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Evaluation and prediction of membrane fouling in a submerged membrane bioreactor with simultaneous upward and downward aeration using artificial neural network-genetic algorithm

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ABSTRACT

This paper describes the effect of simultaneous upward and downward aeration on the membrane fouling and process performances of a submerged membrane bioreactor. Trans-membrane pressure (TMP) and membrane permeability (Perm) were simulated using multi-layer perceptron and radial basis function artificial neural networks (MLPANN and RBFANN). Genetic algorithm (GA) was utilized in order to optimize the weights and thresholds of the models. The results indicated that the simultaneous aeration does not significantly improve the removal efficiency of contaminants. The removal efficiencies of BOD, COD, total nitrogen, $NH_4^+ - N$ and TSS were 97.5%, 97%, 94.6%, 96% and 98%, respectively. It was observed that the TMP increases and the Perm decreases as operational time increases. The TMP increasing rate (dTMP/dt) and the Perm decreasing rate (dPerm/dt) for the upward aeration were 2.13 and 2.66 times higher than that of simultaneous aeration, respectively. The training procedures of TMP and Perm models were successful for both RBFANN and MLPANN. The train and test models by MLPANN and RBFANN showed an almost perfect match between the experimental and the simulated values of TMP and Perm. It was illustrated that the GA-optimized ANN predicts TMP and permeability more accurately than a network with a trial-and-error approach calibration.

1. Introduction

Biological procedures to treat municipal and industrial wastewaters using membrane bioreactors (MBR) have many advantages over conventional activated sludge procedures (Meng et al., 2008; Verrecht et al., 2010). Some of these advantages, which have increased the application of MBR in the wastewater treatment including superior treated wastewater quality, improved process control, more stable operation for changing loading conditions and reduction of sludge (Patsios and Karabelas, 2011). Two different configurations of MBR are commonly used: side-stream MBR and internal submerged MBR. Side-stream MBR uses cross-flow membranes, placed outside the biological reactor, and were the first generation of MBR (Artiga et al., 2005). An important development of this technology came with the utilization of MBR in which the membranes were submerged in the biological reactor (Ct and Thompson, 2000; Gander et al., 2000). Submerged membrane

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Nomenclature

MBR	membrane bioreactor
SMBR	submerged membrane bioreactor
TSS	total suspended solids
HRT	hydraulic retention time
DO	dissolved oxygen
TMP	trans-membrane pressure
PSA	particle size analyzer
SEM	scanning electron microscopy
CLSM	confocal laser scanning microscopy
XRF	X-ray fluorescence
EDX	energy diffusive X-ray analyzer
FT-IR	Fourier transform infrared
ASP	activated sludge process
ASM	activated sludge model
ANN	artificial neural network
MLP	multi-layer perceptron
RBF	radial basis function
FANN	feed forward artificial neural network
RBFANN	radial basis function artificial neural network
MLPANN	multi-layer perceptron artificial neural network
TDS	total dissolved solids
TP	total phosphorous
BOD	biochemical oxygen demand
COD	chemical oxygen demand
GA	genetic algorithm
Perm	permeability
RMSE	root mean squared error
R^2	coefficient of determination
SRT	sludge retention time
MLVSS	mixed liquor volatile suspended solids
MLSS	mixed liquor suspended solids
TN	total nitrogen
RNN	recurrent neural network
ESN	echo-state network
F/M	food to microorganism

bioreactors (SMBR) have many advantages such as higher quality of effluent, absolute control of total suspended solid (TSS), reduction of hydraulic retention time (HRT), smaller size and lower energy consumption over other membrane systems. On the other hand, the SMBRs are not good at nitrogen removal because of the high dissolved oxygen (DO) in the bulk liquid which is hard to induce forming an anoxia or anaerobic area for denitrification (Dong et al., 2009; Wang et al., 2013). In addition, the problems of membrane fouling have limited excessive advantages of SMBRs in the wastewater treatment processes (Martin and Nerenberg, 2012).

Membrane fouling, which results in the increase of trans-membrane pressure (TMP) or the decline of membrane flux dependent on the employed operational modes, is one of the major drawbacks for wider applications of SMBRs (Delgrange et al., 1998b; Guglielmi et al., 2007; Zhu et al., 2011). During the operation of SMBRs, colloidal particles and macromolecules tend to deposit in the pore of the membrane and on the membrane surface (Park et al., 2008; Park et al., 2010). Hence, it is of great significance to understand membrane foulants properties and membrane fouling mechanisms (Delgrange et al., 1998a; Shetty and Chellam, 2003; Zhu et al., 2011). Previous studies had been focused on the membrane foulants in an SMBR for synthetic wastewater treatment using particle size analyzer (PSA), scanning electron microscopy (SEM), confocal laser scanning microscopy (CLSM), X-ray fluorescence (XRF), energy diffusive X-ray analyzer (EDX), and Fourier transform infrared (FT-IR) spectroscopy (Cho and Fane, 2002; Chon et al., 2013). They approved that the small particles in sludge suspension, bacterial clusters, polysaccharides, proteins and inorganic compounds played a significant role in membrane fouling (Meng et al., 2007; Zhu et al., 2011).

Generally, to reduce membrane fouling, several strategies such as the pre-treatment of feed water, chemical or physical cleaning of membrane, flux reduction, and application of turbulent air sparging are employed (Chen and Kim, 2006; Judd, 2010; Sahoo and Ray, 2006). Membrane air sparging, in particular, is postulated to be a critical factor in controlling membrane fouling in an SMBR (Ueda et al., 1997). Air sparging produces effective turbulence and membrane movement, which results in scouring the particles and other deposited materials away from the membrane surface. This produces an increase in the air flow rate at the membrane surface which increases the flux due to an increased back-transport of deposited materials on the membrane surface by turbulent shear (Liu et al., 2009; Trussell et al., 2006).

Usually, vertical flat sheet or vertically/horizontally mounted hollow fiber membranes are used in SMBRs. Hollow fiber modules are generally cheaper to fabricate, provide high specific membrane area and can tolerate vigorous back washing (Chang et al., 2002; Liu and Kim, 2008). 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 (Zarragoitia-González et al., 2008). Vertically oriented hollow fiber membrane modules, in which the dual header design has both top and bottom headers where membrane fibers are potted (e.g., Zeon's Zee Weed modules), have been widely introduced (Cui et al., 2003; Judd, 2010; Park et al., 2010).

Treatment process models are essential tools to assure proper operation and better control of activated sludge processes (ASPs). Considerable effort has been devoted to the modeling of ASP since early 1970s (Moral et al., 2008). Some deterministic models have been developed basing on the fundamental biokinetics such as activated sludge model number one (ASM1) (Henze et al., 1987). Parameter estimation and calibration of ASM models require expertise and significant effort. Moreover, calibration has to be performed for each specific treatment system. Therefore, application of ASM models can be cumbersome and problematic (Börger et al., 2000; Moral et al., 2008). On the other hand, understanding and optimizing a system as complex as a real wastewater treatment plant with membrane bioreactors is difficult and time-consuming (Geissler et al., 2005; Naessens et al., 2012). This is due to the complex biological reactions, as well as the highly time-varying and multi-variable aspects of operation of a real wastewater treatment plant with membrane bioreactors. Moreover, the determination of all model parameters is an expensive and time-consuming process. Over the past decade, the complexity of the simulating models has increased noticeably with the discovery of new processes. As a result the modeling of real systems became more time consuming with ad hoc calibration of the model parameters. A real wastewater treatment plant with membrane bioreactors is composed of many subprocesses that are highly coupled. Next to the biokinetic processes for bioconversion of pollutants, the separation process takes place as well