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Original research article

Effect of Organic Loading and Nitrogen Concentration on the Efficiency of the Sequencing Batch Reactor (SBR) System with Electroplating Wastewater (EPWW)

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ABSTRACT

The study was concerned with the effects of the organic loading as food/microbe (F/M) and nitrogen concentration as BOD_5: TN on the sequencing batch reactor (SBR) system efficiency and performance with 1:5 diluted-electroplating wastewater (EPWW) solutions. The results showed that chemical oxygen demand (COD) and biological oxygen demand (BOD_5) removal efficiencies were almost the same with the organic loadings of 0.125-0.375 kg BOD_5/m^3.d. The CN^- and Zn^{2+} loadings of 1.2-2.9 and 1.6-4.0 g/m^3.d did not show strong repression effects to the COD and BOD_5 removal efficiencies. In addition, the high Zn^{2+} removal efficiency level of 94-96% was detected. Moreover, the system did not show any difference in Zn^{2+} and COD removal efficiencies at the BOD_5: TN ratios of 100:5-100:10. Urea and $(NH_4)_2SO_4$ could be used as the nitrogen source of 1:5 diluted-electroplating wastewater solution. The highest COD, BOD_5, Zn^{2+}, CN^-, Total Kjeldahl nitrogen (TKN) and total nitrogen (TN) removal efficiencies of 98.0±0.2, 97.0±0.7, 97.7±0.1, 93.3±1.2, 86.5±1.1 and 80.9±0.5%, respectively, were detected at the BOD_5:TN ratio of 100:10 and $(NH_4)_2SO_4$ was used as the nitrogen source. The system also showed good bio-sludge performance with the Sludge Volume Index (SVI) and Sludge Retention Time (SRT) values of 51±4 mL/g and 29±3 days, respectively.

Keywords: F/M; Sequencing batch reactor system; Electroplating wastewater; CN^-; Zn^{2+}

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1. Introduction

Electroplating wastewater (EPWW) contains high concentrations of CN^- and heavy metals such as Pb^{2+}, Zn^{2+}, Cu^{2+}, Cd^{2+}, Cr^{+3} and so on according to the type of electroplating [1,2]. Moreover, the electroplating process includes the washing step that causes organic matter pollutants in the wastewater, then, EPWW contains not only heavy metals and CN^- compounds, but also organic matters [1,3]. Theoretically, a biological wastewater treatment process is suitable for organic wastewater, but inorganic wastewater is usually treated by a chemical treatment process. Moreover, the use of a chemical treatment process has disadvantages such as high chemical agent costs and chemical waste generation. Furthermore, it is well documented that heavy metals at high concentrations or loadings is toxic to microorganisms [4-6]. Several researchers studied the biological process for treating EPWW due to the composition of wastewater, treatment cost and downstream process for sludge waste disposal. Cyanide compounds are normally treated by chemical and physical processes such as chlorination, ozonization, ion exchange, and so on. Heavy metals are usually removed by chemical precipitation [7]. It is well documented that cyanide compounds can be removed by biological processes and heavy metals were adsorbed on the surfaces of bio-sludge or microbial cells [8, 9].

From previous works, two types of aerobic-biological treatment systems such as the suspended growth (activated sludge system) and attached growth systems (rotary biological contractor: RBC and packed cage-RBC systems) were applied to treat wastewater containing both organic and inorganic matters [2, 4, 7, 8, 10, 11]. The suspended growth system as the sequencing batch reactor (SBR) system might be a suitable system due to its easy operation and control under the high sludge age (SRT). Unfortunately, high concentrations or loadings of CN^- and heavy metals gave a repression effect to the growth and activity of microorganisms or bio-sludge [2-4,12]. Consequently, an SBR system was selected for this study. The EPWW containing Zn^{2+} and CN^- as the main components was collected from the electroplating factory in Samut Prakan Province of Thailand for use in the experiments. As mentioned above, EPWW contained high CN^- and Zn^{2+} concentrations of 53.5±0.2 mg CN^-/L and 74.6±0.5 mg Zn^{2+}/L, respectively, which might affect the growth and activity of bio-sludge. This could be confirmed by the previous works [2-4, 9]. EPWW should then be diluted before being used as the influent of the SBR system; a 1:5 diluted-EPWW solution was selected. But, the organic content of the wastewater was diluted too, then, the organic contents of the diluted-EPWW solution should increase which should result in the increase of biological activities. To confirm the above hypothesis, the suitable operation conditions for the laboratory scale SBR system to remove organic matters and toxic substances (CN^- and Zn^{2+}) from1:5 diluted-EPWW solution supplemented with glucose and nitrogen compounds (urea and $[NH_4]_2SO_4$) at various BOD_5:TN ratios of 100:5 and 100:10 were investigated. The highest removal efficiency was also observed with various F/M ratios of 0.125, 0.10 and 0.15.

2. Materials and Methods

2.1 Wastewater sample

The wastewater from the storage tank of the chemical wastewater treatment plant of the electroplating factory (EPWW) in Samut Prakan Province, Thailand [3,4] was collected once and kept in a cool storage room (4 ºC) to prevent the changing of the chemical properties. The EPWW was diluted with distilled water at the ratio of 1:5 and supplemented with glucose and nitrogen compounds (urea or $[NH_4]_2SO_4$) as shown in Table 1 before being used as the influent of the SBR system.

Table 1. Chemical property of various types of electroplating wastewater (EPWW).

Parameters	Raw EPWW[a]	1:5 diluted-EPWW solution containing various glucose concentrations to adjust various F/M ratios at the HRT of 3 days[b]			1:5 diluted-EPWW solution containing various glucose concentrations to adjust various F/M ratios at the HRT of 7.5 days[c]			1:5-diluted-EPWW solution with BOD_5:TN[d] ratios of	
		F/M=0.05	F/M=0.10	F/M=0.15	F/M=0.05	F/M=0.10	F/M=0.15	100:5	100:10
COD, mg/L	893±40	610±10	1230±10	3070±10	1480±10	2500±15	4900±20	1200±30	1200±30
BOD_5, mg/L	12±4.2	360±10	670±10	1,000±15	940±10	1570±10	2230±15	920±10	920±10
pH	12.1±0.1	8.2±0.3	8.2±0.3	8.2±0.3	8.2±0.3	8.2±0.3	8.2±0.3	8.5±0.1	8.5±0.1
CN^-, mg CN^-/L	53.5±0.2	8.7±0.1	8.7±0.1	8.7±0.1	8.7±0.1	8.7±0.1	8.7±0.1	8.7±0.3	8.7±0.3
CN^-, mg N/L	28.8±0.1	4.4±0.1	4.4±0.1	4.4±0.1	4.4±0.1	4.4±0.1	4.4±0.1	4.9±0.2	4.9±0.2
TKN, mg/L	8.0±1.8	3.7±0.2	3.7±0.2	3.7±0.2	3.7±0.2	3.7±0.2	3.7±0.2	39.0±1.0	85.3±1.0
Organic-N, mg/L	5.5±0.8	1.3±0.2	1.3±0.2	1.3±0.2	1.3±0.2	1.3±0.2	1.3±0.2	1.3±0.1	1.2±0.3
NH_4^+, mg/L	2.5±0.5	2.4±0.2	2.4±0.2	2.4±0.2	2.4±0.2	2.4±0.2	2.4±0.2	37.7±1.0	84.1±0.8
NO_2^-, mg/L	2.1±0.2	1.2±0.1	1.2±0.1	1.2±0.1	1.2±0.1	1.2±0.1	1.2±0.1	1.0±0.1	1.0±0.1
NO_3^-, mg/L	1.5±0.2	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.2±0.1	0.2±0.1
TN, mg/L	42.9±1.5	9.4±0.1	9.4±0.1	9.4±0.1	9.4±0.1	9.4±0.1	9.4±0.1	95.6±2.0	51.6±2.0
Zn^{2+}, mg/L	74.6±0.5	12.2±0.1	12.2±0.1	12.2±0.1	12.2±0.1	12.2±0.1	12.2±0.1	12.0±0.2	12.0±0.2

