Journal of Environmental Management 228 (2018) 529–537

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Two-way switch: Maximizing productivity of tilted panel in membrane bioreactor

A. Eliseus[a], M.R. Bilad[a,b,*], N.A.H.M. Nordin[a], Asim L. Khan[c], Z.A. Putra[a], M.D.H. Wirzal[a], Muhammad Aslam[c], A. Aqsha[a], J. Jaafar[d]

[a] Chemical Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 32610 Perak, Malaysia
[b] Jurusan Pendidikan Kimia, Institut Keguruan Ilmu Pendidikan, Jalan Pemuda No 59A, Mataram, Indonesia
[c] Department of Chemical Engineering, COMSATS University Islamabad, Lahore Campus, Pakistan
[d] Advanced Membrane Technology Research Centre (AMTEC), Faculty of Chemical and Natural Resources Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

ARTICLE INFO

Keywords:
Tilted panel
Activated sludge filtration
Membrane bioreactor
Membrane fouling
Multi-phases flow

ABSTRACT

Membrane fouling is a major challenge in membrane bioreactors (MBRs) and its effective handling is the key to improve their competitiveness. Tilting panel system offers significant improvements for fouling control but is strictly limited to one-sided panel. In this study, we assess a two-way switch tilting panel system that enables two-sided membranes and project its implications on performance and energy footprint. Results show that tilting a panel improves permeance by up to 20% to reach a plateau flux thanks to better contacts between air bubbles and the membrane surface to scour-off the foulant. A plateau permeance could be achieved at aeration rate of as low as 0.90 l min^{-1}, a condition untenable by vertical panel even at twice of the aeration rate. Switching at short periods (< 5min) can maintain the hydraulic performance as in no-switch (static system), enables application of a two-sided switching panel. A comparison of vertical panel under 1.80 l min^{-1} aeration rate with a switching panel at a half of the rate, switched at 1 min period shows ≈10% higher permeance of the later. Since periodic switching consumes a very low energy (0.55% of the total of 0.276 kWh m^{-3}), with reduction of aeration by 50%, the switching tilted panel offers 41% more energy efficient than a referenced full-scale MBR (0.390 kWh m^{-3}). Overall results are very compelling and highly attractive for significant improvements of MBR technologies.

1. Introduction

Membrane bioreactors (MBRs) combine biological treatment with membrane filtration for treating of domestic or industrial wastewaters to produce clarified and largely disinfected effluents. The technology is increasingly favored especially for effluent reuse purpose. MBRs have been implemented worldwide in more than 200 countries with global market growth rates of ≈15%. However, membrane fouling remains as the major hurdle to boost their competitiveness and to enhance its productivity. Membrane fouling diminishes permeance, eventually leading to operation beyond feasibility if not managed properly.

Substantial works have recently been reported in attempt to address membrane fouling problems. It has been reported that small floc in MBR had high specific contact interaction energy. It is easily adheres to membrane especially in the presence soluble microbial products and colloids and significantly affecting cake resistance due to the osmotic pressure mechanism (Shen et al., 2015). One of recent approach to address the membrane-foulant interaction is by exploiting their interfacial interactions that strongly affected by membrane surface topography (Chen et al., 2017). Both, membrane and floc roughness was found important to control their contact as proven by recent study (Cai et al., 2017). The nano-scale surface contact can be reconstructed by using the fractal geometry, which combined composite Simpson's approach, surface element integration and approximation by computer programming (Chen et al., 2017). Membrane fouling in MBR is also worsened by the presence of gel layer that highly contributing to filtration resistance (J. Chen et al., 2016b), induced by elastic chemical potential change (Teng et al., 2018). The severity of fouling is propagated by initial calcium binding when present in the feed solution (Zhang et al., 2017) facilitated by Ca^{2+} bridging due to chemical potential gap (Zhang et al., 2018).

Various techniques have been introduced to minimize membrane

* Corresponding author. Chemical Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 32610 Perak, Malaysia.
E-mail address: mroil.bilad@utp.edu.my (M.R. Bilad).

https://doi.org/10.1016/j.jenvman.2018.09.029
Received 8 May 2018; Received in revised form 28 August 2018; Accepted 9 September 2018
Available online 29 September 2018
0301-4797/

fouling. The most common ones are by limiting the range of operational flux, implementing periodical cleanings or imposing shear-rates via air bubbles aeration. All techniques are considered partly effective, yet improvements are still possible. As a resultant of all factors in membrane fouling management (backwashing, intermittent filtration, etc.), the average sustainable fluxes of existing full-scale MBR installations is still considerably low ($18.5 \pm 4.8\,l\,m^{-2}\,h^{-1}$), with a peak flux at $26.6 \pm 6.6\,l\,m^{-2}\,h^{-1}$ (Judd, 2016). Better membrane fouling controls can indeed offer higher sustainable fluxes to lower membrane and energy foot-print associated with it.

In addition to the common fouling management approaches, efforts to tackle fouling problem have also been proposed. Particle scouring has been considered as an energy-efficient method. Noticeably, particle fluidization offers > 90% of the energy consumption of gas sparging (Kim et al., 2011), ascribed by the efficient cleaning provided from particle movements that enhance shear-induced diffusion and provide mechanical scouring of foulant atop the membrane surface (Wu et al., 2017). The cleaning efficacy of the fluidizing particles is enhanced at higher velocities but in expense of greater energy consumption and the risk of membrane integrity loss (Wang et al., 2016). This method is also strongly limited by the heterogeneous shear over the whole membrane surface because of size segregation that leads to spatial fouling control maldistribution that eventually propagates the fouling in a long run (Wang et al., 2017b).

