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SEQUENCING BATCH REACTOR UNIT TREATING REAL WASTEWATER FROM AL-BASRA ELECTRICAL PLANT: MODELING AND INVESTIGATION

RUSUL M. RASHID, SAAD ABU-ALHAIL*, WISAM S. AL-REKABI

Civil Engineering Department, College of Engineering,
University of Basrah, 61004, Basra, Iraq
*Corresponding Author: saad.arab@uobasrah.edu.iq

Abstract

The overall task of this paper is to build a mathematical model based on activated sludge model number one (ASM1) matrix and the optimum sequencing batch reactor (SBR) operational parameters using MATLAB programming language to represent the biochemical phenomena occurring in the SBR process. The proposed model is calibrated and validated using an experimental data was found previously to insure the reliability of the model. The results are showing that the built SBR-model was representative to the biological processes in SBR system very well; whereas the correlation coefficient (*R*) for chemical oxygen demand; NH_4-nitrogen; nitrate-nitrogen and TN were 0.91; 0.97; 0.9 and 0.87 respectively; so it can be used successfully as a learning tool to investigate the response of the system to the variation in the design variables like; volume of SBR reactor; total cycle time; and the influent conditions; SBR-model provided a better description to the dynamic of removal for chemical oxygen demand COD and total nitrogen TN components in SBR system; ASM1 is capable of simulating the biological reactions in SBR systems sufficiently; The proposed fractions for COD components represented the characteristics of local domestic wastewater successfully and they are (20.3; 51.5; 7.6; 13.0; 0.0; 7.2 and 0.0) % for (S_S, X_S, S_I, X_I, X_P, X_{BH} *and* X_{BA}) respectively and The used fractions of TN components represented the local domestic wastewater characteristics successfully and they are (66.5; 5.8; 6.8; 12.5 and 8.4) % for (S_{NH}, S_{ND}, X_{ND}, X_{NI} *and* S_{NI}) respectively.

Keywords: ASM1, Mathematical modelling, Nutrient removal, SBR, SBR A/O/A.

1. Introduction

Indeed, the complexity in activated sludge systems makes it subjected to disturbances due to the large variations in the affecting factors such as inflow rates, organic loads, and temperature. Sometimes the process abruptly loses its stability without a known reasons, which is confirming the importance of applying the operational elements in the design of biological wastewater treatment systems. Therefore, there is a permanent need for better understanding to the process mechanism. One of the most successful ways to fulfil this need is the representation by using modeling process which offers better understanding to the mechanism of process and its performance under various dynamic conditions.

The researchers around the world are worked on different processes to understand the mechanism of pollutant removal from wastewater in SBR systems in order to increase the efficiency of the used process. Zhao et al. [1] developed a hybrid model represent the SBR technology. It is consisted of a neural network (residual model) and simplified model (SPM) based on ASM no.2. Andreottola et al. [2] developed a dynamic SBR simulation model based on ASM1 to simulate the nitrogenous components from beggary wastewater. The main enhancement for ASM1 was dividing the nitrification process in to two sub processes of (Nitritation and Nitratation). The researcher is developing an algorithm for optimizing the SBR cycle length and minimizing the effluent nitrogen concentration. The developed model was calibrated and verified successfully showing the behaviour of nitrification and denitrification processes.

Sung and Moon [3] developed a model for on-line estimation for nutrient removal in SBR system using the artificial neural networks. Bench scale of SBR model has been used for removing both COD and nutrients from wastewater. The network performance was improved by rearranging the structure of the ANN in some way that is representing the changing in the operational conditions during the treatment cycle.

Libelli et al. [4] developed an enhanced process model for SBR system depending on ASM2d with new features that represented in separating the nitrification process in two steps process according to the sequence of (Nitrosomonas – Nitrobacter) oxidation and improving the phosphate accumulating organisms XPAO dynamics which is involving in the (anaerobic-oxic) phosphorus removal process. Calibration process for the developed model was done using experimental data of a bench scale (EBPR) SBR with 6 hr cycle of alternating anoxic-anaerobic-oxic reaction phases.

