Journal of Environmental Management 180 (2016) 459–465

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Effect of filtration flux on the development and operation of a dynamic membrane for anaerobic wastewater treatment

Mubashir Saleem [a], Luca Alibardi [b, *], Maria Cristina Lavagnolo [b], Raffaello Cossu [b], Alessandro Spagni [c]

[a] Department of Civil, Environmental and Architectural Engineering, University of Padova, via Marzolo 9, 35131 Padova, Italy
[b] Department of Industrial Engineering, University of Padova, via Marzolo 9, 35131 Padova, Italy
[c] Laboratory of Technologies for Waste, Wastewater and Raw Materials Management, Italian National Agency for New Technology, Energy and Sustainable Economic Development (ENEA), via M.M. Sole 4, 40129 Bologna, Italy

ARTICLE INFO

Article history:
Received 9 January 2016
Received in revised form
11 April 2016
Accepted 23 May 2016
Available online 6 June 2016

Keywords:
Dynamic membrane
Mesh filtration
Membrane bioreactor
Anaerobic process
Flux

ABSTRACT

Dynamic membrane represents a cost effective alternative to conventional membranes by employing fouling as a means of solid-liquid separation. This study evaluated the effects of initial flux on both development rate of dynamic membrane and bioreactor performance during two consecutive experiments. The dynamic membrane was developed over a 200 μm mesh and the reactor was operated under anaerobic conditions. It was found that the effect of an initial higher applied flux on dynamic membrane development was more pronounced than mixed liquor suspended solid concentration inside the bioreactor. The development of the dynamic membrane was therefore positively associated with the applied flux. The rapid development of the dynamic membrane during the second experimental run at high initial fluxes and lower MLSS concentrations also affected the performance of the bioreactor in terms of more efficient COD removal and biogas production. A major shortcoming of applying higher initial applied flux was the formation of a denser and robust dynamic membrane layer that was resistant to applied hydraulic shear to control desired permeability and thus represented an obstacle in maintaining a long term operation with sustainable flux at lower transmembrane pressure (TMP).

1. Introduction

Membrane bioreactors (MBRs) are nowadays extensively applied for the treatment of municipal and industrial wastewater since they allow for rapid start-up, small footprint, less sludge production and improved effluent quality if compared with conventional activated sludge processes (Pretel et al., 2015; Gabarrón et al., 2014; Judd, 2010; Ferraris et al., 2009). Although MBRs have mostly been applied for aerobic processes, their application in anaerobic treatments represents the ideal combination of membrane filtration and biological process. The very efficient solid-liquid separation of membranes enables in fact a complete decoupling of solids retention time (SRT) from hydraulic retention time (HRT). Anaerobic MBRs could therefore be characterised by short HRTs but long SRTs and high concentrations of bacteria inside bioreactors, the latters being key factors for efficient anaerobic treatments due to the low growth rates and yields of anaerobic microorganisms (Smith et al., 2012). Membrane fouling decreases permeate fluxes and is considered the most significant drawback in the application of MBR technologies for wastewater treatment (Judd, 2010). Different results have been reported in different studies on fouling propensities using aerobic and anaerobic sludge filtration through conventional membranes under different operating conditions in conventional MBRs. For instance, Yurtsever et al. (2015) and Spagni et al. (2010) have reported severe fouling during anaerobic MBR operation as compared to aerobic MBR operation. On the contrary, Xiong et al. (2016) observed lower fouling propensity in anaerobic MBR than aerobic MBR treating municipal sewage. Similarly, release of biofoulants due to biomass activity

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Abbreviations: ADMBR, anaerobic dynamic membrane bioreactor; COD, Chemical oxygen demand; CFV, cross flow velocity; DM, dynamic membrane; DMBR, dynamic membrane bioreactor; *J*, flux; HRT, hydraulic retention time; MBRs, membrane bioreactors; MF, microfiltration; ML, mixed liquor; SS, suspended solids; OLR, organic loading rate; SRT, solids retention time; TMP, trans membrane pressure; TS, total solids; UF, ultrafiltration; VS, volatile solids.

