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Modelling of submerged membrane bioreactor: Conceptual study about link between activated slugde biokinetics, aeration and fouling process

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ABSTRACT

A mathematical model was developed to simulate filtration process and aeration influence on submerged membrane bioreactor (SMBR) in aerobic conditions. The biological kinetics and the dynamic effect of the sludge attachment and detachment from the membrane, in relation to the filtration and a strong intermittent aeration, were included in the model. The model was established considering soluble microbial products (SMP) formation-degradation. The fouling components responsible of pore clogging, sludge cake growth, and temporal sludge film coverage were considered during calculation of the total membrane fouling resistance. The influence of SMP, transmembrane pressure, and mixed liquor suspended solids on specific filtration resistance of the sludge cake was also included. With this model, the membrane fouling under different SMBR operational conditions can be simulated. The influence of a larger number of very important process variables on fouling development can be well quantified. The model was developed for evaluating the influence on fouling control of an intermittent aeration of bubbles synchronized or not with the filtration cycles, taking into account the effects of shear intensity on sludge cake removal.

1. Introduction

Membrane bioreactor (MBR) has become a popular biological wastewater treatment technology because it offers numerous advantages over the conventional activated sludge process such as excellent effluent quality, a compact footprint, a more concentrated biomass, and a reduced sludge yield [1–4]. However, membrane fouling is still a major problem that hinders their more widespread and large-scale application [5]. On the point of view of functioning cost, they are even high, due to power requirement that comes mainly from aeration. In hollow fibers SMBR the aeration is used for: (1) the oxygen supply needed for degradation processes, (2) maintaining solids in suspension and (3) to clean the membrane. A turbulent shear and the agitation of fibers are brought about by air bubbles that attenuate the accumulation of sludge cake on the membrane during filtration. The membrane fouling is highly linked to the sludge attachment on the membrane surface, but it is also dependent on the properties of the biomass and the process parameters, including the transmembrane pressure (TMP), filtration flux, sludge concentration, soluble and particulate microbial products concentration, and of course aeration intensity [4–7]. The researchers met difficulties to achieve a comprehensive understanding and description of the fouling phenomenon in SMBR. Due to the high number of interactions in the system, the fouling prediction into the SMBR systems is very complicated. For these reasons a complete general mathematical model for SMBR has not been established yet [8].

Mathematical modelling and simulation are powerful tools with which the specialists can predict the performances of potential systems under different operating conditions. In particular, the dynamic models are very useful because they allow to study the evolution of membrane fouling and the biological system over time. To formulate better dynamic models for the SMBR systems could help to develop more cost-effective strategies for the minimization of the fouling problem. To include the aeration process as an important part in the model and to achieve the process simulation could allow to optimize the filtration-aeration cycles and, consequently, to reduce running cost due to aeration.

Many researchers have proposed dynamic models based upon different concepts and hypothesis. Most of them have been focused on the description of some specific parts of the system such as the behavior of the biological population, the fouling process near the membrane surface. Generally, these models supposed many simplifications. On the other hand, a few models have been developed considering the relations that take place between the different parts

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of the system. The model proposed by Cho et al. [9] describes the dynamic behaviour of the extracellular polymeric substances (EPS) concentration with the change of the biological operating factors such as the organic-loading rate, the hydraulic retention time (HRT) and solids retention time (SRT), calculating the effluent quality and membrane fouling simultaneously using a modified resistance-in-series model. This model does not consider the influence of the aeration on fouling control; therefore, it is not capable to predict the influence of this process variable during filtration.

One more recent model proposed by Li and Wang [10] is a comprehensive mathematical model for membrane fouling in an SMBR. A sectional approach was used to describe the non-uniform distribution of the turbulent shear intensity and the fouling material coverage on the membrane surface. The dynamics of biomass attachment and detachment from the membrane, which are regulated by filtration suction and aeration cleaning, were considered in the model development. In this model, the total fouling resistance was decomposed into the individual components of pore fouling resistance, sludge cake accumulation, and dynamic sludge film formation. The main limitations of this model consist in the assumption that all the biological parameters are constants. In its present form this model is only able to capturing general trends and may not be suitable for applications requiring accurate modelling in membrane fouling phenomena [8]. In addition, during calculation of filtration resistances of the different sludge films, the specific filtration resistance was assumed constant too. For these reasons, with this model it is not possible to analyze during simulation neither the influence of the aeration on biological system variables nor the long term modifications on sludge properties during filtration.

