Int. J. Environ. Sci. Tech., 6 (1), 69-76, Winter 2009
ISSN: 1735-1472

Environmental biological model based on optimization of activated sludge process

[1]*X. X. Zhang; [1]D. Y. Zhao; [1]Z. X. Wang; [1]B. Wu; [1, 2]W. X. Li; [1]S. P. Cheng

[1]State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing, 210093, China

[2]Nanjing Institute of Environmental Sciences, State Environmental Protection Administration of China, Nanjing, 210042, China

Received 27 May 2008; revised 14 August 2008; accepted 25 November 2008; available online 10 December

ABSTRACT: A simplified environmental biological model has been developed based on biodegradation kinetics correlation to regulate and optimize wastewater treatment system of activated sludge process. All parameters included in the model are calibrated in accordance with reference data and experimental results and good agreements are achieved between calculated results and reference data or experimental results. The minimum bioreactor volume is used as objective function in the model and errors between optimal minimum volume of the model and each reported result of three references are found to be no more than 8.63 % after validation. Comparisons between optimal results and experimental data demonstrate that the deviations are negligible. The optimal minimum volume is 9.21 m^3 with the error of 6.40 % to the practical bioreactor volume of a pilot treatment system. The environmental biological model has been applied to economically evaluate a former treatment system with native bacterium YZ1 and four operation periods of the pilot system with functional strain Fhhh compared with YZ1, Fhhh possesses higher biodegradation ability in purified terephthalic acid wastewater and a broader economic potential in the field of wastewater treatment.

Keywords: *Cost evaluation, functional strain, mathematical model, wastewater treatment, biodegradation kinetics*

INTRODUCTION

With rapid development of informatics technology, many advanced informatics methods have been introduced to the field of environmental pollution control (Cheng *et al*., 2002; Glover *et al*., 2006). In order to solve environmental problems more effectively, researchers are focusing on design and optimization of the control processes for environmental pollution through imitation and simulation of these problems (Zeidan *et al*., 2003; Templeton *et al*., 2006; Li *et al*., 2008; Rashidinejad *et al*., 2008). Development of informatics techniques, including mathematical modeling (Panjeshahi and Ataei, 2008), artificial neural network (Choi and Park 2001), fuzzy control (Chen and Chang, 2008), database construction (Okubo *et al*., 1994) and expert system (Ribas *et al*., 2008) has been one of the most exciting progresses in wastewater treatment technology in recent years.

International wastewater association (IWA) Task Group proposed activated sludge model No. 1 (ASM1) in 1987, activated sludge model No. 2 (ASM2) in 1994 and activated sludge model No. 3 (ASM3) in 1999 (IWA Task Group, 2000) which has made major contributions to promote numerical analyses in wastewater treatment. The methods of the parameter estimation and calibration procedures have been presented for the ASMs (Von Sperling, 1994; Reichert *et al*., 1995; Mino *et al*., 1997). Optimal operating modes for biofilm process and sequencing batch reactors were also determined via model based optimization (Suzuki *et al*., 1999; Souza *et al*., 2008). Some models have been developed for optimization of removing nitrogen or other toxic chemicals in activated sludge reactors (Oda *et al*., 2006; Hu *et al*., 2007; Rivas *et al*., 2008).

In those models, main attention was paid to seek reasonable models to simulate activated sludge process by mathematical or informatics techniques, but microbial effects were neglected (Gujer, 2006). Lack of recognition of microbial crucial roles in bioreactors makes the models less reliable, even when heterogenous or functional microorganisms are introduced into bioreactors to improve operation efficiency. However, the problem can be solved with

*Corresponding Author Email: *zhangxx@nju.edu.cn*
Tel.: +8625 8359 5995; Fax: +8625 8359 5995

microbial degradation kinetics which deals with the relationship between microbial growth rate and pollutant degradation rate, as well as the effects of environmental factors on the microbial growth and pollutant removal (Hosseini *et al*., 2007; Mohanan *et al*., 2007).

Different from the above methods, in this paper an environmental biological model (EBM) is developed with the special attention paid to biodegradation kinetics parameters which can reflect the biodegradation and adaptation abilities of various microorganisms in different wastewaters. The aims of this work are:

1. Regulate and optimize wastewater treatment system of activated sludge process with the simplified model based on biodegradation kinetics correlation;
2. Comparatively assess the treatment system of purified terephthalic acid (PTA) wastewater with functional strains cultivated in the bioreactor which was operated in Nanjing Yangtze wastewater treatment plant (Nanjing, China) from 2002 to 2004.

MATERIALS AND METHODS

Mathematical equations and parameters

EBM optimization and evaluation function is achieved based on activated sludge process. The flow sketch and related parameters are shown in Fig. 1. The validity of mathematical equations depends on its reasonability.

