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Model-based optimization of a sequencing batch reactor for advanced biological wastewater treatment

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1. INTRODUCTION

Sequencing batch reactor (SBR) technology for nutrient removal has received great attention from the wastewater treatment community [1-2]. A SBR process has a unique cyclic batch operation for biological wastewater treatment. Most of the advantages of SBR processes may be attributed to their single-tank designs and the flexibility allowing them to meet many different treatment objectives [3-5]. Due to the ever-stricter demands on effluent discharge quality, an existing SBR plant may require optimization in terms of nutrient removal, but this often needs a better understanding and quantification of the biological processes occurring in each phase of the SBR operation. A calibrated activated sludge model is a practical tool to try numerous operating scenarios within a short evaluation time when an upgrade of the SBR is considered.

In this study, Activated Sludge Model No. 2d (ASM2d) is employed to model a lab-scale SBR [6]. Then, based on a survey of the relevant literature and a preliminary model-based analysis of the system [1,7], the following degrees of freedoms were identified and used for the SBR optimization: oxygen set-point in the aerobic phase (S_O) and the lengths of anaerobic (T_{AN}), aerobic (T_A), and feeding (T_F) phases. A grid of scenarios is formulated as full-factorial experimental design to simulate the effect of the key degrees of freedom in the SBR system. Effluent quality in combination with a robustness index for each of the scenarios is used to select the best operational strategy for the SBR system.

2. SEQUENCING BATCH REACTOR

The data used in this study were collected from a lab-scale SBR system as shown in Fig. 1. A fill-and-draw SSBR system with a 4-liter working volume was operated in an 8 h cycle mode and each cycle consists of 2 h anaerobic (initially anoxic), 4 h 30 min aerobic, 1 h 30 min settling and fill/draw stages. Temperature was controlled at the reactor that was jacked with water for temperature control at 20±1℃ using a water circulation system. Clarified supernatant of 2 liters was withdrawn from the reactor at the end of settling stage and fresh (synthetic) wastewater of 2 liters was pumped into the reactor during the filling stage. Solid

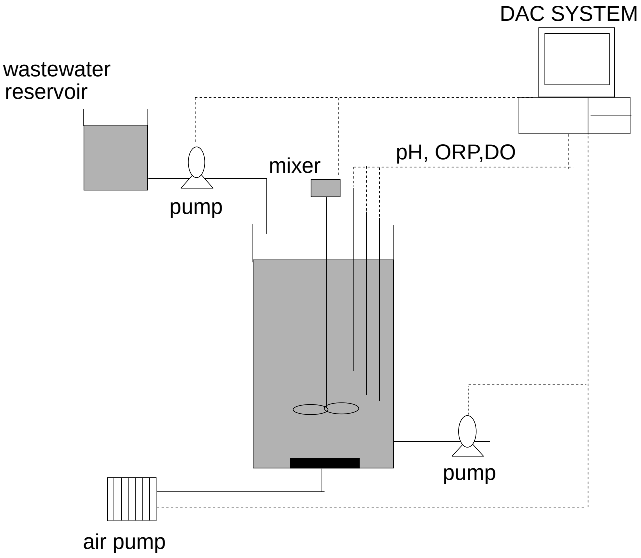

Fig. 1. Schematic diagram of a lab-scale sequencing batch reactor

retention time (SRT) was maintained at about 12 days by wasting mixed liquor suspended solids (MLSS) at the end of the aerobic phase. Loading amounts of COD (as CH_3COOH), NH_4^+-N, and PO_4^{3-}-P per cycle in a standard condition were 600, 40, and 15 mg l^{-1} respectively.

The controls of duration/sequence of stages and on/off of peristaltic pumps, mixer, air supply were automatically achieved by an in-house developed data acquisition and control (DAC).

