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Characterisation of polymeric fouling in membrane bioreactors and the effect of different filtration modes

Uli Metzger [b], Pierre Le-Clech [a,*], Richard M. Stuetz [c], Fritz H. Frimmel [b], Vicki Chen [a]

[a] *UNESCO Centre for Membrane Science and Technology, School of Chemical Sciences and Engineering, University of New South Wales, Sydney, Australia*
[b] *Engler-Bunte-Institut, Chair of Water Chemistry, University of Karlsruhe, Germany*
[c] *Centre for Water and Waste Technology, School of Civil and Environmental Engineering, University of New South Wales, Sydney, Australia*

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Abstract

The effects of four different filtration modes (i.e. relaxation, backwash, mixed and continuous) producing the same flux productivity (time average flux) on membrane fouling were investigated in membrane bioreactors (MBRs). The fouling behaviour was found to be strongly dependent on the applied instantaneous flux rather than the filtration modes themselves. The transmembrane pressure (TMP) obtained after 24 h of filtration was dominated by the fouling rates calculated within the first hour of the experiment. After the filtration experiments, the resulting fouling layers were fractionated by rinsing, backwashing and then chemical cleaning, with the foulant removal reflecting the strength of attachment to the membrane. An analysis of the three different fouling layers provided a unique insight into the composition (protein and carbohydrate) and spatial distribution of the particulate and soluble foulants. The upper fouling fraction consists of a porous, loosely bound cake layer with a similar composition to the biomass flocs. The intermediate fraction, which consists of equal parts of soluble molecular products (SMP) and biomass aggregates, features a higher concentration of carbohydrates and possibly plays a significant in the formation of consecutive cake layer. The lower fraction, representing the irreversible fouling fraction and predominantly consisting of SMP, features a relative higher concentration of strongly bound proteins. Whereas the lower and the intermediate fractions showed similar properties for all filtration modes, the upper fraction was influenced by the instantaneous flux.

Keywords: Membrane bioreactor; Fouling; EPS/SMP; Filtration mode; Physical cleaning

1. Introduction

Membrane bioreactors (MBRs) are now widely used to treat municipal and industrial wastewaters. However, membrane fouling remains a major operational issue leading to higher operational costs compared to current treatment technologies. To sustain an efficient process, membranes may require frequent cleaning either by physical or chemical means [1].

In situ physical cleaning techniques for MBRs typically involves aeration, membrane relaxation (where filtration is paused) and membrane backwashing (where permeate is pumped in the reverse direction through the membrane). They have been incorporated in most MBR designs as standard operating strategies to limit fouling [2]. However, to maintain a given flux productivity, higher instantaneous fluxes are required to compensate for the filtration downtime due to relaxation and backwashing. Many studies have compared the fouling behaviour of MBRs when applying different fluxes and different physical cleaning intensities [2]. However, different physical cleaning techniques are rarely tested using the same flux productivity (time average flux), making the efficiency of the filtration modes difficult to assess.

Extracellular polymeric substances (EPS) are the construction materials for microbial aggregates such as biofilms, and activated sludge flocs. They consist of different classes of organic macromolecules such as polysaccharides, proteins, nucleic acids, (phospho)lipids and other polymeric compounds and have been found at or outside the cell surface and in the intercellular space of microbial aggregates [3]. In activated sludge, EPS encapsulate bacterial cells and can be extracted and categorised as extractable EPS (eEPS) [2]. EPS are also released from the microbial aggregates into the water phase and are then

* Corresponding author. Tel.: +61 293855672; fax: +61 293855966.
E-mail address: p.le-clech@unsw.edu.au (P. Le-Clech).

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named soluble microbial products (SMP) [4]. The effect of EPS on MBR filtration has been reported for more than a decade [5] and has received renewed attention in recent years. Many reports indicate that EPS is the most significant factor affecting fouling in MBR [6,7,4]; however, the mechanism of EPS fouling is not well understood due to its variability in composition, concentration, and heterogeneity in real MBR systems [8].