EBM is developed based on biodegradation kinetics and mass balance theory and the methods are described in detail in Table 1. Total twenty eight mathematical equations (divided into four groups) are employed to develop EBM and the equations are set up with the following suppositions:

1. EBM is proposed with V_{min} as objective function and V_{min} errors between EBM computed results and reference or experimental data are considered as the main evaluation factors for the model validity;
2. The mathematical equations of wastewater treatment process and the relationship between objective function and process parameters are achieved with Q_r, S_e and X_e as recycled variables according to mass balance theory and Monod equations (Qin, 1989);
3. It is thought that there is no effective biomass in the bioreactor influent wastewater based on the facts of high toxicity induced by PTA wastewater and very few microorganisms living in the wastewater (Zhang *et al*., 2005).
4. According to reported data from references, some coefficients of the mathematical equations such as λ_1, λ_2, γ_1 and γ_2 have been determined for cost evaluation (Middleton and Lawrence, 1974; Gu, 1993).

Forty eight variables used in EBM equations are divided into eight groups:

1. Optimization computation objective function V_{min};
2. Degradation kinetics parameters, including q_{max},μ_{max}, K_{sq}, K_{si}, K_d and Y_t;
3. Natural parameters of water quality, including Q_o, S_o and X_o;
4. Wastewater treatment process parameters, including HRT, M_t, Q_e, q, Q_s, SRT, SVI, V, X, X_r, X_s, Y_{obs} and μ;
5. Recycled variables, including Q_r, S_e and X_e;
6. Control parameters of water quality, including S_{ei} and X_{ei};
7. Conventional experienced coefficient, including $C_{sm(20)}$, E_A, $K_La_{(20)}$, α, β, λ_1 , λ_2, γ_1, γ_2 and
8. Cost evaluation parameters, including A_T, C, E_e, E_f, G_s, R, T_d, T_s, V_d, V_s and ZSV.

Operation strategy and programming

EBM optimization computation is achieved through recycle operation of computer. The model has been programmed with Visual Basic 7.0 language (Microsoft Co., USA). EBM operation strategies are described as following:

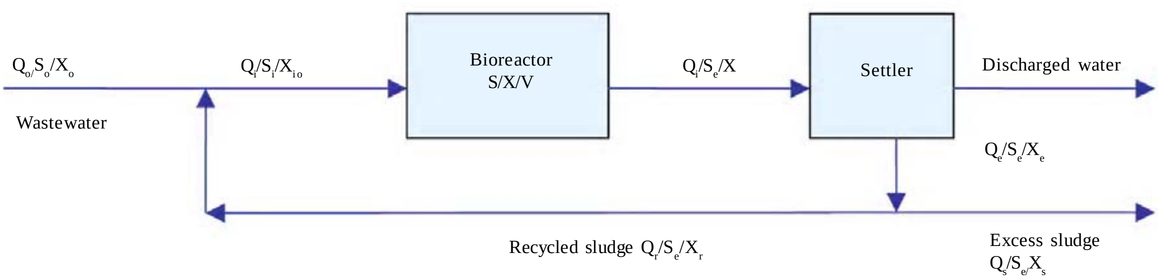

Fig. 1. Flow sketch of conventional activated sludge process

Table 1: Mathematical equations of environmental biological model (EBM)

