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Enhanced performance of submerged hollow fibre microfiltration by fluidized granular activated carbon

Bing Wu [a], Yuanyuan Wang [a,b], Weikang Lim [a], Jia Wei Chew [a,c], Anthony G. Fane [a,b], Yu Liu [b,d,*]

[a] Singapore Membrane Technology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, CleanTech One #06-08, Singapore 637141, Singapore
[b] School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
[c] School of Chemical and Biomedical Engineering, Nanyang Technological University, 62 Nanyang Drive, Singapore 637459, Singapore
[d] Advanced Environmental Biotechnology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, CleanTech One #06-08, Singapore 637141, Singapore

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ABSTRACT

The effect of fluidized granular activated carbon (GAC) on membrane filtration performance was investigated using a bench-scale upflow hollow fibre membrane filtration setup under constant flux operation. The membrane fouling tendencies were compared among five different experimental parameters, namely, GAC size, GAC packing amount, hollow fibre spacing, filtration/idle duration, and fluidization/idle duration. The results indicate that larger-sized GAC particles, higher packing amounts and a ratio of hollow fibre spacing to fluidized particle size of approximately 3–5 are most beneficial for fouling control. Unexpectedly, the intermittent filtration (under continuous fluidization) could not further alleviate membrane fouling compared to continuous filtration, possibly due to inefficient interaction of fluidized GAC particles with membrane surface in absence of permeate driving force. To lower energy consumption, the optimization of intermittent fluidization (under continuous filtration) was performed. Results indicate that the nature of the cake layer formed during non-fluidization period determined the membrane fouling development rather than the fluidization time span. Finally, by comparing the membrane permeability, sodium alginate rejection rate, and membrane properties before and after GAC abrasion, the GAC scouring on membrane integrity was negligible.

1. Introduction

Water and wastewater recycling processes using membrane separation technology have been developed for a few decades [1]. However, the occurrence of membrane fouling due to the unfavourable interactions of the filtered substances with membranes reduces the membrane performance and increases the operating cost. Plenty of studies on fouling control strategies in membrane filtration processes on the basis of physical, chemical, and mechanical cleaning have been carried out and reported [2,3].

Periodically physical cleaning (hydraulic approaches, pneumatic approaches, sonication, and vibration, etc.) is generally performed as effective strategies to recover the membrane performance [4]. Among these approaches, the addition of suitable fouling reducers in membrane filtration processes has been attempted. Some filter-aid agents facilitate to reduce the interaction or modify the adherence mode between the potential foulants and membrane surfaces by adsorption [5], flocculation [6], or formation of a second membrane on the primary membrane surface [7]. On the other hand, some particles enhance shear-induced diffusion [8] or provide mechanical abrasion force along the membranes due to their physical natures [9]. According to the inertial lift model in a cross-flow filtration process, the presence of the added particles enhances the shear stress on the membrane surface and increases lateral inertial lift velocity (i.e., an increase of shear-induced diffusion). Thus, the added particles tend to remove the existing cake layers from membranes or prevent the foulants further deposition on membranes, both of which facilitate membrane filtration [9].

The potential of preventing membrane fouling by using liquid fluidized particles (such as glass beads, steel beads) has been illustrated in a few early-published research literatures [10–12]. These studies emphasized that the fluidized particles as turbulence promoters could increase mass transfer, therefore improving the permeate flux and rejection rate. Recently, researchers have

* Corresponding author at: School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore. Fax: +65 6790 6813.
E-mail address: cyliu@ntu.edu.sg (Y. Liu).

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proven that the mechanical scouring induced by the added granular activated carbon (GAC, suspended via aeration) facilitated to mitigate cake layer fouling in aerobic membrane bioreactors (MBRs) [9,13–17]. Meanwhile, the integration of liquid fluidized GAC particles with membrane filtration has been proposed to polishing the anaerobic bioreactor effluent, and the presence of GAC particles could prevent deposition of potential foulants on the membrane surface [18–21]. However, it should be realized that GAC particles at a relatively high dosage may affect membrane integrity, fouling behaviours and operation cost [22,23].

Two-phase GAC fluidization requires the minimum fluidization velocity (U_{mf}), above which the frictional pressure drop across the bed of GAC particles becomes constant [24]. Theoretically, the minimum velocity to fluidize GAC particles is dependent on particle size and amount [24]. On the other hand, the fluidization velocity and GAC configurations determine the scouring shear force along the membranes. Thus, besides membrane performance, the total energy consumed for GAC fluidization and membrane filtration needs to be carefully evaluated. To minimize energy usage in membrane filtration while ensuring filtration performance, the optimizations of GAC particle fluidization and membrane filtration conditions are necessary. However, so far, there is lack of studies on this issue.

