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An efficient approach based on bi-sensitivity analysis and genetic algorithm for calibration of activated sludge models

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HIGHLIGHTS

- An efficient approach for calibration of ASMs was proposed.
- Five influential parameters were added during the second sensitivity analysis.
- Sensitivities of K_{O_2}, K_{NH_4} and K_{ALK} were influenced by NH_4^+-N concentration.
- Computational time could be reduced by using C-code and parallel computing.
- Rapid convergence of the proposed approach could be observed.

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ABSTRACT

An efficient approach employing bi-sensitivity analysis and genetic algorithm was proposed for calibration of activated sludge models. The approach mainly contained twice sensitivity analyses and twice calibrations through minimizing cost function by genetic algorithm, and which was evaluated on Step A^2/O activated sludge process with Commutative Multi-influent (SA^2/OCM) at low temperature, where effluent COD, TN, TP and NH_4^+-N were used. The model was calibrated at HRT 16 h under steady state, while model validation was carried out under HRT 20 h and HRT 24 h using dynamic data. Results showed that, model with default ASM2d parameters had poor predictions of TN and NH_4^+-N at low temperature. Sensitivities of K_{O_2}, K_{NH_4} and K_{ALK} located in switching functions would be increased along with the decreasing of NH_4^+-N, thus these parameters were missed during the first sensitivity analysis owing to that NH_4^+-N was poorly predicted, however they were selected during the second sensitivity analysis based on the calibrated model 1. Consequently predictions of the calibrated model 2 were better than that of the calibrated model 1. In addition, computational time of this approach could be reduced by using the efficient C code and the parallel computing.

1. Introduction

Activated sludge process (ASP) is widely used for municipal and industrial wastewater treatment. Nowadays, modeling of ASP using activated sludge models (ASMs) [1] proposed by the International Water Association (IWA) is widely extended. ASMs are also incorporated in some contemporarily used commercial simulation software, e.g., BioWin, GPS-X, WEST, ASIM, DESSAS [2–4], which can be used to design ASP [5–7], develop control strategies and optimize processes [8–13].

In order to successfully apply ASMs in simulation of wastewater treatment processes, there are several steps starting from (1) definition of modeling objective, (2) data collection and the quality check, (3) programing of the models for different units of processes, including hydraulics, (4) model calibration and to (5) model validation and model using [14]. Among them model calibration is the core, which is defined as the adjustment of specific model parameters so that model outputs can be fitted a certain set of experimental data from the process under study [15]. Several calibration guidelines have been proposed so far, particularly the WERF protocol [16], the STOWA protocol [17] and the HSG

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guidelines [18] and the extended protocol in BIOMATH [19,20]. A detailed comparison of the existing model guidelines can be found in Sin et al. [14].

Model calibration is usually conducted by calculating the best parameter values according to a cost function (CF), which generally describes the difference between model prediction and experimental data. However, ASMs contain many parameters, and which leads to the well-known problem of poorly identifiable parameters [21], making it hard to decide which parameters must be calibrated. The calibration procedure usually employs lots of experience obtained from activated sludge systems [22], which is difficult for newbie engineers or researchers. While some studies have presented the systematic approach based on mathematical methods to select parameters. They studied the identifiability of parameters in ASMs calculated by the sensitivity analysis [21,23–25], where influences of parameters on model outputs can be determined, and then adequate influential parameters should be selected and estimated [26].

In fact, in most model application cases, only small number of parameters are estimated, either by manual trial and error method or combining an optimization algorithm [27,28], while most parameters are remained at their default values. Sin et al. [27] introduced an efficient approach using Monte Carlo method to complete the tedious manual trial and error way of model calibration automatically. However, there are some drawbacks in the method combining optimization algorithm. Many studies [21,29,30] revealed that these methods were time-consuming, and local optimization algorithm would get troubled easily in local minimum, while global optimization method, e.g., genetic algorithm, would require large numbers of simulations until offering the satisfying parameter estimates [27].

Therefore, there are still two difficulties in ASMs calibration, the first is how to define an unbiased parameter subset, which contains as less parameter as possible but it's sufficient to get a satisfying calibrated model; and the second is to obtain a global optimized CF value with the minimal time-consuming demand. Having recognized these difficulties, this study proposed a systematic calibration approach based on bi-sensitivity analysis and genetic algorithm. On the one hand, sensitivity analysis of parameters were calculated twice, where the second sensitivity analysis was calculated relying on the first parameter estimation to identify the missed influential parameters caused by the poor prediction of model with the default values, on the other hand, computational time could be reduced by means of the efficient C code and with the help of parallel computing in MATLAB. All these will become clear below.