Mathematical equations	Eq. No.	Annotation
Group (A): Optimization equations for computation of V_{min} (Qin, 1989; Corbitt *et al*., 1998)		
$q = \frac{(dS/dt)}{X} = \frac{q_{max} S}{K_{sq} + S}$	(1)	Monod equation
$-(\frac{K_{sq} + S}{S}) dS = (q_{max} X) dt$	(2)	Substrate concentration decreases along the stream of bioreactor. Integral of Eq. 1 along bioreactor length produces Eq. 2 and 3 and the latter can be transformed to Eq. 4.
$-\int_{S_o}^{S_e} dS - K_{sq} \int_{S_o}^{S_e} \frac{dS}{S} = \int_0^{HRT} q_{max} X dt$	(3)	
$(S_o - S_e) + K_{sq} \ln(\frac{S_o}{S_e}) = q_{max} X \cdot HRT$	(4)	
$HRT = \frac{1}{q_{max} X}\left[(S_o - S_e) + K_{sq} \ln(\frac{S_o}{S_e})\right]$	(5)	Eq. 5 is derived from Eq. 4.
$q = \frac{(dS/dt)}{X} = \frac{S_o - S_e}{HRT \cdot X}$	(6)	HRT is used to compute q.
$q = \frac{q_{max}(S_o - S_e)}{(S_o - S_e) + K_{sq} \ln(S_o / S_e)}$	(7)	Eq. 7 is deduced from Eq. 5 and 6.
$\mu = \frac{\mu_{max}(S_o - S_e)}{(S_o - S_e) + K_{s\mu} \ln(S_o / S_e)}$	(8)	Eq. 8 is developed according to Eq. 7.
$K_d = qY_t - \mu$	(9)	Eq. 9 is used to compute K_d.
$SRT = \frac{1}{\mu}$	(10)	The reciprocal of SRT is μ.
$Y_{obs} = \frac{\mu}{q} \times 100\%$	(11)	Y_{obs} is expressed as the quotient of μ and q.
$X_s = X_r = \frac{1000}{SVI}$	(12)	X_s is thought to be equal to X_r.
$X(Q_o + Q_r) = Q_o Y_{obs}(S_o - S_e) + X_r Q_r$	(13)	Eq. 13 is developed according to mass balance theory.
$X = \frac{Q_o Y_{obs}(S_o - S_e) + X_r Q_r}{Q_o + Q_r}$	(14)	Computing formula of X is derived from Eq. 13.
$HRT = \frac{SRT \cdot Y_{obs}(S_o - S_e)}{X}$	(15)	HRT is determined by X and SRT.
$V = \frac{SRT \cdot Q_o Y_{obs}(S_o - S_e)}{X}$	(16)	Eq. 16 is used to compute V.
$M_t = \mu XV = Q_s X_s + (Q_o - Q_s) X_e$	(17)	Eq. 17 is developed according to mass balance theory.
$Q_s = \frac{M_t - Q_o X_e}{X_s - X_e}$	(18)	Computing formula of Q_s is derived from Eq. 17.
$Q_e = Q_o - Q_s$	(19)	Eq. 19 is used to compute Q_e.
Group (B): Screening equations for data validity (Qin, 1989)		
$Y_{obs} < Y_t$ and $K_d > 0$	(20)	Respiration and death can not be avoided for microorganisms in bioreactor.
$\mu XV - (X_e Q_e + X_s Q_s) \geq 0$ and $qXV - Q_o(S_o - S_e) - \frac{K_d VX}{Y_{obs}} \leq 0$	(21)	Biomass and substrate concentration must satisfy mass balance theory.
Group (C): Computation equations of settler parameters (Fu and Cheng, 1985; Corbitt *et al*., 1998)		
$A_T = \frac{Q_o}{1440 \times ZSV}$	(22)	ZSV is determined by SVI and X_s.
$V_d = \frac{Q_o T_d X}{12(X + X_r)}$	(23)	T_d is determined by X and SVI.
$V_s = V_d + Q_o T_s$	(24)	T_s is determined by X and SVI.
Group (D): Computation equations of air supplies in bioreactor (Gu, 1993; Gao and Peng, 2004)		
$R = \frac{\alpha \cdot K_{La(20)} V_{min}(\beta C_{sm(20)} - C)}{1000}$	(25)	It is supposed that α, β, $K_L a_{(20)}$ and $C_{sm(20)}$ are 0.40, 0.85, 1.024 and 9.87 mg/L, respectively.
$G_s = \frac{24 \times 365 \times R}{0.3 \times E_A}$	(26)	E_A is supposed to be 10%.
Group (E): Economic benefit evaluation equations (Middleton and Lawrence, 1974)		
$E_e = \frac{0.6 \times G_s}{365 \times 20 \times Q_o}$	(27)	Price of electricity energy is proposed to be 0.6 CNY per kW.h
$E_f = \lambda_1 A_T^{\gamma_1} + \lambda_2 V_{min}^{\gamma_2}$	(28)	It is proposed that λ_1, λ_2, γ_1 and γ_2 are 0.69, 0.30, 0.88 and 0.83, respectively.

1. After input of the values of ten parameters (q_{max}, K_{sq}, μ_{max},$K_{s\mu}$, Y_t, SVI, Q_o, S_o, S_{ei} and X_{ei}) into EBM, corresponding calculation of μ, q, θ_c, K_d and Y_{obs} will be carried out with S_e as recycled variable;
2. The produced data arrays must be verified with Eq. 20 on account of microbial respiration and death which are inevitable during the growth. With S_e, X_e and Q_o as recycled variables, the eligible data arrays can be used to calculate the matrix including, X, X_s, X_r, θ, V, M_t, Q_o and Q_e;
3. The results in the matrix must be screened with Eq. 21 for mass balance verification. If no data arrays in the matrix can satisfy the condition, it demonstrates that no optimal result is produced by EBM in the wastewater treatment system;
4. However, in the case of more than one eligible data array , the array with the minimum volume of bioreactor can be assigned to be the optimal result (V_{min}). The corresponding recycled variables (S_e, X_e and Q_o) are also obtained in the optimal data array. Original and final values and steps of the three variables are shown in Table 2;
5. Subsequently, equations in group (C) can be employed to calculate related parameters of settlers based on the values of Q_o, X, X_r and SVI in the optimal data array and those in group (D) are used for determination of R and G_s based on V_{min} value;
6. After the values G_s, A_T and V_{min} are obtained, calculation for E_f and E_e can be performed with equations in group (E) to evaluate the wastewater treatment systems economically.

