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Soluble microbial products and suspended solids influence in membrane fouling dynamics and interest of punctual relaxation and/or backwashing

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ABSTRACT

To favor the control of membrane fouling on line by relaxation and backwash sequencing, two major fouling origins are considered: the former is due to retention of large particles on the membrane surface forming a growing deposit that can be controlled by tangential shear stresses, the second is due to the retention of the largest soluble polymers forming a thin layer on the membrane surface including pore blocking and inducing a progressive reduction of the deposit porosity, the influence of this second fouling origin can only be reduced by backwashing. A simple model was developed to represent (i) the accumulation of two types of compounds and its consequences and the evolution with time of the hydraulic resistance of the system and (ii) the role of relaxation and backwashing to reduce the fouling impact. Some simulations were presented according to the values of the three model parameters. Simulations were also compared to experimental data obtained on biological suspensions.

1. Introduction

Membrane bioreactors are now a mature technology for the treatment of industrial or urban wastewaters. The total rejection of biomass by the membrane allows a significant improvement of water quality (absence of SS and advanced disinfection) with respect to that obtained with conventional systems. Moreover because the membrane rejection does not depend on biomass concentration in the bioreactor, it is possible to intensify the biological processes by increasing sludge retention time or decreasing the reactor volume. Nevertheless major drawbacks still hinder MBR development, that are membrane fouling, high energy requirements and lack of simple tools to optimize online MBR control. Depending on numerous factors, membrane fouling in MBR appears as a combination of complex phenomena [1]. It is directly related to the filtration phase during which largest compounds retained by the membrane cut-off accumulate on the membrane surface [2]. It also depends on physical-chemical interactions between smaller compounds and the membrane material (pore blocking, adsorption notably). The only tool to quantify online the intensity of fouling is the monitoring of the Trans-Membrane Pressure (TMP). Many works have been trying to study the TMP dynamics. Based on an experimental observation highlighting a two step TMP increase: a slow increase followed by a TMP jump, Sarjo et al. (2008) [3] and Ognier et al. (2004) [4] have proposed models assuming that a progressive pore blocking would lead to a local flux increase and consequently to an increase of membrane fouling. Other studies assumed that TMP increase would go through three stages [5]: an initial stage of short-term TMP rising due to soluble microbial products (SMP) deposition or bioflocs adsorption leading to a pore blocking, a second stage of long-term TMP rising either linearly or weakly exponential due to the development of cake formed by either the suspended solids SS or SMP, and a third stage of sudden TMP rising also know as the TMP jump due to inhomogeneous fouling. Different mechanisms

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explaining the TMP jump have been proposed and modelled such as the area loss model [6], the pore narrowing model [7], the pore loss model [8] and the critical suction pressure model [9].

Even though, TMP measurement is a global evaluation of instantaneous fouling intensity. It does not allow any differentiation of the relative importance of the different fouling processes and it is then difficult to optimize the operation and energy requirements. In practice, the filtration step is then essentially controlled using two criteria: average TMP variation during defined time periods and the maximal TMP value allowed.

In association with the monitoring of such criteria, the operator has different options to minimize fouling dynamics during operation including parietal shear stresses as tangential flow circulation, gas injection (air for aerobic process) close to the membrane surface to detach a large part of the compounds accumulated onto the membrane surface, backwash to eject compounds blocking the pores to partially deconstruct the deposit/biofilm onto the membrane surface, and chemical cleaning to desorb compounds linked to materials, even destroying biofilm structure.

Numerous models were developed to give a better understanding and quantification of the different fouling modes including the role of parietal shear stresses to minimize deposit influence [10–12]. Such models also took into account the biological functioning conditions to include the role of SS, EPS and SMP concentrations in both reversible and irreversible fouling [13]. However, very few of them develop simulations by including the role of periodic relaxation and backwash on the instantaneous modification of the different fouling origins and their relative intensities [13,14]. It is precisely the objective of this work to develop a simple model including mass balance when operating a filtration with air injection and periodic backwash. The simple model is confronted to experimental data obtained under several operating conditions and simulations are analyzed to point out the specific role of some fundamental criteria.

