Study on Modelling and Simulation of Wastewater Biochemical Treatment Activated Sludge Process

X.J. Du[1,*], X.H. Hao[1], H.J. Li[1,2] and Y.W. Ma[1,2]

[1]College of Electrical and Information Engineering, Lanzhou University of Technology, Lanzhou, P.R. China
[2]Key Laboratory of Gansu Advanced Control for Industrial Processes, Lanzhou, P.R. China

*Corresponding author: Fax: +86 931 2973902; Tel: +86 931 2973506; E-mail: 8843079@qq.com

International Water Association and the European Co-operation in the field of Scientific and Technical Research (COST) action 682/624 develop the activated sludge wastewater treatment Benchmark simulation model No. 1 (BSM1). The main purpose is to establish an activated sludge process control program development platform. This paper describes how to use Matlab M-files to establish BSM1 and then gives out the results of the model simulation.

Key Words: Modeling, Simulation, Activated sludge process, Benchmark simulation model No. 1, Wastewater treatment.

INTRODUCTION

Being a basic and main method in wastewater treatment, the activated sludge process (ASP) aims to achieve, at minimum costs, a sufficiently low concentration of biodegradable matter in the effluent together with minimal sludge production. To do this, the process has to be controlled and the key problem is to establish an accurate model. In recent decades, the mathematical models of the activated sludge wastewater treatment process have been fully developed, there are the early and more applied model ASM1 (activated sludge model No. 1)[1] to improved models ASM2[2], ASM2d[3] and ASM3[4]. For a complete activated sludge wastewater treatment process, it includes a secondary settler after a biological treatment unit with the activated sludge. Takács double exponential settling velocity model[5] is the internationally recognized mathematical model of the secondary settler. With the successful establishment of these mathematical models, the process control and simulation works will be done easily.

Simulations provide a cost-effective means for the evaluation of control strategies, but the unlimited number of simulation permutations makes the need for a standardized protocol very important if different strategies (and different simulation results) are to be compared. Each control strategy must be simulated under the same conditions to ensure unbiased comparisons. Validation of the computer simulations is difficult without supporting experimental or full-scale data, but the value of the work is enhanced through the use of accepted activated sludge models. Because appropriate simulation tools for the activated sludge process are available this approach has numerous advantages, but still there is a need for a standardized procedure.

The idea to produce a standardized 'simulation benchmark' was first devised and developed by the first IAWQ task group on respirometry-based control of the activated sludge process[6,7]. This original benchmark was subsequently modified by the European Co-operation in the field of Scientific and Technical Research (COST) 682/624 actions in co-operation with the second International Water Association respirometry task group[8,9]. In an attempt to standardize the simulation procedure and the evaluation of all types of control strategies, the two groups have jointly developed a consistent simulation manual[10].

EXPERIMENTAL

Benchmark simulation model No. 1 overview

Plant layout: BSM1 plant design is comprised of five reactors in series with a 10-layer secondary settler. Fig. 1 shows a schematic representation of the layout.

Benchmark simulation model No. 1 layout combines nitrification with predenitrification. The plant was designed to treat an average flow of 2×10^4 m^3 d^{-1} with an average biodegradable COD concentration of 300 g m^{-3}. The plant consists of a 5 bioreactors (5999 m^3 total) and a 10 layers secondary settler (6000 m^3). For a sludge concentration of 3 kg m^{-3}, this corresponds to a sludge load of *ca.* 0.20 kg (BOD$_5$) kg^{-1}(sludge) d^{-1} which is sufficient at 15 ºC, to ensure that the effluent composition will be sensitive to the applied control strategy.