RESULTS AND DISCUSSION

Calibration with reference data

Comparisons between EBM optimal results and the reference data have been performed. The reference data of twenty two operational parameters was obtained from different wastewater treatment systems with activated sludge process (Lee and Lin, 1999; Qin, 1989; Woodard, 2001). Ten reference data (q_{max}, K_{sq}, μ_{max}, $K_{s\mu}$, Y_t, SVI, Q_o, S_o, S_{ei} and X_{ei}) have been input into EBM on the interface (Table 3) and the optimal values of other sixteen parameters (S_e, X_e, X, X_s, X_r, HRT, V_{min}, M_t, Q_r, Q_s, Q_e, μ, q, SRT, K_d and Y_{obs}) are produced on output interface of the software (Table 3). After comparisons between EBM optimal results and reference data, the differences of most parameters, including V_{min}, HRT, SRT and Q_r between the two groups are not significant and can be negligible. The V_{min} errors between the EBM optimal results and the reported data from the three references are 4.44 %, 8.63 % and 5.93 %, respectively. It is found that EBM exhibits a high validity when it is used for optimization computation of wastewater treatment system.

Table 2: Original and final value and step of EBM recycled variables

Recycled variable	Original value	Final value	Step
S_o	0.01 S_o	S_o	0.01 S_o
S_e	0.01 S_{ei}	S_{ei}	0.01 S_{ei}
Q_r	0.01 Q_o	1.99 Q_o	0.01 Q_o

Pollutant removal efficiency of activated sludge process depends on wastewater components (various pollutants and different concentrations) and species or characteristics of microorganisms in bioreactor (Gujer *et al*., 1999). The different wastewater conditions and structural variations of microbial communities make the kinetic parameters (q_{max}, K_{sq}, μ_{max}, $K_{s\mu}$, Y_t and K_d) vary greatly in the three examples (Table 3). EBM is a mathematical model developed according to the principle that operational parameters must be adjusted with the changes of wastewater characteristics and biodegradation kinetic parameters which makes a great contribution to EBM validity.

Calibration with experimental results

To calibrate the EBM with experimental results, PTA wastewater was subject to biodegradation kinetics test to quantify the six parameters, including q_{max}, K_{sq}, μ_{max}, $K_{s\mu}$, Y_t and K_d. Degradation kinetic experiments were carried out according to Cheng *et al*. (2003). PTA wastewater was treated with activated sludge process (Fig. 1). Functional strain Fhhh constructed through protoplast fusion with the three parental strain of *Phanerochaete chrysosporium*, *Saccharomyces cerevisiae* and native bacterium *Bacillus* YZ1 at laboratory, was cultivated in bioreactor at Nanjing Yangtze wastewater treatment plant (Nanjing, China) to improve the removal efficiency of pollutants in PTA wastewater (Hao *et al*., 2003; Sun *et al*., 2005; Zhang *et al*., 2006a). The treatment system with bioreactor effective volume of 9.84 m^3 was operated continuously and stably for more than 180 days in the plant. According to regulation strategies (Table 4), the treatment system was regulated and optimized in terms of process parameters, metallic ions and nutrition factors and also the whole operation time was divided into four periods. The experimental results of biodegradation kinetic parameters and operational parameters in the pilot treatment system have been shown in Table 5. EBM optimal results are achieved after the input of the 10 parameters (q_{max}, K_{sq},

Table 3: Comparisons between EBM optimal results and reference data

Parameters	Lee and Lin, 1999		Woodard, 2001		Qin, 1989	
	** R. D.	***C. D.	R. D.	C. D.	R. D.	C. D.
q_{max}, 1/d	2.30	2.30*	2.87	2.87*	3.50	3.50*
K_{sq}, g/L	0.15	0.15*	0.33	0.33*	0.31	0.31*
μ_{max}, 1/d	0.61	0.61*	1.03	1.03*	1.4	1.4*
$K_{s\mu}$, g/L	0.12	0.12*	0.36	0.36*	0.25	0.25*
Y_t, kg/kg	0.50	0.50*	0.57	0.57*	0.50	0.50*
SVI, ml/g	134	134*	50	50*	100	100*
Q_o, m^3/d	27,648	27,648*	1,136	1,136*	20,000	20,000*
S_o, g/L	0.24	0.24*	1.71	1.71*	0.20	0.20*
S_{ei}, g/L	$\leqslant$ 0.020	$\leqslant$ 0.020*	$\leqslant$ 0.050	$\leqslant$ 0.050*	$\leqslant$ 0.020	$\leqslant$ 0.020*
X_{ei}, g/L	$\leqslant$ 0.024	$\leqslant$ 0.020*	$\leqslant$ 0.020	$\leqslant$ 0.020*	< 0.020	$\leqslant$ 0.020*
μ, 1/d	0.125	0.087	-	0.122	-	0.102
q, 1/d	0.320	0.271	-	0.376	-	0.208
HRT, d	0.20	0.19	0.50	0.46	0.22	0.21
SRT, d	10.00	1.48	10.00	8.18	11.60	9.83
Y_{obs}, kg/kg	0.313	0.322	-	0.325	-	0.489
K_d, 1/d	0.060	0.048	0.056	0.092	0.050	0.0023
X, g/L	2.40	2.69	8.66	5.67	3.20	2.97
X_s, g/L	7.44	7.46	20.00	20.00	10.00	10.00
X_r, g/L	7.44	7.46	20.00	20.00	10.00	10.00
M_t, kg/d	1,676	1,263	409	360	-	1,251
Q_r, kg/d	13,112	15,352	954	842	9,240	8,283
Q_s, kg/d	270	230	-	18	-	157
Q_e, kg/d	27,266	27,418	-	1,118	-	19,843
S_e, g/L	0.006	0.020	0.004	0.049	-	0.020
X_e, g/L	0.0240	< 0.001	-	< 0.001	-	< 0.001
V_{min}, m^3	5,586	5,834	568	519	4,400	4,139
Errors of V_{min}	4.44 %		8.63 %		5.93 %	

