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Factors that affect the permeability of commercial hollow-fibre membranes in a submerged anaerobic MBR (HF-SAnMBR) system

A. Robles [a,*], M.V. Ruano [b], J. Ribes [b], J. Ferrer [a]

[a] Institut Universitari d'Investigació d'Enginyeria de l'Aigua i Medi Ambient, IIAMA, Universitat Politècnica de València, Camí de Vera s/n, 46022 Valencia, Spain

[b] Departament d'Enginyeria Química, Escola Tècnica Superior d'Enginyeria, Universitat de València, Avinguda de la Universitat s/n, 46100 Burjassot, Valencia, Spain

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ABSTRACT

A demonstration plant with two commercial HF ultrafiltration membrane modules (PURON®, Koch Membrane Systems, PUR-PSH31) was operated with urban wastewater. The effect of the main operating variables on membrane performance at sub-critical and supra-critical filtration conditions was tested. The physical operating variables that affected membrane performance most were gas sparging intensity and back-flush (BF) frequency. Indeed, low gas sparging intensities (around 0.23 $Nm^3\ h^{-1}\ m^{-2}$) and low BF frequencies (30-s back-flush for every 10 basic filtration–relaxation cycles) were enough to enable membranes to be operated sub-critically even when levels of mixed liquor total solids were high (up to 25 g L^{-1}). On the other hand, significant gas sparging intensities and BF frequencies were required in order to maintain long-term operating at supra-critical filtration conditions. After operating for more than two years at sub-critical conditions (transmembrane flux between 9 and 13.3 LMH at gas sparging intensities of around 0.23 $Nm^3\ h^{-1}\ m^{-2}$ and MLTS levels from around 10–30 g L^{-1}) no significant irreversible/irrecoverable fouling problems were detected (membrane permeability remained above 100 LMH bar^{-1} and total filtration resistance remained below $10^{13}\ m^{-1}$), therefore no chemical cleaning was conducted. Membrane performance was similar to the aerobic HF membranes operated in full-scale MBR plants.

1. Introduction

1.1. Anaerobic treatment of urban wastewater using MBR technology

In recent years there has been increased interest in assessing the feasibility of the anaerobic treatment of urban wastewater at ambient temperatures. This interest focuses on the sustainable advantages of anaerobic rather than aerobic processes, i.e. anaerobic processes generate little sludge due to the low anaerobic biomass yield; consume little energy because no aeration is needed; and generate biogas that can be used as an energy resource. The total greenhouse gas emissions of this technology are, therefore, low because low

* *Corresponding author*. Tel.: +34 96 387 99 61; fax: +34 96 387 90 09.
E-mail addresses: ngerobma@upv.es (A. Robles), m.victoria.ruano@uv.es (M.V. Ruano), josep.ribes@uv.es (J. Ribes), jferrer@hma.upv.es (J. Ferrer).

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energy consumption indirectly means low gas emissions. The main challenge of anaerobic biotechnology is to develop treatment systems that prevent biomass loss and enable high sludge retention times (SRTs) in order to offset the low growth rates of anaerobic biomass at ambient temperatures (Lin et al., 2010). In this respect, submerged anaerobic membrane bioreactors (SAnMBRs) are a promising technology for urban wastewater treatment. However, operating membrane bioreactors with high SRTs may lead to high mixed liquor total solids (MLTS) at a specific reacting volume. This is one of the main constraints of using membranes (Judd and Judd, 2011) since it can result in high membrane fouling propensities.

1.2. Membrane fouling in SAnMBRs

The key challenge in SAnMBR technology is how to optimise membrane operating in order to minimise any kind of membrane fouling, especially the irrecoverable/permanent component that cannot be eliminated by chemical cleaning. The extent of irrecoverable/permanent fouling is what ultimately determines the membrane lifespan (Judd, 2008; Drews, 2010; Patsios and Karabelas, 2011). Several strategies to control fouling (see, for example, Liao et al., 2006) aim to optimise filtration whilst minimising investment and operating costs. In this respect, the SAnMBR design strategy must be carefully selected. Depending on the design strategy, different design criteria can be adopted. One such criterion is based on operating membranes in sub-critical filtration conditions that are limited by the so-called critical flux (J_C) (Bachin et al., 1995; Field et al., 1995). Operating membranes sub-critically gives membranes long lifespans, which reduces replacement and maintenance costs (by minimising physical cleaning costs, i.e. membrane scouring or back-flush). In this respect, MLTS has been widely identified as one of the factors that affect J_C most. Thus, an investment compromise between operating reactor volume and filtration area should be selected in order to keep MLTS at sub-critical levels for a given transmembrane flux (J). Another design criterion is based on operating membranes at critical or supra-critical filtration conditions. This reduces initial investment costs because it requires lower operating volumes and/or lower membrane surfaces than when operating membranes at sub-critical filtration conditions, however, replacement, maintenance and operating costs are probably higher.