Process models: To increase the acceptability of the results, two internationally accepted process models were chosen. The IAWQ's ASM1 was chosen as the biological process model[1]
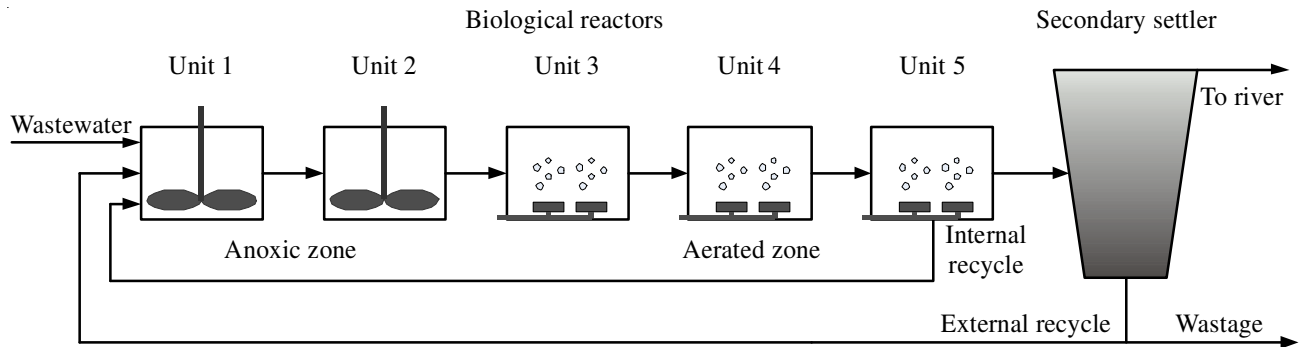
Fig. 1. Schematic representation of Benchmark simulation model No. 1 configuration

and the double-exponential settling velocity function[5] was chosen as a fair representation of the settling process model.

In ASM1, 13 state variables are used to track the fate of biodegradable and unbiodegradable, soluble and insoluble, carbon and nitrogen-based material, including two functional groups (heterotrophs and autotrophs) through the system[1].

As with the biological process model, international acceptability was the over riding criteria for choosing a settling model. The double-exponential settling velocity function[5], shows as eqn. 1, is based on the solids flux concept and is applicable to both hindered and flocculent settling conditions[5].

$$v_{sj} = v_0 e^{-\eta_h X^*_j} - v_0 e^{-r_p X^*_j}$$
$$0 \leq v_{sj} \leq v'_0$$
(1)

where: v_{sj} (m d^{-1}) is the settling velocity in layer j; X^*_j (g m^{-3}) is the suspended solids concentration in layer j, subject to the limiting condition that $X^*_j = X_j - X_{min}$; X_j; (g m^{-3}) is the suspended solids concentration in layer j; X_{min} (g m^{-3}) is the minimum attainable suspended solids concentration calculated from $X_{min} = f_{ns} \cdot X_{in}$; X_{in} (g m^{-3}) is the mixed liquor suspended solids concentration entering the settling tank; f_{ns} is the non-settleable fraction.

Three influent file with disturbances (dry weather, a storm event and a rain event) can be downloaded from the website http://www.benchmarkWWTP.org/[11]. The data are given in the following order:

time S_I S_S X_I X_S X_{BH} X_{BA} X_P S_O S_{NO} S_{NH} S_{ND} X_{ND} S_{ALK} Q_0

Each file contains two weeks of dynamic weather influent data that can be used in simulation work.

Progamme in Matlab M-files to establish the BSM1 model: A number of parameters are used in this paper has been defined in the following Table-1. The table lists the parameters, giving a description of each parameter, an associated symbol and the parameter units.

Programme the model is to write out the differential formulas of the corresponding variable in all 5 reactors and the secondary settler based on the first principle. There are 145 formulas include 65 of the 5 reactors and 80 of the secondary settler and they can be described in state space style to reduce the amount of the formulas.

