WATER RESEARCH 47 (2013) 6358–6366

Available online at www.sciencedirect.com

SciVerse ScienceDirect

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

Novel electrokinetic approach reduces membrane fouling

Sharif Ibeid [a,*], *Maria Elektorowicz* [a], *Jan A. Oleszkiewicz* [b]

[a] Dept. of Building, Civil and Environmental Eng., Concordia University, Montreal, Canada H3G 1M8

[b] Dept. of Civil Engineering, University of Manitoba, Winnipeg, Canada R3V 1T9

ARTICLE INFO

Article history:
Received 14 April 2013
Received in revised form
4 July 2013
Accepted 6 August 2013
Available online 22 August 2013

Keywords:
Submerged membrane electro-bioreactor (SMEBR)
Membrane bioreactor (MBR)
Extra-polymer substances (EPS)
Membrane fouling
Electrokinetics
Soluble microbial products (SMP)
Floc-bound water

ABSTRACT

An innovative submerged membrane electro-bioreactor (SMEBR) was built to reduce membrane fouling through a combination of various electrokinetic processes. The objective of this research was to assess the capability of SMEBR to reduce fouling under different process conditions. At the bench scale level, using synthetic wastewater, membrane fouling of the SMEBR was compared to the fouling of a membrane bioreactor (MBR) in five runs. Different protein concentrations in the influent synthetic wastewater were selected to develop different membrane fouling potentials: high (240 mg/l), low (80 mg/l) and zero protein addition. The MBR and SMEBR were operated at a flux equal to the membrane critical flux in order to create high fouling rate conditions. Membrane fouling rate, expressed as the change in the trans-membrane pressure per day (kPa/d), decreased in the SMEBR 5.8 times (standard deviation (SD) = 2.4) for high protein wastewater, 5.1 times (SD = 2.4) for low protein content, and 1.3 times (SD = 0.7) for zero protein, when compared to the MBR. The supernatant concentrations of the soluble microbial products (SMP) were 195–210, 65–135 and less than 65 mg/l in respective experimental series. Following the bench scale study, membrane fouling was assessed in a pilot scale SMEBR, fed with raw unclarified municipal wastewater, and operated under real-sewage variable quality conditions. The pilot SMEBR exhibited three times smaller membrane fouling rate than the MBR. It was concluded that electrokinetic processes generated by SMEBR led to a reduction of membrane fouling through: i) removal of soluble microbial products (mainly protein and polysaccharides) and colloidal organic materials; ii) change of the structure and morphology of the suspended solids due their conditioning by DC field.

1. Introduction

In spite of the growing applications of submerged membrane bioreactors (MBRs), the reduction of flux over time caused by membrane fouling remains the major issue to be resolved to ensure the sustainability of this technology (Drews, 2010; Meng et al., 2009; Le-Clech et al., 2006; Chang et al., 2002). Fouling has been typically classified as reversible (recoverable by physical methods) and irreversible (recoverable by chemical cleaning). This classification is not entirely useful as membrane permeability deteriorates over time, even when the best management practices are implemented. Meng et al. (2009) classified fouling as removable through physical cleaning, irremovable or removable only through chemical cleaning and irreversible fouling that cannot be removed by any means. Even more precisely, Drews (2010) classified

* *Corresponding author*. Tel.: +1 514 803 2216.
E-mail addresses: s_ibeid@encs.concordia.ca, shareefobaid@hotmail.com (S. Ibeid).
0043-1354/$ – see front matter
http://dx.doi.org/10.1016/j.watres.2013.08.007

fouling into reversible, irreversible that can be removed through maintenance cleaning, irreversible that can be removed through the major chemical cleaning and the irrecoverable fouling. Regardless of the fouling types and classification systems it was generally agreed that activated sludge characteristics determine the severity and the propensity for membrane fouling. Fouling increases with the increase of the mixed liquor suspended solids (MLSS) concentration (Trussel et al., 2007; Psoch and Schiewer, 2006; Defrance et al., 2000), with the increase in the bound extra-polymer substances (EPS) (Ramesh et al., 2007; Ahmad et al., 2007; Cho et al., 2005); with the concentration of colloids (Bouhabila et al., 2001) and with the soluble microbial products (SMP) concentration (Gao et al., 2013; Geng and Hall, 2007; Rosenberger et al., 2006). The key individual dominant factor has not yet been identified; for example, Le-Clech et al. (2006) reported after reviewing 13 studies on membrane fouling that contribution of soluble and colloidal foulants ranges between 20 and 90%. No impact of bound EPS on fouling was reported by Yamato et al. (2006) and Rosenberger and Kraume (2003). Drews et al. (2008) reported no influence of SMP at small membrane pore size and long solids residence time, SRT of 20–30 days. This divergence of conclusions can perhaps be explained by the differences in operating conditions, biomass characteristics, composition of influent and the type of membrane used in these studies. Operating conditions indirectly affect fouling through their influence on sludge characteristics. Membrane fouling propensity increases with the decrease of solid retention time (Ahmad et al., 2007; Zhang et al., 2006) and the decrease of hydraulic retention time, HRT, (Meng et al., 2007; Chae et al., 2006).

