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# Biological removal of cyanide compounds from electroplating wastewater (EPWW) by sequencing batch reactor (SBR) system

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**Abstract**

Biological treatment system especially, sequencing batch reactor (SBR) system could not be applied to treat the raw electroplating wastewater (EPWW) due to the low organic matter concentration of 10 ± 3 mg-$BOD_5$/L and toxic of high cyanide concentration of 23.0 ± 2.2 mg-CN/L. However, EPWW could be used as the nitrogen source for the bio-sludge of SBR system. And 10% of EPWW (the final cyanide concentration of 2.3 ± 0.2 mg/L) was most suitable to supplement into the wastewater as the nitrogen source. SBR system showed the highest COD, $BOD_5$, TKN and cyanide removal efficiencies of 79 ± 2%, 85 ± 3%, 49.0 ± 2.1% and 97.7 ± 0.7%, respectively with 4-times diluted Thai-rice noodle wastewater (TRNWW) containing 10% EPWW and 138 mg/L $NH_4Cl$ ($BOD_5$: TN of 100:10) at SRT of 72 ± 13 days (under organic and cyanide loadings of 0.40 kg-$BOD_5$/$m^3$ d and 0.0023 kg-CN/$m^3$ d, respectively). However, the effluent ammonia was still high of 22.6 ± 0.4 mg-N/L while the effluent nitrate and nitrite was only 9.9 ± 0.4 and 1.2 ± 0.9 mg-N/L, respectively. And SVI and effluent SS of the system were higher than 95 and 75 mg/L, respectively.


*Keywords:* Biological removal of cyanide; Cyanide; Electroplating wastewater; Environmental; Sequencing batch reactor (SBR); Treatment

## 1. Introduction

Many industries such as photo-processing, electroplating, gold mining and chemical-fertilizer generate large amount of wastewater containing high concentration of cyanide and cyanate compounds as serious hazardous substances due to their strong effects on both the environment and human [1–6]. The chemical treatment processes, especially, chemical oxidation and coagulation are common use and suitable to treat above wastewater due to the high concentration of cyanide compounds, but they produced large amount of hazardous sludge. Several researchers tried to apply the biological process to remove or degrade cyanide compounds and recover some valuable materials from the wastewaters [2,5,7–12]. For example, the combination of bio-sorption and biodegradation processes was applied for degradation of free and metal complexed cyanides and recover of metals from wastewater [9,10,12]. It is well documented that cyanide compounds at high concentration is toxic to the living organisms in aquatic environments. Many researchers reported that the cyanide compounds could be degraded and utilized by the microorganisms such as fungus and bacteria [9,12,13–18]. But, cyanide compounds at high concentration are toxic to the microorganisms or the bio-sludge of biological treatment system. Anyways, bioremediation of cyanide compounds from above wastewaters is of major importance, as it offers a potential alternative to chemical oxidation (conventional process) for the recovery of the cyanide compounds and using it as the nitrogen source for the bio-sludge of biological treatment system [19–24]. However, the bio-sludge of the biological treatment system required both carbon and nitrogen

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**Nomenclature**

| | |
|---|---|
| AS | Activated sludge system |
| $BOD_5$ | Biochemical Oxygen demand |
| COD | Chemical Oxygen demand |
| EPWW | Electroplating wastewater |
| HRT | Hydraulic retention time |
| MLSS | Mixed liquor suspended solids |
| SBR | Sequencing batch reactor |
| SRT | Solids retention time; Sludge age |
| SS | Suspended solids |
| SVI | Sludge volume index |
| TKN | Total kjeldahl nitrogen |

sources for growth [19,22–24]. Then, the concentration of both cyanide and organic matter in the wastewater had to be considered [6,14,19,20,25].

To treat wastewater containing high cyanide concentration and low organic matter ($BOD_5$) as EPWW by biological wastewater treatment process might be difficult but the cyanide compounds of the EPWW might be used as the nitrogen source for the bio-sludge of the biological treatment process [2,6,19,20]. And the ammonia was the metabolite of the biodegradation of cyanide compounds [6,19,26].

The SBR system is a modified activated sludge (AS) system used in solving the low-density bio-sludge and bulking sludge problems due to the large volume of clarifier [19]. Also, the SBR system can easily be modified for both carbon and nitrogen (especially, cyanide and by-products of bio-degradation of cyanide) removal, with the appropriate operational program. In this study, the biological treatment of EPWW by SBR system was tested. The application of EPWW as the nitrogen source for non-nitrogen compound contained wastewater (both synthetic wastewater and industrial wastewater: Thai rice noodle wastewater; Khanom-chin: TRNWW) on the efficiency of SBR system and bio-sludge quality was also studied.

## 2. Materials and methods

### 2.1. Wastewater (WW)

Three types of wastewater were used in this study as electroplating wastewater (EPWW), Thai rice noodle wastewater (Khanon-chin: TRNWW) and synthetic wastewater (SWW), were mentioned as follows:

#### 2.1.1. Electroplating wastewater (EPWW)

EPWW was collected from the electroplating factory in Nakhonpathom province, Thailand. The chemical property of this EPWW was shown in Table 1.

#### 2.1.2. Thai rice noodle wastewater (Khanom-chin: TRNWW)

TRNWW was collected from the Thai rice noodle (Khanom-chin) factory in Rajchaburi Province, Thailand. The chemical property of TRNWW was shown in Table 1.

