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Modeling and optimization of activated sludge bulking for a real wastewater treatment plant using hybrid artificial neural networks-genetic algorithm approach

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ABSTRACT

Prediction of sludge bulking is a matter of growing importance around the world. Sludge volume index (SVI) should be monitored to predict sludge bulking for a wastewater treatment plant. This study was an effort to develop hybrid artificial neural network-genetic algorithm models (MLPANN-GA and RBFANN-GA) to accurately predict SVI. Operating parameters, including MLVSS, pH, DO, temperature, TSS, COD and total nitrogen were the inputs of neural networks. Genetic algorithm was utilized in order to optimize weights and thresholds of the MLPANN and RFBANN models. Training procedures for SVI estimation were successful for both the MLPANN-GA and RBFANN-GA models. The training and validation models showed an almost perfect match between experimental and predicted values of SVI. The results indicated that with low experimental values of input data to train ANNs, the MLPANN-GA compared with the RBFANN-GA is more accurate due to higher coefficient of determination (R^2) and lower root mean squared error (RMSE) values. The values of RMSE and R^2 for the optimal models approached 0 and 1, respectively. The mean average error for the ANN models did not exceed 3% of the input values of the measured SVI. The GA increased the accuracy of all the MLPANN and RBFANN models.

1. Introduction

The activated sludge process (ASP) is the most commonly applied technology for wastewater treatment processes. The anoxic–anaerobic–oxic (A2/O) process is widely used in wastewater treatment plant (WWTP) for phosphorus and nitrogen removal, however, sludge bulking and foaming are the most frequent operational problems in plants under this process. This is caused either due to the presence of non-degradable surfactants or the overgrowth of filamentous bacteria such as *Microthrix parvicella* (Rossetti et al., 2005), *Sphaerotilus natans* (Suzuki et al., 2002), Eikelboom type 021N, and *Thiothrix* spp. (Vaiopoulou et al., 2007). The diversity of the biological community is very large. The wastewater treatment process operators thus need to compensate for the nonlinear dynamic behavior of the processes involved and for variations that may be caused by operating changes dictated by the environmental and operational conditions

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Nomenclature

ASP	activated sludge process
A2/O	anoxic–anaerobic–oxic
WWTP	wastewater treatment plant
DGGE	denaturing gradient gel electrophoresis
CLSM	confocal laser scanning microscopy
FISH	fluorescent in situ hybridization
DO	dissolved oxygen
F/M	food to microorganism
ASM1	activated sludge model No. 1
SVI	sludge volume index
ARX	autoregressive exogenous
ANNs	artificial neural networks
MLP	multi-layer perceptron
RBF	radial basis function
RNN	recurrent neural network
ESN	echo-state network
FANNs	feed forward artificial neural networks
TSS	total suspended solids
BOD	biochemical oxygen demand
COD	chemical oxygen demand
SORBF	self-organizing radial basis function
GA	genetic algorithm
MLPANNs	multi-layer perceptron artificial neural networks
RBFANNs	radial basis function artificial neural networks
MLVSS	mixed liquor volatile suspended solids
T	temperature
TN	total nitrogen
RMSE	root mean squared error
R^2	coefficient of determination
HRT	hydraulic retention time
TP	total phosphorus
TDS	total dissolved solids
MLSS	mixed liquor suspended solids
SSV	settled sludge volume
SV	sample volume
SSC	suspended solids concentration
BP	back propagation
LM	Levenberg–Marquardt
FBNN	feed-forward back-propagation neural network
MB	momentum backpropagation
S	sigmoid
P	pure linear

(Han and Qiao, 2012). This makes the operation, prediction, and modeling of wastewater treatment processes difficult, particularly in the case of sludge bulking (van den Akker et al., 2010). Sludge bulking is a term to describe the excessive growth of filamentous bacteria (Wang et al., 2010). When sludge bulking appears, it causes poor settleability of sludge that results in a poor effluent quality, loss of active biomass, increased costs, and poses a number of environmental hazards (Jin et al., 2011). Prediction of sludge bulking is a subject of growing importance around the world such that better understanding of sludge characteristic is needed for a better treatment plants control (Dalmau et al., 2010).

In spite of the introduction of considerable efforts, these results are still unsatisfying to suppress sludge bulking. Understanding the microbial ecology of activated sludge is the basis of pursuing suitable remediation to resolve this problem (Jin et al., 2011). In the past years, many researchers focused on the enumeration of the bacterial community present in activated sludge by using molecular approaches, including denaturing gradient gel electrophoresis (DGGE), 16S rRNA gene clone library analysis (Choi et al., 2007; Eschenhagen et al., 2003), transmission electron microscopy (Liss et al., 1996), confocal laser scanning microscopy (CLSM) (Schmid et al., 2003), and fluorescent in situ hybridization (FISH) technology (Wagner et al., 2006). These studies have been developed to identify filamentous bacteria. The next step is to find relationships between the most predominant filamentous bacteria, their physiology and the operational conditions such as dissolved oxygen (DO) concentration and food to microorganism (F/M). However, microscopic identification of filamentous bacteria based on floc morphology requires a well-trained operator, otherwise a wrong judgment can easily be made (Kotay et al., 2011). To study complex ecosystems, like activated sludge cultures, in which many factors are acting together, many other researchers have viewed mathematical modeling as a very useful tool (Han and Qiao, 2012; Moral et al., 2008). Considerable effort has been devoted to the modeling of ASP since early 1970s (Moral et al., 2008). Some deterministic models have been developed based on the fundamental biokinetics such as activated sludge model No. 1 (ASM1) (Gernaey et al., 2004; Henze et al., 1987). Following ASM1, ASM2, ASM2d and ASM3 models were developed. The ASM2 (Henze et al., 1995) models extended the capabilities of ASM1 to involve the biological phosphorus and nitrogen removals. Whereas, ASM3 (Chen et al., 2012; Gujer et al., 1999) introduced an alternative concept to the previous ASM biokinetics and aimed at simplifying the model application. Despite the availability of ASM models, the diagnosis of the process interactions and modeling of ASP in a real WWTP is still difficult (Diehl and Farås, 2013; Moral et al., 2008). This is due to the complex biological reactions, as well as the highly time-varying and multivariable aspects of operation of a real WWTP (Busch et al., 2013; Hong et al., 2003; Moral et al., 2008).

Recently, in order to quantify the sludge bulking, the sludge volume index (SVI) is usually discussed. As a general guideline, bulking is said to occur when the SVI is higher than 150 mL/g, regardless of its cause (Martins et al., 2004). The value of SVI should be monitored in order to predict sludge bulking for a real wastewater treatment plant. Smets et al. studied a dynamic autoregressive exogenous (ARX) model to predict the evolution of the SVI (Smets et al., 2006). The proposed dynamic ARX model was investigated as a function of organic loading and digital image analysis information. The model's performance was compared on the basis of squared errors like quality criterion. Mesquita et al. (2009) applied image analysis methods to find the correlations between sludge settling ability and image analysis information using partial least squares. However, few engineering approaches were employed to solve the problem of sludge bulking. These approaches primarily relied on the past observations of sludge bulking without sufficient microbiological insight (Nagy Kiss et al., 2011). Xavier et al. proposed an approach including a risk assessment model based on a knowledge-based decision tree to detect favorable conditions for the development of sludge bulking (Flores-Alsina et al., 2009). The simulation results of their research demonstrated that including the effect of filamentous bulking in the secondary clarifier model results in a more realistic plant performance. A nonlinear model was detected by the use of an integrated settling characteristics