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Effects of relaxation time on fouling propensity in membrane bioreactors

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ABSTRACT

A lab-scale filtration cell was used to determine the optimum relaxation time for membrane bioreactor (MBR) membranes. Sludge from 15 plants was analysed with fixed filtration times and intermittent relaxations of decreasing durations. By determining the average flux, the optimum relaxation time was found to be 0.2–4 min; therefore, the optimal relaxation time should be determined for the actual sludge and not based on the manufacturer's standard. It may also be necessary to change the relaxation protocol as the sludge properties change. Test on the lab-scale filtration cell and a pilot MBR shows that the highest net flux was obtained with the same relaxation time, i.e., the lab-scale filtration cell can be used to optimize the relaxation time in large-scale MBR systems. The permeate flux was significantly higher in the lab-scale filtration cell than the MBR system due to sludging/irreversible fouling in the pilot MBR. Mathematical simulations indicated that approximately 85% of the membrane area in the pilot MBR plant was blocked during operation. The results indicate that the lab-scale filtration cell can be used independently to check both sludge filterability and membrane condition in full-scale MBR systems, and that the optimal relaxation time for large-scale MBRs can be determined in lab-scale systems.

1. Introduction

Membrane bioreactors (MBRs) have been developed to a state where they are competitive with conventional activated sludge (CAS) plants in terms of operational expenses while offering benefits such as higher effluent quality and more compact plant design. The technology is now being applied in many newly built or retrofitted wastewater treatment plants (WWTPs) [1]. The most costly part of the MBR system is the membranes and the energy used to ensure a high flux through them. The membranes foul during operation, reducing their capacity, increasing energy consumption, increasing the need for chemical cleaning, and shortening membrane lifetime. Hydraulic cleaning, for example, via relaxation or backwash, is usually used periodically during operation to reduce the effect of membrane fouling, thereby increasing membrane capacity. However, to exploit the membrane's full potential, the optimal relaxation or backwashing frequency must be identified.

The MBR market includes many manufacturers whose systems have specific configurations, for example, of membrane, module, and tank design. The filtration protocols applied for operation, involving factors such as transmembrane pressure (TMP), permeate flux, air scouring intensity, and relaxation or backwashing frequency, differ and are typically based on manufacturers' standard recommendations [2]. However, the survey by Bugge et al. found that sludge quality varied significantly depending on plant configuration, wastewater characteristics, and operational conditions [3]. Moreover, the sludge properties at a given WWTP are known to change, for example, in periods of higher or lower loads or during incidents such as flooding. It is therefore important to have methods that can be applied to optimize membrane operation. Various methods have been developed to determine fouling propensity, namely, the Delft Filtration Characterisation method (DFCm), membrane bioreactor-VITO fouling measurement (MBR-VRM), Berlin Filtration Method (BFM), and, most recently, Aalborg Filtration Property Analysis (AaFPA) [4–7]. These methods use filtration experiments in small filtration units to assess the fouling propensity of sludge samples. Huyskens et al. assessed the development of the reversible and irreversible fouling potentials of MBR sludge through tracing the development of hydraulic

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resistance before and after relaxation [5]. The filtration experiments were conducted at constant TMP and using fixed filtration and relaxation times. Van der Marel et al. developed a method to determine the degree of irreversible fouling in flux-stepping experiments by implementing intermittent relaxations between filtration steps [8]. By studying the permeability recovery between steps, the degree of reversibility can be assessed. However, the fouling remaining after a relaxation may not be irreversible, as insufficient relaxation will lead to remaining, reversible fouling that accumulates over the filtration cycles [9]. Therefore, it is essential for sustainable operation to use relaxation and filtration steps that are long and frequent enough to efficiently remove reversible fouling.

Nevertheless, few studies have investigated the influence of backwash and relaxation times on MBR performance. A study of backwash time demonstrated that increasing the backwash time and flow reduces fouling [10]. Accordingly, Wu et al. studied the influence of relaxation time and frequency in 24-h constant-flux filtration experiments [11]. Experiments using two different relaxation times and frequencies, respectively, demonstrated that longer relaxation phases relative to filtration phases slow the development of fouling as more fouling is removed. However, increasing the relaxation frequency increases fouling even though the filtration-to-relaxation ratio is the same. This is in accordance with the results of Maqbool et al., who found that a long relaxation relative to filtration phase gives lower net fouling rates, but that frequent relaxations give higher net fouling rates due to irreversible fouling [12]. The positive effect of relaxation time was also demonstrated by Hong et al. [13]. Chua et al. found that 4 min relaxation time for 8 min filtration was adequate to completely recover the permeate flux in contrast to 2 min relaxation [14]. Gui et al. found that the average TMP increase rate decreases linearly with relaxation time, and increases linearly with filtration time for system operated at constant flux [15]. The literature therefore indicates that it is essential for sustainable membrane operation that the membrane is sufficiently cleaned by relaxation, though it follows that relaxation phases should not be too long. As the relaxation phase is associated with a stop in permeate production, unnecessarily long relaxation phases should be avoided as they will result in lower net fluxes. Especially for constant TMP filtration, this is important as the gain in flux should compensate for the duration of the relaxation periods, when no permeate is produced.