2. Material and methods

2.1. Pilot plant

The pilot plant studied was the Step A^2/O activated sludge process with Commutative Multi-influent (SA^2/OCM, Fig. 1) developed by Southeast University of China, which combined excellent features of UNITANK and A^2/O. SA^2/OCM consists of five bioreactors and one clarifier for sludge-water separation. The dimension of each bioreactor is 280 * 240 * 900 mm^3, and that of the clarifier is 360 * 280 * 900 mm^3, the available depth is 700 mm.

The pilot plant was controlled with a PLC control system. Each bioreactor fixes aerator and stirrer and conditions of anaerobic, anoxic and aerobic can be achieved by changing the process parameters. Raw wastewater can be pumped into all of the bioreactors; however the returned sludge from the bottom of clarifier can be only recycled to tank2, tank3 and tank4. The step operating time, working time of the aerators and stirrers, on and off of solenoid valves can be adjusted manually or automatically from the touch screen of PLC control system.

The cycle of SA^2/OCM is divided into the exactly symmetrical two periods: the first half (step 1, step 2 and step 3) and the second half (step 4, step 5 and step 6). Partial sludge distribution and recycle can be realized as a result of water flow direction changing caused by the multi-influent.

2.2. Plant settings and experimental process

The pilot plant was located in Qingtan WWTP of Jiangsu, China. Raw wastewater was from sump, and the sludge was taken from the aeration tank of the WWTP directly. The SA^2/OCM plant was operated for about 4 months containing 3 successive runs with different hydraulic retention time (HRT). Run1 was at HRT 16 h, operated 70 days, including the period of sludge acclimation (about 50 days), Run2 and Run3 were separately operated at HRT 20 h and 24 h, lasting 20 days. Average sludge concentration was remained at about 3000 mg/L. Sludge retention time (SRT) was kept at about 13 days by controlling the waste sludge rate. The dissolved oxygen (DO) was manually controlled by manipulating the aeration rate. Conditions of the pilot plant during the experimental periods are listed in Table 1. The analytical methods for chemical oxygen demand (COD), ammonia nitrogen (NH_4^+-N), total nitrogen (TN), total phosphorus (TP), and mixed liquor suspended solids (MLSS) were analyzed according to standard methods. The DO was measured by a DO meter (YSI DO200, USA).

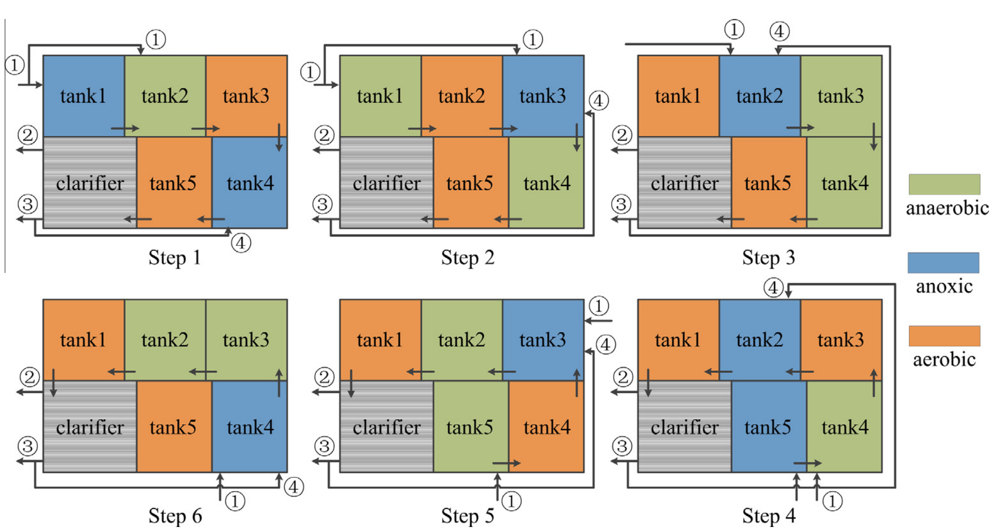

Fig. 1. Configuration of Step A^2/O activated sludge process with Commutative Multi-influent. ① – influent; ② – effluent; ③ – waste sludge; ④ – return sludge.