a: The raw of electroplating wastewater was collected from the sump tank of the electroplating factory wastewater treatment plant at Samut Prakan Province of Thailand.

b: 730, 1480, and 3990 mg/L of glucose was added into 1:5 diluted-EPWW solutions and the MLSS of the system was 2,500 mg/L to adjust the F/M of 0.05, 0.10 and 0.15, respectively at an HRT of 3.0 days.

c: 1,780, 3,000, and 5,900 mg/L of glucose was added into 1:5 diluted-EPWW solutions and the MLSS of the system was 2,500 mg/L to adjust F/M of 0.05, 0.10 and 0.15, respectively at an HRT of 7.5 days.

d: Two nitrogen compounds, $(NH_4)_2SO_4$ and urea, were used in these experiments as follows:

- 216 and 432 mg/L of $(NH_4)_2SO_4$ were added into 1:5 diluted EPWW solution to adjust the BOD_5:TN ratios of 100:5 and 100:10, respectively.
- 99 and 198 mg/L of urea were added into 1:5 diluted EPWW solution to adjust the BOD_5:TN ratios of 100:5 and 100:10, respectively.

e: TKN:Total kjeldahl nitrogen = organic-N^+, NH_4^+-

2.2 Acclimatization of bio-sludge

The bio-sludge from the bio-sludge storage tank of the central sewage treatment plant of Bangkok, Thailand (Sripaya sewage treatment plant) was used as the inoculum for the SBR system after being acclimatized in the SBR system with 1:5 diluted-EPWW solution containing the BOD_5:TN ratio of 100:10 as shown in Table 1 at an HRT of 10 days for 10 days.

2.3 Sequencing batch reactor *(*SBR*)*

Eight 10-L SBR reactors, made from acrylic plastics (5 mm. in thick) as shown in Fig. 1, were used in this study. Each reactor had an 18cm-diameter and 40 cm-height with a working volume of 7.5 L (total volume of 10 L). Complete mixing in the reactor was adjusted by controlling the speed of the turbine-shaped impeller to 60 rpm. A low speed gear motor, model P 630A-387, 100V, 50/60 Hz, 1.7/1.3 A (Japan Servo Co. Ltd., Japan), was used for driving the turbine-shaped impeller. One set of air pumps, model EK-8000, 6.0 W (President Co. Ltd., Thailand), was used to supply air to two sets of reactors (the system had enough oxygen as evidenced by the dissolved oxygen in the system that was about 2-3 mg/L) [4,8]. The excess sludge was removed during the draw and idle period to control the MLSS of the system (Table 2).

2.4 Operation of the SBR system

The SBR system was operated at 1 cycle/day under the HRTs of 3.0 and 7.5 days. The experimental design was followed the procedure of SBR system principle [12]. Exactly1.4 L of 10 g/L of acclimatized bio-sludge from Section 2.2 was inoculated in each reactor and 1:5 diluted-EPWW solutions were added (final volume of 7.5 L) within 1 h. During the reaction period, the system was continuously aerated for 19 h. Aeration was then shut down for 3 h. After the sludge was fully settled, the supernatant was drawn out within 0.5 h and the system was kept under anoxic conditions for 0.5 h. After that, the reactor was filled with fresh 1:5 diluted-EPWW solutions to the final volume of 7.5 L and the above operation was repeated. The operation parameters of the SBR system with EPWW solutions were described in Table 2. The experiments were carried out for 12 months, during July 2012-June 2013.

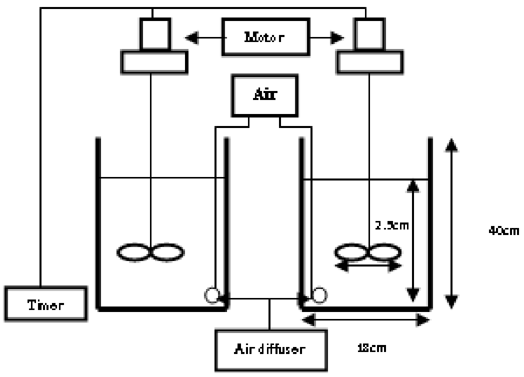


Fig. 1. Flow diagram of the SBR systems**.**

2.5 Chemical analysis

Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), TKN, Organic-N, NH_4^+-N, NO_3^--N, NO_2^--N, Total Nitrogen (TN), CN^-, Zn^{2+}, suspended solids (SS), organic matter, inorganic matter and pH of influent and effluent were determined according to the standard methods for the examination of water and wastewater [13]. The mixed liquor suspended solids (MLSS) was determined by weighting the total solids as dry basis of mixed liquor of SBR reactor during operation.

Sludge volume Index (SVI) of SBR system was determined as the volume of bio-sludge per g of bio-sludge as dry basis [13]. The bio-sludge age was determined as the ratio of total biomass (mixed liquor suspended solids: MLSS) of the system to the amount of excess sludge wasted per day. The F/M ratio was calculated as the ratio of the amount of BOD_5 loading and MLSS of the system [13].

Table 2. Operating parameters of the SBR system.

Operating parameters	Hydraulic retention time: HRT (days)	
	3	**7.5**
Cycle, (batch/d)	**1**	**1**
Each step of the cycle (h)		
- Fill up step	1	1
-Aeration step	19	19
-Settle step	3	3
-Draw & Idle step	1	1
Working volume of the reactor (mL)	7500	7500
Replacement volume (mL/d)	2500	1000
MLSS (mg/L)	2500	2500
Hydraulic loading (L/L-d or m^3/m^3.d)	0.33	0.13

2.6 Statistical analysis method

Each experiment was repeated at least three times. All the data were subjected to two-way analysis of variance (ANOVA) using the statistical analysis system (SAS) [14].