In this study, a bench-scale upflow hollow fibre membranes filtration cell was used to simulate liquid GAC fluidization-microfiltration process. A model foulant solution consists of sodium alginate, bovine serum albumin, humic acid and bentonite was used to simulate the bioreactor effluent. The membrane performance, fouling control mechanism, and calculated energy consumption were systematically evaluated with regard to various GAC properties (GAC size, GAC packing ratio), membrane module configuration (hollow fibre spacing) and filtration/fluidization conditions (intermittent/continuous filtration, intermittent/continuous fluidization). Whether GAC scouring could influence hollow fibre membrane integrity was further assessed.

2. Materials and methods

2.1. Model foulant solution

The model foulant suspension was formulated to simulate the effluent of an anaerobic bioreactor. Accordingly, bovine serum albumin (BSA, 100 mg/L, Sinopharm Chemical Reagent Co. Ltd., China), sodium alginate (SA, 100 mg/L, Hanawa Chemical, Japan), humic acid (HA, 100 mg/L, Aldrich-Sigma, USA), and bentonite (100 mg/L, Aldrich-Sigma, USA) were used to represent protein, polysaccharides, humic substances, and suspended particles, respectively.

2.2. Filtration cell setup

A bench-scale hollow fibre membrane filtration assay was setup to investigate the membrane performance in the presence of GAC fluidization (Fig. 1a). The feed solution was pumped to the filtration cell and retention solution was recycled back to the feed beaker. The feed pump provided a certain upflow velocity which ensured GAC fully fluidized. A pulse damper (Core-Palmer, USA) was used to eliminate pulsation in the feed flow. The permeate flux was regulated by controlling the flowrate of the permeate pump (Core-Palmer, USA). An electronic balance (Mettler Toledo, Switzerland) measured the weight of permeate collected over time and two pressure transducers (Cole-Palmer, USA) measured the feed pressure and permeate pressure respectively. Transmembrane pressure (TMP) was calculated as the difference of feed pressure and permeate pressure. The permeate weight and TMP were recorded via Labview (National Instruments, USA) installed on a computer.

The filtration cell had a fluidization channel with dimension of 0.15 m (H) × 0.022 m (W) × 0.01 m (T) (Fig. 1b). Each membrane module contained three PVDF hollow fibres with a nominal pore size of 0.1 μm and an effective membrane area of 14.13 cm^2. The spacing among the hollow fibres in each membrane module was controlled 0, 2 and 5 mm respectively, whereas the looseness of each hollow fibre was kept at 0%, i.e. no movement of hollow fibres.

The GAC particles purchased from Calgon Carbon Corporation (USA) were separated into different sizes (0.5–1, 1–1.4, and 1.4–2 mm) by sieving (W.S. Tyler Industrial Group, USA). Before experiment, the fresh GAC particles were washed with distilled water to remove the trapped air within the GAC particles and fine carbon powder loosely attached on GAC particles. Then the GAC particles were soaked into the model solution for a few hours to reach adsorption saturation (Fig. S1 in the Supplementary data). In this study, the saturated GAC particles were fluidized to the similar height (90% of the filtration channel height) for all the experimental conditions.

2.3. Threshold flux determination

The threshold flux (i.e., the critical flux which demarcates between low-fouling and high-fouling) of the model mixture was determined using the following protocol [25]: (i) Incrementally increasing the flux at 15 min intervals, (ii) Calculating the slope of the TMP profile (d(TMP)/dt) at each flux step, and (iii) Determining the threshold flux, which is the flux whereby the regression lines

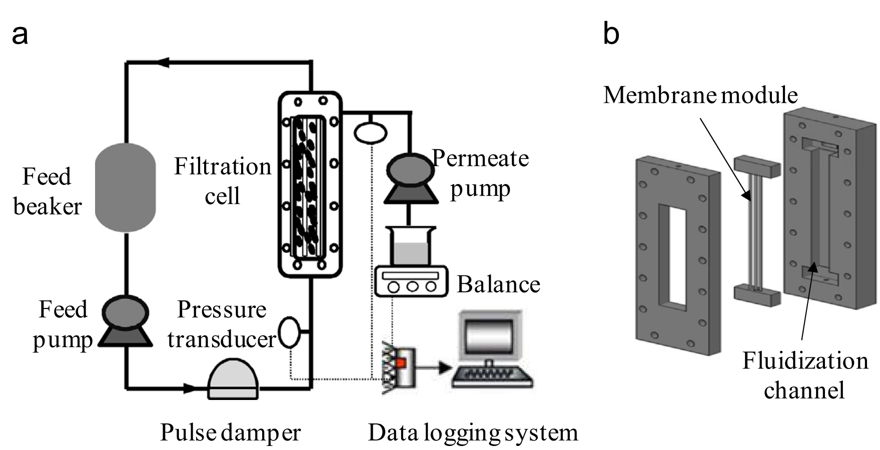

Fig. 1. A schematic diagram of GAC fluidization-filtration setup (a) and details of filtration cell (b).