Hong et al. [5] developed a software sensor using ANN model for estimating the nutrients in the sequencing batch reactor technology utilizing a reliable online measurements of DO; ORP and PH as an input data. A small scale of SBR with 4 L of working volume has been used to collect the experimental data that is needed in this work. The developed software sensor works affectively on municipal wastewater and can be used as a tool to optimize and adjust the phases' interval of sequencing batch reactor operation in a real time.

Nasr et al. [6] worked on modeling a real SBR unit (EL-AGAMY- WWTP) as a case study utilizing the GPS-X simulator to study the performance of the real plant throughout six cases of different periods of filling: reaction and settling phases. The ASM1 was considered as the bio-kinetic model for biological processes; while BOD based influent represented the influent characterization model. The research results showed the rule of denitrification process by anoxic conditions for (nitrate & nitrite)-nitrogen removal. Moreover, denitrification process considers as a successful way to prevent the problem of the filamentous sludge bulking which represent the main problem in EL-AGAMY wastewater; also reducing the total energy required for aeration during the treating cycle time.

Abu-Alhail and Xi [7] built a computer program depending on ASM2d to simulate the performance of five-step continuous flow process which is like SBR Process. They found that the constant of autotrophic growth rate is 2.4 d-1 with coefficient of yield equal to 0.14. Also, the results showed that the heterotrophs; autotrophs and PAO were decreasing in the (An) compartments due to the reaction of lysis while they were increasing in the (Ox) compartments as a result of its growth in aerobic conditions. They also noticed that the quantities of the mentioned organisms were raised when the operational condition is changed from (anaerobic to aerobic) and reduced in the changing from aerobic to anoxic conditions. Man et al. [8] developed a simplified copy of ASM1 for modeling an SBR unit treating industrial wastewater (paper industry effluent).

Therefore, the aim of this study is to build a computer program to simulate the interacting processes occur in the SBR system treating real wastewater from Basra electrical plant depending on (Activated Sludge Model No.1) and the optimum operational conditions which were determined experimentally, using MATLAB simulator for better understanding the biological processes in SBR system in Basra environment.

2. Materials and methods

2.1. SBR plant

The constructed SBR plant which used in this study is shown in Fig. 1, consists of the SBR reactor (vol. 250 litre), air compressor, electrical mixers, three pumps, collecting tank(vol. 500 litre), air flow meter and conduction pipe. All parts were connected to the Aurduino panel program.

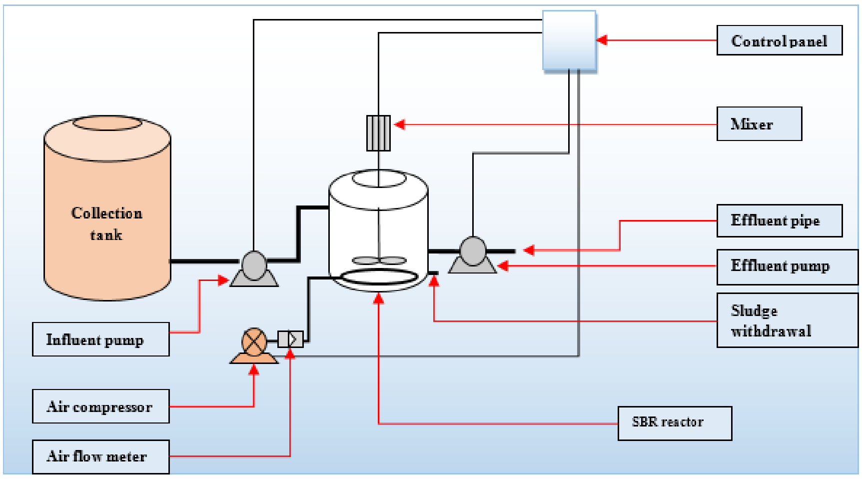


Fig. 1. SBR model with all detail.

