Bioresource Technology 113 (2012) 161–164

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Influence of biofilm carriers on membrane fouling propensity in moving biofilm membrane bioreactor

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ARTICLE INFO

Article history:
Available online 28 January 2012

Keywords:
Moving biofilm MBR
Membrane fouling
Specific cake resistance
Filamentous bacteria
Extra polymeric substance (EPS)

ABSTRACT

In moving biofilm membrane bioreactor (MB-MBR) sponge carriers for biofilm growth were coupled with conventional submerged membrane bioreactor (C-MBR). This study compared the fouling propensity of C-MBR with MB-MBR and investigated factors affecting fouling variations in both the systems. Membrane fouling tendencies were monitored in terms of trans-membrane pressure (TMP) and the fouling characterization included membrane fouling resistances in situ and specific cake resistance (SCR) in batch filtration cell. Comparison of TMP profiles depicted prolong filtration periods in MB-MBR. Cake layer resistance (R_c), pore blocking resistance (R_p) as well as SCR were higher in C-MBR. The study reveals that hybrid biomass in MB-MBR creates relatively more porous cake structure in the absence of filamentous bacteria which were found in abundance in C-MBR. Filamentous bacteria were also responsible for the release of high concentration of carbohydrates in the form of soluble extra polymeric substance (EPS) contributing to higher R_p in C-MBR.

1. Introduction

The need of the day is to reduce the constantly growing stress on existing water resources for sustainable development. One possible solution to the problem is wastewater reclamation and reuse. Processes used to make water more acceptable for a desired end-use is termed as wastewater reclamation. Groundwater recharging is one of the major benefits of wastewater reclamation in arid regions. Moreover, the end product can be used for irrigation, industrial processes, and other non-potable purposes. Currently, development of compact wastewater treatment unit capable of achieving high quality effluent is emphasized as part of the decentralized wastewater treatment strategy. In this context, membrane bioreactor (MBR) is an attractive option with high quality effluent, compact system and economical management. However, one of the major hurdles in the progress of MBR technology is membrane fouling, which can be defined as the undesirable deposition and accumulation of microorganisms, colloids, solutes, and cell debris within/on membranes (Meng et al., 2009). The use of free-floating media in MBR could be a better alternative to conventional MBR which may reduce membrane fouling (Leiknes and Ødegaard, 2001). Research has been done on different growth media (carriers) added to submerged MBRs including polyurethane cubes, polystyrene beads, polyethylene carriers (Kaldnes), activated carbon (granular and powdered), zeolite, blasted clay granules and sponge in MBR (Huang et al., 2008; Jamal Khan et al., 2011; Lee et al., 2006). Sponge acts as a mobile carrier for active biomass and retains microorganisms by incorporating a hybrid growth system including both their attached and suspended growth environments. It has been considered as a feasible growth media with high porosity for microbial immobilization, good mechanical strength for membrane fouling control, and low cost (Chu and Wang, 2011). A couple of previous studies (Guo et al., 2010; Ngo et al., 2008) on sponge carriers have concluded that the addition of sponge in terms of bioreactor volume fraction of 10–20% results in effective biofilm growth for nutrients removal as well as membrane scouring for fouling reduction. In this study, fouling phenomenon was evaluated and discussed in conventional submerged MBR (C-MBR) compared to hybrid moving biofilm MBR (MB-MBR) containing sponge as growth media operated under similar operational conditions. The impact of sponge carriers on sludge characteristics and its relationship with membrane fouling tendency was investigated.

2. Methods

2.1. Wastewater composition

Synthetic wastewater replicating high strength domestic wastewater was fed continuously to the MBR systems at uniform organic

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doi:10.1016/j.biortech.2012.01.033

loading rate of 3 kg-COD/m^3/d and COD:N:P of 100:10:2. The synthetic wastewater constituents have been discussed previously in Jamal Khan et al. (2011).

2.2. Experimental set-up

Two identical reactors made of acrylic having an effective volume of 14 L were run continuously for a period of 90 days. Each reactor was divided into three compartments using two porous baffles and hollow fiber membrane (Mitsubishi Rayon, Japan) was submerged in the middle compartment having a nominal pore size of 0.1 μm and surface area of 0.2 m^2. Peristaltic Pump (Master Flex, Cole-Parmer, USA) was used to periodically draw the permeate at a cycle of 10 min filtration and two minutes relaxation. Aeration rate of 7 L/min was maintained to keep the media in circulation and meet the desired DO concentration of 2 mg/L. Both reactors were operated simultaneously with HRT of 8 h and SRT of 25 days. Data logging manometer (Sper-Scientific 840099, Taiwan) were used to record the trans-membrane pressure (TMP) continuously which was used as an indicator of the membrane fouling propensity. The membranes were operated till TMP reached 50 kPa after which they were physically cleaned by washing with a tap water followed by chemical cleaning as per the guidelines of the manufacturer (Mitsubishi Rayon, Japan).

2.3. Biofilm carrier

Polyurethane sponge from United Foam Industries (Pvt.) Ltd. Pakistan was used as media in the biofilm membrane bioreactor (MB-MBR) having dimensions of $1 \times 1 \times 1$ cm and acclimatized to synthetic wastewater before usage. Twenty percentage of the reactors effective volume was filled with sponge and equally distributed among the three reactor compartments.