#### 2.1.3. Synthetic wastewater (SWW)

SWW was prepared to have the $BOD_5$ concentration of 400 mg/L. The chemical composition of SWW was shown in Table 1. The SWW containing EPWW (SWW-EPWW) was prepared with various concentration of glucose and 10% EPWW. The chemical composition of SWW-EPWW was shown in Table 1.

Table 1
Chemical composition and properties of electroplating wastewater (EPWW), Thai-rice noodle (Khanom-chin) wastewater: TRNWW and synthetic wastewater (SWW)

| Raw wastewater | | | Synthetic wastewater | | | |
|---|---|---|---|---|---|---|
| Chemical properties of raw wastewater | | | Synthetic wastewater (SWW)[b] | | Synthetic wastewater with cyanide (SWWC) | |
| Parameters | Electroplating wastewater (EPWW) | Thai rice noodle (Khanom-chin: TRN) wastewater | Parameters | Concentration (mg/L) | Parameter | Concentration (mg/L) |
| COD (mg/L) | 516 ± 36 | 11,791 ± 1133 | Glucose (mg/L) | 560 | Glucose (mg/L) | [c] |
| $BOD_5$ (mg/L) | 10 ± 3 | 8398 ± 1117 | $NH_4Cl$ (mg/L) | 153 | Urea (mg/L) | 153 |
| pH | 12.5 ± 0.4 | 5.5 ± 0.2 | $FeCl_2$ (mg/L) | 3.5 | $FeCl_2$ (mg/L) | 3.5 |
| Cyanide as mg CN/L | 23.0 ± 2.2 | ND[a] | $NaHCO_3$ (mg/L) | 65 | $NaHCO_3$ (mg/L) | 65 |
| Cyanide as mg N/L | 13.0 ± 0.0 | ND[a] | $KH_2PO_4$ (mg/L) | 6 | $KH_2PO_4$ (mg/L) | 6 |
| TKN (mg/L) | 25.0 ± 1.2 | ND[a] | $MgSO_4.7H_2O$ (mg/L) | 1.3 | $MgSO_4.7H_2O$ (mg/L) | 1.3 |
| $NH_4^+$ (mg/L) | 4.4 ± 0.3 | ND[a] | | | EPWW (%) | 10 |
| $NO_2^-$ (mg/L) | 0.03 ± 0.02 | 0.24 ± 0.02 | | | | |
| $NO_3^-$ (mg/L) | 1.96 ± 0.07 | ND[a] | | | | |
| Total nitrogen:TN (mg/L) | 39.5 ± 0.3 | 0.24 ± 0.02 | | | | |
| $Cu^{2+}$ (mg/L) | 27.0 ± 0.5 | ND[a] | | | | |

[a] ND: Non-detective.
[b] SWW containing 400 mg/L $BOD_5$.
[c] Amount of glucose was varied at 0, 280, 370, 560, 840 and 1120 mg/L.

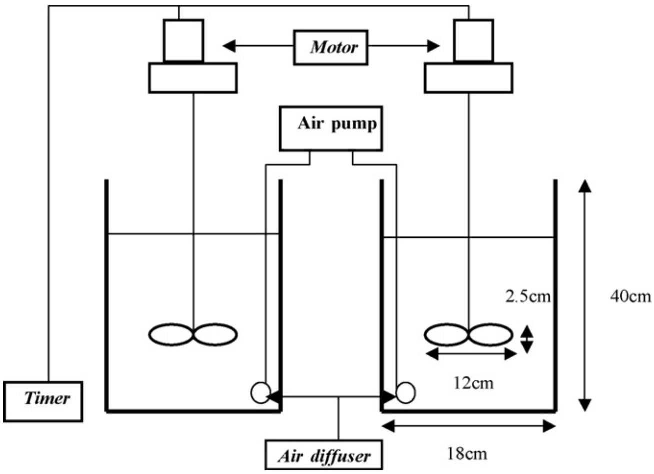


Fig. 1. Schematic diagram of the SBR system.

### 2.2. Bio-sludge and acclimatization of bio-sludge for SBR system

Bio-sludge collected from the central municipal wastewater treatment plant of Bangkok municipality, Thailand (Sriphaya central wastewater treatment plant) was used in this study. The bio-sludge was acclimatized in SWW for 1 week in the SBR system under a hydraulic loading of 0.1 $m^3/m^3$ d before using as the inoculum.

### 2.3. SBR system

Six 10 L reactors made from acrylic plastic (5 mm thick) were used in this study (Fig. 1). The dimensions of each reactor were 18 cm diameter and 40 cm height. The total volume and working volume of the reactor were 10.0 and 7.5 L, respectively. Low speed gear motors, model P 630A-387, 100 V, 50/60 Hz, 1.7/1.3 A (Japan Servo Co. Ltd., Japan), were used for driving the paddle shaped impeller. The speed of the impeller was adjusted to 60 rpm. One air pump system, model EK-8000, 6.0 W (President Co. Ltd., Thailand), was used for supplying air to each set of two reactors (the system had enough oxygen, as was evidenced by the dissolved oxygen in the system of approximately 1.5–2.0 mg/L). The excess sludge was drawn during draw and idle period to control the mixed liquor suspended solids (MLSS) of the system.