The dominant approaches to fouling control continue to involve the traditional methods of backwash, filtration relaxation and application of the sub-critical flux. Other approaches reported to reduce membrane fouling included enhancement of the aeration efficiency through optimization of hydrodynamic conditions, air intensity (Han et al., 2005), bubble size (Prieske et al., 2008), reactor shape and membrane modules configuration (Wicaksana et al., 2006). Fouling could be mitigated through the application of flux enhancers such as activated carbon adsorbent (Akram and Stuckey, 2008), coagulants (Ji et al., 2008) and cationic polymers (Koseoglu et al., 2005). Alternative approaches include the use of sludge granulation (Li et al., 2005), application of nanoparticles (Chae et al., 2009) and biomass ozonation (Huang and Wu, 2008). From the review it becomes clear that the need for an effective and powerful method of fouling reduction at an acceptable energy consumption remains a formidable challenge.

An innovative submerged membrane electro-bioreactor (SMEBR) was recently developed (Bani-Melhem and Elektorowicz, 2011, 2010; Elektorowicz et al., 2009) to reduce membrane fouling and enhance the treatment efficiency. In this system, the activated sludge biological treatment, membrane filtration and a direct current (DC) field are combined to enhance the performance of the wastewater treatment. This new technology provides several advantages in one operation unit: higher effluent quality (i.e. COD (chemical oxygen demand), phosphorus and nitrogen removal) as well as electrical-sludge conditioning for more efficient dewatering (Ibeid et al., 2013) and decreasing of the membrane fouling. These benefits can be achieved only if the SMEBR is operated at conditions allowing the maintenance of high microbial activity. In this context, the current density (CD) should be below 25 A/m^2 and applied at an intermittent exposure (Wei et al., 2011). For tested ranges of the MLSS concentrations, a time-OFF is recommended to be at least three times the time-ON. These operating conditions ensure high microbial activity as demonstrated through high COD and nitrogen removal (Hasan et al., 2012). The microbial diversity is likely to change due to the capability of SMEBR system to create simultaneous nitrification/denitrification conditions for nitrogen removal (Ibeid et al., 2011). The objective of this paper was to show the capability of this new SMEBR system to reduce fouling as well as to illustrate the mechanisms of electrokinetic processes responsible for such reduction.

2. Materials and methods

The outcomes from the bench and pilot scale investigations were used to demonstrate membrane fouling mitigation through the application of the SMEBR system.

2.1. *Bench scale experimental set-up*

One continuous flow submerged membrane electro-bioreactor SMEBR (Fig. 1) and one continuous flow submerged membrane bioreactor (MBR) without an electrical field (as the control system) were operated simultaneously. They were fed with the same synthetic wastewater and run at the same operating conditions (details in section 2.2). The SMEBR outer body was composed of a cylindrical polyethylene container (20 l). The design was identical to a patented SMEBR system reported by Elektorowicz et al. (2009). A cylindrical ultra-filtration Zeeweed-1 (GE, Canada) hollow fiber membrane module with 0.04 μm pore size and 0.047 m^2 surface area was placed vertically in the centre of each reactor. Two air diffusers were inserted above and below the membrane to

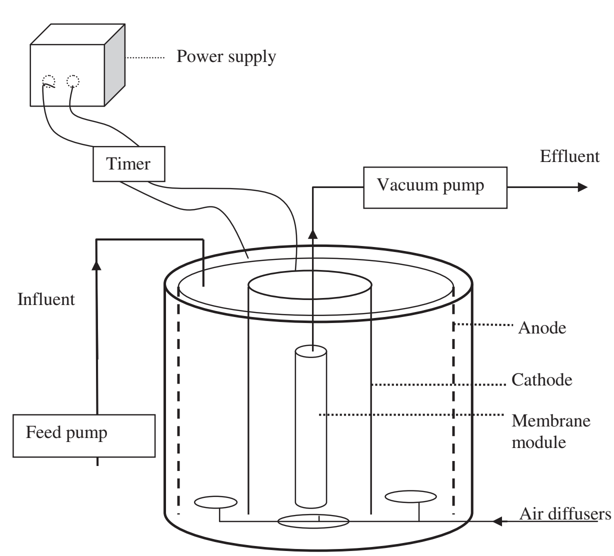

Fig. 1 – Experimental set-up of SMEBR.