WATER RESEARCH 59 (2014) 11–22

Available online at www.sciencedirect.com

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

Implications of changes in solids retention time on long term evolution of sludge filterability in anaerobic membrane bioreactors treating high strength industrial wastewater

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ARTICLE INFO

Article history:
Received 24 December 2013
Received in revised form
26 March 2014
Accepted 28 March 2014
Available online 12 April 2014

Keywords:
Anaerobic membrane bioreactor
Corn thin stillage
Membrane fouling
Sludge filterability
Solids retention time

ABSTRACT

Long-term experiments were conducted to assess the impact of changing the solids retention time (SRT) on sludge filterability in anaerobic membrane bioreactors (AnMBRs), treating corn-based bioethanol thin stillage. Well established parameters, such as capillary suction time (CST) and specific resistance to filtration (SRF), developed for sludge dewatering, were used to evaluate the SRT effect on sludge filterability. Our results clearly demonstrated that SRT is one of the most important factors influencing sludge filterability in AnMBRs. SRT effects the accumulation of fine particles and solutes, which were found to affect attainable flux and fouling, in reactor broth. A better filterability was observed at a SRT of 20 days compared to elevated SRTs, i.e. 50 days. A clear correlation between sludge filtration characteristics and membrane filtration resistance could not be established especially at short SRTs, whereas many parameters such as total suspended solids (TSS), CST, soluble microbial products (SMP) and supernatant filterability were found to be mutually correlated. Net membrane fluxes between 9 and 13 L m^{-2} h^{-1} were obtained at 0.5 m s^{-1} cross-flow velocity and the long term fouling was controlled by using frequent filtration and backwash cycles.

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http://dx.doi.org/10.1016/j.watres.2014.03.073

1. Introduction

The success and widespread application of aerobic MBRs stimulated the combination of membrane filtration and anaerobic processes for municipal and industrial wastewater treatment (Dereli et al., 2012; Ozgun et al., 2013). Likewise their aerobic counterparts, AnMBRs take advantage of membrane filtration for the separation of the biomass from effluent and provide complete sludge retention. In fact, AnMBR is an emerging treatment technology for industrial wastewaters/slurries with extreme properties, which often cause biomass retention problems in conventional anaerobic granular sludge bed reactors. Thus, AnMBRs can provide an alternative reactor technology with a high treatment performance and permeate quality that enables water reuse for industrial wastewaters. Moreover, anaerobic digestions is a low sludge producing and net energy yielding process, which can help to reduce carbon emissions originating from fossil fuel consumption (van Lier, 2008).

Despite their many advantages, AnMBRs obviously inherit some constraints related to the membrane filtration process such as membrane fouling, high investment and operation costs, and process complexity with increased automation needs due to additional pumps and pressure sensors used on membrane modules. Among these constraints, membrane fouling seems to be most important, limiting the wide-spread application of AnMBRs. Membrane fouling is a very complex and multi-variable phenomenon dependent on sludge characteristics as well as on the filtration process itself (Le-Clech et al., 2006). Thus, parameters related to mixed liquor characteristics such as biomass concentration, extracellular polymeric substances (EPS), soluble microbial products (SMP), particle size distribution, hydrophobicity and surface charge, seem to have an influence on fouling (Meng et al., 2009). In fact, all these parameters are related to substrate characteristics, bioreactor operation, i.e. SRT, organic and sludge loading rate (OLR and F:M), and membrane operation, i.e. shear rate, and the filtration–backwash–relaxation cycles. Therefore, understanding the relation of these factors with each other and optimization of them for each specific case to improve sludge filterability and to mitigate fouling is of crucial importance.

Several researchers have attempted to find a relation between sludge physical characteristics, such as suspended solids concentration, particle size, viscosity and dewaterability, and membrane filtration performance in aerobic MBRs (Khongnakorn et al., 2007; Lyko et al., 2008; Delrue et al., 2011; van den Broeck et al., 2011). Well established standard tools that had been developed, especially for sludge dewaterability such as CST and SRF, can be used to compare the filterability characteristics of sludge in membrane bioreactors. In fact, CST was proposed as an early warning parameter for membrane cleaning schedules due to its good correlation with membrane filtration resistance and easiness to use (Pollice et al., 2008; Laera et al., 2009). Wang et al. (2006) could establish a non-linear relationship between critical flux and CST. Pollice et al. (2007) observed a good correlation between SRF and CST parameters. They stated that above a threshold TSS concentration such as 20–22 g L^{-1}, the CST and SRF increased rapidly indicating a deterioration of filterability. However, in some studies, although it was shown that sludge dewaterability and physicochemical characteristics are interrelated, a clear correlation between these parameters and membrane fouling could not be established (Khongnakorn et al., 2007; Lyko et al., 2008; Delrue et al., 2011). All in all, these parameters can be used as practical tools to compare the sludge filterability under different conditions. Although, these parameters have been frequently used to characterize the filterability of the sludge in aerobic MBRs, they have been rarely implemented in AnMBRs. Recently, Ersahin et al. (2014) used CST and SRF tests to compare sludge filterability in dynamic AnMBRs, operated at different SRTs. Their results indicate a worse sludge filterability at increased SRTs. Therefore, we expect that CST and SRF are useful parameters to characterize sludge in AnMBR systems, while studying the long term filtration performance and membrane fouling as it is commonly applied in MBR research.

The SRT is often considered as the most fundamental parameter that controls the process performance in biological treatment systems. The SRT in AnMBRs, can be controlled much easier than other types of anaerobic reactors and it is completely independent from the hydraulic retention time (Liao et al., 2006). Theoretically, the operation of AnMBRs at infinite SRT, i.e. without any sludge withdrawal, is possible. In literature, AnMBRs were reported to operate at various SRTs in the range of 30–350 days (Dereli et al., 2012). Generally, high SRTs correspond to more biogas production due to the improved stabilization of organic matter by overcoming hydrolysis limitations, less sludge production and higher biomass concentrations in the reactor. However, increased SRTs also yield to sludge stabilization, which means less active biomass and accumulation of inert organic and inorganic matter, such as biomass decay products and inorganic precipitates, in the reactor (Lee et al., 2003; Liao et al., 2006). The SRT is considered as the most important parameter which determines the fouling propensity of the mixed liquor cultivated in MBRs (Le-Clech et al., 2006). Unfortunately, it is very difficult to assess and evaluate the impact of SRT on membrane fouling since many parameters, i.e. biomass concentration, sludge viscosity, F:M ratio and EPS concentrations, which are also related to fouling, inevitably change depending on the variations of this parameter. Therefore, contradictory results have been reported over the years on this subject (Meng et al., 2009). Thus, the exact role of SRT on biological and filtration performance of AnMBRs has not yet been elucidated, requiring further investigations.

The aim of this study is to identify the effect of SRT on long term filtration performance and sludge filterability in AnMBRs. Therefore, long term evolution of sludge physicochemical characteristics has been monitored by using standardized tests to establish a link between sludge filterability characteristics and long term membrane filtration performance.

2. Materials and methods

2.1. Reactor set-up and operation

Three AnMBRs were operated, each having 10 L effective volume and equipped with cross-flow tubular membranes.