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Design, analysis and validation of a simple dynamic model of a submerged membrane bioreactor

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ABSTRACT

In this study, a simple dynamic model of a submerged membrane bioreactor (sMBR) is proposed, which would be suitable for process control. In order to validate the proposed model structure, informative data sets are generated using a detailed simulator built in a well-established environment, namely GPS-X. The model properties are studied, including equilibrium points, stability, and slow/fast dynamics (three different time scales). The existence of slow-fast dynamics is central to the development of a dedicated parameter estimation procedure. Finally, a nonlinear model predictive control is designed to illustrate the potential of the developed model within a model-based control structure. The problem of water treatment in a recirculating aquaculture system is considered as an application example.

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1. Introduction

Submerged membrane bioreactors (sMBR) are increasingly used for wastewater treatment with a relative success (Judd and Judd, 2011). In its simplest configuration, a sMBR combines the functions of an activated sludge aerobic system, secondary clarifier, and tertiary filter in a single tank (Atasi et al., 2006). The advantages are the footprint reduction, high effluent quality and the decoupling of the hydraulic retention time (HRT) and solid retention time (SRT). Due to filter pore size, particles however start to attach on membrane surface, forming a deposition of solid matter, responsible for fouling. Membrane fouling decreases membrane permeability, increasing operating costs.

One of the greatest challenges for process optimization is the development of an integrated model (comprising biological phenomena and filtration mechanism). In general, sMBR

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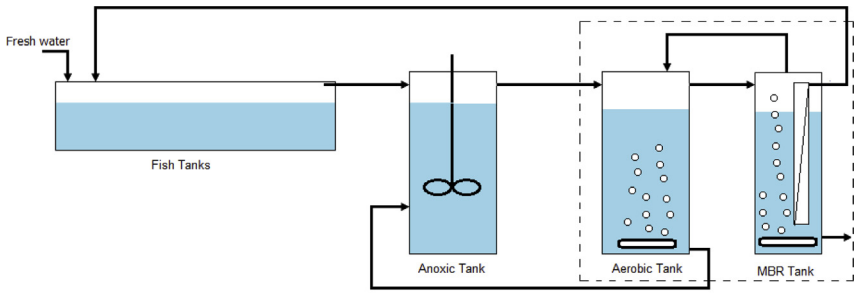
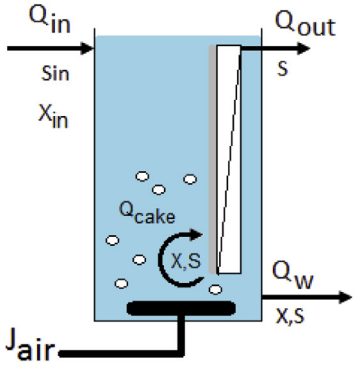
models are stand-alone filtration models including aeration (Ferrero et al., 2011), cake formation (Li and Wang, 2006), filtration and fouling (Robles et al., 2013a,b; Charfi et al., 2012), physical and bioprocess description (Bella et al., 2008; Mannina et al., 2011). Regarding the biological phenomena, the activated sludge models (ASM) are widely accepted (Henze et al., 1987). Studies have shown that ASM can be directly implemented or modified taking the fouling interference on activated sludge biology (SMP/EPS) into account (Fenu et al., 2010; Naessens et al., 2012). ASM1, ASM3 and ASM2d have been extensively used to predict the effluent quality related to soluble matter (Sarioglu et al., 2009; Lee et al., 2002; Jiang et al., 2009; Zarragoitia-González et al., 2008). A critical review of sMBR models has been done by Fenu et al. (2010) and Naessens et al. (2012) presenting biokinetics, filtration, hydrodynamics and integrated models intended for process description and understanding. These models cover a wide range of phenomena, from empirical to first principles, and have been used mainly for process cognition development (Naessens et al., 2012). In order to compare and evaluate control strategies, an sMBR benchmark for wastewater treatment has been developed by Maere et al. (2011).

However, those models include many parameters which can be delicate to estimate from experimental data and they are in general too complex for control purposes. As a general rule, it is always necessary to make a trade-off between model complexity and dynamic predictive capability. For control purposes, a model should not be more detailed than required by a specific control task (Kokotović et al., 1986). In this context, there are only a few proposals of sMBR models based on empirical approaches (Khan et al., 2009), artificial neural network models (Choi et al., 2012) or black box model to estimate filtration performance (Dalmau et al., 2013).

The main objective of this study is to develop a simplified sMBR model, and to validate it by comparison with a well established simulator, e.g., GPS-X (Hydromantis, 2012). In this connection, the detailed simulator is used as an emulation of a real plant to generate realistic data. The advantage of a simulator is of course that data can be produced easily and without the operational constraints of a real-life plant. Hence, more informative data sets (i.e. data sets exploring the plant behavior in a wider operating range, and containing sufficient information on the plant dynamics) can be used to test and validate the simplified model. To this end, a dedicated parameter estimation strategy is proposed and applied to fit the reduced model to these data sets. This identification study is the opportunity to emphasize the need for an appropriate design of experiments to ensure a sufficient level of information. An interesting feature of the system dynamics is the possibility to consider different time scales (fast and slow dynamics), which are evidenced in this study using singular perturbation theory. This approach reveals conditions on the model parameters to obtain reduced models at three different time scales. The time scale separation can be used advantageously in system identification, as subsets of parameters can be estimated on different time intervals, and the identification problem can in this way be divided into simpler subproblems. Once the simplified model has been identified, it can be used in model-based control schemes and a "proof of concept" is showed at the end of this study, where nonlinear model predictive control (NMPC) is used as an appealing approach. It is important to stress that model based control could be very



(a) Recirculating aquaculture system fitted with an sMBR.



(b) sMBR process sketch

Fig. 1 – sMBR process structure.

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