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# Applicability of dynamic membrane technology in anaerobic membrane bioreactors

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ABSTRACT

This study investigated the applicability of dynamic membrane technology in anaerobic membrane bioreactors for the treatment of high strength wastewaters. A monofilament woven fabric was used as support material for dynamic membrane formation. An anaerobic dynamic membrane bioreactor (AnDMBR) was operated under a variety of operational conditions, including different sludge retention times (SRTs) of 20 and 40 days in order to determine the effect of SRT on both biological performance and dynamic membrane filtration characteristics. High COD removal efficiencies exceeding 99% were achieved during the operation at both SRTs. Higher filtration resistances were measured during the operation at SRT of 40 days in comparison to SRT of 20 days, applying a stable flux of 2.6 L/$m^2$ h. The higher filtration resistances coincided with lower extracellular polymeric substances concentration in the bulk sludge at SRT of 40 days, likely resulting in a decreased particle flocculation. Results showed that dynamic membrane technology achieved a stable and high quality permeate and AnDMBRs can be used as a reliable and satisfactory technology for treatment of high strength wastewaters.



## 1. Introduction

Anaerobic technology for wastewater treatment has evolved into a consolidate alternative for a wide variety of wastewaters. Particularly the avoidance of fossil energy use while converting the chemically stored energy in the organic pollutants into energy-rich biogas, has made anaerobic treatment an attractive alternative in the last few decades. Industrial wastewater

*Abbreviations:* AnDMBR, Anaerobic dynamic membrane bioreactor; AnMBR, Anaerobic membrane bioreactor; COD, Chemical oxygen demand; CST, Capillary suction time; $CST_n$, normalized CST; DM, Dynamic membrane; EGSB, Expanded granular sludge bed; EPS, Extracellular polymeric substances; F/M, Food/mass ratio; HRT, Hydraulic retention time; MBR, Membrane bioreactor; OLR, Organic loading rate; P/C, Protein/carbohydrate ratio; PBS, Phosphate buffered saline; PSD, Particle size distribution; $R_T$, Total filtration resistance; SRT, Sludge retention time; SMA, Specific methanogenic activity; SMP, Soluble microbial products; SRF, Specific resistance to filtration; TMP, Transmembrane pressure; TN, Total nitrogen; TP, Total phosphorus; TS, Total solids; TSS, Total suspended solids; UASB, Upflow anaerobic sludge blanket; VS, Volatile solids; VSS, Volatile suspended solids.

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treatment has been mostly benefited from anaerobic technology owing to the development of anaerobic high-rate reactors such as the upflow anaerobic sludge blanket (UASB) reactors and the expanded granular sludge bed (EGSB) reactors (van Lier, 2008; Ersahin et al., 2011). Since the growth rate of the anaerobic microorganisms is much lower than that of aerobic ones, high biomass concentrations are needed inside the anaerobic reactors. High-rate anaerobic processes are characterized by an uncoupling of the solids retention time (SRT) from the hydraulic retention time (HRT). The increased SRT is a result of effective biomass retention, largely facilitated by (auto)immobilization of anaerobic bacteria in biofilms, flocs or granular sludge. When biomass immobilization cannot be guaranteed, alternatively membrane separation can be used to retain biomass. Anaerobic membrane bioreactors (AnMBRs) are of growing interest and have been researched for the treatment of different kinds of wastewater including municipal and industrial wastewaters (Liao et al., 2006; Dereli et al., 2012; Ozgun et al., 2013; Lin et al., 2013). AnMBRs combine the advantages of anaerobic processes with the production of solids free effluents. AnMBR technology has been considered as an appropriate alternative to provide a complete biomass retention enabling independent control of HRT and SRT (Jeison et al., 2008; Zhang et al., 2010).