2.2. Raw wastewater characteristics

The raw wastewater was collected from Al-Basra electrical plant Accommodation Campus which is used in this study as shown in Table 1.

Table 1. Characteristics of wastewater.

Index	Range	Average
COD (ppm)	235.0-625.0	430.0
TKN (ppm)	30.0-53.0	41.50
NH_4-N (ppm)	20.0-34.0	27.0
NO_3^-.N (ppm)	0.150-0.540	0.350
pH	6.60-7.140	6.870

2.3. Sludge acclimation

The sludge was brought from a Basra central treatment plant. The mixed liquor suspended solid concentration was developed firstly from 1.64 to 2.14 g/l , Then the contents of the reactor was activated on the sequence of anoxic-oxic conditions for more than one month from Feb. 16, 2018 to Mar. 18, 2018. The final mixed liquor suspended solid concentration was 4.82 g/l at the end of activation with Hydraulic retention time 15 and 18 hr.

2.4. Experimental work procedure

To get the best operation parameters for SBR plant the following are guided. Samples were collecting from the septic tank of accommodations campus which is used for the required analyses. At the end of fill phase, samples are taken for doing (MLSS) and (SV) sludge volume tests. Settling phase is following the reaction phase. The reactor contents are allowed to settle for half an hour under suitability conditions. After settling, the Decanting phase is start, in which the clear supernatant is withdrawing and samples were collecting from the outlet supernatant for the required tests. Idle phase is the last one, it represents a period between cycles which used for excess sludge wasting or to adjust phases' time in the next cycles.

3. Mathematical Modelling of SBR System

3.1. Activated sludge model No. 1

The major processes in ASM.1 are growth and decay of microorganisms; organic-nitrogen’s ammonification and hydrolysis. These processes are divided into 8 sub-processes as shown in Fig. 2. They are described briefly using Monod kinetics.

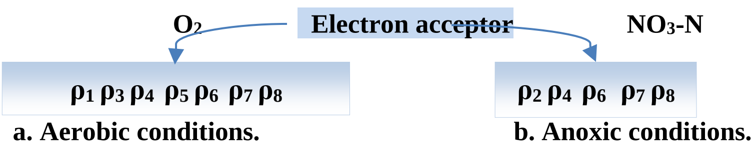


Fig. 2. Schematic diagram for ASM1 processes.

3.2. Modelling assumptions

In order to simplify the biological processes in the SBR system and achieve the specified requirements; some of assumptions were considered; they are**:**

- The biological removal of phosphorus was not taken into account.
- The applied reaction phases are anoxic and oxic steps.
- The concentration of nutrient and microorganisms are homogenous anywhere in the SBR reactor.
- The process of simultaneous nitrification-denitrification (SND) is neglected.
- The settling process is considered to be ideal .
- Typically, there is no removal for the pollutants occur during settling

3.3. Basic equations

The mass balance equation for any system with specified limits is [9]:

Accumulation=inflow mass-outflow mass + mass formed by reaction

The items of inflow and outflow masses are found by the physical characteristics of the process. The formative mass by the reaction is determined by the expression below: $r_i = \sum v_{ij} \rho_j$ where ρ_j is the rate of process for component i .For sequencing batch reactor; the mass balance equation takes the following expression [10]:

$$\frac{dC_i}{dt} = \frac{Q}{V}\left(C_{if} - C_i\right) + r_i$$

For fill phase *tf*: There is no biological reactions are supposed; So, for time interval: $0 < t < t_f$

$$V = V_O + \int_0^{t_f} Q\, dt \;\; ; \frac{dC_i}{dt} = \frac{Q}{V}\left(C_{if} - C_i\right), \text{ and } \frac{dS_O}{dt} = \frac{Q}{V}\left(So_f - So_i\right)$$

For react phase *tr*: The discharge equal zero in batch reactor system; So: V = constant, $\frac{dC_i}{dt} = r_i$.

