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Effect of bio-sludge concentration on the efficiency of sequencing batch reactor (SBR) system to treat wastewater containing Pb^{2+} and Ni^{2+}

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ABSTRACT

The removal efficiency of sequencing batch reactor (SBR) system with synthetic industrial estate wastewater (SIEWW) containing Ni^{2+} or Pb^{2+} was increased with the increase of mixed liquor suspended solids (MLSS). But, the sludge volume index (SVI) of the system was increased up to higher than 100 mL/g under MLSS of up to 4000 mg/L. Also, the effluent NO_3^- was decreased with the increase of MLSS. The heavy metals (Ni^{2+} or Pb^{2+}), BOD_5, COD and TKN removal efficiencies of SBR system with SIEWW containing 5 mg/L heavy metal (Ni^{2+} or Pb^{2+}) under MLSS of 3000 mg/L were 83–85%, 96–97%, 95–96% and 83–94%, respectively. The increase of heavy metal (Ni^{2+} or Pb^{2+}) concentrations of SIEWW from 5 to 50 mg/L were not significantly effected to both COD and BOD_5 removal efficiencies (they were reduced by only 4–5%), but they were strongly effected to both TKN and heavy metals removal efficiencies (they were reduced by 15 and 20–30%, respectively). Both Ni^{2+} and Pb^{2+} could repress the growth of both nitrification and denitrification bacteria. And Ni^{2+} was more effective than Pb^{2+} to reduce the heavy metals removal efficiency. The SBR system could be applied to treat the industrial estate wastewater (IEWW) containing both Pb^{2+} and Ni^{2+} even the heavy metals concentrations was up to 5 mg/L, but the removal efficiency was quite low and excess bio-sludge did not produce. However, the system efficiency could be increased with the increase of BOD_5 concentration of the wastewater. The Pb^{2+}, Ni^{2+}, COD, BOD_5 and TKN removal efficiencies of the system with IEWW containing 500 mg/L BOD_5, 5 mg/L Ni^{2+} and 5 mg/L Pb^{2+} under HRT of 3 days were 85.68 ± 0.31%, 87.03 ± 0.21%, 86.0 ± 0.5%, 94.04 ± 0.4% and 90.5 ± 0.9%, respectively. And the effluent SRT, SS and SVI of the system were 44.7 ± 0.6 days, 150 ± 6 mg/L and 100 mL/g, respectively.

1. Introduction

In Thailand, some industrial estate parks consisted of various types of industry such as food, chemical, automobile and electrochemical industries and so on. Then, the wastewater from such industrial parks contained not only organic matter but also inorganic matter as heavy metals. Then, the selection of wastewater treatment process should be carefully considered [1,2]. A biological treatment process is suitable for the wastewater containing organic matter such as the wastewater from the food industry, while the chemical treatment process is suitable for wastewater containing inorganic matters as heavy metals such as electroplating industry [1–5]. It is well documented that heavy metals at high concentrations are toxic to the bio-sludge of biological treatment process [2,6–9]. Also, Cheng et al. [9] reported that the heavy metals concentration of wastewater was reduced after treated by aerobic activated sludge system. However, bioremediation of heavy metals from wastewaters containing both organic matter and heavy metal is the most importance, as it offers a potential alternative to chemical treatment (conventional process) for the recovery of the valuable metal together with the removal of organic matter. It was well-known that the chemical precipitation is suitable for wastewater containing high heavy metal concentration, but it produce large amount of hazardous sludge [2]. Several researchers reported that heavy metals (zinc, cupper, cadmium, chromium, lead and so on) in the wastewater could be adsorbed onto the surface of fungal cell (both dead and living cells) such as *Aspergillus niger*, *Candida utilis*, *Trichloderma* sp., *Penicillium spnulosum* and so on [6,7,9,10–21]. The heavy metal adsorption capacity was increased with the increase of cell age (solids retention time: SRT) [14,16,22,23] Also, the heavy metal adsorption capacity of dead mycelium of *Penicillium spnulosum*, *Aspergillus niger* and *Trichloderma* sp. were increased with the decrease of reaction solution pH [12,24]. Our previous works

Abbreviations: BOD_5, biochemical oxygen demand; COD, chemical oxygen demand; F/M, food (BOD5 loading)/microbe (total bio-sludge); HRT, hydraulic retention time; MLSS, mixed liquor suspended solids; Ni^{2+}, nickel ion; Pb^{2+}, lead ion; SBR, sequencing batch reactor; SRT, solid retention time; SS, suspended solids; SVI, sludge volume index; IEWW, industrial estate wastewater; SIEWW, synthetic industrial estate wastewater; TKN, total kjeldahl nitrogen; TN, total nitrogen.