3. Results

3.1 Effect of the F/M ratio on the efficiency and performance of the SBR system

The SBR system was operated at the MLSS of 2,500 mg/L and HRTs of 3.0 and 7.5 days with 1:5 diluted-EPWW solutions containing various glucose concentrations to adjust the F/M ratios of 0.05, 0.10 and 1.5 (organic loading of 0.125, 0.250, 0.375 kg BOD_5/m^3.d), as shown in Table 1. The system's efficiency and performance were observed and reported in Tables 3-4 and Figs. 2 - 3.

3.1.1 COD and BOD_5

COD and BOD_5 removal efficiencies were in the high level of 96-97% and 89-92%, respectively, under the F/M ratios of 0.05-0.15 and HRTs of 3.0 and 7.5 days (organic loadings of 0.125-0.375 kg BOD_5/m^3.d, CN^- loadings of 1.2-2.9 g CN^-/m^3.d and Zn^{2+} loadings of 1.6-4.0 g Zn^{2+}/m^3.d) as shown in Table 3. Moreover, the HRT did not show any effects on the COD and BOD_5 removal efficiencies at the same organic, CN^- and Zn^{2+} loadings as shown in Table 3.

3.1.2 Nitrogen compounds

TKN and TN removal efficiencies were increased with the decrease of the organic loading as shown in Table 3. The highest TKN and TN removal efficiencies of 68.9±2.9 and 51.4±2.6%, respectively, were detected at the organic, CN^- and Zn^{2+} loadings of 0.125 kg BOD_5/m^3.d, 1.2 g CN^-/m^3.d and 1.6 g Zn^{2+}/m^3.d, respectively. Unfortunately, at the same organic loading, the TKN and TN removal efficiencies were increased with the decrease of CN^- and Zn^{2+} loadings as shown in Table 3. Moreover, the SBR system showed interesting results on the effluent nitrogen compounds as shown in Table 3 and Fig. 2. Organic-N and NH_4^+-N of the wastewater were rapidly decreased during treatment by the SBR system as shown in Fig. 2 (a) and 2 (b) and Fig. 3 (a) and 3 (b). The effluents organic-N and NH_4^+-N were 0.09-0.39 and 0.9-1.7 mg/L, respectively, while the influents organic-N and NH_4^+-N were 5.5 and 2.5 mg/L, respectively, as shown in Table 1 and Table 3.

3.1.3 CN^- and Zn^{2+}

CN^- removal efficiency in each organic loading as shown in Table 3. The highest CN^- removal efficiency of 86.4±0.8% was detected at the organic loading of 0.125 kg BOD_5/m^3.d as shown in Table 3.

Table 3. Removal efficiency and effluent nitrogen compounds of the SBR system with 1:5 diluted-EPWW solutions containing various glucose concentrations[a] at the MLSS of 2,500 mg/L to adjust the F/M[a] of 0.05, 0.10 and 0.15 and HRTs of 3 and 7.5 days.

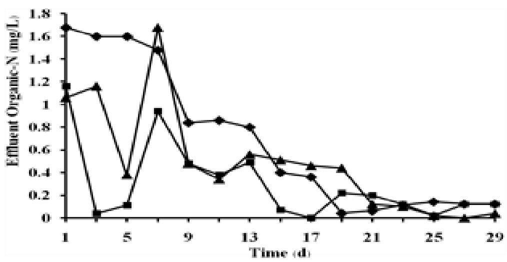
HRT (d)	F/M[a]	Organic loading ($kgBOD_5/m^3.d$)	CN^- loading ($g\ CN^-/m^3.d$)	Zn^{2+} loading ($g\ Zn^{2+}/m^3.d$)	Removal efficiency (%)						Effluent nitrogen compound (mg/L)			
					CN^-	Zn^{2+}	BOD_5	COD	TKN	TN	Organic -N	NH_4^+-N	NO_2^--N	NO_3^--N
3	**0.05**	**0.125**	2.9	4.0	86.3±2.3	95.2±0.2	91.3±0.6	97.3±0.2	65.1±3.0	49.4±3.1	0.11±0.01	1.1±0.1	2.52±0.02	0.67±0.04
	0.1	**0.250**	2.9	4.0	80.5±2.8	94.7±0.1	90.7±0.3	96.3±0.1	53.5±2.9	43.2±4.0	0.09±0.01	1.6±0.1	2.36±0.02	0.71±0.03
	0.15	**0.375**	2.9	4.0	79.3±1.3	94.2±0.1	90.4±0.2	95.8±0.1	49.4±6.1	38.5±4.2	0.11±0.01	1.7±0.1	2.72±0.03	0.96±0.02
7.5	**0.05**	**0.125**	1.2	1.6	86.4±0.8	96.0±0.4	92.0±0.4	97.4±0.1	68.9±2.9	51.4±2.6	0.20±0.01	0.9±0.1	2.46±0.07	1.96±0.05
	0.1	**0.250**	1.2	1.6	81.2±1.2	95.1±0.2	89.2±0.2	96.4±0.1	59.5±1.2	42.7±4.4	0.37±0.04	1.1±0.1	2.77±0.05	2.00±0.02
	0.15	**0.375**	1.2	1.6	79.6±1.0	94.8±0.2	89.9±0.1	96.2±0.1	57.6±3.9	41.0±3.8	0.39±0.02	1.1±0.1	2.81±0.05	2.10±0.02

a: 730, 1,480 and 3,990 mg/L of glucose were added into 1:5 diluted-EPWW solution to adjust the F/M of 0.05, 0.10 and 0.15 at an HRT of 3.0 days.
1,780, 3,000 and 5,900 mg/L of glucose were added into 1:5 diluted-EPWW solution to adjust the F/M of 0.05, 0.10 and 0.15 at an HRT of 7.5 days.

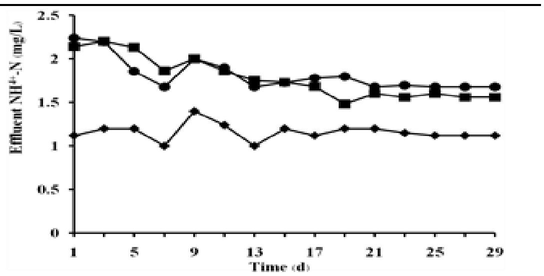
Table 4. Bio-sludge performance of the SBR system with 1:5 diluted-EPWW solutions containing various glucose concentrations[a] at the MLSS of 2,500 mg/L to adjust the F/M of 0.05, 0.10 and 0.15 and HRTs of 3 and 7.5 days.