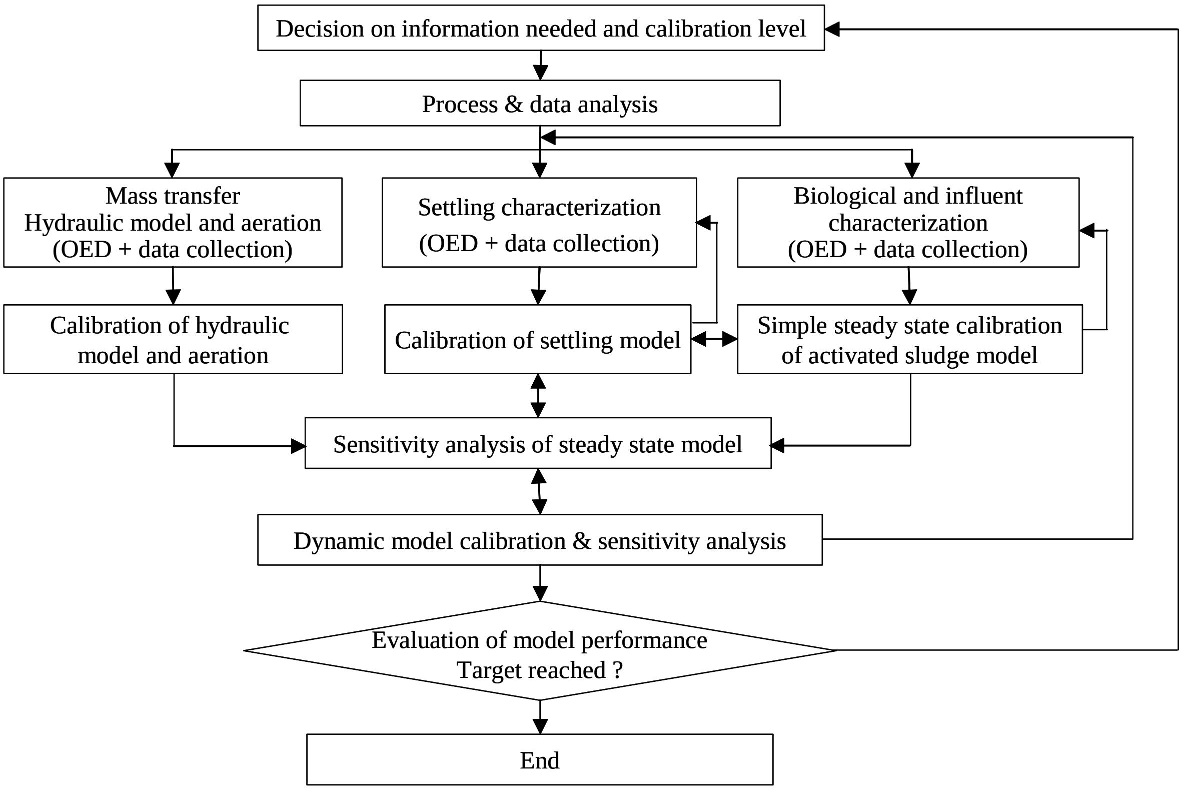

Fig. 2. A systematic methodology for the calibration of activated sludge models

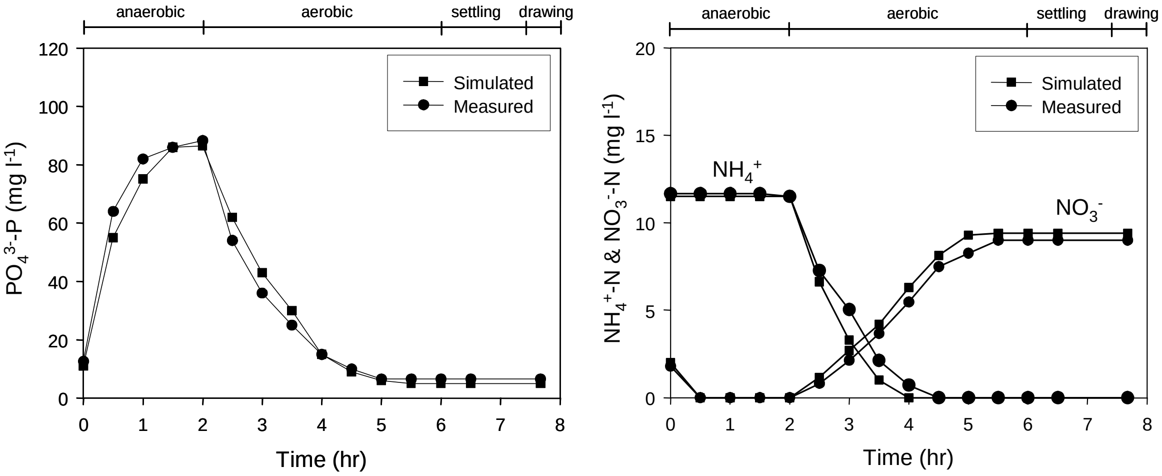

Fig. 2. Measurements and simulation results for nutrient concentrations in a SBR cycle

The DAC system consisted of computer, interface cards, meters, transmitters, and solid state relays (SSR). Electrodes of pH (Ingold), Oxidation-Reduction Potential (Cole-Parmer), and Dissolved Oxygen (Ingold) were installed and connected to individual meter. The status of reactor and the value of electrode signal were displayed in a computer monitor, and stored in data file.

3. RESULTS AND DISCUSSION

In the model simulations, the settling and decanting phase were characterized by a reactive point-settler model. The simulations were carried out using matlab 6.5 simulation platform. A systematic model calibration methodology as described in Fig. 2 was applied to the SBR. Fig. 3. shows the simulation results from the calibrated model. The model predicted the dynamics of the SBR with good accuracy.

A grid of scenarios considering the degrees of freedom and the constraints of the system mentioned above was formulated as a full-factorial experimental design [8]. The combination of these degrees of freedom under the SBR operation constraints results in 108 scenarios, which is expected to be sufficient to provide significant insight into the optimal operational scheme for the SBR system. In this way, the optimal scenario of the SBR operation can be searched using the predefined criteria. The grid of scenarios presented in Table 1 is simulated for 36 days, equal to 3 times the system SRT. The scenario analysis results (SCA) indicate that the best system performance for P-removal is obtained under different operating

Table 1
The grid of scenarios to simulate the effect of key degrees of freedom on the SBR system

Degrees of freedom			
S_O (mg O_2 l^{-1})	T_F (min)	T_{AN} (min)	T_A(min)
