Journal of Colloid and Interface Science 446 (2015) 84–90

Contents lists available at ScienceDirect

Journal of Colloid and Interface Science

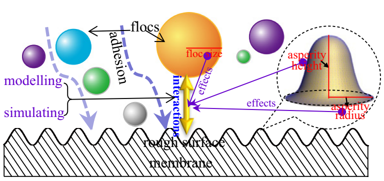
www.elsevier.com/locate/jcis

Influence of membrane surface roughness on interfacial interactions with sludge flocs in a submerged membrane bioreactor

Leihong Zhao [a,b], Liguo Shen [a], Yiming He [c], Huachang Hong [a], Hongjun Lin [a,*]

[a] College of Geography and Environmental Sciences, Zhejiang Normal University, Jinhua, 321004, PR China
[b] Institute of Physical Chemistry, Zhejiang Key Laboratory for Reactive Chemistry on Solid Surfaces, Zhejiang Normal University, Jinhua 321004, PR China
[c] Department of Materials Physics, Zhejiang Normal University, Jinhua, 321004, PR China

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 September 2014
Accepted 7 January 2015
Available online 13 January 2015

Keywords:
Membrane bioreactor
Membrane fouling
Interfacial interaction
Roughness

ABSTRACT

In this study, the interfacial interactions between sludge flocs and a rough membrane surface in a submerged membrane bioreactor were investigated. Models describing these interfacial interactions were firstly proposed based on the surface element integration (SEI) method. Surface properties of sludge flocs and membrane were experimentally determined to simulate the models through composite Simpson's rule. It was found that, roughness on membrane surface significantly decreased interaction strength, which enabled the sludge flocs to more easily attach on and detach from the rough membrane surface. Further analysis showed that the value of total interaction energy increased with asperity radius, while the strength of total interaction energy decreased with asperity height. Results also demonstrated that increase in floc size would significantly decrease the attractive specific total interaction with rough membrane surface. It was revealed that there existed a critical asperity radius above which the total interaction energy in certain separation distance coverage was continuously repulsive, facilitating membrane fouling control in MBRs. This study demonstrated the possibility to mitigate membrane fouling by "tailoring" membrane surface roughness.

1. Introduction

Membrane bioreactor (MBR), which integrates membrane separation with biological treatment, has been increasingly used for treatment of varied wastewaters [1–4]. However, the economy and practicability of MBR have been greatly impeded by membrane fouling [5–7]. Therefore, exploring the mechanisms, factors and control strategies of membrane fouling is still the primary research interest in MBR to research community although remarkable efforts have been made.

It is well accepted that membrane fouling in MBRs is resulted from the interactions between sludge suspension and membrane [5,8]. As one of the most important interactions, interfacial interactions between sludge and membrane directly determines foulants adhesion and cake layer formation, and thus highly influences membrane fouling in MBRs [8–10]. The interfacial interactions accounting for attractive Vander Waals (LW), attractive acid-base (AB) and repulsive electrostatic double layer (EL) interactions, have been traditionally described by the extended Derjaguin–Landau–Verwey–Overbeek (XDLVO) theory [11,12]. Sludge suspension in

* Corresponding author.
E-mail address: hjlin@zjnu.cn (H. Lin).

http://dx.doi.org/10.1016/j.jcis.2015.01.009
0021-9797/

MBRs is a collection of various materials (foulants) mainly including sludge flocs, colloids, biopolymer matters (such as extracellular polymeric substances (EPS), soluble microbial products (SMP) and biopolymer clusters (BPC)), inert particles and metals. Investigating the interfacial interactions between these foulants and membrane may give significant insights into membrane fouling. Many studies have investigated the interactions between foulants and membrane in MBRs. By using XDLVO analysis, Feng et al. [9] found that a dominating strain (*Klebsiella oxytoca*) in cake layer had stronger attractive interactions with polypropylene (PP) membrane than polyvinylidenefluoride (PVDF) membrane in a MBR. Hong et al. [13] reported that, as compared to large floc, small floc would adhere to membrane more easily in a MBR due to its higher attractive specific interaction energy (interaction energy per unit mass). Zhang et al. [14] found that, by adding polyvinyl alcohol (PVA) into membrane casting solution, the prepared modified PVDF/polyethersulfone (PES) blend membrane possessed enhanced energy barrier with SMP, which therefore reduced the adsorption of foulants in a MBR. Meanwhile, XDLVO theory has been also applied to describe attachment of model foulants or biopolymers on different kinds of membranes [15–18]. These studies significantly improved the understandings of membrane fouling mechanisms.

However, most previous studies on interfacial interactions were carried out based on the assumption of infinite smooth membrane surface. Actually, membrane surface is far from "smooth". Atomic force microcopy (AFM) scans have shown that most commercial membranes were significantly varied in surface roughness/morphology in nanometer scale [19–22]. It has been reported that membrane surface roughness could strongly affect interfacial interactions between colloids [19,23], SMP [20] and membranes. Meanwhile, for MBR systems, sludge flocs generally account for more than 90% of total biomass, and thus are the predominated components in sludge suspension [8]. While roughness is a primary parameter of surface morphology, and may exert profound impacts on membrane fouling, the information regarding how membrane surface roughness affects interfacial interactions between sludge flocs and membrane in MBRs is still very limited. To our knowledge, no study has quantitatively assessed the interactions between sludge flocs and rough membrane surface. Therefore, it is quite necessary to investigate effects of membrane surface roughness, which will be helpful to understand membrane fouling mechanisms, and also facilitate to control membrane fouling in MBRs.