### 2.4. Operation of SBR system

A 1.4 L of acclimatized bio-sludge (10 g/L of SS) was inoculated in each reactor, and the SPPWW was added (final volume of 7.5 L) within 1 h. During feeding of the wastewater several types of wastewater as mentioned in Tables 2–5, the system had to be fully aerated and the aeration continued for 19 h. Aeration was then shut down for 3 h. After the sludge was fully settled, the supernatant was removed (the removed volume of the supernatant was based on the operation program mentioned in Table 2) within 0.5 h and the system kept under idle conditions for 0.5 h. Then, the raw wastewate was filled into the reactor to the final volume of 7.5 L and the above operation was repeated. Each experiment was carried out for 1.5 month. Both effluent and influent were collected once a day for chemical analysis.

Table 2
Operating parameters of sequencing batch reactor (SBR) system

| Operation parameter | Hydraulic retention time of 10 days |
|---|---|
| Cycle (batch/d) | 1 |
| Each step of the cycle (h) | |
| Fill up step | 1 |
| Aeration step | 19 |
| Settle step | 3 |
| Draw & Idle step | 1 |
| Working volume of the reactor (mL) | 7500 |
| Replacement volume (mL/d) | 750 |
| MLSS (mg/L) | 2500 |
| Hydraulic loading (L/L d or $m^3/m^3$ d) | 0.1 |

### 2.5. Chemical analysis and calculation of operation parameters

The $BOD_5$, COD, TKN, suspended solids (SS) ammonium, nitrate, nitrite and $Cu^{+2}$ of wastewater (influent and effluent), Mixed liquor suspended solids (MLSS), Mixed liquor volatile suspended solids, excess bio-sludge, and sludge volume index (SVI) of the system were determined using standard methods for the examination of water and wastewater [27]. Solid retention time (SRT) or sludge age was determined by measuring the average residence time of the microorganisms (bio-sludge) in the system. Food to microorganism ratio (F/M) is presented as the ratio of $BOD_5$ loading to total bio-sludge of the system. Total cyanide (both free and complexed cyanides) of both influent and effluent was determined by colorimetric method (4500-CN E.) after distillation with 1.0 mol/L sodium hydroxide solution [27].

### 2.6. Statistical analysis method

Each experiment was repeated three times. All the data were subjected to two-way analysis of variance (ANOVA) using SAS Windows Version 6.12 [28]. Statistical significance was tested using least significant difference (LSD) at the $p < 0.05$ level. The results are presented as mean ± the standard deviation.

## 3. Result

### 3.1. Effects of glucose concentration on the efficiency of SBR system

The raw-EPWW which was added with glucose at the concentrations of 0, 280, 370, 564, 840 and 1120 mg/L to adjust the $BOD_5$: TN ratios of 10:40, 100:20, 100:15, 100:10, 100:6.7 and 100:5, respectively, was used for testing the efficiency of

Table 3
Removal efficiency and effluent nitrogen compounds of SBR system with EPWW containing various glucose concentrations under HRT of 10 days

| Type of experiment* | $BOD_5$: TN | Organic loading ($kgBOD_5/m^3$ d) | Cyanide loading ($kgCN/m^3$ d) | Removal efficiency (%) | | | | | Effluent nitrogen compound (mgN/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $CN^-$ | $BOD_5$ | COD | TKN | TN | Organic-N | $NH_4^+$-N | $NO_2^-$-N | $NO_3^-$-N |
| R1 | 10:40 | 0.01 | 0.023 | 4.2 ± 5.2 | – | 18 ± 5 | 45.7 ± 5.1 | 22.3 ± 0.5 | 10.9 ± 2 | 2.7 ± 0.6 | 3.2 ± 0.4 | 2.9 ± 0.0 |
| R2 | 100:20 | 0.20 | 0.023 | 10.8 ± 4.1 | 31 ± 18 | 36 ± 10 | 59.0 ± 6.2 | 36.0 ± 0.8 | 6.4 ± 4.7 | 2.7 ± 0.9 | 3.0 ± 0.3 | 3.0 ± 0.0 |
| R3 | 100:15 | 0.267 | 0.023 | 14.4 ± 3.2 | 55 ± 23 | 52 ± 6 | 65.3 ± 5.1 | 38.6 ± 1.1 | 5.2 ± 0.9 | 3.4 ± 0.4 | 3.1 ± 0.1 | 2.9 ± 0.1 |
| R4 | 100:10 | 0.40 | 0.023 | 36.5 ± 6.2 | 71 ± 7 | 54 ± 7 | 66.2 ± 6.0 | 47.0 ± 2.0 | 4.9 ± 1.4 | 3.5 ± 0.2 | 2.6 ± 0.3 | 2.9 ± 0.1 |
| R5 | 100:6.7 | 0.60 | 0.023 | 11.3 ± 6.3 | 69 ± 10 | 42 ± 6 | 65.9 ± 2.6 | 39.4 ± 2.1 | 5.1 ± 0.5 | 3.4 ± 0.4 | 2.4 ± 0.1 | 2.9 ± 0.1 |
| R6 | 100:5 | 0.80 | 0.023 | 6.9 ± 4.2 | 69 ± 3 | 39 ± 5 | 43.0 ± 6.1 | 23.8 ± 2.1 | 10.6 ± 4.2 | 3.6 ± 0.2 | 2.4 ± 0.1 | 2.9 ± 0.1 |

* EPWW was added with glucose as various concentration of 0 (R1), 280 (R2), 370 (R3), 560 (R4), 840 (R5) and 1120 (R6) mg/L.

