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Mechanisms of action of particles used for fouling mitigation in membrane bioreactors

P. Loulergue [a,b,c,*], M. Weckert [a,b,c,d], B. Reboul [a,b,c], C. Cabassud [a,b,c], W. Uhl [d], C. Guigui [a,b,c]

[a] Université de Toulouse, INSA, UPS, INP, LISBP, 135 Avenue de Rangueil, F-31077 Toulouse, France
[b] INRA, UMR792 Ingénierie des Systèmes Biologiques et des Procédés, F-31400 Toulouse, France
[c] CNRS, UMR5504, F-31400 Toulouse, France
[d] Technische Universitat Dresden, Institute of Urban Water Management, Chair of Water Supply Engineering, 01062 Dresden, Germany

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ABSTRACT

Adding chemicals to the biofluid is an option to mitigate membrane fouling in membrane bioreactors. In particular, previous studies have shown that the addition of particles could enhance activated sludge filterability. Nevertheless, the mechanisms responsible for the improved filtration performance when particles are added are still unclear. Two main mechanisms might occur: soluble organic matter adsorption onto the particles and/or cake structure modification. To date, no studies have clearly dissociated the impact of these two phenomena as a method was needed for the in-line characterization of the cake structure during filtration. The objective of this study was thus to apply, for the first time, an optical method for in-situ, non-invasive, characterization of cake structure during filtration of a real biofluid in presence of particles. This method was firstly used to study local cake compressibility during the biofluid filtration. It was found that the first layers of the cake were incompressible whereas the cake appeared to be compressible at global scale. This questions the global scale analysis generally used to study cake compressibility and highlights the interest of coupling local characterization with overall process performance analysis. Secondly, the impact of adding submicronic melamine particles into the biofluid was studied. It appears that particles added into the biofluid strongly influence the cake properties, making it thicker and more permeable. Furthermore, by using liquid chromatography with an organic carbon detector to determine the detailed characteristics of the feed and permeate, it was shown that the modification of cake structure also affected the retention of soluble organic compounds by the membrane and thus the cake composition. Simultaneous use of a method for in-situ characterization of the cake structure with a detailed analysis of the fluid composition and monitoring of the global performance is thus a powerful method for evaluating cake structure and composition and their impact on global process performance. The use of this methodology should allow “cake engineering” to be developed so that cake properties (structure, composition) can be controlled and process performance optimized.

* Corresponding author. LISBP/INSA, 135 Avenue de Rangueil, 31077 Toulouse Cedex 4, France. Tel.: +33 5 61 55 97 90; fax: +33 5 61 55 97 60.
E-mail address: ploulerg@alumni.insa-toulouse.fr (P. Loulergue).
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Nomenclature

C	mass of deposited compound per permeate volume unit (kg m^{-3})
C_b	DOC concentration in the bulk phase (mg L^{-1})
C_p	DOC concentration in the permeate (mg L^{-1})
DOC	dissolved organic carbon (mg L^{-1})
EPS	extra-cellular polymeric substances
J	permeate flux (m^3 m^{-2} s^{-1})
LC–OCD	liquid chromatography with organic carbon detector
LSGI	laser sheet at grazing incidence
MBR	membrane bioreactor
n	compressibility factor (–)
NMR	Nuclear magnetic resonance
NOM	natural organic matter
R	elimination rate (%)
R_d	cake resistance (m^{-1})
R_m	virgin membrane resistance (m^{-1})
SMP	soluble microbial products
S_f	filtration surface area (m^2)
t	filtration time (s)
TMP	transmembrane pressure (Pa)
TSS	total suspended solid
UTDR	Ultrasonic time domain reflectometry
UV	Ultra-violet
V	cumulated filtered volume (m^3)

Greek letters

α	cake specific resistance (m kg^{-1})
α_0	constant (m kg^{-1} Pa^{-n})
μ	permeate viscosity at 20 °C (Pa S)

1. Introduction

Membrane fouling remains a major drawback of membrane bioreactors (MBR). Filtration of a biofluid can lead to the formation of a complex biocake including compounds of different natures (flocs, bacteria, metabolites, humic substances) that have very different physicochemical properties (particles, colloids, soluble compounds). The formation of the cake may cause process performance to decrease and, in MBR applications, this is detected through transmembrane pressure (TMP) increases with time. Classically, TMP first increases slowly and in a linear fashion. Then an abrupt change of slope occurs as TMP increases dramatically. This phenomenon, known as "TMP Jump" (Cho and Fane, 2002), is frequently reported in the literature but, to date, the mechanisms leading to this behaviour are still under discussion (Hwang et al., 2012).

The hypothesis proposed by Cho and Fane is that a modification of local flux due to membrane fouling would lead to local increase of the flux above the "critical flux". Hwang et al. (2008). They linked this phenomenon to an increase of extracellular polymeric substances (EPS) at the bottom of the cake due to cell decay. Another hypothesis is that the TMP jump could be due to a modification of cake properties (thickness, porosity) with time (e.g. Gao et al., 2011; Zhang et al., 2006). It has especially been stated that biocakes formed on a membrane surface are compressible (Bugge et al., 2012; Iritani et al., 2007; Le-Clech et al., 2006). However, the mechanisms structuring these cakes remain largely unknown.

A number of studies have focused on the addition of various chemical compounds into the activated sludge in order to increase its filterability and thus mitigate membrane fouling and the beneficial effects of salts or polymers (Iversen et al., 2009; Koseoglu et al., 2008), particulate compounds such as powder activated carbon (Jamal Khan et al., 2012; Lesage et al., 2008; Pirbazari et al., 1996; Remy et al., 2009), or colloidal particles (fullerene, latex or melamine beads) (Chae et al., 2009; Teychene et al., 2011) have already been shown.

Nevertheless, the mechanisms responsible for the improvement of process performance when these compounds are added are still not fully understood. Thus, in the case of addition of solid compounds (such as activated carbon powder), different mechanisms of action are suggested in the literature.

When highly adsorbent particles (activated carbon, zeolites) are added to a biofluid, organic compounds are likely to adsorb on the particle surfaces. This leads to a reduction in the total quantity of "free" organic compounds that can be deposited on the membrane surface (Akram and Stuckey, 2008; Fang et al., 2006; Lee et al., 2001; Lesage et al., 2008; Remy et al., 2009). According to Ying and Ping (2006), these adsorption effects might be coupled with a scouring effect of activated carbon particles on the biocake surface that lowers its hydraulic resistance.

Particles are also likely to modify the structure of flocs. They can be entrapped within the flocs, thus making them less compressible and more resistant to shear stress in the neighbourhood of the membrane surface (Lee et al., 2001; Remy et al., 2010). Other authors have highlighted the effect of particle addition on cake structure. Biocakes formed in the presence of activated carbon became less resistant and less compressible (Jamal Khan et al., 2012; Lesage et al., 2008; Li et al., 2005; Pirbazari et al., 1996). These findings might be explained by a modification of the cake structural properties due to the presence of particles and their interactions with other cake constituents. This phenomenon was also observed by Teychene et al. (2011) during the filtration of an MBR supernatant (sludge liquid phase obtained by centrifugation) in presence of colloidal melamine particles. The addition of particles led to a less resistant and less compressible cake while increasing the rejection of soluble organic compounds by the membrane.

To date, it has not been possible to distinguish between the impacts of organic compound adsorption onto particles and a modification of cake structural properties. To dissociate these