HRT (d)	F/M	Organic Loading ($kg\ BOD_5/m^3.d$)	CN^- Loading ($g\ CN^-/m^3.d$)	Zn^{2+} Loading ($g\ Zn^{2+}/m^3.d$)	SVI (mL/g)	SS (mg/L)	SRT (d)	pH	
								Influent	Effluent
3	**0.05**	0.125	2.9	4.0	57±4	13±2	50±6	8.7±0.1	7.9±0.1
	0.1	0.25	2.9	4.0	62±2	26±1	184±32	8.7±0.1	8.0±0.1
	0.15	0.375	2.9	4.0	73±6	39±1	219±71	8.7±0.1	8.0±0.1
7.5	**0.05**	0.125	1.2	1.6	55±4	10±1	28±6	8.7±0.1	7.9±0.1
	0.1	0.250	1.2	1.6	61±4	23±1	61±7	8.7±0.1	8.0±0.1
	0.15	0.0375	1.2	1.6	71±5	35±1	95±10	8.7±0.1	7.9±0.1

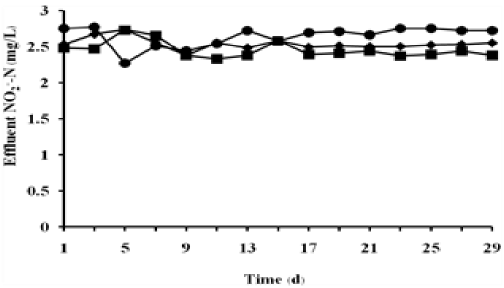
a: 730, 1480 and 3990 mg/L of glucose were added into 1:5 diluted-EPWW solution to adjust the F/M of 0.05, 0.10 and 0.15 at an HRT of 3.0 days.
1,780, 3,000 and 5,900 mg/L of glucose were added into 1:5 diluted-EPWW solution to adjust the F/M of 0.05, 0.10 and 0.15 at N HRT of 7.5 days



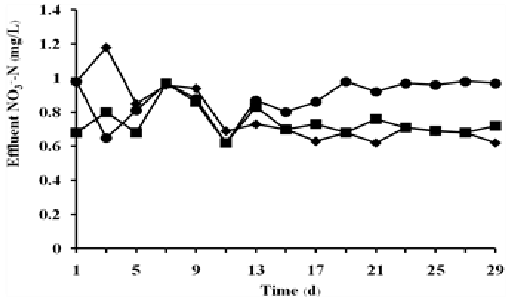
a: Organic-N



b: NH_4^+-N

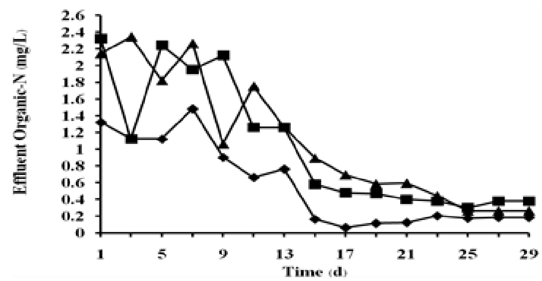


c: NO_2^-N

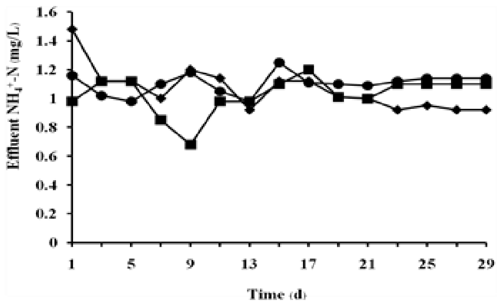


d: NO_3^-N

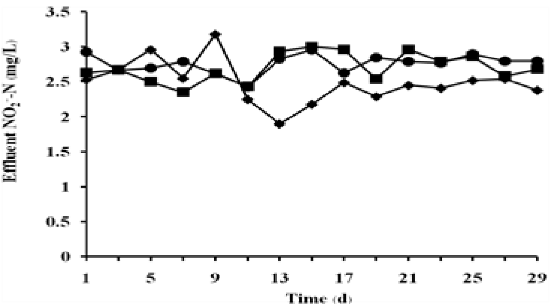
Fig. 2. Effluent nitrogen compounds (a: organic-N; b: NH_4^+-N; C: NO_2^--N; d: NO_3^-**-N**) profiles of the SBR system with 1:5 diluted-EPWW solution containing various glucose concentrations of 150, 300 and 450 mg/L at the MLSS of 2,500 mg/L (F/M of 0.05 [♦], 0.10 [■] and 0.15 [●], respectively) and HRTs of 3 days.



a: Organic-N



b: NH_4^+-N



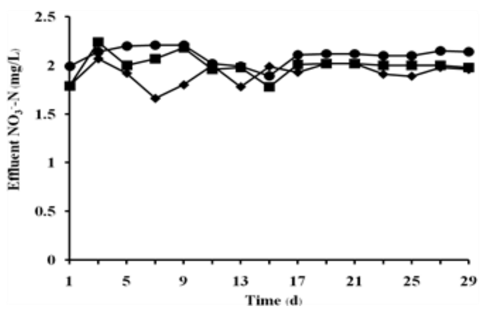
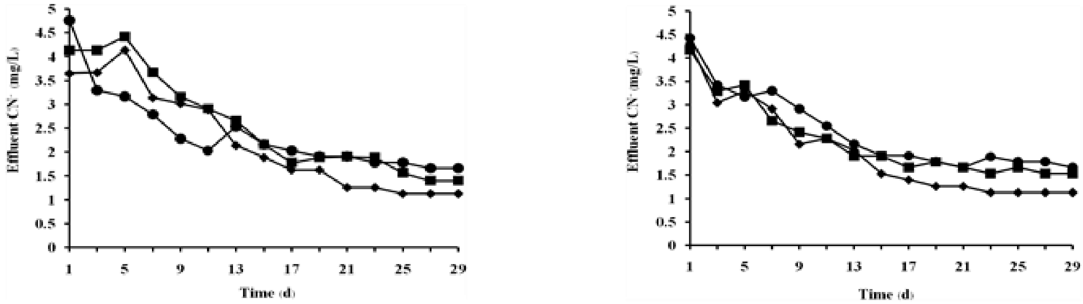
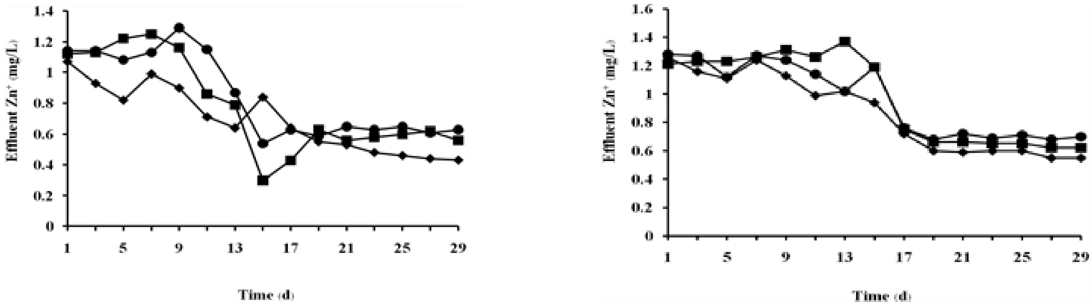