Accumulation of solid particles such as microbial cells, extracellular organics, and inorganic precipitates on the membrane surface is a common phenomenon that occurs in (An)MBRs during filtration. The accumulated matter on the membrane surface becomes denser over time and forms a cake layer that governs fouling and flux limitation (Jeison and van Lier, 2008; Lin et al., 2009; Waeger et al., 2010). In fact, the cake layer is the most important barrier in AnMBR systems (Jeison and van Lier, 2008). The formation and the effective use of this cake layer on a support layer, such as a mesh or woven filter cloth instead of a membrane present a new concept, which is called dynamic membrane (DM) filtration (Ersahin et al., 2012). Since the cake (DM) layer can easily be removed from the surface of the support material and can be re-established again in a short time, this layer is termed "dynamic membrane". DM layer can be used as a filter prior to the support material; thus, even the support material has a big pore size, the dense and compact DM layer provides an effective retention in anaerobic dynamic membrane bioreactors (AnDMBRs) (Kiso et al., 2000; Jeison et al., 2008; Zhang et al., 2010). Therefore, cheap materials can be used as the support material, enabling AnMBR applications at much lower capital exploitation costs. In the proposed concept, the cake layer plays a crucial role. For effective DM layer formation and consolidation, the selection of appropriate type of support material regarding its structure, e.g. yarn type, pore size, and availability is an important issue (Ersahin et al., 2013). The most common support material types used in various studies, including both aerobic and anaerobic dynamic MBR applications, were mesh, woven and non-woven fabrics (Ersahin et al., 2012).

DM technology in AnMBRs was applied for the treatment of municipal wastewaters in various studies (Ho et al., 2007; An et al., 2009; Zhang et al., 2010, 2011). Jeison et al. (2008) found that almost complete retention of solids could be achieved by AnDMBRs. However, they could not get a stable flux that had a range between 0.5 and 3 L/m$^2$ h under both thermophilic and mesophilic conditions. With non-woven fabric support layer, chemical oxygen demand (COD) removal of 87% was achieved by an AnDMBR treating municipal wastewater (An et al., 2009). Zhang et al. (2011) located a DM module with a mesh support material at the top of a UASB reactor, thereby filtering the supernatant instead of the sludge. They found that high flux values, e.g. 65 L/m$^2$ h, are achievable in long term operation. Although they had a stable COD removal of about 63.4%, this efficiency is significantly lower than those obtained by conventional AnMBRs. The research on DM technology has been mainly focused on the applications in aerobic MBRs rather than anaerobic ones (Ersahin et al., 2012). A few studies have been conducted for AnDMBRs, which focused mostly on the treatment of low strength wastewaters, e.g. municipal wastewaters. There is quite limited information about the potential and applicability of DM technology for treatment of high-strength/concentrated waste(water)s in AnMBRs. Therefore, the main goal of this research was to investigate the applicability of the DM technology in AnDMBRs treating high strength organic wastewaters. Within this concept, different SRTs were applied in a submerged AnDMBR in order to understand the effects of SRT on the removal efficiency and sludge filterability. For this purpose, COD removal, total suspended solids (TSS) retention capacity, biogas (methane) generation, evolution of trans-membrane pressure (TMP) and specific resistance to filtration (SRF) change, particle size distribution (PSD), and extracellular polymeric substances/soluble microbial products (EPS/SMP) formation in the bulk sludge were investigated.

## 2. Material and methods

### 2.1. Experimental set-up

A laboratory scale submerged AnDMBR set-up was used in this study (Fig. 1). The AnDMBR system consisted of a completely mixed glass reactor that had an effective volume of 6.8 L and a submerged flat sheet (Fig. 1) membrane module. The rectangular membrane module had two filtering sides with a total filtration area of 0.018 m$^2$. A monofilament woven fabric, which was made of polypropylene material (Lampe BV, the Netherlands) with an average pore size of 10 μm, was used as the support material. Two peristaltic pumps (Watson Marlow 120U/DV) were separately used to feed substrate into the anaerobic reactor and to collect permeate from the membrane module. TMP was measured by a pressure sensor (AE Sensors, ATM −800/+600 mbar) placed on the permeate line. Produced biogas was recycled by a diaphragm pump (KNF, N86 KTDCB) via two diffusers to provide mixing inside the bioreactor and to scour the DM surface for fouling control. Mixing diffuser was located at the bottom of the bioreactor and the biogas sparging diffuser was placed under the membrane module (Fig. 1). Biogas production was measured by a gas counter (Ritter, Milligas Counter MGC-1 PMMA). Two baffles were included inside the bioreactor in order to obtain even distributed mixing conditions. Temperature and pH inside the bioreactor were measured on-line by a probe combined with a transmitter