With the above in view, this study aims to investigate influences of membrane surface roughness on interfacial interactions in a MBR system. Accordingly, the surface element integration (SEI) combined with composite Simpson's rule were firstly used to model and calculate the interfacial interactions between a sludge floc and rough membrane surface. A lab-scale MBR was continuously run to supply samples of sludge and membrane. The surface properties (zeta potential, contact angle, and roughness) of virgin membrane and sludge were experimental determined. The effects of factors including asperity radius, asperity height and floc size on interfacial interactions between a sludge floc and membrane surface were analyzed.

2. Material and methods

2.1. Experimental setup and operation

A submerged MBR (SMBR) setup with a working volume of 65 L (Fig. 1) was continuously operated for treatment of synthetic municipal wastewater in this study. The composition of synthetic wastewater could refer to our previous study [24]. A membrane

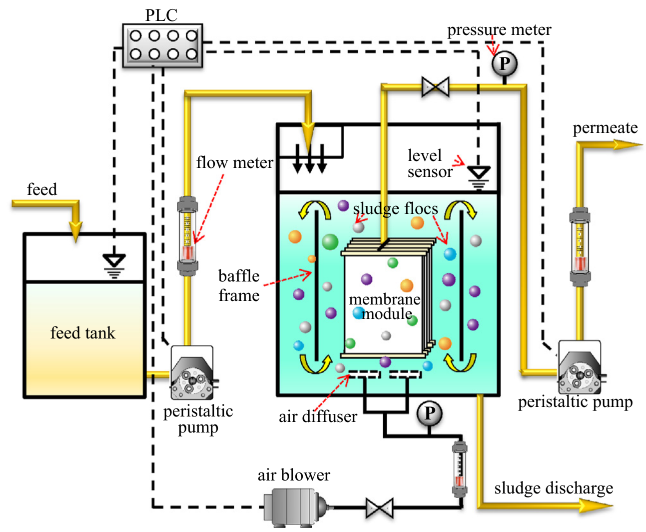


Fig. 1. Schematic diagram of SMBR setup.

model containing five membrane elements (each has 0.02 m^2 effective filtration area) was vertically placed in the bioreactor. The membrane (0.3 μm normalized pore size) was made of PVDF material, and provided by Shanghai SINAP Co. Ltd. Aeration rate at level of 180 $m^3_{air}/m^3_{permeate}$ was achieved by an air blower to supply oxygen for microbial growth and shear stress for fouling mitigation. A peristaltic pump operated in intermittent suction mode (4-min-on and 1-min-off) was used to obtain permeate. Membrane flux and hydraulic retention time (HRT) was controlled at 30 L m^{-2} h^{-1} (LMH) and 5.5 h, respectively. Mixed sludge suspended solids (MLSS) concentration was controlled at range of 10–14 g/L by sludge discharge during the experimental period.

2.2. XDLVO approach

Interfacial interactions including LW, EL and AB interaction between a sludge floc and a membrane in water can be described by XDLVO theory [12]. The individual XDLVO interaction energy per unit area (ΔG^{LW}, ΔG^{AB} and $\Delta G^{EL}(D)$) between two infinite planar surfaces is given by:

$$\Delta G^{LW}(D) = -\frac{A_H}{12\pi D^2} \tag{1}$$

$$\Delta G^{AB}(D) = \Delta G^{AB}_{D_0} \exp\left(\frac{D_0 - D}{\lambda}\right) \tag{2}$$

$$\Delta G^{EL}(D) = \varepsilon_r \varepsilon_0 \kappa \zeta_f \zeta_m \left(\frac{\zeta_f^2 + \zeta_m^2}{2\zeta_f \zeta_m}(1 - \coth \kappa D) + \frac{1}{\sinh \kappa D}\right) \tag{3}$$

where D is the separation distance between two planar surfaces; A_H $(= -12\pi D_0^2 \Delta G^{LW}_{D_0})$ is Hamaker constant; Contact of two planar surfaces is assumed to occur at a hypothetical minimum equilibrium cut-off distance (minimum separation distance (D_0), assigned to be 0.158 nm) [25]; $\lambda (= 0.6\ \text{nm})$ is the decay length of AB energy in water; $\varepsilon_r \varepsilon_0$ is the permittivity of sludge suspension; ζ_f and ζ_m are the surface zeta potential of floc and membrane, respectively; κ is the reciprocal Debye length; $\Delta G^{LW}_{D_0}$, $\Delta G^{AB}_{D_0}$ and $\Delta G^{EL}_{D_0}$ are the LW, AB and EL interaction energy per unit area between two infinite planar surfaces at the minimum separation distance (D_0), respectively, which are given by Eqs. 4–6, respectively.

$$\Delta G^{LW}_{D_0} = -2\left(\sqrt{\gamma_m^{LW}} - \sqrt{\gamma_w^{LW}}\right)\left(\sqrt{\gamma_f^{LW}} - \sqrt{\gamma_w^{LW}}\right) \tag{4}$$