the SBR system. The results on the effect of glucose addition on the efficiency and performance of the SBR system were shown in Tables 3 and 4. The raw-EPWW could not be treated by the SBR system (The SBR system was operated under low organic loading of 0.01 kg-$BOD_5/m^3$ d and high cyanide loading of 0.023 kg-CN/$m^3$ d). The effluent $BOD_5$ was increased from 10 ± 3 to 62 ± 11 mg/L (data did not show) and the effluent SS was also increased up to 291 ± 19 mg/L. The MLSS of the system was decreased form 2500 mg/L to about 2107 ± 160 mg/L within 2 weeks (data did not show). SVI was increased up to 226 ± 19 mL/g after 2 weeks operation. However, the system efficiency could be increased by supplementation with glucose (organic matters). Also, the system efficiency was increased with the increase of glucose concentration (organic loading increasing). The highest COD, $BOD_5$, TKN and cyanide removal efficiencies of 54 ± 7%, 71 ± 7%, 66.2 ± 6.0% and 36.5 ± 6.2%, respectively was detected under organic loading of 0.40 kg-$BOD_5$ /$m^3$ d and cyanide loading of 0.023 kg-CN/$m^3$ d. But, it showed no good bio-sludge performance. SVI was higher than 170 mL/g as shown in Table 4. The MLSS was gradually decreased during operation and the effluent SS was increased up to higher than 300 mg/L as shown in Table 4. The effluent nitrate and nitrite was in the range of 3–4 mg/L as shown in Table 3.

### 3.2. Effects of dilution rate of EPWW on the efficiency and performance of SBR system

The SBR system was operated with 2.5, 5 and 10 times-diluted EPWW solution which was supplemented with and without glucose as shown in Table 5 (in the case of diluted EPWW containing glucose, the $BOD_5$: TN ratio was adjusted at 100:10). The SBR system with diluted-EPWW solution showed very low removal efficiency and bio-sludge performance as shown in Tables 5 and 6. But the diluted-EPWW was more easily to be treated by SBR system when it was added with glucose (Table 5). Also, the removal efficiency of SBR system was increased with the increase of the dilution rate as shown in Table 5. The system with 10-times diluted EPWW containing 560 mg/L glucose showed the highest COD, $BOD_5$, TKN and cyanide removal efficiencies of 81 ± 0%, 72 ± 3%, 68.2 ± 2.1% and 97.5 ± 1.2%, respectively under organic loading of 0.40 kg-$BOD_5/m^3$ d and cyanide loading of 0.0023 kg-CN/$m^3$ d. SVI value of the system with diluted-EPWW solution containing glucose was lower than that with diluted-EPWW solution as shown in Table 6. SVI of the system with diluted-EPWW solution was higher than 120 mL/g, but it was less than 100 mL/g with diluted-EPWW containing glucose.

### 3.3. Effects of $BOD_5$: TN ratio on the SBR system efficiency with SWW and TRNWW containing 10% EPWW

The SBR system was operated with SWW and diluted-TRNWW solutions which supplemented with 10% EPWW and ammonium chloride to reach the final $BOD_5$: TN ratio of 40:40, 100:20, 100:15, 100:10, 100:6.7 and 100:5 as shown in Table 7.

Table 4
Bio-sludge properties of SBR system operation with EPWW containing various glucose concentrations under HRT of 10 days

| Type of experiment[a] | $BOD_5$: TN | Bio-Sludge properties | | | | |
|---|---|---|---|---|---|---|
| | | F/M ratio | Excess sludge (mg/d) | Sludge age: SRT (days) | SVI (mL/g) | SS (mg/L) |
| R1 | 10:40 | 0.004 | – | – | 226 ± 19 | 291 ± 23 |
| R2 | 100:20 | 0.08 | – | – | 240 ± 12 | 307 ± 26 |
| R3 | 100:15 | 0.11 | - | – | 216 ± 6 | 340 ± 15 |
| R4 | 100:10 | 0.16 | – | – | 172 ± 12 | 327 ± 11 |
| R5 | 100:6.7 | 0.24 | – | – | 180 ± 14 | 454 ± 14 |
| R6 | 100:5 | 0.32 | – | – | 203 ± 14 | 566 ± 12 |

[a] EPWW was added with glucose as various concentration of 0 (R1), 280 (R2), 370 (R3), 560 (R4), 840 (R5) and 1120 (R6) mg/L.

The results on the effects of $BOD_5$: TN on the efficiency and performance of the SBR system were shown Tables 7 and 8 as follows:

*3.3.1. SWW*

The results on the effects of $BOD_5$: TN ratio on the efficiency and performance of SBR system with SWW were shown in Tables 7 and 8. The SBR system efficiency was increased with the increase of $BOD_5$: TN ratio or organic loading. The highest COD, $BOD_5$, TKN and cyanide removal efficiencies of 80 ± 1%, 76 ± 3%, 45.3 ± 3.0% and 98.0 ± 11.0%, respectively were detected under organic and cyanide loadings of 0.40 kg-$BOD_5$/m$^3$ d and 0.0023 kg-CN/m$^3$ d, respectively. But, the effluent SS was high as 77 ± 15 mg/L. However, the COD, $BOD_5$ and TKN efficiencies of the system were slightly decreased and the effluent SS was increased while the cyanide removal efficiency still remained higher than 95% under organic loading of higher than 40 kg-$BOD_5$/m$^3$ d ($BOD_5$: TN of SWW was higher than 100:10.) as shown in Table 7. The excess sludge production and SVI of the system were 260 ± 12 mg/d (SRT of 74 ± 9 d) and 97 ± 12 mL/g, respectively under organic loading of 40 kg-$BOD_5$/m$^3$ d ($BOD_5$: TN ratio of 100:10). And the SRT and SVI of the system were increased with the increase of glucose concentration of higher than 560 mg/L ($BOD_5$: TN of lower than 100:10) as shown in Table 8.