* Corresponding author. Present address: Cranfield Water Science Institute, Cranfield University, Bedford MK43 0AL, UK.

E-mail address: l.alibardi@cranfield.ac.uk (L. Alibardi).

http://dx.doi.org/10.1016/j.jenvman.2016.05.054

under different operating conditions affects fouling in both aerobic and anaerobic MBR systems (Robles et al., 2012). Therefore, different solutions attempting to reduce membrane fouling and improving aerobic and anaerobic sludge filterability have been evaluated (Trzcinski and Stuckey, 2016; Wong et al., 2015; Yang et al., 2012).

In this view, application of dynamic membrane technology in biological treatments can offer benefits over traditional membranes by precluding the need for frequent replacement of costly membrane modules, improving membrane fluxes and reducing the energy consumption (Alibardi et al., 2014; Ersahin et al., 2012). A dynamic membrane (DM) is formed by the deposition of suspended solids, colloids and microbial cell particles over an underlying support material which can be of different nature and characteristics (Loderer et al., 2013; Ersahin et al., 2012; Li et al., 2011). While fouling represents an important drawback for conventional membrane filtration, in the innovative approach of DM filtration it is purposefully exploited to create a low-cost, regenerative, self-forming filtration surface (Alibardi et al., 2014; Ersahin et al., 2014; Zhang et al., 2014).

Solids rejection of DMs is not comparable to microfiltration (MF) and ultrafiltration (UF) membranes due to the very different cut-off (Alibardi et al., 2014). Nevertheless, DM could represent a compromise between solids removal and plant costs; such a compromise appears even more significant in anaerobic plants since post-treatment is usually considered (e.g. nutrient removal or recovery) prior to final water discharge (Puchongkawarin et al., 2015; Sánchez-Ramírez et al., 2015; Zhang et al., 2014).

DM filtration has initially been studied for aerobic wastewater treatment systems (Wang et al., 2013; Ren et al., 2010; Fan and Huang, 2002; Kiso et al., 2000). Nevertheless, owing to the benefits offered by anaerobic process, recent studies mainly focused on exploiting DMs under anaerobic conditions (Alibardi et al., 2016; Ersahin et al., 2014; Zhang et al., 2010).

Meshes are indicated as interesting underlying support materials in DM filtration to curtail capital and management costs of MBRs (Alibardi et al., 2014; Loderer et al., 2013; Jeison et al., 2008). Recent studies reported that DM formation evolves from phases characterised by cake layers loosely bounded to the support materials, to phases where thick, stable and robust biofilms are formed (Alibardi et al., 2014; Zhang et al., 2010; Alavi Moghaddam et al., 2002). However, DM formation process is greatly affected by the different materials, pore sizes and structures of meshes (Zhang et al., 2014; Ersahin et al., 2013) and to the best of Authors' knowledge operating conditions specifically affecting DM development have not been studied yet.

This study aimed at assessing the development of the DM in an anaerobic dynamic membrane bioreactor (ADMBR) when different filtration fluxes (*J*) were applied. The study also evaluated the reactor performances resulting from different *J*, HRTs and organic loading rates (OLRs).

2. Materials and methods

2.1. Experimental setup

The research was conducted on a bench-scale ADMBR, coupled with an external cross-flow filtration module (Fig. 1). The external configuration was preferred since it can facilitate membrane maintenance operations while preserving anaerobic conditions in reaction tank.

The reactor had a total volume of 898 mL (WxHxD: 9.5 × 10.5 × 9 cm) and a working volume of 684 mL. A monofilament woven mesh made of polyamide/nylon (SaatiMil PA 7 XXX, Saatis.p.a., Italy) with openings of 200 μm, thread diameter of 120 μm, mesh count of 31/cm and 39% opening area (data from the supplier) was inserted in the central longitudinal part of a filtration support with a total volume of 48 mL (W × H × D: 20 × 1.2 × 2 cm) and a filtration area of 40 cm^2 (L × W: 20 × 2 cm).

