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Application of Biowin to Biological Nutrient Removal (Bnr) Modeling

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ABSTRACT. *Biological nutrient removal (BNR) is required for many wastewater treatment plants (WWTPs). Due to the complexity of BNR processes in activated sludge system, mathematical models of the BioWin General Model are introduced to evaluate and optimize system configurations for BNR. Simulators of BioWin are real computer programs for BNR system design and optimization. A case of application of BioWin to BNR modeling in Beijing Wastewater Treatment Plant A (BWTPA, China) was studied to verify the reliability of the simulator.*

KEYWORDS: *Biowin; Biological nutrient removal (bnr); Modeling*

1. Introduction

As a major biological treatment component, biological nutrient removal (BNR) is applied in many wastewater treatment plants (WWTPs). Due to the complexity of BNR processes, mathematical models have been developed for new design evaluation, optimization, and troubleshooting (WEF et al. 2006). The best-known models for activated sludge systems are Activated Sludge Models (ASM1, ASM2, ASM2d, ASM3) developed by the International Water Association (IWA) and the BioWin General Model developed by EnviroSim Associates Ltd. (Henze et al. 2000, EnviroSim 2007). Among these models, the ASM2d model and the BioWin General Model are very successful and widely used for BNR modeling.

Mechanistic models incorporate mathematic expressions representing the biological processes while simulators solve the IWA ASM models using real computer programs. BioWin, GPS-X, EFOR, SimWorks are some typical computer software for BNR modeling (WEF et al. 2006). The BioWin software using the BioWin General Model related to the IWA ASM models has proved to be the most popular because it is user-friendly and so has been applied in the WWTPs worldwide (Hu et al. 2008a and 2008b).

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The objective of the project was to explore the application of BioWin simulator for BNR modeling in activated sludge system in WWTPs. Specifically, a case of the application of the BioWin software to the BNR modeling was introduced to explore the effect of simulation. It was reported that the simulator for BNR modeling was very promising by comparing the simulated results and experimental data in Beijing Wastewater Treatment Plant A (BWTPA, China).

2. Biowin Models and Software for Bnr Processes

The BioWin General Model is very powerful because it has 50 state Variables and 60 process expressions describing the biological processes occurring in activated sludge and anaerobic digestion systems and also considering several chemical precipitation reactions and gas-liquid transfer behavior for six gases (EnviroSim, 2007). The BioWin Activated Sludge Model is the major part of the BioWin General Model considering the BNR activated sludge system. The BioWin Activated Sludge Model includes seven functional categories in the BioWin General Model. The following is a summary of the functional categories from the Process Model Formulation (EnviroSim 2007): Growth and Decay of Ordinary Heterotrophic Organisms, Growth and Decay of Methylotrophs, Hydrolysis, Adsorption, Ammonification and Assimilative Denitrification, Growth and Decay of Ammonia Oxidizing Biomass (AOB)

Growth and Decay of Nitrite Oxidizing Biomass (NOB), Growth and Decay of Anaerobic AMMonia Oidizers (ANAMMOX), Growth and Decay of Phosphorus Accumulating Organisms (PAOs). Furthermore, Petersen et al. (2002) summarized the major steps for model calibration including: (1) information collection (2) organizing intensive sampling campaigns, (3) lab analysis for characterization of wastewater, (4) defining model structure followed by parameter adjustment to obtain a good fit between predicted value and measured value.

As for each BNR activated sludge system model (including the general model), Hu et al. (2007a) proposed the following procedure: (1), Obtain System design and operating parameters from the reported data; (2), Determine wastewater characteristic parameters; (3), Calibrate the maximum specific growth rate of nitrifiers (μ_{NIT}); (4), Take the values for the kinetic and stoichiometric parameters from Hu et al. (2007a and 2007b) as the starting point but the two values of the anoxic reduction factor (η_H for OHOs and η_H for PAOs) need calibration.

Additionally, in the BioWin General Model, there are 246 model parameters, which are all considered to be effective (Hu et al., 2008a). In the BioWin Activated Sludge Model, 78 kinetic parameters and 54 stoichiometric coefficients are included and most of them are relatively stable and the default values in the BioWin Activated Sludge Model are from the recent and authoritative literature or calibrated parameters from full-scale WWTPs. Therefore, in the real simulation in WWTPs only a few parameters need to be calibrated, i.e. maximum specific growth rates for heterotrophs, for OHOs and for PAOs (Shen et al. 2009, Hu et al. 2008a and 2008b). The task of the Bio Win Activated Sludge Model Calibration should be focused on

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the wastewater characterization in WWTPs and the assessment of monitoring data; fortunately, the task has been standardization in North America so that the mathematical simulation will be a routine engineering tool in WWTPs (Hu et al. 2008a).

