containing bentonite particles was selected as the water matrix for the filtration experiments. Filtration was performed at a constant permeate flux of 120 L/m^2 h with a solution of tap water containing bentonite at either 250 or 750 mg/L. A solution containing 750 mg/L of bentonite was used for the experiments investigating the effect of pulse bubble sparging at high frequencies because the fouling rate observed with a 250 mg/L of bentonite was too low. At a permeate flux of 120 L/m^2 h and a solids concentration of 750 mg/L, the total solids flux to the membrane is 0.09 kg/m^2 h, which is in the range typical of full-scale membrane bioreactors. The average particle size of the bentonite in the tap water was approximately 2 μm, while the size of the smallest particle was