* EBM input data; ** R. D.: Reported data in references; *** C. D.: EBM computed results.

Table 4: Regulation strategies of treatment system for purified terephthalic acid wastewater

Periods	Regulation types	Regulation factors
Period (A)	Single-item regulation	Operation parameters such as Q_o, Q_r and HRT
Period (B)	Double-item regulation	Operation parameters and metallic ions Mn^{2+}, Cu^{2+}, Zn^{2+} and Se^{4+}
Period (C)	Three-item regulation	The above items and nutrition factors of nitrogen and phosphorus
Period (D)	Optimization regulation	Optimization regulation based on period (C)

Table 5: Comparisons between EBM optimal results and experimental data of pilot treatment system

Parameters	**E. D.	***C. D.	Errors (%)	Parameters	E. D.	C. D.	Errors (%)
q_{max}, 1/d	2.82	2.82*	--	SRT, d	15.38	16.36	6.37
K_{sq}, g/L	0.39	0.39*	--	Y_{obs}, kg/kg	0.213	0.194	8.92
μ_{max}, 1/d	0.56	0.56*	--	K_d, 1/d	0.069	0.077	11.59
$K_{s\mu}$, g/L	0.40	0.40*	--	X, g/L	2.88	2.79	3.13
Y_t, kg/kg	0.44	0.44*	--	X_s, g/L	8.26	8.13	1.57
SVI, ml/g	121	123*	--	X_r, g/L	8.26	8.13	1.57
Q_o, m^3/d	8.00	8.00*	--	M_t, kg/d	1.83	1.55	15.30
S_o, g/L	1.52	1.52*	--	Q_r, m^3/d	4.24	3.90	8.02
S_{ei}, g/L	< 0.050	< 0.050*	--	Q_s, m^3/d	0.22	0.19	13.64
X_{ei}, g/L	< 0.070	< 0.070*	--	Q_e, m^3/d	7.78	7.81	0.39
μ, 1/d	0.065	0.061	6.15	S_e, g/L	0.036	0.042	16.67
q, 1/d	0.304	0.315	3.62	X_e, g/L	0.010	0.003	70.00
HRT, d	1.23	1.14	7.32	V_{min}, m^3	9.84	9.21	6.40

* EBM input data; ** E. D.: Experimental data; *** C. D.: EBM computed data

μ_{max}, $K_{s\mu}$, Y_t, SVI, Q_o, S_o, S_{ei} and X_{ei}) into the model (Table 5). After comparisons between the two groups, it is found that among the 16 pairs of parameters, the errors of 11 pairs are less than 10 %, including μ, q, HRT, SRT, Y_{obs}, X, X_s, Q_r, S_e, Q_e and V_{min} and those of 4 pairs range from 10 % to 17 %, including K_d, M_t, Q_s and S_e. Only one parameter error (X_e) is more than 17 % which probably results from the EBM hypothesis that there is no biomass in the bioreactor influent. EBM optimal V_{min} is obtained to be 9.21 m^3 and V_{min} error between optimization value and experimental result is only 6.40 %. Dependent on the waste amounts and microbial characteristics, the bioreactor volume is the most crucial parameters for the design of wastewater treatment system which exerts a great influence on other process parameters, including hydraulic retention time, recycled sludge rate and air supplies (Gu, 1993; Rivas *et al*., 2008). A good V_{min} agreement results in small errors of other variables between calculated results and experimental results. Therefore, EBM can be used to forecast operational state of activated sludge process accurately and to regulate and optimize the treatment system successfully.