Establish the bio-reactors model: The model is established in proper order according to sequence of the wastewater flow in the 5 reactors, where the 13 components are in the

TABLE-1
PARAMETERS AND ITS DESCRIPTION AND UNITS IN THIS PAPER

	Parameter	Description	Unit
Bio-reactor	Q_0	Wastewater flow rate	m^3 d^{-1}
	Q_f	Flow rate from the 5th reactor to the secondary settler	m^3 d^{-1}
	Q_a	Internal recycle flow rate	m^3 d^{-1}
	Z_0	A vector of the wastewater variables concentration	–
	V	Volume of reactor tank	M^3
	r	Observed conversion rates	g m^{-3} d^{-1}
	x(i), i = 1 to 13	Variables come out from the 1st reactor	g m^{-3}
	x(i), i = 14 to 26	Variables come out from the 2nd reactor	g m^{-3}
	x(i), i = 27 to 39	Variables come out from the 3rd reactor	g m^{-3}
	x(i), i = 40 to 52	Variables come out from the 4th reactor	g m^{-3}
	x(i), i = 53 to 65	Variables come out from the 5th reactor	g m^{-3}
	dx(i), i = 1 to 65	Differential of the corresponding variable in all 5 reactors	–
Secondary settler	Q_e	Plant exit flow rate	m^3 d^{-1}
	Q_r	External recycle flow rate	m^3 d^{-1}
	Q_w	Wastage flow rate	m^3 d^{-1}
	x(i), i = 66 to 75	Variables of the total particulate matter from bottom to top	g m^{-3}
	x(i), i = 76 to 145	Variables of the soluble matter in each layer	g m^{-3}
	dx(i), i = 66 to 145	Differential of the corresponding variable in all 10 layers	-
	v_{up}	Up-flow velocity	m d^{-1}
	v_{dn}	Down-flow velocity	m d^{-1}
	X_f	Concentration of the total particulate matter	g m^{-3}

order of the influent file form. For example, the 1st component come out from the 1st reactor is S_I (coded in 1), then the last is S_{ALK} (coded in 13) and so on, the 13th component come out from the 5th reactor is S_{ALK} (coded in 65). X_f, variables of the total particulate matter, from the bottom to the top layer in the secondary settler are coded in 66 to 75 and the variables of the soluble matter in each layer are coded in 76 to 145 in layer sequence from the bottom to the top.

Use the 8 processes and 13 components' reaction rates to write out the 65 differential formulae like:

$$dx(i) = (Q(x(i)-x(i+13)))/V+r_j,$$
$$i = 1,2,...52 \text{ and } j = 1,2....13 \qquad (2)$$

Special case for the 1st reactor because of the Q_r and Q_a are both input in it with Q_0, so the differential formula of the first component S_I in the first reactor should be wrote in:

$$dx(1) = (Q_0Z_0(1) + Q_ax(53) + Q_rx(76) -$$
$$(Q_0 + Q_a + Q_r)x(1))/V_1 + r_I \qquad (3)$$

where: 76 is the first component S_I in the bottom layer of the settler.

When the wastewater flow into the 2nd reactor, the differential formula of the component S_I is:

$$dx(14) = ((Q_0 + Q_a + Q_r)(x(1)-x(14))/V_2 + r_I \qquad (4)$$

For the other components in reactor 1, the formulae are similar to eqns. 3 and 4.

Establish the secondary settler model: The settler is subdivided into 10 layers, there are 8 components in each layer, 7 soluble components (same to the 5 reactors) and one component X_f (total particulate matter). So, there are 8 formulae in each layer have to write out and a total of 80 formulas for all the layers. The total particulate matter component X_f is calculated in:

$$X_f = 0.75(X_{I5} + X_{S5} + X_{BH5} + X_{BA5} + X_{ND5}) \qquad (5)$$

The differential formulae will be easily to write out according to Takacs *et al.*[5] and Copp *et al.*[12]. For example, the 66th variable of the model is the X_f in the bottom layer and it should be wrote in:

$$dx(66) = (v_{dn}(x(67) - x(66)) + \min(J_S(2),J_S(1)))/z_m \qquad (6)$$

where: $J_S(\bullet)$ is the solid flux due to gravity and z_m is the height of each layer m.