For special case of oxygen [11]: $\frac{dS_O}{dt} = kla*(S_{Osat}\text{-}S_O) + r_O$

The two reactions terms *ri* and *ro* are specified based on ASM1 matrix

3.4. Auxiliary equations

3.4.1. Oxygen transfer rate coefficient

The coefficient of oxygen transfers rate (K_La) in diffused aeration systems at 20°C can be computed by the following equation [12].

$$K_La = [6.85\times d_{Bh}^{-1.309}\times V_{G0}^{0.926}\times(W^*/H^*)^{-0.488}\times(H^*/h)^{1.623}\times((ps^{0.074}-ps^{-0.436})/ps-1]$$

$$Ps = Pd^*/101.325$$

where *ps* (dimensionless) and *pd** (atm)is the static and atmospheric pressure respectively at the depth of air diffuser.

The two empirical parameters are often used for correcting for process condition called α and θ factors. The value of Alpha factor is varying between (0.3-0.9) for fine bubble diffusers [13]. It is expressed as follows [9]: α = *(KLa) wastewater/(KLa) tap water.* The coefficient of oxygen transfer rate is a temperature dependent as shown below [10]:

$$K_L a\ (T^{\circ}C) = K_L a(20^{\circ}C) \times \theta^{T-20}$$

3.4.2. Dissolved oxygen saturation

For diffused aeration system the saturation dissolved oxygen; is computed by the following equation [12]:

$$S_{O\,sat} = 0.338 \times S_{O\,sat(T\,°C)} \times ((ps^{1.51}-1)/(ps^{0.51}-1)).$$

The oxygen saturation can be computed using [14]:

$$Osat(T°\mathrm{C}) = 14.61996 - 0.40420T + 0.00842T^2 - 0.00009T^3$$

For fresh water, S_{Osat} is corrected using a β factor [15]:

$$\beta = ((S_{O\,sat})\ wastewater)/((S_{O\,sat})\ tap\ water\ )$$

where β can be obtained using the following equation [15]:

$$\beta = 1 - 5.7\times10^{-6} \times TDS$$

β Value ranged from 0.7 to 0.98 with a typical value of 0.95 for wastewater [16].

3.5. Stoichiometric and kinetic parameters

For solving the equations of SBR-model; it is required to specify the value of ASM1 parameters. Initially, the default values of these parameters in ASM1 were used. The values' set at a temperature of 20 °C are selected. Then, SBR-model results shall be evaluated based on field measurements that measured in temperature are varied from the default value. So ASM1 parameters shall be changed in the calibration process to match with our local conditions.

3.6. State variables of ASM.1

The state variables of ASM.1 model are obtained as fractions of TCOD and TKN, respectively [17]. The values of these fractions are derived based on its values in municipal wastewater listed in Tables 2 and 3 while S_{NO} concentration is measured directly.

Table 2. Fractions of COD in raw municipal wastewater [18].

Component	S_S	X_S	S_I	X_I	X_P	X_{BH}	X_{BA}
Fraction %	20.3	51.5	7.6	13.0	0.0	7.2	0.0

Table 3. Total Kjeldahl nitrogen fractions of municipal wastewater [18].

Component	S_{NH}	S_{ND}	X_{ND}	X_{NI}	S_{NI}
Fraction %	66.5	5.8	6.8	12.5	8.4

3.7. Model calibration

In this study, the most important results are those of chemical oxygen demand; nitrate-nitrogen and ammonia-nitrogen. Thus, the calibration process is performed to get the best agreement between simulated and observed data of chemical oxygen demand; nitrate-nitrogen and ammonia-nitrogen. The model's calibration was done manually by running the program many times adopting different values of ASM1 parameters. The adopted values are selected within the ranges in literatures. The calibration process is performed by changing the value of one parameter and fixing the values of the others. Then, the predicated distribution of ASM.1 component were compared with the measured ones and the value that gives close results to the observed data is chosen. After that, another parameter is varied and so on.