Cost evaluation of wastewater treatment system

EBM has been applied to economically evaluate the former treatment system (with bacterium YZ1 cultivated in the bioreactor to treat PTA wastewater) and the four operation periods of pilot treatment system (with functional strain Fhhh introduced into the bioreactor to improve degradation efficiency). As shown in Table 6, when influent flow arrives at 10,000 m^3/d, EBM optimal V_{min}, A_T, E_e and E_f in the pilot treatment system are achieved to be 6,529 m^3, 553 m^2, 0.88 CNY/m^3 and 6.19 million-CNY, respectively. However, the four parameters of former treatment system are obtained to be 86,383 m^3, 3,401 m^2, 11.70 CNY/m^3 and 46.4 million-CNY. EBM optimal V_{min}, A_T, E_e and E_f in the pilot treatment system are 7.56 %, 16.26 %, 7.52 % and 13.35 % in former treatment system and 19.36 %, 6.24 %, 19.26 % and 16.40 % in period (A), respectively in which the system has not been regulated by metallic ions and nutrition factors. The results demonstrate that Fhhh presents a more economical form than YZ1 in PTA wastewater treatment and metallic and nutritional factors play important roles in biodegradation of the pollutants by Fhhh (Zhang *et al*., 2006a). Biodegradabilities of pollutants by microorganisms vary greatly (Zhang *et al*., 2006b), Thus, the biodegradation kinetics parameters must be taken into account for both design and optimization of activated sludge process.

ACKNOWLEDGMENTS

This research was financially supported by International Foundation for Science (No. W/4215-1) and Nanjing University Innovative Foundation (2006071009). The authors also would like to thank Nanjing Yangtze wastewater treatment plant (Nanjing, China) for the support of the pilot experiment.

Nomenclature

A_T, m^2	Area of secondary settler
BOD_5	Biochemical oxygen demands for 5 days
C, mg/L	Oxygen concentration in wastewater
$C_{sm(20)}$, mg/L	Oxygen solubility in distilled water at 20 °C
E_A, 100 %	Oxygen absorptivity
E_e, CNY/m^3	Electricity costs of wastewater treatment
E_f, million-CNY	Equipment costs of reactor and settler

Table 6: Cost evaluation of different wastewater treatment systems

Parameters	Former system	Period (A)	Period (B)	Period (C)	Period (D)
Microorganisms	YZ1	Fhhh			
Q_o, m^3/d	10,000	10,000	10,000	10,000	10,000
V_{min}, m^3	86,383	33,718	24,350	18,824	6,529
SVI, mL/g	287	491	347	196	121
X_s, mg/L	3.14	2.06	3.05	5.76	8.13
A_T, m^2	3,401	8,869	4,233	1,266	553
V_d, m^3	1,066	1,869	1,524	645	363
V_s, m^3	2,356	3,763	3,228	1,708	1,088
R, m^3/h	243.8	95.2	68.7	53.1	18.4
G_s, m^3/y	7.12×10^7	2.78×10^7	2.01×10^7	1.55×10^7	5.38×10^6
W, kw·h/y	3.56×10^6	1.39×10^6	1.00×10^6	7.76×10^5	2.69×10^5
E_e, CNY/m	11.70	4.57	3.30	2.55	0.88
E_f, million-CNY	46.4	37.7	23.8	14.3	6.19

G_s, m^3/y	Air supplies in bioreactor
HRT, d	Hydraulic retention time
K_d, L/d	Cell decay coefficient
$K_La_{(20)}$, $1/h$	Oxygen total transfer coefficient at 20 °C
K_{sq}, g/L	Substrate concentration at one-half q_{max}
$K_{s\mu}$, g/L	Substrate concentration at one-half μ_{max}
M_t, kg/d	Total mass of sludge production
q, L/d	Specific degradation rate
q_{max}, L/d	Maximum specific degradation rate
Q_e, m^3/d	Effluent flow
Q_o, m^3/d	Influent flow
Q_r, m^3/d	Return sludge flow
Q_s, m^3/d	Waste sludge flow
R, kg/h	Oxygen absorbency in bioreactor
S, g/L	BOD_5 concentration in bioreactor
S_e, g/L	Effluent soluble BOD_5 concentration
S_{ei}, g/L	EBM input data of S_e
S_o, g/L	Influent BOD_5 concentration
SRT, d	Sludge retention time
SS, g/L	Suspended solids
SVI, mL/g	Sludge volumetric index
t, h	Microbial growth or degradation time
T_d, h	Sludge deposition time
T_s, h	Sludge settling time
V, m^3	Bioreactor volume
V_d, m^3	Deposition volume of settler
V_{min}, m^3	Minimum volume of bioreactor
V_s, m^3	Total volume of settler
X, g/L	SS concentration in bioreactor
X_e, g/L	Effluent suspend solids
X_{ei}, g/L	EBM input data of X_e
X_o, g/L	Influent suspend solids
X_r, g/L	Return SS concentration
X_s, g/L	Waste SS concentration
Y_{obs}	Observed yield coefficient
Y_t	Theoretical yield coefficient
ZSV, m/min	Zone sedimentation velocity
α	K_La ratio
β	Oxygen solubility ratio
λ_1	Coefficient of settler E_f
λ_2	Coefficient of bioreactor E_f
γ_1	Exponential coefficient of settler E_f
γ_1	Exponentialcoefficientof bioreactor E_f
μ, L/d	Specific growth rate
μ_{max}, L/d	Maximum specific growth rate

REFERENCES

Chen, J. C.; Chang, N. B., (2008). Mining the fuzzy control rules of aeration in a submerged biofilm wastewater treatment process., Eng. Appl. Artif. Intel., 20 (7), 959-969.