For the other components, the formulae are similar to eqn. 6.

At last, use the initial values (dynamic load averages to be used as inputs during the stabilization period posted into do model initialization[12].

RESULTS AND DISCUSSION

Simulation results: Firstly, we should do the 100 days steady state simulation of the model and then compare the results with the the reference values in Table-1 in the website[11] until the values are closed up to Table-1. After that, we can do the dynamic simulation work in the next.

In this paper, odd15s was choose for solving the dynamic simulation. With choosing the dry weather influent file simulated into the dynamic simulation, Fig. 2 shows the results of that the K_La (oxygen transfer coefficient) with sine wave excitation:
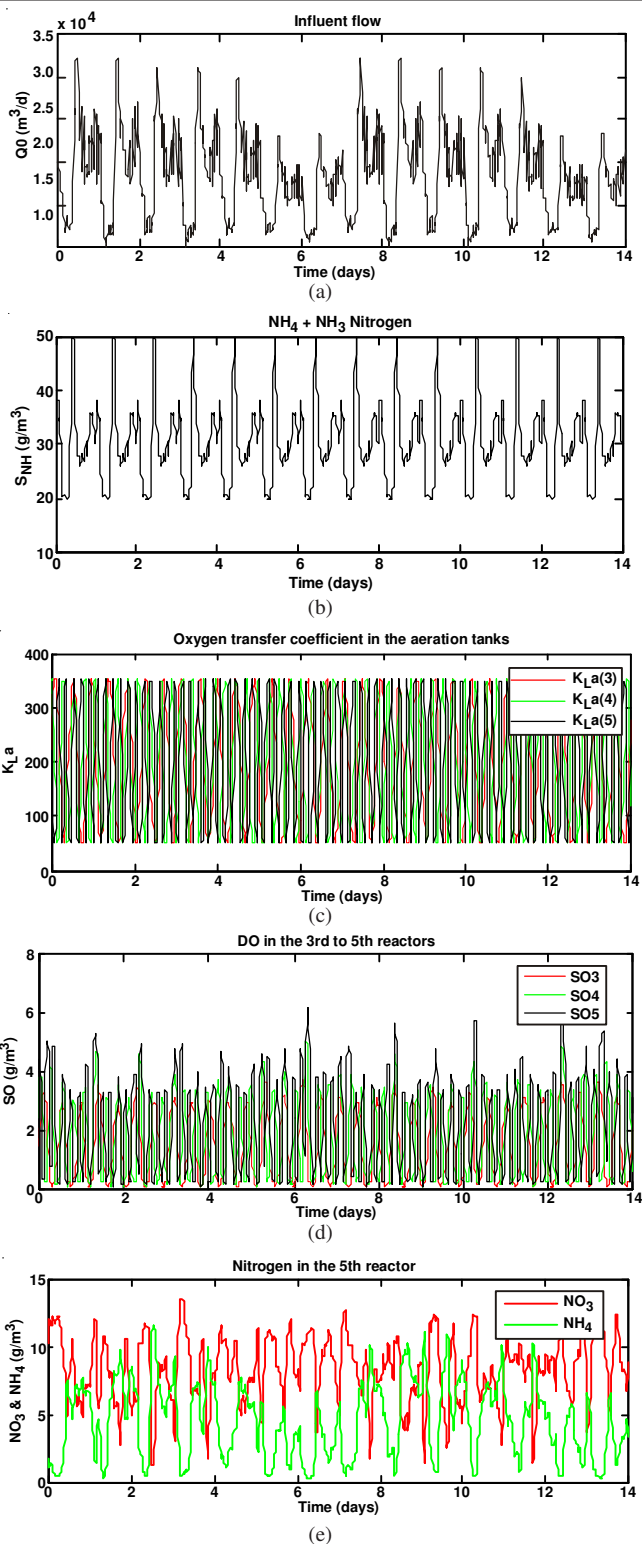