3.8. Model validation

The calibrated SBR- model was run for 90 cycles using the measured initial and influent wastewater characteristics to simulate the real process. Then the correlation coefficient between observed and model predicted data is calculated.

4. Results and Discussion

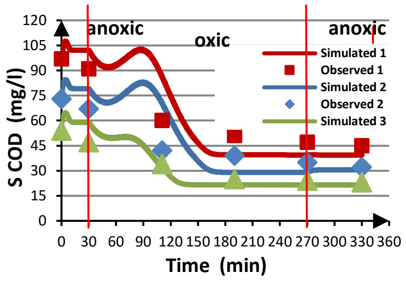
4.1. Results of SBR-Model calibration

SBR-model calibration is done manually using field data were collected in this study. The values of kinetic and stoichiometric parameters are adjusted to minimize the difference between the predicted and observed data. Observed data for six cycles was collected; through 11 days from (17/4/2018 -27/4/2018) while the predicted data is getting on by running the SBR-model depending on the observed ones. Figure 3(a) to (f) show the variation of predicted and observed data with time; for (SCOD; NH_4-N and NO_3-N) before and after calibration for three cycles with different influent characteristics. Table 4 shows the characteristics of these cycles. The applied composition of influent wastewater is calculated based on the fractions of TCOD and TKN as listed in Tables 2 and 3 for composition of municipal wastewater [18]. The calibrated values of ASM1 parameters are shown in Table 5.

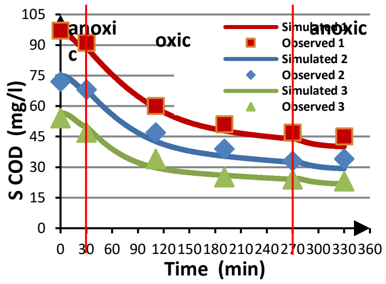
4.2. SBR-Model validation

The validation process is involving the use of the calibrated SBR-model with another group of data are different from that which used for model calibration; to check whether the measured and model predicted values are still fit well or not. The measured data is obtained experimentally from operating the CSBR unit for 90 consecutive cycles during one month from (29/4/2018) to (28/5/2018) using the optimum operation parameters. Then the calibrated SBR- model was run for 90 cycles using the measured initial and influent characteristics to simulate the real process. The results of SBR-model validation are shown in Fig. 4(a) to (d).

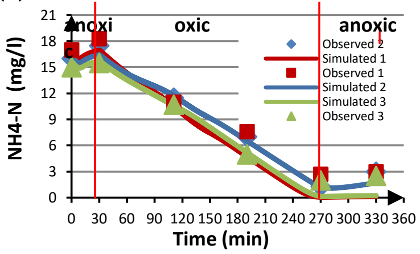
The validation results are showing that; SBR-model prediction matches fairly well with the observed data; whereas the correlation coefficient (R) for Chemical oxygen demand; NH_4-Nitrogen; Nitrate-Nitrogen and TN were 0.91; 0.97; 0.9 and 0.87 respectively; so, it confirms that; SBR- model is a representative and has a very well prediction to the studied real system.



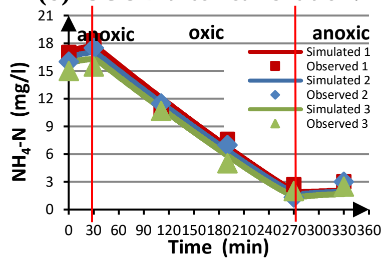
(a) SCOD before calibration.



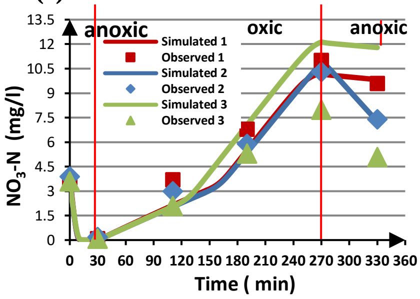
(b) SCOD after calibration.



