European Water 58: 371-374, 2017.

Understanding the anaerobic fluidized membrane bioreactor for wastewater treatment

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Abstract: The fluidization of Granular Activated Carbon (GAC) particles has received much attention in recent years as a promising method for mitigating membrane fouling particularly in membrane bioreactors (MBRs). In particular, the fluidized GAC particles are acknowledged to be beneficial in terms of adsorption of organic foulants, and mechanical scouring and surface shear of the membrane surface. Both lab-scale and pilot-scale studies have affirmed the efficacy of GAC fluidization in maintaining a depressed extent of membrane fouling in anaerobic fluidized bed - membrane bioreactors (AnFMBRs). More in-depth studies have also correlated the hydrodynamics of fluidized GAC particles with the effectiveness of membrane fouling mitigation. This study aimed at understanding the improvement of fine (micron-sized) particle critical flux in the presence of fluidized GAC via the Direct Observation Through the Membrane (DOTM) technique. The model foulant was a suspension of polystyrene particles (5 mm sized), and the parameters investigated included GAC particle diameter (d_p), superficial liquid velocity (U_l) and thereby power requirement (P_r), and height along the vertically aligned membrane. Results indicate that: (i) fluidized GAC increased the critical flux by an order-of-magnitude relative to that with tangential liquid shear alone; (ii) the overall critical flux ($J_{critical,overall}$) expectedly increased with power input (P_r), but the relationship between local critical flux ($J_{critical}$) and power input (P_r) depended on the position along the membrane height; (iii) at the same P_r, although the larger GAC particles were more effective locally (i.e., higher $J_{critical}$) due to greater particle inertia, the smaller GAC particles were more effective overall (i.e., higher $J_{critical,overall}$) due to greater bed expansion enabling scouring of more membrane heights; and (iv) a higher power input (P_r) was required for sufficient bed expansion to enable more consistent critical flux ($J_{critical}$) values over the whole membrane height.

Key words: membrane fouling mitigation; liquid-solid fluidization; critical flux; direct observation; energy input

1. INTRODUCTION

Membrane bioreactors (MBRs) are becoming increasingly popular for wastewater treatment, because of the significant advantages of high efficiency, small footprint and high quality of effluent. The major obstacle for more widespread use of MBRs is the severe membrane fouling, which significantly increases the maintenance and operation cost (Le-Clech et al., 2006). The introduction of unsteady-state tangential shear on the membrane surface as an energy-efficient means of fouling mitigation holds much promise (Jaffrin, 2011; Zamani et al., 2015). The fluidization of powdered activated carbon (PAC, whose particle diameter is about 100 μm) has been presented as a viable alternative to bubbling (Park et al., 1999), and more recently the fluidization of the larger millimetre-sized granular activated carbon (GAC) has been reported to confer membrane-fouling mitigation with energy requirements at least an order-of-magnitude lower than that of bubbling (Kim et al., 2011). Reports on the efficacy of fluidized millimeter-sized GAC particles have since flourished (Bae et al., 2014; Bae et al., 2013; Gao et al., 2014a, b; Hu and Stuckey, 2007; Kim et al., 2011; Li et al., 2014; Ren et al., 2014; Shin et al., 2014; Yoo et al., 2014, 2012). Other than the capability to adsorb organic contaminants, our previous studies have confirmed that the hydrodynamics of the fluidized GAC is directly relatable to the effectiveness of fouling mitigation even for inorganic foulants (e.g., bentonite) (Wang et al., 2016a, b). The current study aims to investigate this further, and represents the first systematic study of the effect of millimetre-sized

GAC particle fluidization on critical flux ($J_{critical}$) in the microfiltration of fine (micron-sized) particulate foulants.

2. MATERIALS AND METHODS

2.1 Experimental setup

The Direct Observation Through the Membrane (DOTM) technique, first reported in 1998 (Li et al., 1998), was used in this study for characterizing the critical flux in a liquid-solid fluidization membrane filtration cell. The key component is the Zeiss microscope coupled with a camera (Axiocam 105 Color), which allowed for the visual observation of the deposition of the foulant on the feed-membrane interface. Two pumps allowed for cross-flow of the feed and permeate, while another was used for the permeate flux across the membrane.

The membrane used was an Anopore disk (Whatman, Germany), which was transparent when wetted, with a diameter of 47 mm and nominal pore size of 0.2 µm. Polystyrene (also known as latex) particles (Sigma Aldrich, Singapore) with particle diameter of 5 µm were used as the model foulant. The GAC particles (FILTRASORB 300, Calgon Carbon Corporation) obtained were first sieved using Cole-Parmer U.S. Standard Brass Test Sieves and the Ro-Tap sieve-shaker in order to investigate specific sizes with a narrower particle size distribution (PSD).

2.2 Determination of critical flux

Critical flux is defined as the flux above which fouling occurs significantly and below which negligible fouling occurs (Field et al., 1995). In the current study, the flux-stepping method was adopted to characterize critical flux. Specifically, each flux was held constant for 10 minutes, at the end of which the flux was increased by 5 L/(m^2 h), and two DOTM images were captured for each flux at the end of the 1st and 10th minute. The percentage change in the number of deposited polystyrene particles was calculated as follows:

$$\frac{dN}{dt} = \frac{N_{10th\,minute} - N_{1st\,minute}}{9\text{ min}} \tag{1}$$

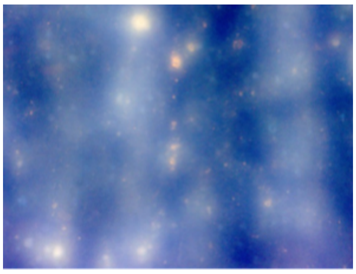
A plot of *dN/dt* versus flux identified the critical flux as the flux at which *dN/dt* started to rapidly increase.

