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Distribution of surface shear stress for a densely packed submerged hollow fiber membrane system

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HIGHLIGHTS

- Surface shear stress was characterized for different air sparging of a UF module.
- Shear stress was greatest on the outside plane of a densely-packed membrane module.
- Pulse bubble sparging was most efficient (high shear stress at low air flow rates).

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ABSTRACT

Surface shear stress induced by different air sparging regimes on a submerged hollow fiber ultrafiltration module with horizontally-oriented, densely packed fibers was characterized. Continuous and intermittent (cycling on and off) coarse bubbles (0.75–2.5 mL), as well as large pulse bubble (150 and 500 mL) sparging were considered for a range of air flow rates. The power required to induce surface shear stress on the surface of the hollow fibers was substantially lower when using large pulse bubble sparging compared to both continuous and intermittent coarse bubble sparging. Results indicated that the air flow required for pulse bubble sparging was more than 80% lower than that required for coarse bubble sparging to induce comparable surface shear stress (and corresponding fouling control). This study demonstrates the potential value and efficiency of pulse bubble air sparging as a fouling control option in densely packed hollow fiber membrane systems.

1. Introduction

Air sparging is commonly used as a fouling control strategy for membrane bioreactors (MBRs) used in wastewater treatment [1,2]. It may also serve as a cost-effective ultrafiltration fouling control strategy for drinking water treatment [3]. Bubbles rising along the fibers impart shear stresses at the fiber surface which act to prevent the deposition of fouling material (via back-transport) or to aid in scouring accumulated surface fouling [4]. Optimization of bubble size and frequency has been examined and results have reported that fouling control is greater for intermittent (i.e., cycling sparging on and off) or large pulse bubble (>100 mL volume) sparging [5], as compared to conventional continuous coarse bubble aeration [6–8]. As such, pulse bubble sparging has recently been introduced by a number of membrane manufacturers (e.g., GE, Samsung, Evoqua) for fouling control in submerged hollow fiber membrane systems. Improved performance of pulse bubble sparging has been attributed to more efficient power transfer to the fibers [9]. As a result, the sparging air flow rate required for fouling control is significantly lower for pulse than coarse bubble sparging [8,9], which could potentially lead to capital and operational cost savings.

To-date, studies examining surface shear stress induced by different air sparging regimes on membrane fibers have only considered modules with vertically-oriented fibers and a relatively low packing density [7,9]. However, a number of membrane systems are configured with horizontally-oriented fibers with high packing density i.e., ZW1000 systems (GE Water & Process Technologies). The present study focused on characterizing the shear stress induced onto horizontally-oriented fibers in a densely packed membrane module using different air sparging regimes.

2. Materials and methods

The experimental apparatus consisted of a membrane tank and membrane module, as well as air sparging, permeation, and shear stress measurement systems. The membrane tank was constructed of plexiglass with dimensions of 1 m (height) × 1 m (width) × 0.14 m (depth/thickness), into which a single ZW1000 membrane module (GE Water and

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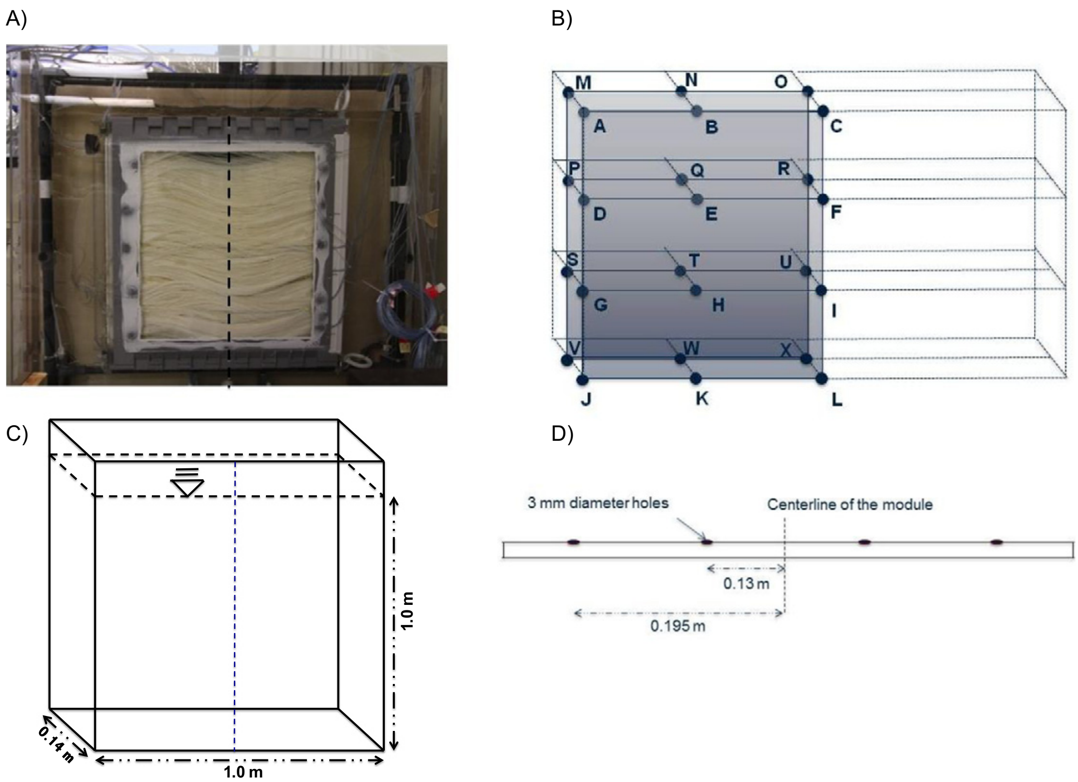