*3.3.2. TRNWW*

The results on the effects of $BOD_5$: TN ratio on the efficiency and performance of SBR system with diluted-TRNWW solution containing 10% EPWW were similar to in the case of SWW as shown in Tables 7 and 8. The highest COD, $BOD_5$, TKN and cyanide removal efficiencies of 79 ± 2%, 85 ± 3%, 49.0 ± 2.1% and 97.7 ± 0.7%, respectively were detected with 4-times diluted TRNWW solution containing 10% EPWW under organic loading of 0.40 kg $BOD_5$/m$^3$ d and cyanide loading of 0.0023 kg-CN/m$^3$ d. But, the effluent $NH_4^+$ was high as 21.4 ± 0.3 mg/L. The effluent SS of the system was 73 ± 15 mg/L. However, the SBR system efficiency was slightly decreased and the effluent SS was increased up to more than 110 mg/L under the organic loading of higher or lower than 0.40 kg-$BOD_5$/m$^3$ d. The system showed the good performance of bio-sludge under the $BOD_5$: TN of 100:10 (4-times diluted TRNWW solution containing 10% EPWW).

It could be concluded that the use of 10% EPWW as the nitrogen source for both SWW containing 400 mg/L $BOD_5$ and 4 times-diluted TRNWW solution was most suitable for the SBR system, but $NH_4Cl$ had to be added to adjusted the $BOD_5$: TN of 100:10. It showed the highest removal efficiency and good bio-sludge performance at the organic loading of 0.40 kg-$BOD_5$/m$^3$ d and cyanide loading of 0.0023 kg-CN/m$^3$ d. The cyanide removal efficiency could be reached up to more than 95% with the SRT of higher than 70 days. But the effluent SS was still high of 75–130 mg/L.

## 4. Discussion

The biological treatment of raw-EPWW by SBR system was still unsuitable due to the low $BOD_5$ concentration of 10 ± 3 mg/L and high cyanide concentration of 23.0 ± 2.2 mg/L [5,6,16,19,20,29]. According to the high cyanide concentration, the bio-sludge of the system might be killed and autolysis resulted to increase the effluent $BOD_5$ and SS and decrease the MLSS of the SBR system [14,19,30]. Also, the $Cu^+$ concentration of 27.0 ± 0.5 of the raw-EPWW might effect to both efficiency and performance of SBR system [31]. However, cyanide compounds of EPWW could be used as the nitrogen source for the bio-sludge of biological wastewater treatment system [5,8–10,16,19,26,30,32,33]. But, the heavy metals as $Cu^+$ of EPWW effected to growth and performance of bio-sludge [31]. Also, the lack of $BOD_5$ (organic matters) in the EPWW might effect to the growth and removal efficiency of bio-sludge [19,26]. But, the addition of glucose into raw-EPWW could increase both organic and cyanide removal efficiency of the system resulted by stimulation the bio-sludge growth [19,26]. However, the removal efficiency was quite low even, the glucose was supplemented up to 1120 mg/L ($BOD_5$: TN of up to 100:5). Also, the system showed no good bio-sludge quality. The MLSS of the system was slightly decreased during operation (data did not show). It might be the effect of cyanide and some other toxic substance of raw-EPWW [6,9–11,22,32]. However, the relevant data for toxicity test of cyanide compounds and other toxic substances of EPWW on the bio-sludge was not collected in this study. It is therefore recommended that further research regarding the toxicity test of cyanide compounds and other toxic substances such as heavy metals had to be conducted to further advance the understanding of toxic of heavy metals and cyanide compounds.

Table 5
Removal efficiency and effluent nitrogen compounds of SBR system with diluted-EPWW solution supplemented with (G) and without glucose (NG) under HRT of 10 days