More recent studies indicate that SMP, in particular, adsorbs on the membrane surface, blocks membrane pores and/or forms a gel-like structure on the membrane surface, resulting in a hydraulic resistance to permeate flow [9]. The attached SMP also increase the stickiness of the membrane surface, which enables an easier and faster adhesion of biomass flocs to the membrane [10]. It has been observed that half of the total fouling resistance could be caused by SMP [11]. Additionally, eEPS bind the attached biomass flocs more tightly together, also increasing the hydraulic filtration resistance. Hence, both eEPS and SMP are involved in the fouling process in different ways and are responsible for the creation of a significant barrier to permeate flow in MBRs. Further insights into EPS identification and fouling were recently obtained for MBR systems [12,13] and a functional relationship between specific resistance, mixed liquor suspended solid (MLSS), transmembrane pressure (TMP), permeate viscosity and EPS was obtained by dimensional analysis [14]. Although eEPS and SMP has been subject of many studies, only a few have considered the heterogeneity of the fouling materials on the membrane surface as compared to bulk compositions. The composition and the distribution of different fouling layers and their fouling compounds, such as pore foulants and cake foulants, and their influence on the hydraulic performance of the MBR system, have not been well characterised yet.

In this study, the fouling behaviours of MBRs operated with different filtration modes were evaluated and a unique insight in the composition of the fouling layers and their effects on the fouling hydraulic resistance is assessed. For this purpose, fouling experiments were conducted applying different filtration modes, but all generating the same flux productivity. The resulting fouling layers have been fractionated by different removal mechanisms and their organic composition has been thoroughly characterised. From these results, the cross comparison of hydraulic performances and biopolymeric composition of the different fouling layers was possible.

2. Materials and methods

2.1. The MBR rig

The fouling experiments were conducted on a lab-scale aerobic MBR with a working volume of 30 L (Fig. 1). The MBR was composed by an aeration bioreactor (a) and a membrane tank (b). The membrane tank was equipped with six submerged hollow-fiber membrane modules, each with an approximate surface of 0.05 m^2. The hydrophilic polyvinylidene fluoride (PVDF) membranes used in this study (Memcor Ltd., Windsor, Australia) had a nominal pore size of 0.2 μm. While four membrane modules were used for long-term operation of the MBR, two others were operated in shorter termed fouling experiments (24 h). The permeate produced during the 24 h experiments was recycled into the bioreactor to maintain the hydraulic retention time (HRT) of 15 h set up by the long-term modules. Aeration of the bioreactor was provided through a porous air diffuser at the bottom of the reactor. The membrane tank was also aerated with a porous air diffuser as well as coarse bubble aerators at the bottom of the membrane modules. Pressure transducers were located at the permeate side of the membrane module to monitor TMP continuously. Data acquisition was conducted with LabView (National Instruments, Austin, USA).

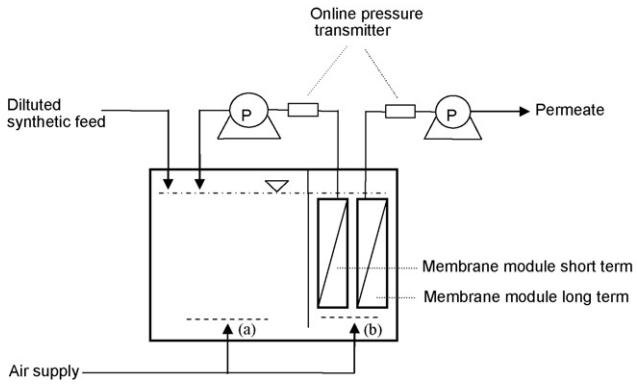

Fig. 1. MBR rig.

Table 1
Composition of concentrated (100×) synthetic wastewater

Compounds	Concentration (g/L)
Glucose	31.6
Sodium acetate	12.7
Peptone	7
Meat extract	4.3
$MgSO_4$	2.5
K_2HPO_4	1.3
$Fe_2(SO_4)_3$	1.3

2.2. Cultivation and characterisation of biomass

The bioreactor was originally seeded with sludge collected in a local sewage treatment plant and fed with synthetic wastewater. A concentrated wastewater solution was prepared with the composition shown in Table 1. The feed solution was autoclaved and diluted 1:100 with tap water before being introduced into the

Table 2
Operating conditions and biomass characterization under steady state

HRT (h)			15
COD removal (%)			97
MLSS (g/L)			5.5 ± 0.2
MVSS (g/L)			5.3 ± 0.2
	Protein	Carbohydrate	P/C
Biomass (mg/L)	3316 ± 215	1750 ± 267	1.9
eEPS (mg/g MVSS)	45.9 ± 7.8	22.9 ± 4.0	2.1
SMP (mg/L)	3.3 ± 0.5	1.2 ± 0.8	2.5