3. RESULTS AND DISCUSSION

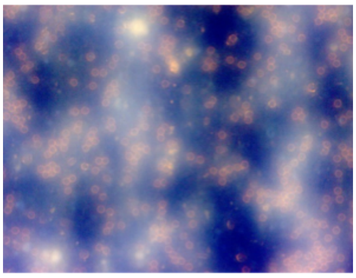
3.1 Critical flux

Figure 1 shows that polystyrene particles started to deposit discernibly at critical flux, while many polystyrene particles deposited above critical flux. Critical flux was determined as the onset of a significant change in the rate of the number of deposited polystyrene particles (*dN/dt*), as presented in Eq. (1).

Figure 2 shows a plot of *dN/dt* versus flux at a superficial liquid velocity (U_l) of 0.032 m/s and dimensionless height (*h/H*) of 0.46 for conditions with and without GAC. The critical fluxes were 45.8 L/(m^2 h) and below 5 L/(m^2 h) for the cases of fluidized GAC with d_p = 1.85 mm and when GAC was absent, respectively. This underscores the significant effect of ‘large particle’ (i.e., millimeter-sized) fluidization on the polarization of ‘fine particles’ (i.e., micron-sized).



Flux = 45.8 L/(m² h)
Critical Flux



Flux = 60.4 L/(m² h)
Above critical Flux

Figure 1. DOTM images at U_l = 0.032 m/s (3.5 times U_{mf}) and h/H = 0.46 for the fluidized GAC particles with d_p = 1.85 mm at the 10th minute of the flux of (a) 15.7 L/(m^2 h) (i.e., below critical flux), (b) 45.8 L/(m^2 h) (i.e., at critical flux), and (c) 60.4 L/(m^2 h) (i.e., above critical flux).

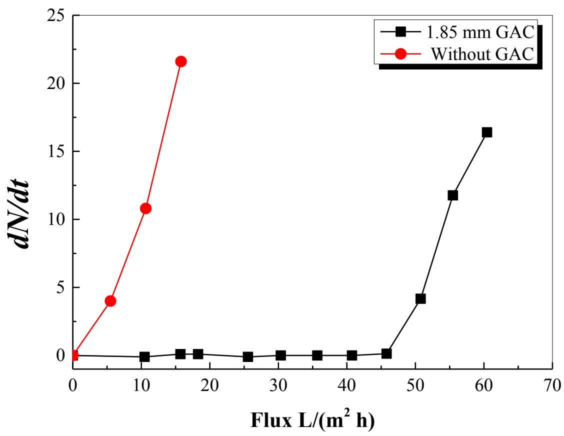


Figure 2. Rate of change of the number of deposited polystyrene particles (dN/dt) versus flux at U_l = 0.032 m/s and h/H = 0.46. Critical fluxes were determined as 45.8 L/(m^2 h) and 5 L/(m^2 h) for the cases of fluidized GAC with d_p = 1.85 mm and when GAC was absent, respectively.

3.2 Power requirement

The power required for fluidizing the GAC particles (P_r; unit of kW) can be calculated by:

$$P_r = \Delta P_{bed} Q \tag{2}$$

where ΔP_{bed} is the pressure drop across the liquid-solid fluidized bed (kPa) and Q is the volumetric flow rate (m^3/s). The volumetric flow rate (Q) has to high enough to enable the particles to be fluidized.

Figure 3 depcits the overall critical flux ($J_{critical,overall}$) as a function of power requirement (P_r) for the three GAC particle diameters (d_p) investigated. For each particle diameter (d_p), a higher power input (P_r) expectedly gave a higher $J_{critical,overall}$ value. Notably, at the same power input (P_r), the smaller particles gave higher $J_{critical,overall}$ values, which agreed with our previous study on the effect of $U_l - U_{mf}$ (Wang et al., 2016a). The largest particle required at least 50% more power (P_r) than the smallest particle to confer the same $J_{critical,overall}$.

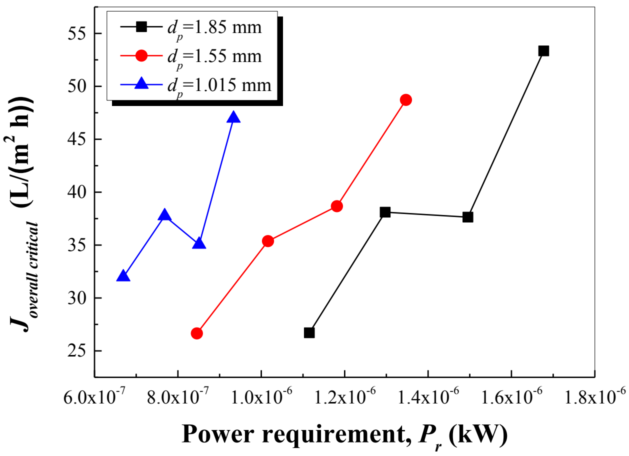


Figure 3. Overall critical flux ($J_{critical,overall}$) versus power requirement with GAC particle diameters of 1.85 mm, 1.55mm, and 1.015 mm.

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