Another shear-induced membrane fouling control strategy, involving rotating and vibrating the flat sheet membranes (commonly known as dynamic membrane system), has shown great promises (Akoum et al., 2002; Bilad et al., 2012). However, the application of such systems is limited due high energy required for moving the module system (membrane panel and water inside it) and, more importantly, a complex mechanical design that lead to difficult scale-up.

Air bubbling has become a standard method for membrane fouling control in various membrane processes, particularly in MBRs (Braak et al., 2011; Wibisono et al., 2014). The air bubbles that flow atop the membrane surface carry hydrodynamic forces, hence maximizing the tangential shear-rates (Hwang et al., 2015). Generally, the forces induced by the air bubbles are drag-force, impact force and lift-force, all closely deal with filtrate flow, cross-flow velocity and near-wall velocity gradient. The local shear transients restricts membrane fouling by constant removal of foulant or limits its accumulating (Le-Clech et al., 2006).

Fouling mitigation via air bubbles is largely affected by the bubble size and the types of the multi-phase flow, and is known to be highly effective under slug-flow condition (Wu et al., 2016). For the later, its effectiveness is compensated by a high air pumping energy that currently is still a major energy contributor. Large pulse bubbles that bring about high impact force, offer improved fouling control efficiency compared to the smaller ones in continuous supply (Jankhah and Bérubé, 2014). Continuous bubbling is generally more effective for membrane fouling control than the intermittent one because continuous scouring-off the foulant (Tian et al., 2010). In contrast for intermittent bubbling, cake-layer formation or large particle deposition are formed easily during relaxation.

Despite of all aforementioned advantages, air bubble scouring has few inherent limitations (Bilad et al., 2012). They only produce relatively weak shear rates, the impact reaches a “plateau” at a certain air supply, and most importantly it is difficult to impose intense contacts of air bubbles with the membrane surface because they tend to reside in the center-space between adjacent panels (the furthest distance from the membrane surface).

The conventional vertical panel suffers from low contacts of air bubbles on the membrane surface. In a vertical alignment, air bubbles prefer to move in the center of space between two adjacent panels, hence diminishing their scouring roles. Under this situation, only arbitrary impact force from bubbles bouncing between two panel surfaces that helps to scour-off the foulant. This can actually be managed by implying higher bubble sizes, or even by engineering the flow type under slug-flow, but in expense of high energy of compressor to accommodate high volumetric velocity (Wu et al., 2016). Finding a more energy efficient system is thus imperative.

As an attempt to improve air bubbles efficacy for membrane fouling control, Hwang et al. (2015) proposed an inventive bubble generator device. It is an ejector-type bubble generator (called bubble generator plate) that is highly effective in controlling membrane fouling and shows a remarkable improvement in productivity by doubling the membrane permeance. In their system, the membrane is placed horizontally (active layer facing down) and the air bubbles are supplied from underneath leading to full-contact of air bubbles with membrane surface to scour the foulant effectively it can be postulate that the air bubbles scouring the foulant were maximized through the impact force (in contact with membrane surface) and drag force (when travels atop membrane surface).

Recently, we proposed a tilted module concept that also helps to maximize air bubbles contacts with membrane surface (Eliseus et al., 2017). As the panel is tilted, higher contacts between air bubbles and membrane surfaces are facilitated, hence results in better cleaning efficacy, showing of up to 2.7 folds of permeance increment for a tilting angle of 20°. However, the bubble generator devise is difficult for scale-up, while the hydraulic productivity of the tilted panel is largely limited because it allows mounting a membrane-sheet only on one side of the panel. Membrane orientation with respect to aeration was also proven important being at inclination of 50° as the most optimum for tubular ceramic membrane (Cheng, 2002), and horizontally (180°) for flat-sheet ultrafiltration membrane (Cheng and Lin, 2004). Other approaches on exploiting membrane structure (in a form of surface corrugation) and addition of bio-carriers have also been proposed base on the similar principle of improving efficacy of air bubbles for scouring-off foulant (Bilad et al., 2015a,b; Chen et al., 2016a; Kharraz et al., 2015; Marbelia et al., 2016).

In this study, we assess the performance of tilted panel in submerged MBR system treating activated sludge. The filterability of the panel was first evaluated via parametric study on the impact of tilting angles and aeration rates. Later, to accommodate two-sided membranes, the impact of switching period was also studied. The mechanisms of membrane cleaning via air-bubble scouring that lead to operation under limiting flux was thoroughly investigated by estimating all dominant forces that play roles. Lastly, we assess the feasibility of the new concept by estimating its energy consumption and compare it with a reference full-scale submerged MBR system.

2. Materials and methods

2.1. Membrane preparation and characterization

Phase inverted polyvinylidene fluoride (PVDF) membrane was prepared via immersion precipitation using PVDF (Arkema, MW = 300 kDa), dimethylacetamide (DMAC, Sigma-Aldrich) and demineralized water as the polymer, solvent and non-solvent, respectively. After being thoroughly dissolved and degassed, the dope solution (15%wt PVDF in DMAC) was cast using a doctor blade in a wet casting thickness of 0.22 mm at room temperature and humidity atop a non-woven support (Novatexx 2471, Freudenberg-Filter, Germany) to avoid shrinkage (Bilad et al., 2015a,b). The cast film was then immersed in a bath containing DI water immediately. The membrane was stored wet until usage. To be applicable for filtration, the membrane sheet was assembled into a panel with an effective membrane area of $0.012\,m^2$ (1-sided surface of 0.10×0.12 m).

The clean water permeance was measured after they were assembled into a filtration panel in a submerged filtration system. The filtration flux (J) and permeance (L) were calculated by using Eqs. (1) and (2), respectively.