To identify the most sensitive parameters in the Bio Win Activated Sludge Model, Liwarska-Bizukojc and Biernacki (2010) found 17 influential parameters in the BioWin Activated Sludge Model through sensitivity analysis with two different measures of sensitivity (the normalized sensitivity coefficient and the mean square sensitivity measure). It is also proved that half of the 17 influential parameters have relationship with the growth and decay of phosphorus accumulating organisms (PAOs). Comparatively, using a process engineering based approach instead of a sensitivity analysis-based approach, Veldhuizen et al. (1999) found 3 out of the 60 default parameters should be changed approximately 40% to calibrate the IWA ASM2 model in Holten WWTP (HWWTP, Netherlands) to achieve biological nitrogen and phosphorus removal. However, in the case, the IWA ASM2 model was used along with a metabolic model for bio-P removal in the simulator SIMBA 3.0 (based on MATLAB/SIMULINK) because the bio-P removal process was not well-understood in 1999.

To meet stringent nutrient requirements, full scale calibration and verification of process models are highly demanded. Latimer et al. (2009) calibrated some important parameters such as the nitrite half saturation values ($K_{s,NOB}$ and $K_{NO2,OHO}$) for both NOB growth and OHO denitrification, relating to the utilization of nitrite when nitrification and denitrification are modeled as two-step processes for the Neuse River WWTP (NRWWTP, USA) modeling in the one-step (BioWin 2) model or in the two-step (BioWin 3.0.1) model.

3. Case Study of the Application of Biowin to Bnr Modeling: Beijing Wastewater Treatment Plant a

The application of BioWin simulator includes two steps. The first step is to specify information for the various elements in the reactor configuration and the flow scheme. The second step is to perform mass balances over each reactor (zone). Using mass balances, the behavior of activated sludge systems for BNR can be characterized when a set of simultaneous state equations are solved (EnviroSim, 2011a; WEF et al. 2006). As an environmental simulator, BioWin can be used for BNR modeling. Some steps should be taken including the specification of the reactor configuration and the flow scheme and then the performance of mass balance over each reactor (or reactor zone) (WEF et al. 2006). In the BioWin Activated Sludge Model, there are seven functional categories related to BNR processes and some other functional modules. The BioWin simulator suite has two modules: a steady-state module and an interactive dynamic simulator (EnviroSim 2011a and 2011b). They perform system analysis based on constant influent loading or time varying inputs.

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Ubay-Cokgor et al. (2005) evaluated the performance of the Tyson Foods wastewater treatment plant for nitrogen removal using the BioWin program. the BioWin simulation results and comparison of the predicted and measured effluent concentrations are summarized in Table 1 and 2. As can be seen, the BioWin program could reasonably model the performance of nitrogen removal in the WWTP.

Table 1 Summary of Biowin Simulation Results (from Ubay-Cokgor et al. 2005)

Configuration	Nitrate Recycle	NH_4-N	Soluble organic N	Soluble TKN mg/L	NO_3-N	Total nitrogen	Soluble COD
Current WWTP		0.47	0.73	1.19	57.6	60	52.3
Option 1 RAS = 2.25Q	1Q	0.37	0.73	1.12	39.1	41.3	52
	2Q	0.39	0.73	1.12	31.6	33.8	52
	4Q	0.40	0.73	1.13	22.9	25.2	52
Option 2 RAS = 1Q	1Q	0.40	0.73	1.13	54.8	57.1	52
	2Q	0.40	0.73	1.13	41.1	43.4	52
	4Q	0.40	0.73	1.13	27.5	29.8	52

Table 2 Comparison of The Predicted and Measured Effluent Concentrations (from Ubay-Cokgor et al. 2005)

Parameter	Measured concentration	Predicted concentration
Ammonia-N	0.28	0.47
Nitrate-N	46.3	57.6
Soluble organic-N	N/A	0.73
Total nitrogen	57.3	60.0

As for the BNR modeling, a case was reported by Shen et al. (2009) on the application of BioWin to BNR removal modeling in Beijing Wastewater Treatment Plant A (BWTPA, China). Details are described as follows.

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3.1 Facility Design

Shen et al. (2009) reported a case of the application of BioWin to BNR removal modeling in Beijing Wastewater Treatment Plant A (BWTPA, China). BWTPA was designed to treat domestic wastewater with an average daily flow of 600 ML/D, using the A^2/O process configuration as the main biological treatment component. The aerobic zone has four passes. In the secondary treatment, primary effluent is distributed into 16 parallel bioreactors each having the same configuration. Hydraulic retention time (HRT) and volume of each zone in each bioreactor are shown in Table 3.

