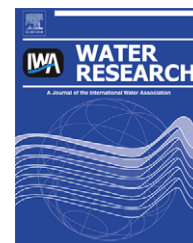


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Influence of filtration conditions on membrane fouling and scouring aeration effectiveness in submerged membrane bioreactors to treat municipal wastewater

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ABSTRACT

Membrane fouling and scouring aeration effectiveness were studied using three large pilot-scale submerged membrane bioreactors (MBRs) operated at a series of permeate fluxes, scouring aeration intensities and cyclic aeration frequencies to treat municipal wastewater. The results showed that when operated at the sustainable conditions, the MBRs had a stable reversible fouling resistance. At unsustainable conditions, the reversible fouling resistance increased exponentially as filtration progressed. For each of above two cases, the fouling ratios newly defined by Eqs. (7) and (8) were calculated from the transmembrane pressure increases to compare the relative reversible fouling rates. With the range of sustainable filtration conditions, the fouling ratios at the same reference scouring aeration intensity were found to be proportional to permeate flux. Similarly, the fouling ratios calculated with the same reference permeate flux decreased exponentially with increasing scouring aeration intensity. Moreover, the effects of scouring aeration intensity and permeate flux on the fouling ratios were found to be independent of one another. As a result, an empirical relationship was derived to relate the stable reversible fouling resistance to sustainable permeate fluxes and scouring aeration intensities. Its application was demonstrated by constructing transmembrane pressure contours overlaid with scouring aeration effectiveness contours to aid in the selection of optimal MBR filtration conditions.

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1. Introduction

Membrane bioreactors (MBRs), which combine conventional wastewater activated sludge processes with membrane filtration, have excellent solid–liquid separation efficiency and yield high quality effluent in wastewater treatment and reuse. Additional advantages include small footprint, robust resistance to influent loading variations, potentially reduced sludge production and modular design. However, MBR capital

and operating costs remain one of the most critical obstacles for their widespread application in practice. A large portion of operating energy costs results from the scouring aeration necessary for effective fouling control. Although treatment costs declined by 80% and energy requirements dropped by 85% between 1994 and 2000 due to process improvements and technological advances in membrane production (H. Husain, pers. comm. 2005), further advances to reduce scouring aeration energy costs are yet desirable.

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List of Notations

θ	temperature correction coefficient	MLSS	mixed liquor suspended solids, g/L
μ	dynamic viscosity, N s/m ²	MLVSS	mixed liquor volatile suspended solids, g/L
A_m	membrane surface area, m ²	Q	scouring aeration intensity, m ³ /h
a	permeate flux proportionality constant	$Q_{(i)}$	scouring aeration intensity at operating condition i , m ³ /h
c	scouring aeration intensity proportionality constant	$Q_{(ref)}$	scouring aeration intensity at reference operating condition, m ³ /h
F	fouling ratio	Q_{net}	net air flow rate, m ³ /h
F/M	food/microorganism ratio	R_f	fouling resistance, m ⁻¹
HRT	hydraulic retention time, time	$R_{f(i)}$	fouling resistance at operating conditions i , m ⁻¹
J	permeate flux, L/m ² /h	$R_{f(ref)}$	fouling resistance at reference operating conditions, m ⁻¹
J_c	critical flux, L/m ² /h	R_{ir}	irreversible resistance, m ⁻¹
J_i	permeate flux at operating condition i , L/m ² /h	R_m	membrane resistance, m ⁻¹
$J_{o(ref)}$	reference permeate flux at point O (see Fig. 8a), L/m ² /h	R_o	membrane resistance at reference point O (see Fig. 8a), m ⁻¹
J_{ref}	permeate flux at reference operating condition, L/m ² /h	R_t	total filtration resistance, m ⁻¹
J_s	sustainable flux, L/m ² /h	$R_{t(i)}$	total resistance at operating conditions i , m ⁻¹
k	permeate flux exponent	R_w	clean water resistance, m ⁻¹
l	scouring aeration intensity exponent	SRT	solid retention time, time
$M_{t(i)}$	total mass of MLSS transported by permeate convection per unit membrane area at operating condition i , g/m ²	T	temperature, °C
$M_{t(ref)}$	total mass of MLSS transported by permeate convection per unit membrane area at the reference operating condition i , g/m ²	t	time, s
		t_g	fraction of permeation time with scouring aeration
		TMP	transmembrane pressure, kPa
		$V_{(t)}$	total volume permeated at time t , L

Membrane fouling occurs through the accumulation of dissolved and suspended solids on the membrane surface. The resulting increase in hydraulic filtration resistance across the membrane necessitates the frequent cleaning and replacement of membrane modules. It is generally accepted that fouling results from adsorption, pore deposition, cake formation, concentration polarization and/or biofouling (Le-Clech et al., 2003). Their relative magnitudes depend on membrane material and configuration, operating conditions and mixed liquor characteristics. Particles can be transported to the membrane surface by the permeate drag. Depending on the particle–particle interactions, particle–membrane interactions and hydrodynamic condition at the membrane surface, the deposited particles can be transported back into bulk liquid via physical mechanisms such as Brownian diffusion, inertial lift, shear induced dispersion, etc. (Wiesner et al., 2005). From an operational perspective, however, membrane fouling is often divided into reversible and irreversible fouling. Reversible fouling is defined as the deposits that can be removed by physical backwash or relaxation, while the irreversible fouling is defined as solids which may be partially or completely removed by chemical cleaning. Even though long-term performance limits of the MBRs are largely controlled by the irreversible fouling, cake compaction could convert reversible fouling into irreversible fouling.

The rate of membrane fouling is specific to each mixed liquor. Extracellular polymeric substances (EPS) have been suggested among the most important components responsible for membrane fouling. However, different extraction and analytical techniques, such as centrifugation, heating, ultrasonication, etc., have produced conflicting results (Martin,

2005). Differing results have also been reported for the effects of MLSS concentration (Yamamoto et al., 1989), but generally it is agreed that it poses little direct influence (Rosenberger et al., 2002). Rather, it is the particle size distribution and the quantity of colloidal particles (Fan et al., 2006; Wisniewski and Grasmick, 1998) that appear to contribute significantly to cake formation. Additionally, particle surface charge and pH have been found to affect the filterability of mixed liquor.

Numerous researchers have shown that for submerged hollow fibre MBRs, fouling decreases with increasing the scouring aeration intensity due to the increased hydraulic shear on membrane surface and the swaying movement of hollow fibres (Chang and Judd, 2002; Engelhardt et al., 1998). A prolonged reduction in aeration can lead to a rapid accumulation of fouling material on the membrane surface (Chang et al., 2002). However, it has also been shown that there is an optimum aeration intensity which maximizes fouling suppression (Bouhabila et al., 1998; Le-Clech et al., 2003). Chua et al. (2002) suggested that beyond this critical value, the fouling may actually increase because the shear force breaks up larger particles and causes redistribution of particles in the cake. Furthermore, there may be an optimal aeration sequence and duration when cyclic aeration mode is used to improve the scouring aeration effectiveness. Guinzburg (2003) found that reducing the aeration on-time to off-time ratio by a factor of 6 did not produce a significant change to the TMP in a submerged MBR used to treat municipal wastewater.

While scouring aeration has been found to be the most advantageous method for fouling control in submerged MBRs in treating municipal wastewaters, substantial energy savings can be realized by optimizing scouring aeration condition.

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