Fig. 3. Effluent nitrogen compounds (a: organic-N; b: NH_4^+-N; c: NO_2^--N; d: NO_3^-**-N**) profiles of the SBR system with 1:5 diluted-EPWW solution containing various glucose concentrations of 150, 300 and 450 mg/L at the MLSS of 2,500 mg/L (F/M of 0.05 [♦], 0.10 [■] and 0.15 [●], respectively) and HRTs of 7.5 days.



a: HRT of 3 days   b: HRT of 7.5 days

Fig. 4. Effluent CN^- profiles of the SBR system with 1:5 diluted-EPWW solution containing various glucose concentrations of 150, 300 and 450 mg/L at the MLSS of 2,500 mg/L (F/M of 0.05 [♦], 0.10 [■] and 0.15 [●], respectively) and HRTs of 3 (a) and 7.5 (b) days.



a: HRT of 3 days   b: HRT of 7.5 days

Fig. 5. Effluent Zn^{2+} profiles of the SBR system with 1:5 diluted-EPWW solution containing various glucose concentrations of 150, 300 and 450 mg/L at the MLSS of 2,500 mg/L (F/M of 0.05 [♦], 0.10 [■] and 0.15 [●], respectively) and HRTs of 3 (a) and 7.5 (b) day

For the effluent CN^- and Zn^{2+} profiles, the CN^- of wastewater was rapidly decreased within the first 17 days of operation. After that, the effluent CN^- was almost stable as shown in Fig. 4. Also, the wastewater Zn^{2+} rapidly decreased and became stable after 18-20 days of operation as shown in Fig. 5.

3.1.4 Effluent SS

Effluent SS was increased with the increase of the organic loading. Moreover, the effluent SS of the system was not affected by the increase of CN^- and Zn^{2+} loadings. The lowest effluent SS of 10 ±1 mg/L was detected with the organic loading of 0.125 mg BOD_5/m^3.d. as shown in Table 4. And, the effluent SS was increased up to 39 mg/L at the organic loading of 0.375 mg BOD_5/m^3.d, CN^- loading of 2.9 g CN^-/m^3.d and Zn^{2+} loading of 4.0 g Zn^{2+}/m^3.d as shown in Table 4.

3.1.5 pH

Influent pHs of the system with 1:5 diluted-EPWW solutions at various F/M ratio operations were in the basic range (pH of 8.7±0.1) and the pH of wastewater was decreased after treatment by the SBR system. However, the effluent pHs were still higher than 7.0 as shown in Table 4.

3.1.6 Bio-sludge performance

Interesting results on the bio-sludge performance were observed during operation of the system with 1:5 diluted-EPWW solutions at the MLSS of 2,500 mg/L, F/M ratios of 0.05-0.15 and HRTs of 3.0 and 7.5 days (organic loadings of 0.125-0.375 kg

BOD_5/m^3 d). In the bio-sludge quality, the SVI was less than 80 mL/g in all experiments tested as shown in Table 4. Unfortunately, the amount of excess sludge was decreased with the increase of organic, CN^- and Zn^{2+} loadings. The shortest SRT of 28.6 days was observed at the organic loading of 0.125 mg BOD_5/m^3.d, CN^- loading of 1.2 g CN^-/m^3.d and Zn^{2+} loading of 1.6 g Zn^{2+}/m^3.d as shown in Table 4.

From the above results, it could be suggested that the 1:5 diluted-EPWW solution supplemented with glucose might be suitable to be treated by the SBR system which resulted from the de-toxicity of toxic substances, especially CN^- and Zn^{+2} in EPWW, and increased organic matters of BOD_5. Unfortunately, the dilution of EPWW reduced the nitrogen content in the wastewater. Then, the nitrogen compound was needed to add to the 1:5 diluted-EPWW solution to adjust the BOD_5: TN. Then, the 1:5 diluted-EPWW solution supplemented with 240 mg/L glucose to adjust the BOD_5 of 200 mg/L. and various concentrations of nitrogen compounds (urea and $[NH_4]_2SO_4$) to adjust the BOD_5:TN ratios of 100:5 and 100:10 were selected for further experimentation at the HRT of 7.5 days as shown in Table 1.

3.2 Effect of BOD: TN ratios and types of nitrogen sources on the efficiency and performance of the SBR system

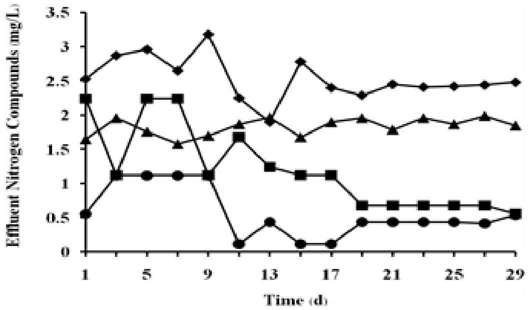
The experiments were carried out in the SBR system with 1:5 diluted-EPWW solution containing 240 mg/L glucose and various amounts of nitrogen sources at the MLSS of 2,500 mg/L and HRT of 7.5 (BOD_5:TN ratios of 100:1.2, 100:5 and 100:10); the F/M operation was controlled at 0.05 (organic loading of 0.125 kg BOD_5/m^3.d, CN^- loading of 1.2 g CN^-/m^3.d and Zn^{2+} loading of 1.6 g Zn^{2+}/m^3.d) . The system's efficiency and performance were investigated and reported in Tables 5-6 and Figs. 4-5.

3.2.1 COD and BOD_5

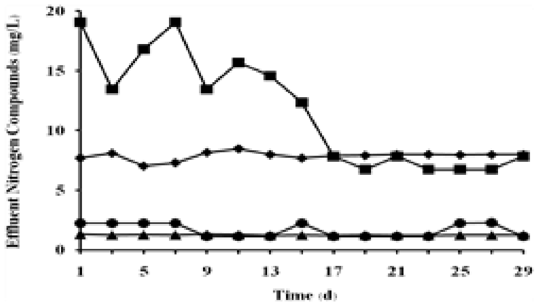
The SBR system with 1:5 diluted-EPWW solution containing 200 mg BOD_5/L did not show any difference in the COD removal efficiency even though the nitrogen source was supplemented as shown in Table 5. But, the BOD_5 removal efficiency could be increased by supplementing with a nitrogen source as shown in Table 5. Moreover, the types of nitrogen source including urea and $(NH_4)_2SO_4$ did not show any difference in the increase of BOD_5 and COD removal efficiencies as shown in Table 5. The highest COD and BOD_5 removal efficiencies with 1:5 diluted-EPWW solution containing the BOD_5:TN ratio of 100:10 at the HRT of 7.5 days were in the ranges of 98-99 and 96-97%, respectively. They were 97.4±0.1 and 92.0±0.4%, respectively, with 1:5 diluted-EPWW solution containing the BOD_5:TN ratio of 100:1.2 at the HRT of 7.5 days as shown in Table 5.