Regardless of the design criterion adopted, it is necessary to determine which filtration conditions (Drews et al., 2010) are most suitable in order to optimise the membrane module design and configuration. An exhaustive analysis in the different potential operating conditions is, therefore, necessary in order to optimise both membrane lifespan (i.e. membrane replacement cost) and operating and maintenance costs (i.e. the cleaning mechanism). In this respect, it is necessary to assess the impact of the main operating variables upon membrane performance, i.e. frequency and duration of the physical cleaning stages (back-flush and relaxation); gas sparging intensity; cross-flow sludge velocity over the membrane surface (for cross-flow membrane configurations); up-flow sludge velocity in the membrane tank (submerged membrane configurations) which determines the sludge concentration factor when the membranes are located in external tanks; and maximum operating transmembrane pressure (TMP).

1.3. Full-scale implementation of SAnMBRs

Membrane technology has been used increasingly to treat wastewater over the last decade (Lesjean and Huisjes, 2007) even in large urban WWTPs. The treatment capacity of urban MBR WWTP has significantly increased (to maximum design flow rates of more than 150000 $m^3\ d^{-1}$) in just a few years (Huisjes et al., 2009). As regards membrane configuration, flat-sheet (FS) membranes are used mostly in small plants (<5000 $m^3\ d^{-1}$), whilst hollow-fibre (HF) membranes are used for the entire flow range and prevail in large plants (>10,000 $m^3\ d^{-1}$) and account for about 75% of all total MBR installed capacity (Cote et al., 2012).

Nevertheless, it is important to highlight that all these urban MBR WWTPs are aerobic wastewater treatments. Although MBR technology has not yet been applied to full-scale anaerobic urban wastewater treatment, the scientific community is showing increasing interest in the feasibility of its full-scale implementation because of the above-mentioned advantages. Indeed, several studies which assess the feasibility of using SAnMBR technology to treat urban wastewater at the laboratory scale have been published (Jeison and van Lier, 2007; Huang et al., 2008; Lew et al., 2009). However, the impact of the main operating conditions upon membrane fouling cannot be determined exactly at the lab scale because they depend heavily on the membrane size. In HF membranes in particular, HF length is a key performance parameter. In this respect, there is still a lack of thorough knowledge about fouling mechanisms, mainly as regards hydraulic performance and membrane permeability (Guglielmi et al., 2007; Di Bella et al., 2010; Mannina et al., 2011). In addition, it is expected that membrane fouling will be affected to a considerable degree by the different characteristics of aerobic and anaerobic mixed liquors, such as particle size distribution, extracellular polymeric substances (EPS), soluble microbiological products (SMP), biomass concentration, inorganic and organic compounds (Lin et al., 2009), or pH values affecting both biofouling (Sweity et al., 2011) and formation of chemical precipitates.

Therefore, since membrane performance cannot be scaled up directly from laboratory to plant dimensions, especially in the case of HF-based technology (Liao et al., 2006), further studies of HF-SAnMBR technology on an industrial scale are needed in order to facilitate its design and implementation in full-scale wastewater treatment plants (WWTPs).

To gain more insight into the optimisation of the physical separation process in a SAnMBR system at the industrial scale, this paper shows the impact of the main operating variables upon the performance of industrial HF membranes. Gas sparging intensity, up-flow sludge velocity in the membrane tank, duration and frequency of the different physical cleaning stages (relaxation and back-flush), and length of filtration stage were evaluated in an SAnMBR system featuring commercial HF membrane modules. The effect of these variables at two different membrane operating conditions (sub-critical and critical/supra-critical filtration conditions) was assessed. The plant was operated using Carraixet WWTP