Fig. 1. (A) Picture of the experimental apparatus with membrane module centerline denoted by dotted line, (B) position of shear probes within the module; probes A–L on the outside plane and probes M–X on the inside plane, (C) membrane tank dimensions, and (D) location of diffuser holes in coarse bubble sparger.

Process Technologies, Oakville, ON) was submerged (Fig. 1A and C). Two gas sparging systems were considered. The coarse bubble sparger, fixed to the bottom of the membrane tank, was constructed using PVC pipe (0.0025 m diameter) with four 3 mm diameter diffusers (holes) located at 0.065 m and 0.195 m on either side of the centerline of the module to match the configuration of commercial-sized systems (Fig. 1D). The pulse bubble sparger used in the current study is a proprietary product (GE Water and Process Technologies, Oakville, ON) and therefore details of its configuration cannot be provided; however, it is based on the GE Leap MBR pulse bubble sparger configuration. This sparger was capable of releasing either 150 mL or 500 mL volume bubbles and was located at the centerline of the membrane module. Sparging air flow rates ranged from 5 to 60 L/min. Air flow rates of 40–60 L/min are typically used for sparging in commercial-sized systems (e.g., ZW1000). For intermittent coarse bubble sparging both 6 s (3 s on/3 s off) and 20 s (10 s on/10 s off) cycles were examined. In order to perform measurements with the shear probes, an electro chemical solution (0.003 M ferricynaide, 0.006 M ferrocyanide and 0.3 M potassium chloride [7]) was used as the feed water in the membrane tank. A pump (Iwaki 70RT, J&L Aquatics, Burnaby, Canada) was used to draw permeate through the hollow fibers (i.e., outside-in mode) at a flux of 43 LMH, which is within the range of typical permeate flux for commercial scale ZW1000 systems, i.e., the electrochemical solution was permeated through the membrane. Permeate was returned to the system tank to maintain a constant liquid level. Table 1 summarizes the experimental conditions considered in the study. The shear stress induced on the fibers was measured using an electrochemical approach as described by Jankhah and Bérubé [9]. Electrochemical shear probes were installed flush with the surface of 1.8 mm diameter test fibers as described by Fulton et al. [7]. The shear probes were positioned at different locations within the membrane module as presented in Fig. 1B. All trials were conducted at room temperature (i.e., 18 °C). Due to system symmetry, it was only necessary to monitor shear stress in one half of the system. The root mean square (RMS) was used to summarize the temporally- and spatially-variable shear stresses [6,10]. To assess the effect of the surface shear stress induced by air sparging on membrane integrity, the ZW1000 module was operated for an 8 week period with continuous pulse bubble sparging (5 L/min air flow and 500 mL bubble volume); pressure decay tests (at 35 kPa) were performed on a weekly basis. No breaches in membrane integrity were observed during this period.

3. Results and discussion

Although permeation can influence liquid velocity between fibers in highly packed configurations, it did not significantly affect the magnitude or distribution of the RMS of shear stress in this system (results

Table 1
Experimental conditions examined.

	Continuous coarse bubble					Intermittent coarse bubble				Pulse bubble		
Sparging air flow rate (L/min)[a]	5	10	20	40	60	5	10	20	25	5	10	20[b]
Bubble volume (mL)[c]	0.75–2.5					0.75–2.5				150 and 500		
Sparging flow regime(s)	Continuous					10 s on/10 s off, or 3 s on/3 s off				Pulses of sparged gas		

[a] Presented sparging flow rates correspond to the flow during the portion of the cycle when the air was on. The net average gas flow rate was approximately half of the tabulated value.
[b] Only for 500 mL volume bubbles.
[c] Jankhah and Bérubé [9].