3.2.2 Nitrogen compounds

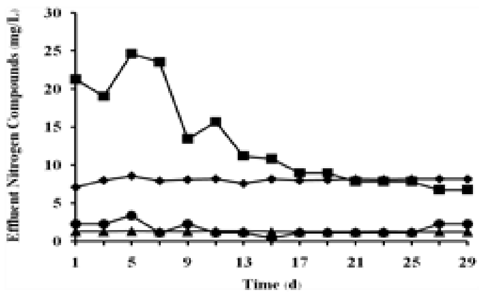
TKN and TN removal efficiencies were increased with the increase of nitrogen concentration or loading as shown in Table 5. Moreover, urea and $(NH_4)_2SO_4$ could be used as the nitrogen source without any significant difference. Moreover, the effluents organic-N, NH_4^+-N, NO_2^--N and NO_3^--N were decreased by supplementing with nitrogen compounds as shown in Table 5. The effluent organic-N, NH_4^+-N, NO_2^--N and NO_3^--N profiles of the system with 1:5 diluted-EPWW solutions containing the BOD_5:TN ratios of 10:1.2, 100:5 and 100:10 showed the same patterns as organic-N and NH_4^+-N, which rapidly decreased and became stable after 15-18 days of operation as shown in Fig. 6. But, the effluents NO_2^--N and NO_3^--N were higher than influents NO_2^--N and NO_3^--N and were almost stable during operation in all experiments tested as shown in Fig. 6.



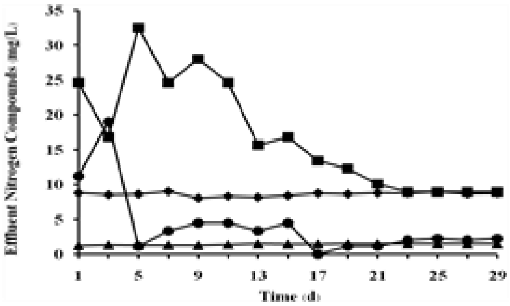
a: No nitrogen addition; BOD_5:TN = 100:1.2



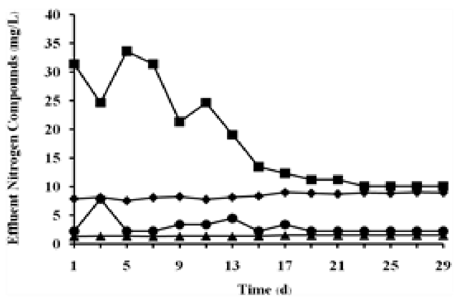
b-1: $(NH_4)_2SO_4$; BOD_5:TN = 100:5



b-2: Urea; BOD_5:TN = 100:5



c-1: $(NH_4)_2SO_4$; BOD_5:TN = 100:10



c-2: Urea; BOD_5:TN = 100:10

Fig. 6. Effluent nitrogen compounds profiles (●: organic-N, ■: NH_4^+-N, ♦: NO_2^--N, and ▲: NO_3^--N) of the SBR system with 1:5 diluted-EPWW solution that was adjusted to the BOD_5:TN ratios of 100:1.2 (a), 100:5 (b) and 100:10 (c) by adding glucose and nitrogen sources at the MLSS of 2,500 mg/L (F/M of 0.05) and HRT of 7.5 days.

Table 5. Removal efficiency and effluent nitrogen compounds of the SBR system with 1:5 diluted-EPWW solution that was adjusted to the BOD_5:TN ratios of 100:1.2, 100:5 and 100:10 by adding carbon [a] (glucose) and nitrogen sources[b] at the MLSS of 2,500 mg/L (F/M of 0.05) and HRT 7.5 days.

N-sources addition	BOD_5: TN	Organic loading ($kgBOD_5/m^3.d$)	CN^- loading ($g\ CN^-/m^3.d$)	Zn^{2+} loading ($g\ Zn^{2+}/m^3.d$)	Removal efficiency (%)						Effluent nitrogen compound (mg/L)			
					CN^-	Zn^{2+}	BOD_5	COD	TKN	TN	Organic-N	NH_4^+-N	NO_2^--N	NO_3^--N
Non-N addition	100:1.2	0.125	1.2	1.6	86.4±0.8	96.0±0.4	92.0±0.4	97.4±0.1	68.9±2.9	51.4±2.6	0.20±0.01	0.9±0.1	2.46±0.07	1.96±0.05
$(NH_4)_2SO_4$	100:5	0.125	1.2	1.6	91.7±1.7	97.5±0.4	95.9±0.5	97.8±0.2	78.0±1.5	68.8±0.6	1.5±0.6	7.1±0.6	4.15±0.15	1.22±0.01
	100:10	0.125	1.2	1.6	93.3±1.2	97.7±0.1	97.0±0.7	98.0±0.2	86.5±1.1	80.9±0.5	1.8±0.5	9.2±0.5	4.82±0.17	1.51±0.01
Urea	100:5	0.125	1.2	1.6	91.9±0.9	97.5±0.2	95.7±0.8	97.6±0.1	76.5±1.1	67.7±1.1	1.5±0.6	7.7±0.8	4.37±0.30	1.23±0.01
	100:10	0.125	1.2	1.6	92.9±0.7	97.7±0.1	96.6±0.9	97.6±0.4	85.1±0.7	79.3±0.7	2.4±0.0	10.3±0.5	4.90±0.10	1.51±0.01

a: carbon source: 240 mg/L of glucose was added into 1:5 diluted-EPWW solution to adjust the BOD_5 of 200 mg/L.

b: nitrogen sources: Two nitrogen compounds, $(NH_4)_2SO_4$ and urea, were used in these experiments as follows:

- 216 and 432 mg/L of $(NH_4)_2SO_4$ were added into 1:5 diluted EPWW solution to adjust the BOD_5:TN ratios of 100:5 and 100:10, respectively.
- 99 and 198 mg/L of urea were added into 1:5 diluted EPWW solution to adjust the BOD_5:TN ratios of 100:5 and 100:10, respectively.
- Non-adding of any nitrogen source for the BOD_5:TN ratio of 100:1.2.

Table 6. Bio-sludge performance of the SBR system with 1:5 diluted-EPWW solution that was adjusted to the BOD_5:TN ratios of 100:1.2, 100:5 and 100:10 by adding carbon [a] (glucose) and nitrogen sources[b] at the MLSS of 2,500 mg/L (F/M of 0.05) and HRT 7.5 days.