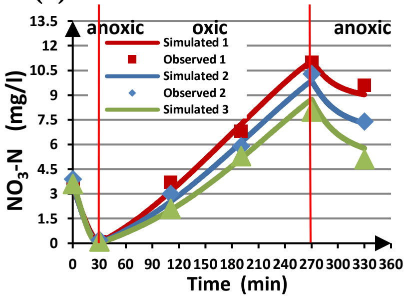
(c) NH4-N before calibration.



(d) NH4-N after calibration.



(e) NO_3-N before calibration



(f) NO_3-N calibration

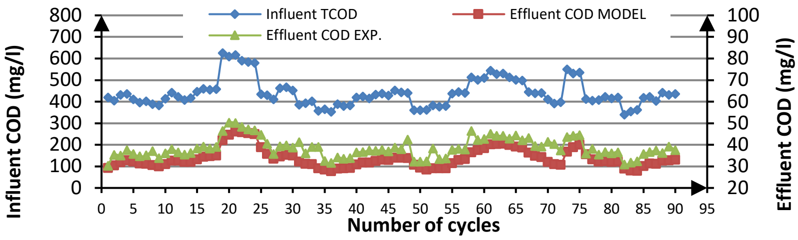
Fig. 3. Predicted and observed data during reaction.

Table 4. The details of SBR-model calibration cycles.

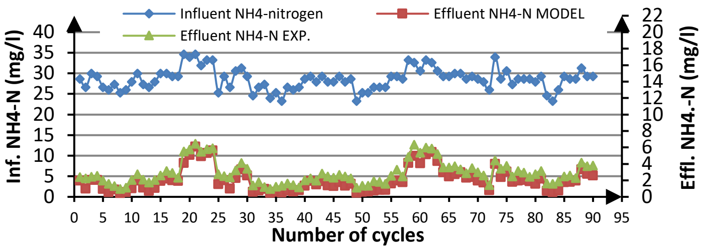
Total cycle time =8 hr		Q = 40 m^3/d		Sludge age=10 d		Total V=241 L	
COD fractions	Inf. conc. mg/l			TN fractions	Inf. Conc. mg/l		
	Cycle 1	Cycle 2	Cycle 3		Cycle 1	Cycle 2	Cycle 3
S_S	103.327	85.057	64.96	S_{NH}	30.59	28.595	23.94
X_S	262.135	215.785	164.8	S_{NO}	0.54	0.52	0.33
X_P	0.0	0.0	0.0	S_{ND}	2.668	2.494	2.088
S_I	38.684	31.844	24.32	X_{ND}	5.75	5.375	4.5
X_I	66.17	54.47	41.6	S_{NI}	3.864	3.612	3.024
X_{BH}	36.684	30.168	23.04	X_{NI}	3.128	2.924	2.448
X_{BA}	0.0	0.0	0.0				

Table 5. The calibrated stoichiometric and kinetic parameters of ASM1.