| Type of experiment[a] | $BOD_5$ (mg/L) | Organic loading ($kgBOD_5/m^3$ d) | Cyanide loading ($kgCN/m^3$ d) | Removal efficiency (%) | | | | | Effluent nitrogen compound (mgN/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $CN^-$ | $BOD_5$ | COD | TKN | TN | Organic-N | $NH_4^+$-N | $NO_2^-$-N | $NO_3^-$-N |
| 10D-NG | 1.2 | 0.0012 | 0.0023 | 78.3 ± 4.0 | – | 18 ± 10 | 57.7 ± 5.0 | −69.1 ± 3.2 | 0.7 ± 0.2 | 5.7 ± 1.7 | 1.8 ± 0.1 | 2.2 ± 0.1 |
| 5D-NG | 3 | 0.003 | 0.0078 | 70.0 ± 6.1 | – | 3 ± 16 | 45.9 ± 1.9 | −33.7 ± 2.2 | 0.2 ± 0.2 | 7.8 ± 0.3 | 1.5 ± 0.3 | 4.2 ± 0.1 |
| 2.5D-NG | 5 | 0.005 | 0.01 | 55.7 ± 5.2 | – | – | 53.7 ± 4.2 | −20.5 ± 2.2 | 0.2 ± 0.2 | 7.5 ± 1.1 | 2.1 ± 0.2 | 5.4 ± 0.1 |
| 10D-G | 400 | 0.4 | 0.0023 | 97.5 ± 0.1 | 72 ± 3 | 81 ± 0 | 68.2 ± 2.1 | 56.2 ± 5.8 | 2.2 ± 0.7 | 5.3 ± 0.4 | 0.2 ± 0.1 | 41.2 ± 0.2 |
| 5 D-G | 400 | 0.4 | 0.0078 | 74.4 ± 1.2 | 59 ± 6 | 69 ± 4 | 61.1 ± 1.1 | 40.5 ± 4.6 | 0.5 ± 0.5 | 9.1 ± 2.2 | 1.1 ± 0.4 | 41.4 ± 0.4 |
| 2.5 D-G | 400 | 0.4 | 0.01 | 56.0 ± 2.1 | 51 ± 6 | 59 ± 1 | 59.7 ± 0.9 | 37.3 ± 3.5 | 1.0 ± 0.4 | 10.2 ± 1.3 | 0.5 ± 0.2 | 41.3 ± 0.4 |

[a] 10D, 5D and 2.5D were 10, 5 and 2.5 times diluted-EPWW, respectively, G indicated the addition of 560 mg/L glucose, 10D-G, 5D-G and 2.5D-G were added with 92, 122, 138 mg/L $NH_4Cl$, respectively.

Table 6
Bio-sludge properties of SBR system operation with diluted-EPWW solution supplemented with (G) and without glucose (NG) under HRT of 10 days

| Type of experiment[a] | $BOD_5$ (mg/L) | Organic loading (kg-$BOD_5/m^3$ d) | Cyanide loading (kg-$CN/m^3$ d) | Bio-sludge properties | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | F/M ratio | Excess Sludge (mg/d) | Sludge age: SRT (days) | SVI (mL/g) | SS (mg/L) |
| 10D-NG | 1.2 | 0.0012 | 0.0023 | 0.0004 | – | – | 129 ± 16 | 105 ± 13 |
| 5D-NG | 3 | 0.003 | 0.0078 | 0.0012 | – | – | 139 ± 17 | 217 ± 25 |
| 2.5D-NG | 5 | 0.005 | 0.01 | 0.002 | – | – | 143 ± 23 | 263 ± 16 |
| 10D-G | 400 | 0.4 | 0.0023 | 0.16 | 214 ± 21 | 88 ± 13 | 93 ± 17 | 97 ± 6 |
| 5 D-G | 400 | 0.4 | 0.0078 | 0.16 | – | – | 94 ± 3 | 217 ± 15 |
| 2.5 D-G | 400 | 0.4 | 0.01 | 0.16 | – | – | 94 ± 6 | 270 ± 10 |

[a] 10D, 5D and 2.5D were 10, 5 and 2.5 times diluted-EPWW, respectively, G indicated the addition of 560 mg/L glucose, 10D-G, 5D-G and 2.5D-G were added with 92, 122, 138 mg/L $NH_4Cl$, respectively.

Table 7
Removal efficiency and effluent nitrogen compounds of SBR system with diluted-TRNWW solutions and SWWC containing 10% EPWW under HRT of 10 days