Previous works have demonstrated the effect of aeration intensity and mixed liquor properties on membrane permeability and the impacts of mixed liquor viscosity on the efficiency of coarse bubble aeration. Furthermore, research has also shown the impact of colloidal material, soluble chemical oxygen demand (COD), SMP, EPS and viscosity at different mixed liquor suspended solids (MLSS) concentration on membrane fouling [11]. Therefore, the objective of this study is to propose a hybrid mathematical model which takes into account the effect of all this variables in SMBRs systems. The model was established considering SMP formation-degradation kinetic based on previous published models [9,12]. A modification of Li and Wang's model allows to calculate the increase of the TMP evaluating, at the same time, the influence on fouling control of an intermittent aeration of bubbles synchronized with the filtration cycles, and to analyze the effects of shear intensity on sludge cake removal. On the other hand, in order to describe the biological system behavior a modified ASM1 model was used. The final hybrid model was developed to calculate the sludge properties evolution, its relation with sludge cake growth, and their influence on membrane fouling. The proposed model was validated in an experimental SMBR installed in a real domestic wastewater treatment plant.

2. Theory and models

2.1. Model development

The goal of this work was to develop an integrated model that allows to couple biomass transformation processes, membrane fouling and the effects of filtration cycles synchronized with intermittent coarse bubbles aeration, following previous efforts related to SMBR model integration [8]. The development of the model was focused on the description of the influence of mixed liquor properties and aeration on membrane fouling. It takes into account the most reliable theories and evidences, founded during recent researches, related to the existing relationships among the more important system variables, during SMBR operation [7,11,13–15]. The SMBR system is based on biological degradation and physical separation using membranes. Thus, for describing the system it is necessary to model both sections. In order to facilitate the model evaluation, the selection of equations and biological processes considered during modelling was linked to the characteristics of the experimental reactor and its operational conditions. However, the final structure of the model offers the possibility of adding others process rates and stoichiometries. The conceptual schema of the developed model is shown in Fig. 1. It shows the main relations that take place during simulation and, also, the information flow established among the different parts of the model during calculation. The model is divided into three sections, the first considers the bio-

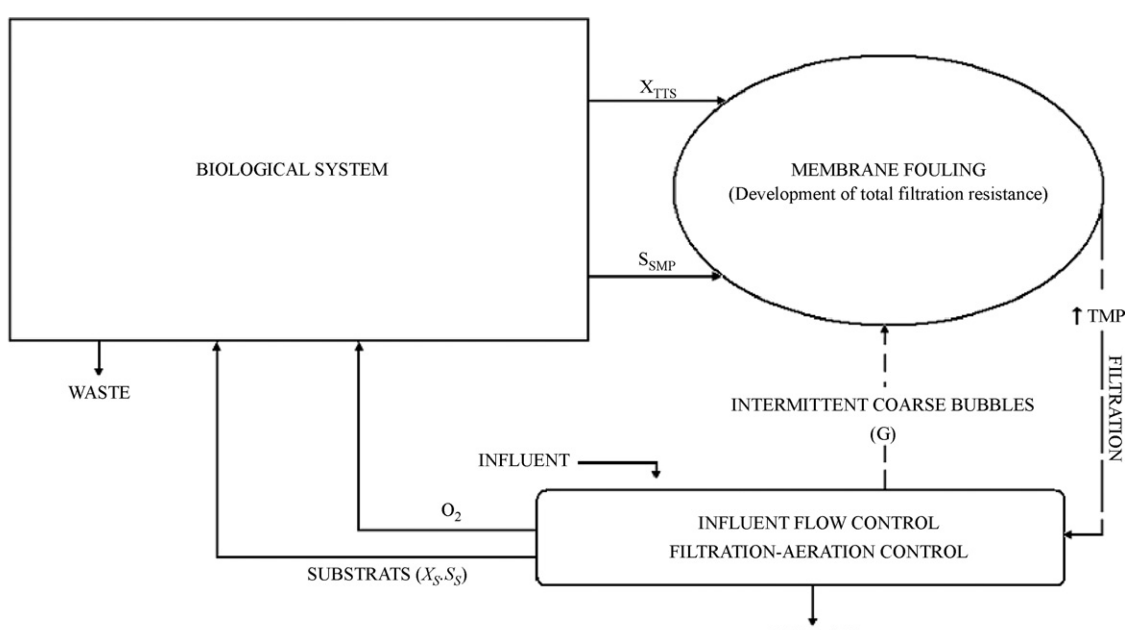

Fig. 1. Conceptual schematic of developed model for SMBR.