[0.5, 1.0, 1.5, 2.0]	[10,20,30]	[100, 120,140]	[210,240,270]
[0.5, 1.0, 1.5, 2.0]	[10,20,30]	[100, 120,140]	[130,140,150]
[0.5, 1.0, 1.5, 2.0]	[10,20,30]	[100, 120,140]	[130,140,150]
[0.5, 1.0, 1.5, 2.0]	[10,20,30]	[100, 120,140]	[130,140,150]

conditions. In this study, the objective was set to improve the P removal defined as PO_4^{3-} concentrations in the effluent. The robustness index (RI) is also used to assess the robustness of each scenario against a change in the system operation conditions [9]. The sensitivity of the SBR under different scenarios was determined by applying the following manipulations: (1) 10 % decrease in the SRT, (2) 10% increase in the HRT, (3) 10% decrease in the organic (COD) loading rate and (4) 25% decrease in the temperature (from 20 to 15°C). The temperature effect on the system performance was modelled using the Arrhenius equation. Based on the effluent quality and robustness index of the best scenarios, the SBR operation under the condition (T_F= 60 min, T_{AN}= 140 min, T_A= 240 min, S_O= 2.0 mgO_2 l^{-1}) appeared to be the best scenario to provide effluent quality below discharge standards accompanied with good system stability. Under this scenario, the existing SBR performance for the P-removal could be improved by 93%.

4. CONCLUSION

A systematic approach to determine the optimal operation strategy for nitrogen and phosphorus removal of sequencing batch reactors has been developed and applied to successfully to a lab-scale SBR. In this optimisation study, the dissolved oxygen concentrations in the aerobic phase and the variable length of the filling, anaerobic and aerobic sequences are selected as key manipulating variables. Based on ASM2d model, each operation scenario is evaluated to improve the effluent quality and the robustness of the process operation. The selected best scenario has been implemented to the lab-scale SBR reactor.

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