2.4. Analytical methods

Chemical oxygen demand (COD), mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were analyzed according to Standard Methods (APHA et al., 2005). DO/pH meter (Oakton PD 300, USA) was used to measure DO and pH on a regular basis in both reactors. The structure of biological flocs from C-MBR and MB-MBR was investigated using scanning electron microscope (SEM) (JOEL, Japan). The spot samples from the MBRs were placed on stainless steel support, dehydrated overnight, gold coated by a sputter and examined in SEM. Sludge particle size distribution (PSD) was analyzed using a particle size analyzer based on laser scattering principle (LA-300, Horiba, Japan) and the results were reported in percentage volume. The sludge samples from MBRs were subject to ultra-sonication for 5 min for proper dispersion of bio-particles prior to PSD analysis. Extra-cellular polymeric substance (EPS) was categorized into soluble and bound EPS. Sludge was centrifuged at 5000 rpm for 15 min and supernatant was isolated for soluble EPS and the remaining portion was used for bound EPS using cation exchange resin (CER) extraction method (Frølund et al., 1996).

2.4.1. Specific cake resistance (SCR) measurement

Specific cake resistance (SCR) of MBR sludge samples was determined by using batch filtration cell (Amicon, Model 8400, USA) attached with weighing balance (Schimadzu, UW6200H, Japan) connected to computer. 0.22-μm flat-sheet cellulose membrane filter (Millipore, GVWP 09050, USA) was used in the test. Pressurized nitrogen gas was used keeping a constant pressure of 50 kPa. The SCR was calculated by (Wang et al. 2007):

$$\alpha = \frac{2000 \cdot A^2 \cdot \Delta P}{\mu \cdot C} \cdot \frac{t/V}{V} \quad (1)$$

where ΔP is the applied pressure (kPa), A is the filtration area (0.00418 m^2), C is the MLSS concentration (kg/m^3), μ is the viscosity of permeate (N-s/m^2) and $[(t/V)/V]$ (s/m^6) is the slope of the straight portion of the curve that is obtained by plotting the time of filtration to volume of filtrate (t/V) versus the filtrate volume (V).

3. Results and discussions

3.1. Membrane fouling tendencies

Membrane fouling was evaluated with the help of TMP profiles obtained during membrane filtration at a constant flux of 8.75 L/m^2 h. Four typical TMP profiles of C-MBR and MB-MBR are shown in Fig. 1. The average filtration time recorded was 37 and 50 h in C-MBR and MB-MBR, respectively. The MB-MBR filtration runs exhibited 33% increase as compared to that in C-MBR due to the presence of sponge media. Lee et al. (2006) also reported that membrane coupled moving bed biofilm reactor (MC-MBBR) showed much lower biofouling rate than conventional MBR. The collision between circulating media and hollow fibers resulted in frictional forces that mitigated cake formation on membrane fibers, thus resulting in prolonged filtration.

3.2. Membrane fouling resistances

The resistance-in-series model was applied to evaluate the filtration characteristics.

$$R_t = \frac{\Delta P}{J \cdot \mu \cdot f_t} \quad (2)$$

$$R_t = R_m + R_c + R_p \quad (3)$$

where J is operational flux, ΔP is TMP, μ is viscosity of permeate, f_t is temperature correction to 20 °C, $f_t = e^{-0.0239(T-20)}$, R_t = total hydraulic resistance, R_m = intrinsic membrane resistance, R_c = reversible cake resistance formed by the cake layer and R_p = irreversible pore blocking resistance caused by adsorption and precipitation of dissolved and colloidal matter inside the pores (Rosenberger et al., 2006; Meng et al., 2009). The resistance analysis results are summarized in Table 1 which represents the averaged resistance values

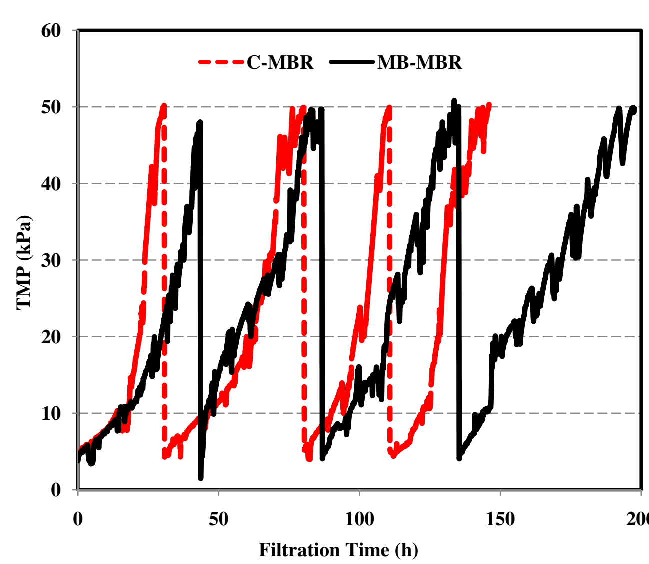

Fig. 1. TMP profiles in the C-MBR and MB-MBR systems.