| Type of experiment[a] | $BOD_5$: TN | Organic loading (kg-$BOD_5/m^3$ d) | Cyanide loading (kg-$CN/m^3$ d) | Removal efficiency (%) | | | | | Effluent nitrogen compound (mgN/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $CN^-$ | $BOD_5$ | COD | TKN | TN | Organic-N | $NH_4^+$-N | $NO_2^-$-N | $NO_3^-$-N |
| Synthetic wastewater was supplemented EPWW as the nitrogen source | | | | | | | | | | | | |
| SWW-G1-EPWW | 40: 40 | 0.04 | 0.0023 | 82.6 ± 1.2 | 40 ± 6 | 61 ± 8 | 27.3 ± 6.0 | -0.2 ± 0.0 | 0.0 ± 0.0 | 30.5 ± 2.6 | 8.7 ± 1.3 | 0.2 ± 0.1 |
| SWW-G2-EPWW | 100: 20 | 0.20 | 0.0023 | 96.8 ± 0.4 | 44 ± 9 | 66 ± 6 | 20.1 ± 3.0 | -9.4 ± 0.8 | 0.0 ± 0.0 | 33.0 ± 1.2 | 10.8 ± 1.6 | 2.8 ± 0.2 |
| SWW-G3-EPWW | 100: 15 | 0.267 | 0.0023 | 97.5 ± 0.9 | 52 ± 7 | 67 ± 8 | 17.6 ± 4.8 | -3.7 ± 0.5 | 1.8 ± 1.6 | 33.0 ± 1.3 | 8.8 ± 0.7 | 1.6 ± 0.3 |
| SWW-G4-EPWW | 100: 10 | 0.40 | 0.0023 | 98.4 ± 0.5 | 76 ± 3 | 80 ± 1 | 45.3 ± 3.0 | 22.7 ± 3.0 | 2.1 ± 0.7 | 20.7 ± 1.4 | 8.9 ± 1.0 | 1.6 ± 0.1 |
| SWW-G5-EPWW | 100: 6.7 | 0.60 | 0.0023 | 98.0 ± 0.2 | 67 ± 7 | 72 ± 7 | 42.8 ± 0.9 | 23.1 ± 2.1 | 1.6 ± 0.5 | 22.1 ± 0.8 | 7.7 ± 1.0 | 1.6 ± 0.1 |
| SWW-G6-EPWW | 100: 5 | 0.80 | 0.0023 | 97.4 ± 0.5 | 68 ± 8 | 61 ± 7 | 42.4 ± 1.0 | 20.2 ± 3.5 | 2.7 ± 2.5 | 21.3 ± 2.6 | 8.8 ± 0.1 | 1.5 ± 0.0 |
| Diluted-TRNWW was supplemented with EPWW as the nitrogen source | | | | | | | | | | | | |
| 8D-TRNWW-EPWW | 100: 20 | 0.20 | 0.0023 | 97.6 ± 0.1 | 72 ± 6 | 63 ± 2 | 45.0 ± 0.6 | 19.0 ± 3.5 | 0.2 ± 0.2 | 23.3 ± 0.5 | 12.4 ± 2.0 | 1.3 ± 0.8 |
| 6D-TRNWW-EPWW | 100: 15 | 0.267 | 0.0023 | 97.6 ± 0.2 | 83 ± 4 | 63 ± 3 | 45.4 ± 2.6 | 25.5 ± 5.5 | 0.6 ± 0.6 | 22.8 ± 0.9 | 10.3 ± 0.8 | 2.2 ± .4 |
| 4D-TRNWW-EPWW | 100: 10 | 0.40 | 0.0023 | 97.7 ± 0.7 | 85 ± 3 | 79 ± 2 | 49.0 ± 2.1 | 15.5 ± 3.2 | 0.6 ± 0.6 | 21.4 ± 0.3 | 9.9 ± 0.4 | 1.2 ± 0.9 |
| 3D-TRNWW-EPWW | 100: 6.7 | 0.60 | 0.0023 | 96.3 ± 2.0 | 84 ± 2 | 74 ± 4 | 44.0 ± 2.0 | 10.3 ± 2.2 | 1.5 ± 0.1 | 22.6 ± 0.4 | 12.4 ± 1.1 | 1.0 ± 0.8 |
| 2D-TRNWW-EPWW | 100: 5 | 0.80 | 0.0023 | 95.6 ± 4.0 | 84 ± 3 | 74 ± 2 | 42.8 ± 1.9 | 15.6 ± 2.3 | 0.2 ± 0.4 | 24.5 ± 0.7 | 13.6 ± 0.9 | 1.5 ± 1.1 |

[a] SWWC-G-EPWW was the synthetic wastewater containing 10% EPWW, 138 mg/L $NH_4Cl$ and glucose as various concentrations of 0 (G1), 280 (G2), 370 (G3), 560 (G4), 840 (G5) and 1120 (G6) mg/L.
D-TRNWW-EPWW was the diluted-TRNWW solution (8, 6, 4, 3 and 2 times diluted-TRNWW) containing 10% EPWW and 138 mg/L $NH_4Cl$.

It was found that only 10% of EPWW could be supplemented as the nitrogen source into SWW containing 400 mg/L $BOD_5$. The SBR system with SWW containing 10% EPWW and 138 mg/L $NH_4Cl$ ($BOD_5$:TN of 100:10) showed the highest organic and cyanide removal efficiencies under organic and cyanide loadings of 0.4 kg-$BOD_5/m^3$ d and 0.0023 kg-$CN/m^3$ d, respectively. But, the optimal $BOD_5$: TN of 100:10 in the SBR system was higher than that of the theoretical $BOD_5$: TN requirement of 100:5 [19]. Because, the nitrogen source of EPWW came from many variety of nitrogen compounds as organic nitrogen, inorganic nitrogen such as $NH_4^+$, cyanide compounds and so on as the hardly biodegradable nitrogen compound when it compare with the nitrogen compounds in the domestic or household wastewater that more easily biodegradable [19,26]. However, the relevant data on the types and amount of nitrogen compounds in EPWW was not collected in this study. It is therefore recommended that further research regarding on the determination of types and amount of nitrogen compounds of EPWW had to be conducted to further advance the understanding of the biodegradation and utilization of cyanide and other nitrogen compounds of EPWW. The effluent $NO_3^-$ was still high of 41.4 ± 0.4 mg/L. It might be the effect of nitrification–denitrification mechanism of SBR system. To reduce the effluent $NO_3^-$, the anoxic period of the SBR operation program had to be increased [3,8,26,30,33,34].