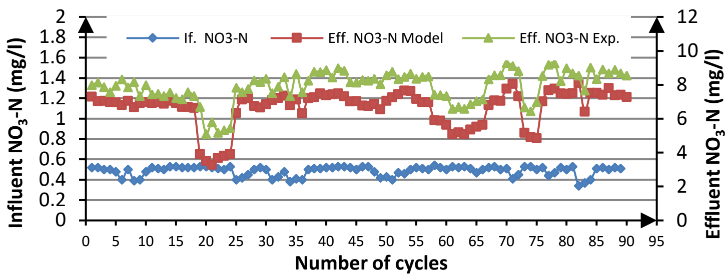
Parameters	**Calibrated values**			**Range in literatures**	
	1St anoxic	**oxic**	**2nd anoxic**	**Min.**	**Max.**
Heterotrophic Yield Y_H	0.4	0.75	0.75	0.38	0.75
Autotrophic Yield Y_A	0.24	0.28	0.24	0.06	0.28
Fraction of biomass yielding part. prod. f_P	0.08	0.08	0.1	0.08	1.0
(Mass N)/(Mass COD) in biomass i_{XB}	0.086	0.08 6	0.04	0.04	0.086
(Mass N)/(Mass COD)prod. from biomass i_{XP}	0.04	0.04	0.04	0.04	0.068
Heterotrophic max. specific growth rate μ_H	0.9	1.2	7.0	0.6	13.2
Heterotrophic decay rate b_H	0.05	0.05	0.05	0.05	4.38
Half Saturation Coeff. (*hsc*) for heterotrophs K_S	20.0	20.0	20.0	5.0	225
Oxygen *hsc* for heterotrophs K_{OH}	0.5	0.01	0.5	0.01	0.5
Nitrate *hsc* for heterotrophs K_{NO}	0.5	0.1	0.5	0.1	0.5
Autotrophic max. specific growth rate μ_A	0.8	0.3	0.8	0.2	1.0
Autotrophic decay rate b_A	0.2	0.05	0.2	0.05	0.2
Oxygen *hsc* for autotrophs K_{OA}	0.4	2.0	0.4	0.2	2.0
Ammonia hsc for autotrophs K_{NH}	1.0	3.6	1.0	0.6	3.6
Correction factor for growth for het. η_g	0.6	0.6	0.6	0.6	1.0
Ammonification rate K_a	0.08	0.16	0.16	0.05	0.16
Max. specific hydrolysis rate K_h	0.3	1.5	0.8	0.05	3.0
Hsc for hydrolysis of slowly biodegr. sub.K_X	0.03	0.15	0.15	0.01	0.15
Correction factor for anoxic hydrolysis η_H	0.4	0.4	0.4	0.4	0.4



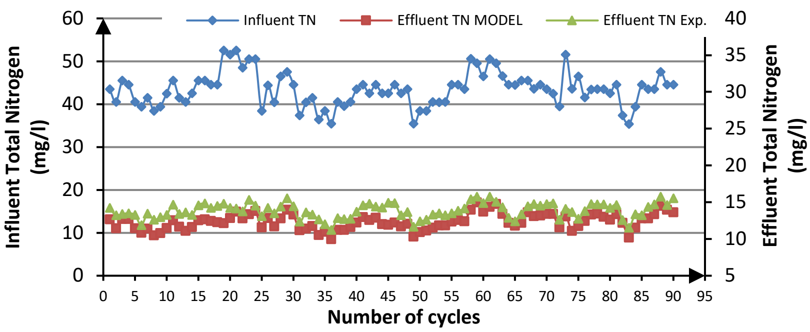
(a) COD.



(b) NH4-N.



(c) NO3-N.



(d) TN.

Fig. 4. Model validation: measured and model predicted data.

5. Conclusions

From the results of SBR-model simulation; it is found that:

- The built SBR-model was representative to the biological processes in SBR system very well; whereas the correlation coefficient (R) for chemical oxygen demand; NH_4-N; Nitrate-Nitrogen and TN were 0.91; 0.97; 0.9 and 0.87 respectively; so, it can be used successfully as a learning tool to investigate the response of the system to the variation in the design variables like; volume of SBR reactor; total cycle time; and the influent conditions.

- The proposed fractions for COD components represented the characteristics of local domestic wastewater successfully and they are (20.3; 51.5; 7.6; 13.0; 0.0; 7.2 and 0.0) % for (S_S, X_S, S_I, X_I, X_P, X_{BH} *and* X_{BA}) respectively.
- The used fractions of TN components represented the local domestic wastewater characteristics successfully and they are (66.5; 5.8; 6.8; 12.5 and 8.4) % for (S_{NH}, S_{ND}, X_{ND}, X_{NI} *and* S_{NI}), respectively.
- The calibrated kinetic and stoichiometric parameters for ASM1 which match our local environmental conditions as listed in Table 5.

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