Cheng, S. P.; Yan, J.; Hao, C. B.; Zhang, X. X.; Shi, L., (2002). Advancement of environmental biotechnology informatics, Environ. Pollut. Control Tech. Equipment, 3 (11), 92-94.

Cheng, S. P.; Zhang, X. X.; Shi, L.; Qu, M. M.; Zhou, T.; Hao, C. B.; Yan, J., (2003). Degradation kinetics for Fhhh strain in PTA wastewater., Chinese J. Environ., Sci, 24 (6), 116-120.

Choi, D. J.; Park, H. Y., (2001). A hybrid artificial neural network as a software sensor for optimal control of a wastewater treatment process., Water Res., 35 (16), 3959-3967.

Corbitt, R. A.; Crawford, H. B.; Gleason, D., (1998). Standard Handbook of Environmental Engineering, 2nd (Ed.) McGraw-Hill Inc, New York, USA, 6-17.

Fu, G. W.; Cheng, S. T., (1985). Design of control system for water pollution, Tsinghua university press, Beijing, China, 77-78.

Gao, J. S.; Peng, Y. Z., (2004). Wastewater treatment systems: Modeling, diagnosis and control, chemical industry press, Beijing, China, 29-31.

Glover, G. C.; Printemps, C.; Essemiani, K.; Meinhold J., (2006). Modelling of wastewater treatment plants - how far shall we go with sophisticated modelling tools?, Water Sci. Tech., 53 (3), 79-89.

Gu, X. S., (1993). Mathematical Model for Biological Wastewater Treatment, Tsinghua university press, Beijing, China, 34-39.

Gujer, W., (2006). Activated sludge modelling: Past, present and future., Water Sci. Tech., 53 (3), 111-119.

Gujer, W.; Henze, M.; Mino, T.; Loosdrecht, M. V., (1999). Activated sludge model No. 3., Water Sci. Tech., 39 (1), 183-193.

Hao, C. B.; Yan, J.; Qu, M. M.; Wang, D.; Cheng, S. P.; Gu, J. D.; Qiu, W. F.; Wang, Y. Y., (2003). Analysis of parental strain DNA fragments existing in GEMs-Fhhh., J. Environ. Sci., 15 (5), 590-594.

Hosseini, F.; Malekzadeh, F.; Amirniiozafari, N.; Ghaemi, N., (2007) Biodegradation of anionic surfactants by isolated bacteria from activated sludge., Int. J. Environ. Sci. Tech., 4 (1), 127-132.

Hu, Z. R.; Wentzel, M. C.; Ekama, G. A., (2007). A general kinetic model for biological nutrient removal activated sludge systems: Model evaluation, Biotechnol. Bioeng., 98 (6), 1259-1275.

IWA Task Group, (2000). Activated sludge models ASM 1, ASM 2, ASM 2D and ASM 3, Scientific and technical report No. 9, IWA Task Group on Mathematical Modelling IWA Publishing, London, UK.

Li, W. X.; Zhang, X. X.; Wu, B.; Sun, S. L.; Chen, Y. S.; Pan, W. Y.; Zhao, D. Y.; Cheng, S. P., (2008) A comparative analysis of environmental quality assessment methods for heavy metal-contaminated soils, Pedosphere, 18 (3), 344-352.

Lee, C. C.; Lin, S. D., (1999). Handbook of Environmental Engineering Calculations, McGraw-Hill Inc, New York, USA, 1.545-1.551.

Middleton, A. C.; Lawrence, A. W., (1974). Cost optimization of activated sludge systems., Biotechnol. Bioeng., 16 (6), 807-826.

Mino, T.; San Pedro, D. C.; Yamamoto, S.; Matsuo, T., (1997). Application of the IAWQ activated sludge model to nutrient removal process., Water Sci. Tech., 35 (8), 111-118.

Mohanan, S.; Maruthamuthu, S.; Muthukumar, N.; Rajesekar, A.; Palaniswamy, N., (2007). Biodegradation of palmarosa oil (green oil) by *Serratia marcescens*., Int. J. Environ. Sci. Tech., 4 (2), 279-283.

Oda, T.; Yano, T.; Niboshi Y., (2006). Development and exploitation of a multipurpose CFD tool for optimisation of microbial reaction and sludge flow., Water Sci. Tech., 53 (3), 101-110.

Okubo, T.; Kubo, K.; Hosomi, M.; Murakami, A., (1994). A knowledge-based decision support system for selection small-scale waste-water treatment processes., Water Sci. Tech., 30 (2), 175-184.

Panjeshahi, M. H.; Ataei A., (2008). Application of an environmentally optimum cooling water system design in water and energy conservation., Int. J. Environ. Sci. Tech., 5 (2), 251-262.

Qin, L. Y., (1989). Biological treatment of wastewater, Tongji University Press, Shanghai, China, 55-71.