For application, the 10% EPWW was also most suitable to apply into the TRNWW as the nitrogen source, but the $BOD_5$ concentration of raw-TRNWW was quite high of 1600 ± 117 mg/L. Then, raw-TRNWW had to be diluted to control $BOD_5$ concentration and $BOD_5$: TN ratio. It was found that 10% EPWW was most suitable to apply for the nitrogen sources of TRNWW, but 138 mg/L $NH_4Cl$ had to be added to adjust the final $BOD_5$: TN ratio of 100:10. The SBR system showed the highest removal efficiency with 4 times-diluted TRNWW containing 10% EPWW and 138 mg/L $NH_4Cl$ ($BOD_5$: TN of 100:10) under organic and cyanide loadings of 0.40 kg-$BOD_5/m^3$ d and 0.0023 kg-$CN/m^3$ d, respectively. It showed the highest $BOD_5$ and cyanide removal efficiencies of more than 85% and 95%, respectively. But the effluent ammonia and nitrite were in the high level of about 20–35 and 10 mg/L, respectively. Even, in the theoretical information, all of nitrogen compounds of the wastewater could be treated by biological process under the assimilation and oxidation-reduction (nitrification–denitrification) processes [19,26]. Effluent ammonia might come from both remained-ammonium chloride, the biodegradation of both organic nitrogen and cyanide compounds [5,7,19,20,26]. And the effluent nitrite might come from the un-completely nitrification reaction [19]. SVI of the bio-sludge was higher than 100 mL/g, then, if the conventional AS system was applied, the designation of clarifier has to be strongly consideration to solve the bio-sludge raising problem [19,30]. However, SBR system was one of the solutions to solve above bio-sludge raising problem. Also, the SBR system had the other advantage on the removal of nitrogen compounds by controlling nitrification–denitrification reaction (oxic and anoxic ratio) [6,19,20].

Table 8
Bio-sludge properties of SBR system operation with diluted-TRNWW solutions and SWWC containing 10% EPWW under HRT of 10 days

| Type of experiment[a] | $BOD_5$: TN | Bio-sludge properties | | | | |
|---|---|---|---|---|---|---|
| | | F/M ratio | Excess Sludge (mg/d) | Sludge age: SRT (days) | SVI (mL/g) | SS (mg/L) |
| Synthetic wastewater was supplemented EPWW as the nitrogen source | | | | | | |
| SWW-G1-EPWW | 40: 40 | 0.016 | – | – | 145 ± 7 | 115 ± 5 |
| SWW-G2-EPWW | 100: 20 | 0.08 | 139 ± 33 | 135 ± 10 | 144 ± 5 | 111 ± 5 |
| SWW-G3-EPWW | 100: 15 | 0.11 | 167 ± 25 | 112 ± 11 | 157 ± 15 | 106 ± 2 |
| SWW-G4-EPWW | 100: 10 | 0.16 | 260 ± 20 | 74 ± 9 | 97 ± 12 | 77 ± 15 |
| SWW-G5-EPWW | 100: 6.7 | 0.24 | 231 ± 26 | 79 ± 12 | 114 ± 12 | 117 ± 6 |
| SWW-G6-EPWW | 100: 5 | 0.32 | 181 ± 40 | 103 ± 13 | 134 ± 3 | 127 ± 15 |
| Diluted-TRNWW was supplemented with EPWW as the nitrogen source | | | | | | |
| 8D-TRNWW-EPWW | 100: 20 | 0.08 | 105 ± 20 | 179 ± 23 | 161 ± 2 | 112 ± 3 |
| 6D-TRNWW-EPWW | 100: 15 | 0.11 | 167 ± 18 | 113 ± 19 | 142 ± 11 | 105 ± 5 |
| 4D-TRNWW-EPWW | 100: 10 | 0.16 | 262 ± 12 | 72 ± 13 | 95 ± 12 | 73 ± 15 |
| 3D-TRNWW-EPWW | 100: 6.7 | 0.24 | 237 ± 15 | 79 ± 16 | 120 ± 16 | 115 ± 13 |
| 2D-TRNWW-EPWW | 100: 5 | 0.32 | 243 ± 21 | 77 ± 17 | 147 ± 17 | 127 ± 15 |

[a] SWWC-G-EPWW was the synthetic wastewater containing 10% EPWW, 138 mg/L $NH_4Cl$ and glucose as various concentrations of 0 (G1), 280 (G2), 370 (G3), 560 (G4), 840 (G5) and 1120 (G6) mg/L. D-TRNWW-EPWW was the diluted-TRNWW solution (8, 6, 4, 3 and 2 times diluted-TRNWW) containing 10% EPWW and 138 mg/L $NH_4Cl$.

## 5. Conclusion

Raw-EPWW could not be biological-treated by SBR system, because of the low $BOD_5$ and high cyanide concentrations of $10 \pm 3$ and $23.0 \pm 2.2$ mg/L. But, cyanide compounds of the EPWW could be used as nitrogen source for the bio-sludge of the biological treatment system. A $2.3 \pm 0.2$ mg-CN/L of cyanide compounds (about 10% of EPWW) was most suitable to supplement into the wastewater as the nitrogen source. Then, to apply the biological treatment process for EPWW, the total cyanide content of the EPWW has to control. A 10% EPWW could be applied into SWW containing 400 mg/L $BOD_5$ or TRNWW solution as the nitrogen source. And the suitable $BOD_5$: TN ratio of the wastewater had to be control as 100:10. The optimal organic and cyanide loadings of the SBR system had to be controlled at 0.40 kg-$BOD_5$/$m^3$ d and 0.0023 kg-CN/$m^3$ d, respectively. The highest COD, $BOD_5$, TKN and cyanide removal efficiencies of $79 \pm 2\%$, $85 \pm 3\%$, $49.0 \pm 2.1\%$ and $97.7 \pm 0.7\%$, respectively were detected when the system was operated with 4-times diluted TRNWW containing 10% EPWW and 138 mg/L $NH_4Cl$ under organic loading of 0.40 g-$BOD_5$/$m^3$ d and cyanide loading of 0.023 kg-CN/$m^3$ d.

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