The reactor was fed by using a peristaltic pump (Watson Marlow 401U/D1) controlled by a level sensor in order to maintain a constant working volume in the bioreactor. The cross-flow regime was established in the external module by using a peristaltic pump (Watson Marlow 403U/R1, Falmouth, Cornwall, UK) that continuously circulated mixed liquor along the mesh surface. Permeate extraction was facilitated by means of another peristaltic pump (Watson Marlow 401U/DM3). The permeate passed through a small airtight vessel of approximately 100 mL (Fig. 1) in order to account for the presence of oversaturated biogas in the effluent.

TMP was measured by using a U-tube pressure gauge filled with water. Three home-made wet-tip gas meters were used to measure biogas production; they were connected to the experimental system in three different locations, i.e. directly on the anaerobic reactor, on the external cross flow module and on the effluent collection vessel (Fig. 1).

Reactor was maintained at mesophilic conditions (35 ± 1 °C) by using a thermostatic bath (ISCo. GTR 2000 "11x", Italy). Mixing of sludge in the reactor was carried out by using a magnetic stirrer (Variomag, Thermo Scientific, Italy).

Two consecutive experimental runs were performed during this study, lasting 68 and 27 days, respectively. Details of the start-up for the first experiment are reported elsewhere (Alibardi et al., 2014). The bioreactor was operated in both runs at similar process conditions but different initial fluxes to assess their effects on DM development and on reactor performances. The filtration area was kept constant during the entire study therefore, any change in flux on the membrane resulted in a change in HRT on the reactor. Furthermore, for both the experiments it was decided to keep the rise in TMP value up to 20 kPa and this value was set as the upper limit of TMP rise.

During the first run the initial *J* was set to 1.0 L m^{-2} h^{-1} and then increased up to 7.2 L m^{-2} h^{-1} (mean value of 3.3 L m^{-2} h^{-1}) corresponding to HRTs changing from 6.8 to 1.0 d (mean value of 3.1 d). During the second run, initial *J* was set to 2.9 L m^{-2} h^{-1} and then increased up to 7.0 L m^{-2} h^{-1} (mean value of 5.1 L m^{-2} h^{-1}) corresponding to HRTs changing from 2.4 to 1.0 d (mean value of 1.4 d).

2.2. Synthetic wastewater and inoculum

The reactor was fed with a synthetic wastewater composed of sucrose as carbon source at a concentration of 5 gCOD L^{-1}. To ensure alkalinity, macro and micro nutrients the followings compounds were also added: $NaHCO_3$ (2 g g COD^{-1}), NH_4Cl (0.04 g N g COD^{-1}), KH_2PO_4 (0.01 g P g COD^{-1}), $FeCl_3{*}6H_2O$ (2.1 mg Fe L^{-1}), $CaCl_2{*}2H_2O$ (8.2 mg Ca L^{-1}), $MgCl_2{*}6H_2O$ (2.4 mg Mg L^{-1}), $Na_2MoO_4{*}2H_2O$ (0.22 mg Mo L^{-1}), $ZnSO_4{*}7H_2O$ (0.23 mg Zn L^{-1}), $CuSO_4{*}5H_2O$ (0.128 mg Cu L^{-1}), $NiCl_2{*}6H_2O$ (0.1 mg Ni L^{-1}), H_3BO_4 (0.007 mg B L^{-1}). These chemicals were dissolved in tap water.

The reactor was inoculated with anaerobic sludge (TS of 13.5 g L^{-1} and VS of 7.1 g L^{-1}) obtained from a full-scale mesophilic sludge digester treating the excess sludge of a municipal wastewater treatment plant located in Padova, Italy.

2.3. Analytical methods

Chemical oxygen demand (COD), total solids (TS), volatile solids (VS), total suspended solids (TSS), volatile suspended solids (VSS), were measured according to Standard Methods (APHA, 2005). Biogas production was measured by home-made wet tip gas meters. Biogas composition was measured by a micro-gas