Table 3 Hrt and Volume of Each Tank in Each Bioreactor (from Shen et al. 2009)

Item	Anaerobic	Anoxic	Aerobic	Second clarifier
HRT/h	1	3	6.6	6
V/m^3	1573	4719	10381	9437

BNR configuration in BWTPA is shown in Fig 1.

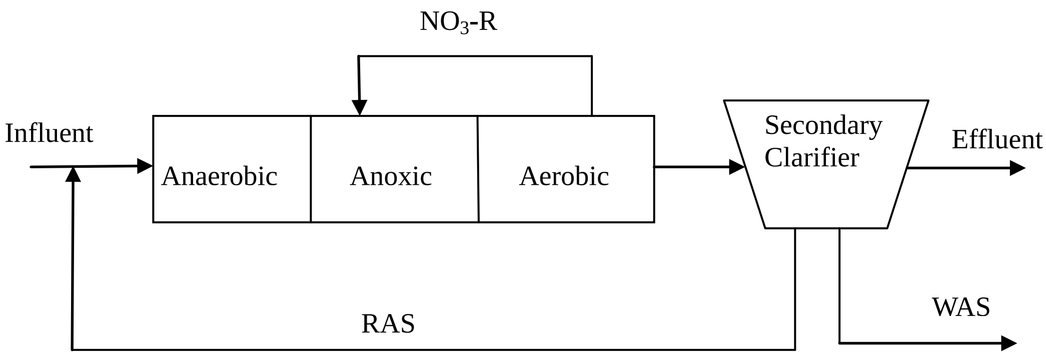

Figure. 1 A^2/O process configuration for BNR at BWTPA

Using the A^2/O system, simultaneous biological nitrogen and phosphorus removal can be achieved in the BWTPA with biological phosphorus removal in the anaerobic zone, nitrate removal in the anoxic zone, and nitrification in the aerobic zone.

3.2 Mathematical Model for the Bnr in the Bwtpa

Based on the facility design and actual operation in the BWTPA, the ASDM model, pH balance model, and gas transfer model were selected as the mathematical model for the BNR modeling.

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3.2.1 Developing Data for Model Input

Developing data for the BNR modeling Input including operational parameters in practice and other data from monitoring or literature are as follows (Shen et al. 2009):

Operational parameters:

Q_r = 75ML/D

Q_R = 37.5ML/D

Q_W = 0.4ML/D

T = 20°C

In the aerobic zone, the air flow rates for the first two passes are 3000 m^3/h and 2800 m^3/h respectively, the DO concentrations for the last two passes are set as 2.5 mg/L and 2 mg/L. Other data from monitoring or literature are listed in Table 4.

Table 4 Values for Influent Components (from Shen et al. 2009)

Symbol	Name	Value	Unit	Note
F_{bs}	Readily biodegradable	0.27	mgCOD/ mg of totalCOD	Default
F_{ac}	Acetate	0.15	mgCOD/ mg of readily biodegradable COD	Default
F_{xsp}	Non-colloidal slowly biodegradable	0.75	mgCOD/ mg of slowly degradable COD	Default
F_{us}	Un-biodegradable soluble	0.09	mgCOD/ mg of total COD	Literature
F_{up}	Unbiodegradable particulate	0.08	mgCOD/ mg of total COD	Default
F_{na}	Ammonia	0.81	$mgNH_3$-N/ mgTKN	Determined
F_{nox}	Particulate organic nitrogen	0.25	mgN/ mg Organic N	Default
F_{nus}	Soluble unbiodegradable TKN	0.02	mgN/ mgTKN	Default
F_{upN}	N:COD ratio for Unbiodegradable particulate COD	0.035	mgN/ mgCOD	Default
F_{PO4}	Phosphate	0.75	$mgPO_4$-P/ mgTP	Determined
F_{upP}	P:COD ratio for Unbiodegradable particulate COD	0.011	mgP/ mgCOD	Default

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3.2.2 Calibration

Since current mathematical simulation model is not perfect due to the complex biological nutrient removal systems in WWTPs, calibration of the BioWin Activated Sludge Model is required. Using the default values suggested in the Biowin model is very helpful and relatively reliable because the default parameters are best from the latest research publications and calibration to full plant data (Shen et al. 2009). Therefore, the calibration effort is greatly reduced. However, for a specific WWTP, wastewater characteristics are subject to change, some parameters should be calibrated in order to simulate more accurately (Hu et al. 2008a and 2008b). Among these parameters, the nitrifier growth rate should be given more consideration due to its high variability (WEF et al. 2006).