N-sources addition	BOD_5:TN	Organic loading (kg BOD_5/m^3.d)	CN^- loading (g CN^-/m^3.d)	Zn^{2+} loading (g Zn^{2+}/m^3.d)	SVI (mL/g)	SS (mg/L)	SRT (d)	pH	
								Influent	Effluent
Non N-source addition	100:1.2	0.125	1.2	1.6	57±3	12±1	33±1	8.5±0.1	7.9±0.1
$(NH_4)_2SO_4$	100:5	0.125	1.2	1.6	54±2	10±1	43±5	8.5±0.1	7.5±0.1
	100:10	0.125	1.2	1.6	51±4	9±1	29±3	8.5±0.1	7.5±0.1
Urea	100:5	0.125	1.2	1.6	55±3	10±2	40±5	8.5±0.1	7.8±0.1
	100:10	0.125	1.2	1.6	55±4	9±2	32±3	8.5±0.1	7.7±0.1

a: carbon source: 240 mg/L of glucose was added into 1:5 diluted-EPWW solution to adjust the BOD_5 of 200 mg/L.

b: nitrogen sources: Two nitrogen compounds, $(NH_4)_2SO_4$ and urea, were used in these experiments as follows:

- 216 and 432 mg/L of $(NH_4)_2SO_4$ were added into 1:5 diluted EPWW solution to adjust the BOD_5:TN ratios of 100:5 and 100:10, respectively.
- 99 and 198 mg/L of urea were added into 1:5 diluted EPWW solution to adjust the BOD_5:TN ratios of 100:5 and 100:10, respectively.
- Non-adding of any nitrogen source for the BOD_5:TN ratio of 100:1.2.

3.2.3 CN^- and Zn^{2+}

The CN^- removal efficiency was slightly increased by the supplemented nitrogen sources and the types of nitrogen sources such as urea and $(NH_4)_2SO_4$ did not show any different effects on the CN^- removal efficiency as shown in Table 5. The CN- removal efficiencies of the system with 1:5 diluted-EPWW containing the BOD_5:TN ratios of 100:1.2, 100:5 and 100:10 were about 86, 92, and 93%, respectively. However, the supplemented nitrogen sources did not affect the Zn^{2+} removal efficiency. The Zn^{2+} removal efficiency with 1:5 diluted-EPWW solutions containing the BOD_5:TN ratios of 100:1.2, 100:5 and 100:10 were about 97-98% as shown in Table 6. Moreover, the type of the nitrogen source such as urea and $(NH_4)_2SO_4$ did not show any difference in the CN^- and Zn^{2+} removal efficiencies as shown in Table 5.

3.2.4 Effluent SS

Effluent SS of the system decreased with the increase of BOD_5:TN. The effluent SS of the system at a BOD_5:TN ratio of 100:1.2 was 12±1 mg/L, while the effluent SS of the system at a BOD_5:TN ratio of 100:10 was about 9±1 mg/L, as shown in Table 5.

3.2.5 pH

All the influent pHs of the system were 8.5±0.1. The pH of the wastewater was decreased after treatment by the SBR system. However, the effluent pHs were higher than 7.0 in all experiments tested as shown in Table 6.

3.2.6 Bio-sludge performance

The system with 1:5 diluted-EPWW solutions containing BOD_5:TN ratios of 100:1.2, 100:5 and 100:10 at the MLSS of 2,500 mg/L and an HRT of 7.5 days showed interesting results on the bio-sludge performance as shown in Table 6. In the bio-sludge quality, the SVI was in the range of 51-57 mL/g in all experiments tested as shown in Table 6. Excess bio-sludge of the system was increased with the addition of nitrogen sources which resulted in the decrease of the bio-sludge age (SRT) as shown in Table 6. Moreover, the SRT was decreased with the increase of the BOD_5:TN ratio. In addition, the type of nitrogen source did not show any difference in the reduction of SRT of the system as shown in Table 6.

4. Discussion

Raw EPWW contained a high COD content of 893±40 mg/L and a low BOD_5 content of 12±4 mg/L. In addition, it also showed high CN^-, TN and Zn^{2+} contents of 53.5±0.2 mg CN^-/L, 42.9±1.5 mg TN /L and 74.6±0.5 mg Zn^{2+}/L, respectively, as shown in Table 1. According to the high concentrations of toxic substances CN^- and Zn^{2+}, the growth and activity of bio-sludge was repressed [3,4]. It was confirmed by previous works that heavy metals contaminated in wastewater could suppress the growth and activity of bio-sludge, especially heterotrophic bacteria [2-4, 7-11]. Cyanide compounds of EPWW could be used as the nitrogen sources of microbe or bio-sludge [3, 4, 7]. It was also suggested that Zn^{2+} was transferred from the wastewater onto bio-sludge. Thus, growth and activity of the bio-sludge were repressed by the adsorbed Zn^{2+}. So, the raw EPWW had to be diluted which resulted in detoxifying both CN^- and Zn^{2+} [2-4, 15, 16]. Unfortunately, the organic matter concentrations of BOD_5 of the diluted-EPWW solution was very low, which resulted in the decrease of the bio-sludge growth and activity [3, 4, 8] so, the glucose carbon source had to be supplemented to increase the growth of bio-sludge.

To confirm the above hypothesis, the experiment was carried out in a laboratory scale SBR system with 1:5 diluted-EPWW solutions containing glucose at various F/M ratios of 0.05, 0.10 and 0.15 to observe the system efficiency and performance. The results showed that the COD and BOD_5 removal efficiencies could not be affected by the organic, CN^- and Zn^{2+} loadings of 0.125-