Rashidinejad, F.; Osanloo, M.; Rezai, B., (2008). An environmental oriented model for optimum cut-off grades in open pit mining projects to minimize acid mine drainage., Int. J. Environ. Sci. Tech., 5 (2), 183-194.

Reichert, P.; Von Schulthess, R.; Wild, D., (1995). The use of AQUASIM for estimating parameters of activated sludge models., Water Sci. Tech., 31 (2), 135-147.

Ribas, F.; Rodriguez-Roda, I.; Serrat, J.; Clara, P.; Comas, J., (2008). Development and implementation of an expert system to improve the control of nitrification and denitrification in the Vic wastewater treatment plant., Environ. Tech., 29 (5), 583-590.

Rivas, A.; Irizar, I.; Ayesa, E., (2008). Model-based optimisation of wastewater treatment plants design., Environ. Modell. Softw., 23 (4), 435-450.

Souza, S. M.; Araújo, O. Q. F.; Coelho, M. A. Z., (2008). Model-based optimization of a sequencing batch reactor for biological nitrogen removal, Bioresource Tech., 99 (8), 3213-3223.

Sun, S. L.; Cheng, S. P.; Wan, Y. Q.; Zhang, X. X.; Shi, L.; Zhu, C. J.; Yu, H. X., (2005). Pilot regulation of MnP-SA to treat PTA wastewater, J. Environ. Sci., 17 (3), 375-378.

Suzuki, Y.; Takahashi, M.; Haesslein, M.; Seyfried, C. F., (1999). Development of simulation model for a combined activated-sludge and biofilm process to remove nitrogen and phosphorus., Water Environ. Res., 71 (4), 388-397.

Templeton, M. R.; Hofmann, R.; Andrews, R. C.; Whitby, G. E., (2006). Biodosimetry testing of a simplified computational model for the UV disinfection of wastewater., J. Environ. Eng. Sci., 5 (1), 29-36.

Von Sperling, M., (1994). Calibration of poorly identifiable systems - Application to activated sludge model., J. Environ. Eng-ASCE, 120 (3), 625-644.

Woodard, F., (2001). Industrial waste treatment handbook. Butterworth-Heinemann Inc, Woburn, USA, 260-261.

Zeidan, A.; Rohani, S.; Bassi, A.; Whitting, P., (2003). BioSys: Software for wastewater treatment simulation., Adv. Eng. Softw., 34 (9), 539-549.

Zhang, X. X.; Cheng, S. P.; Sun, S. L.; Zhu, C. J.; Zhao, D. Y., (2006a). A pilot study on the biological treatment of PTA wastewater with functional strain Fhhh., Environ. Eng. Sci., 23 (6), 1065-1072.

Zhang, X. X.; Cheng, S. P.; Wan, Y. Q.; Sun, S.L.; Zhu, C. J.; Zhao, D. Y.; Pan, W. Y., (2006b). Degradability of five aromatic compounds in a pilot wastewater treatment system, Int. Biodeter. Biodegr., 58 (2), 94-98.

Zhang, X. X.; Wan, Y. Q.; Cheng, S. P.; Sun, S. L.; Zhu, C. J.; Li, W. X.; Zhang, X. C.; Wang, G. L.; Lu, J. H.; Luo, X.; Gu, J. D., (2005). Purified terephthalic acid wastewater biodegradation and toxicity., J. Environ. Sci., 17 (5), 876-880.

AUTHOR (S) BIOSKETCHES

Zhang, X. X., Assistant professor, State Key Laboratory of Pollution Control and Resource Reuse, School of The Environment, Nanjing University, Nanjing 210093, China. Email: *zhangxx@nju.edu.cn*

Zhao, D. Y., Ph.D. student, State Key Laboratory of Pollution Control and Resource Reuse, School of The Environment, Nanjing University, Nanjing 210093, China. Email: *zhaodayong125016@gmail.com*

Wang, Z. X., Ph.D. student, State Key Laboratory of Pollution Control and Resource Reuse, School of The Environment, Nanjing University, Nanjing 210093, China. Email: *wzx1972@yahoo.com.cn*

Wu, B., Ph.D. student, State Key Laboratory of Pollution Control and Resource Reuse, School of The Environment, Nanjing University, Nanjing 210093, China.Email: *pandanju@gmail.com*

Li, W. X., Professor, Nanjing Institute of Environmental Sciences, State Environmental Protection Administration of China, Nanjing 210042, China. Email: *lwxletter@yahoo.com.cn*

Cheng, S. P., Professor, State Key Laboratory of Pollution Control and Resource Reuse, School of The Environment, Nanjing University, Nanjing 210093, China. Email: *ebzxx0408@yahoo.com.cn*

This article should be referenced as follows:

Zhang, X. X.; Zhao, D. Y.; Wang, Z. X.; Wu, B.; Li, W. X.; Cheng, S. P., (2008). Environmental biological model based on optimization of activated sludge process. Int. J. Environ. Sci. Tech., 6 (1), 69-76.