The calibration of the BioWin Activated Sludge Model in the BWTPA was focused on the maximum specific growth rates for heterotrophs and autotrophs and the yield for heterotrophs.

Based on the field tests of respiration rate of activated sludge in the BWTPA, the maximum specific growth rate of heterotrophs was calibrated as 1.5 d^{-1} (the default value is 3.2 d^{-1}); the maximum specific growth rate of autotrophs was calibrated as 0.46 d^{-1}(the default value is 0.9 d^{-1}); and the yield for heterotrophs was calibrated as 0.64 (the default value is 0.67) (Shen et al, 2009).

3.2.3 Modeling Verification

A sample program was conducted during the BNR modeling using the BioWin Activated Sludge Model in the BWTPA. Based on the 14-day continuous field tests, the influent wastewater characterization in the biological treatment units in the BWTPA was listed in Table 5.

Table 5 Hourly Influent To the Biological Treatment Units in the Bwtpa (from Shen et al, 2009)

Time	Flowrate	COD	NH_4-N	OPO_4
00:00	1850	305	45.2	4.4
01:00	1903	306	43.7	4.0
02:00	1889	305	44.2	4.3
03:00	1867	309	43.8	4.3
04:00	1772	299	44.1	4.2
05:00	1450	298	42.7	4.3
06:00	1080	304	42.2	4.2
07:00	1020	298	41.2	4.6
08:00	1046	309	40.4	4.4
09:00	1262	295	40.3	4.2
10:00	1331	296	40.4	4.2
11:00	1760	280	39.3	4.0
12:00	1749	288	40.9	4.0

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13:00	1817	294	43.3	3.8
14:00	1855	313	44.9	4.2
15:00	1845	320	46.2	4.2
16:00	1859	319	49.3	4.4
17:00	1864	299	47.3	4.3
18:00	1841	300	46.5	4.2
19:00	1733	304	47.3	4.3
20:00	1693	307	46.5	4.3
21:00	1645	313	46.2	4.2
22:00	1829	312	46.2	4.1
23:00	1842	311	45.2	4.2

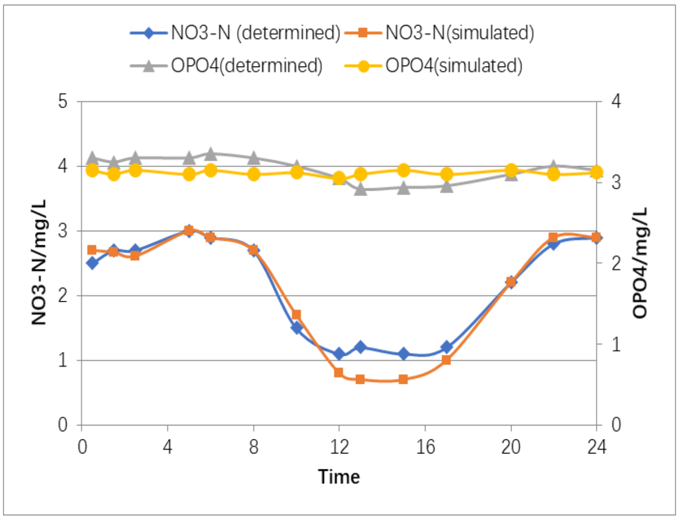

Figure.2 Comparison of Simulated and Determined Results from Bwtpa. (source: Shen et al, 2009)

After the data input, the simulation was conducted using the BioWin simulator. The simulated results of the effluent NH_3-N and OPO_4 were comparable with the real experimental data. As shown in Fig 2, the simulation applying the BioWin simulator to the BNR modeling in the BWTPA was pretty good. Therefore, the case study verified the reliability of the BionWin used for the BNR modeling in BWTPA.

4. Conclusion

Biological nutrient removal (BNR) as one of the most important treatment components, is required in all the WWTPs. Due to the complex processes for nitrogen and phosphorus removal, various process configurations are developed to

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improve the BNR removal efficiencies. The BioWin Activated Sludge Model as well as ASM2d can achieve biological nitrogen and phosphorus removal simultaneously in WWTPs. With the fast development of computer technology, some powerful software packages are used to model BNR process. Among them, the BioWin simulator based on the BioWin General Model is a successful one which has been used to simulate activated sludge BNR modeling in WWTPs worldwide. The case of Beijing Wastewater Treatment Plant A (BWTPA, China) has proved that the application of BioWin to the BNR modeling is reliable and comparable with the experimental results. BioWin has promising prospects for the BNR modeling to process design and operational optimization in WWTPs.

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