2. Model hypothesis

When filtering the mixed liquor suspended solids on membranes, the fouling dynamics is assumed to be due to three main phenomena as shown in Fig. 1 [1,15,16]: (i) deposition of soluble polymers onto the membrane surface with the formation of a thin layer leading to some pore blocking and significantly that reducing the membrane open area and the membrane permeability, (ii) accumulation of particles onto the membrane surface to form a deposit which can also play the role of a porous filter able to retain some soluble fractions that progressively modified the deposit structure and its permeability, and (iii) the adsorption of smallest molecules that enter inside the pores and interact with the membrane material to induce pore's constriction and again reducing membrane permeability.

Nevertheless, many works studying fouling in membrane bioreactors, proved that the internal fouling is minor compared to the surface fouling [2,17] and especially in the case of high suspended solids concentration or when using ultrafiltration [2,18]. Based on these studies and aiming the development of simple model, the resistance due to pore constriction has been neglected in the proposed model.

Even if suspended solids are totally retained by the membrane to form an external deposit, sufficient and effective shear stresses would avoid significant membrane clogging, which make them no longer the main cause of fouling intensity [12,19]. The transfer resistance is then due to a thin film development on the membrane surface (a biofilm in case of bioreactors) that contributes to a drastic decrease of membrane permeability notably if the pore blocking phenomenon is associated to thin layer formation. In fact,

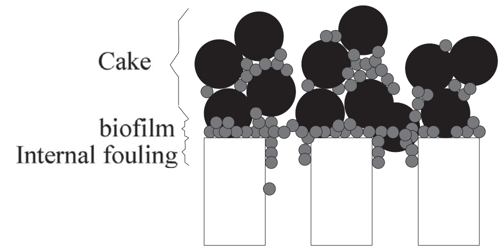

Fig. 1. Different fouling mechanisms.

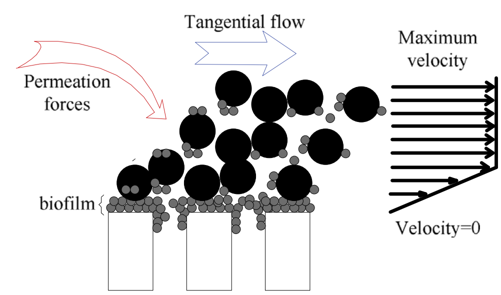

Fig. 2. Shear forces effect on cake's destruction during tangential filtration.

during cross flow filtration, the large soluble polymer compounds, as SMP or soluble EPS in bioreactors, retained by the membrane have lower value of critical flux and are most likely transported to the membrane surface by the imposed flux [20]. This phenomenon characterizes the first fouling phase making concentration of such soluble fraction an important parameter controlling initial fouling dynamics. Most of the soluble foulants interacting with the membrane material and causing pore blocking were characterized as SMP in MBR by Wu et al. (2008) [21].

Figs. 2–4 show some illustrations of the control actions that can be taken online in response to the evolution of the main cleaning process. A parietal shear stress (Fig. 2) favors the reduction of the deposit thickness by inducing an external particle detachment and a laminar movement of deposit that contributes to some deconstruction of the external deposit. During a relaxation period (the parietal shear stress is maintained but the filtration strength on particles is stopped), the parietal shear stresses is intensified (Fig. 3) but the membrane surface fouling (thin film of soluble compound accumulated on the membrane surface and pore blocking) is not modified. At the opposite, when starting backwash (Fig. 4), the compounds blocking physically the pores are ejected and the thin layer deposit (including biofilm) can be deconstructed. The only phenomenon not concerned by the preceding modes of permeability regeneration is the internal adsorption of small molecules inside the pores that necessitates chemical cleaning for their detachment. This internal phenomenon appears generally as the less intensive one [22].

3. Fouling model development

In this section, a simple model to describe and to quantify the most important fouling mechanisms is proposed. It includes the respective role of each hydraulic cleaning method, notably relaxation and backwash. More particularly, this model highlights the effect of particles and large soluble compounds on cake's building and pore blocking and their consequences on fouling intensity and reversibility according to the different modes of hydraulic cleaning such as parietal shear stresses, relaxation and backwash.

The proposed model is based on two foulant families totally retained by the membrane cut-off but differing in sizes. While