0.375 kg BOD_5/m^3.d, 1.2-2.9 g CN-/m^3.d and 1.6-4.0 g Zn^{2+}/m^3.d, respectively (Table 1). This could suggest that the growth and activity of heterotrophic bacteria could not be repressed by the CN^- and Zn^{2+} concentrations of 8.7 mgCN^-/L and 12.2 mgZn^{2+}/L, respectively. In addition, the organic loading of 0.125-0.375 kg BOD_5/m^3.d was suitable for heterotrophic bacteria [2-4, 8-11]. But, it showed the repression effects to the TKN and TN removal efficiencies. This could suggest that the CN^- and Zn^{2+} loadings of 1.2-2.9 g CN^-/m^3.d and 1.6-4.0 g Zn^{2+}/m^3.d, respectively, might repress the growth and activity of nitrogen removing microorganisms as nitrifying and denitrifying bacteria [2-4, 5, 6, 8, 11, 17]. Moreover, the effluents organic-N and NH_4^+-N were quite low, while effluents NO_2^--N and NO_3^--N were higher than influents NO_2^--N and NO_3^--N. It could be concluded that nitrifying bacteria could not be strongly repressed by the CN^- and Zn^{2+} loadings of 1.2-2.9 g CN^-/m^3.d and 1.6-4.0 g Zn^{2+}/m^3.d, respectively. But, it might be repressed by the increase of organic loading (indirect effect)[3], because the increase of organic loading stimulated the growth of heterotrophic bacteria to be the dominated strain. Then, the nitrifying bacteria was indirectly repressed to be the minor population [3, 8, 17], even though the system pH was higher than 7 which resulted in optimizing the growth conditions of nitrifying bacteria [2, 3, 12, 17]. Also, the denitrifying bacteria population of the bio-sludge was repressed by the above conditions which resulted from the accumulation of both NO_2^--N and NO_3^--N in the effluent [2-4, 8]. In addition, the CN^- removal efficiency was decreased with the increase of the organic loading. It could be concluded then that the number of nitrifying and denitrifying bacteria were reduced by the increase of the organic loading, which resulted in the decrease of the CN- removal efficiency [2-5, 17]. On the other hand, it could be suggested that nitrifying and denitrifying bacteria were the main bacterial groups for the nitrogen removing mechanism. For the Zn^{2+} removal mechanism, the heterotrophic bacterial group was the main bacterial group for Zn^{2+} adsorption [2-5]. Moreover, the Zn^{2+} adsorption yield was increased with the decrease of the SRT [2-4, 8-11, 18, 19]. This could confirm that the Zn^{2+} adsorption yield was increased with the increase of the bio-sludge age [2-5, 8-11, 20]. According to the above results, it could be suggested that the suitable operation conditions to treat 1:5 diluted-EPWW solution containing 730 mg/L glucose were the HRT of 7.5 days and F/M ratio of 0.05. Unfortunately, the BOD_5:TN ratio of the above 1:5 diluted-EPWW solution was only 100:1.2. To increase the SBR removal efficiency, the nitrogen compound of urea or $(NH_4)_2SO_4$ was added in the 1:5 diluted-EPWW solution to increase the BOD_5:TN ratio from 100:1.2 to 100:5 and 100:10. The results showed that the system efficiency was increased with the increase of the BOD_5: TN ratio and the suitable BOD_5: TN ratio of 1:5 diluted-EPWW solution for the highest removal efficiency was 100:10. Moreover, the types of nitrogen compounds such as urea or $(NH_4)_2SO_4$ did not show any difference in the increase of system efficiency. The highest COD, BOD_5, TKN, TN, CN^- and Zn^{2+} removal efficiencies of 98.0±0.2, 97.0±0.7, 86.5±1.1, 80.9±0.5, 93.3±1.2 and 97.7±0.1%, respectively, were detected with 1:5 diluted-EPWW solution containing 240 mg/L glucose and 432 g/L $(NH_4)_2SO_4$ (BOD_5:TN ratio of 100:10). But, the effluent NO_2^--N and NO_3^--N of the system were higher than influent NO_2^--N and NO_3^--N. This phenomenon could be used to confirm the above suggestion that the increased organic matter of glucose and nitrogen compounds induced the heterotrophic bacteria to be the dominant strain of the bio-sludge, which resulted in the increase of the organic (BOD_5 and TKN) and Zn^{2+} removal efficiencies [3, 11, 20-23]. The activity of nitrogen removal bacteria, especially denitrifying bacteria, was repressed, which resulted from the accumulation of NO_2^--N and NO_3^--N in the effluent. From all of the above results, it could be concluded that the organic matter of the EPWW was mainly removed by heterotrophic bacteria, while the nitrogen compounds could be removed by assimilation, oxidation, and the reduction mechanisms of bio-sludge. From the theoretical information, the heterotrophic bacteria mainly showed the nitrogen assimilation mechanism, while the nitrogen removal bacteria as nitrifying and denitrifying bacteria mainly showed nitrogen oxidation and reduction mechanisms. Moreover, the CN^- removal yield depended on the growth and activity of nitrifying and denitrifying bacteria [2-5, 8-11, 15, 20]. The Zn^{2+} removal efficiency was increased with the increase of the bio-sludge mass, which resulted from the adsorption mechanism [11]. For the application, the 1:5 diluted-EPWW solution supplemented with 240 mg/L glucose and 198 mg/L urea or 432 mg/L $(NH_4)_2SO_4$ to adjust the BOD_5:TN ratio of 100:10 was suitable to be treated by the SBR system at an HRT of 7.5 days with the highest CN^- and Zn_2^+ removal efficiencies. It was reported that the old aged bio-sludge showed higher heavy metal adsorption yield than young age sludge [9]. Then, the extended activated sludge system might be suitable to remove heavy metals from EPWW. Moreover, all nitrogenous compounds could be completely oxidized to be NO_3^- due to the extended activated sludge system operation. However, the TN removal efficiency of the system quite low, because, the anoxic condition of the system could not be controlled. Form the above results; it could be concluded that the SBR system was the suitable activated sludge system for the treatment of the EPWW when it compared with the conventional or extended activated sludge systems. Because, the SBR system could be easily operated in oxic-anoxic condition resulted to remove heavy metals together with nitrogenous compounds [2-4, 8-11, 24-26]. This might be the advantage of the SBR system for removal of heavy metals together with nitrogenous compounds according to SBR condition to stimulate the nitrogenous compounds removal microbes. Moreover, the nitrogen removal bacteria showed higher Zn^{2+} adsorption ability than the other. To confirm above conclusion According to above information, the further experiment on the microbial diversity of the bio-sludge have to be study.

5. Conclusion

The SBR system showed high efficiency with 1:5 diluted-EPWW solution containing 730 mg/L glucose at the MLSS of 2,500 mg/L and HRT of 7.5 days (organic, CN^- and Zn^{2+} loadings of 0.125 kg BOD_5/m^3.d, 1.2 g CN^-/m^3.d and 1.6 g Zn^{2+}/m^3.d, respectively). According to the above organic, CN^- and Zn^{2+} loadings, the bio-sludge could grow without any repression effects. However, the 1:5 diluted-EPWW solution containing 730 mg/L glucose had a very low BOD_5:TN ratio of 100:1.2, which repressed the growth of bio-sludge. To increase the growth of bio-sludge, the BOD_5: TN ratio should be increased by the addition of urea or $(NH_4)_2SO_4$. The results showed that the removal efficiency was increased with the decrease of the BOD_5:TN ratio. The increase of the nitrogen content of EPWW would stimulate the heterotrophic bacteria as the dominant strain which resulted in the increase of the organic (BOD_5 and TKN) and Zn^{2+} removal efficiencies.

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Nomenclature

BOD_5	Biochemical oxygen demand
CN^-	Cyanide
COD	Chemical oxygen demand
EPWW	Electroplating wastewater
HRT	Hydraulic retention time
NH_4^+-N	Ammonium-nitrogen
NO_3^--N	Nitrate-nitrogen
NO_2^--N	Nitrite-nitrogen
SBR	Sequencing batch reactor
SS	Suspended solids
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
Zn^{2+}	Zinc