This study aimed to develop a fast and simple filtration protocol to identify the optimal relaxation time in MBR systems with flat sheet membranes. Neither the DFCm nor the BFM method has been used to optimize membrane relaxation times. Further, tubular membranes are used in the MBR-VRM setup. The AaFPA method use filtration experiment in a small flat sheet unit operated at an air scouring rate comparable with full-scale MBR systems. For that reason, the AaFPA system has been chosen for fouling characterization to identify the optimal relaxation time in MBR systems. The existing protocols for the small scale filtration units are operated at fixed relaxation times. Hence, a new experimental procedure was developed inspired by Hong et al. [13]. This was done by designing and conducting filtration experiments with fixed filtration times and decreasing relaxation times to minimize the experimental time. The optimal relaxation time was determined for different types of sludge sampled from Danish WWTPs with varying process configurations. To assess the applicability of the method for determining optimal relaxation time, the filtration tests were conducted in a pilot-scale MBR and the results were compared with those of filtration tests conducted in a lab filtration unit using sludge samples from the pilot MBR. The current condition of the pilot MBR membranes was studied by comparing experimental data from both the lab-scale filtration cell and the pilot MBR.

A novel method was introduced and used to identify irreversible fouling and sludging in pilot and full-scale MBR plants. Two fouling models were developed assuming either a homogenously distributed irreversible fouling layer or an inactive membrane area. The permeate flux of a large scale MBR system was then simulated using experimental data obtained from the AaFPA setup. By comparing these data, it was possible to distinguish between the irreversible fouling and sludging.

2. Materials and methods

2.1. Sludge sampling from WWTPs

Ten litres of activated sludge was sampled from the aeration tank of each analysed WWTP. Activated sludge was transported overnight and analysed upon arrival at the laboratory, except in the case of the Aalborg West WWTPs and Aalborg MBR pilot plant, where the sludge was sampled and then transported directly to the laboratory. The wastewater treatment plants are described in detail in Table 1.

2.2. Lab-scale filtration unit and relaxation test protocol

An automated lab-scale filtration cell (i.e., an AaFPA device) was

Table 1
Data on WWTPs where samples were taken.

Plant	Configuration[*]	Flow ($m^3\ d^{-1}$)	SS ($g\ L^{-1}$)	COD ($kg\ m^{-3}$)	N load ($kg\ d^{-1}$)	P load ($kg\ d^{-1}$)	pH	Conductivity ($mS\ cm^{-1}$)
Aalborg West CAS	EBPR	52,906	2.7	19,046	1905	286	6.8	692
Aalborg MBR	EBPR	9	5.7	19,046	1905	286	7.2	1300
Biobooster MBR	BNR	120	11.3	47	3	1	6.8	713
Bjergmarken	EBPR	15,744	6.2	12,013	1008	147	7.3	1903
Bjerringbro CAS	EBPR	5713	5.0	2737	214	61	7.3	697
Boeslum	EBPR	2560	5.2	2511	159	28	7.3	817
Branderup	EBPR	1036	2.9	767	61	11	7.9	3330
Egaa	EBPR	20,530	5.2	12,585	1006	172	7.5	1197
Esbjerg West	EBPR	27,266	4.9	9254	1123	164	7.1	988
Fredericia	EBPR	29,425	7.2	33,956	1866	355	7.2	4350
Lundtofte CAS	EBPR	25,048	7.4	8541	1302	158	7.2	1013
Lundtofte MBR	EBPR	25,048	9.8	8541	1302	158	7.3	1111
Skive	EBPR	7623	4.6	3773	342	54	7.0	919
Tarm	EBPR	7354	4.3	2030	219	31	7.4	508
Aalbæk	EBPR	519	12.7	1891	151	22	7.5	13,420

[*] EBPR: Enhanced Biological Phosphorus Removal and BNR: Biological Nutrient Removal.