Fig. 2.   Simulation results: (a) shows the dynamic flow rate of Q_0; (b) shows the nitrate and nitrite nitrogen, $NH_4^+ + NH_3$ nitrogen concentration (S_{NH}) in the influent; (c) shows the K_La in the three aeration tanks; (d) shows the DO concentration in the three aeration tanks; (e) shows the results of S_{NO5} and S_{NH5} influenced by the K_La with sine wave excitation

$$K_La(3) = 200 + 150\sin(0.15k)$$
$$K_La(4) = 200 + 150\sin(0.25k + 0.75)$$
$$K_La(5) = 100 + 150\sin(0.35k + 1.5) \qquad (7)$$

Fig. 3 shows the results of that the K_La (oxygen transfer coefficient) with random white noise excitation:

$$K_La(3) = 100 + 150 \, rand(1)$$
$$K_La(4) = 100 + 150 \, rand(1) \qquad (8)$$
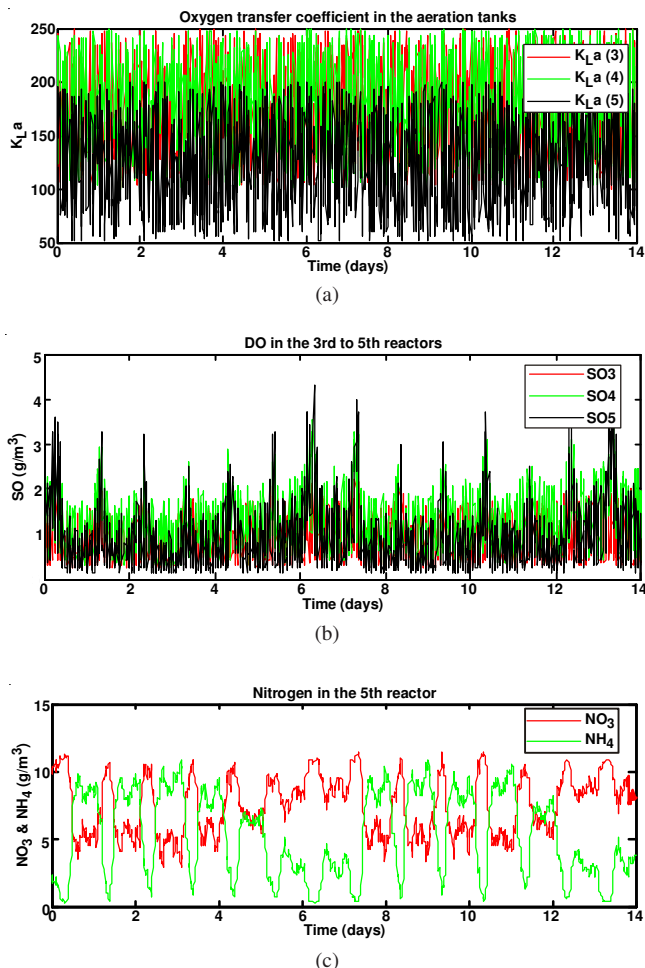$$K_La(5) = 50 + 150 \, rand(1)$$

(a)

(b)

(c)

Fig. 3. Simulation results: (same influent file to Fig. 2): (a) shows the K_La in the three aeration tanks; (b) shows the DO concentration in the three aeration tanks; (c) shows the results of S_{NO5} and S_{NH5} influenced by the K_La with random white noise excitation

Conclusion

The key for an ideal control performance is to establish a good and accurate model. This paper establishes BSM1 simulation model by read the description[12] carefully, the simulation results show that the modeling work is successful. These data obtained from the simulation model can be used for more control method based on model as the input and output. Also, they can be used to do cluster analysis for classification, pattern recognition, model reduction and optimization.

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