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Table 1
Chemical characteristics of raw industrial estate wastewater (IEWW)[a] and the modified IEWW.

Properties	Chemical Properties							
	IEWW	IEWW + glucose	IEWW + Ni^{2+}	IEWW + Pb^{2+}	IEWW + glucose + Ni^{2+}	IEWW + Ni^{2+} + Pb^{2+}	IEWW + glucose + Pb^{2+}	IEWW + glucose + Ni^{2+} + Pb^{2+}
COD (mg/L)	220 ± 20	620 ± 30	220 ± 20	220 ± 20	620 ± 30	220 ± 20	620 ± 30	620 ± 30
BOD_5 (mg/L)	140 ± 15	550 ± 30	140 ± 15	140 ± 15	550 ± 30	140 ± 15	550 ± 30	550 ± 30
TKN (mg/L)	20 ± 3	25 ± 3	20 ± 3	20 ± 3	25 ± 3	20 ± 3	25 ± 3	25 ± 3
NH_4^+ (mg/L)	6 ± 1	7 ± 1	6 ± 1	6 ± 1	7 ± 1	6 ± 1	7 ± 1	7 ± 1
NO_2^- (mg/L)	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01	0.1 ± 0.01
NO_3^- (mg/L)	16 ± 2	18 ± 2	16 ± 2	16 ± 2	18 ± 2	16 ± 2	18 ± 2	18 ± 2
Ni^{2+} (mg/L)	0.41 ± 0.02	0.41 ± 0.02	5.0 ± 0.3	0.41 ± 0.02	5.0 ± 0.3	5.0 ± 0.3	0.41 ± 0.02	5.0 ± 0.3
Pb^{2+} (mg/L)	0.35 ± 0.02	0.35 ± 0.02	0.35 ± 0.02	5.0 ± 0.3	0.35 ± 0.02	5.0 ± 0.3	5.0 ± 0.3	5.0 ± 0.3
pH	7.2 ± 0.3	7.2 ± 0.3	7.2 ± 0.3	7.2 ± 0.3	7.2 ± 0.3	7.2 ± 0.3	7.2 ± 0.3	7.2 ± 0.3

±: Standard deviation of 3 replicates.
IEWW + glucose: IEWW containing 500 mg/L glucose. IEWW + Ni^{2+}: IEWW containing 5 mg/L Ni^{2+}. IEWW + Pb^{2+}: IEWW containing 5 mg/L Pb^{2+}. IEWW + glucose + Ni^{2+}: IEWW containing 500 mg/L glucose and 5 mg/L Ni^{2+}. IEWW + glucose + Pb^{2+}: IEWW containing 500 mg/L glucose and 5 mg/L Pb^{2+}. IEWW + glucose + Ni^{2+} + Pb^{2+}: IEWW containing 5 mg/L $Ni^{2+}$and 5 mg/L Pb^{2+}.
[a] From central wastewater collection pond of industrial estate of East-Bangkok, Thailand.

also found that both dead and living bio-sludge from the conventional biological wastewater treatment plant especially sewage treatment plant, could be used as the adsorbent for some heavy metals such as chromium, lead, cupper, zinc and nickel [17,25]. The heavy adsorption capacity was increased with the increase of the bio-sludge age [17,25,26]. Also, the biological treatment process such as sequencing batch reactor (SBR) and granular activated carbon-SBR (GAC-SBR) systems could be applied to treat wastewater containing heavy metals [17,25,27,28]. And the system removal efficiency was decreased with the increase of heavy metal concentration [25]. Also, the heavy metal removal yield of the system was increased with the increase of excess bio-sludge production [17]. However, the SBR or GAC-SBR systems should be operated under low excess bio-sludge production according to the limitation of the operation condition. Then, in this study, the application of SBR system for treatment of industrial estate containing Pb^{2+} and/or Ni^{2+} under various MLSS was investigated to obtain the optimal MLSS level for the highest heavy metals removal efficiency together with good bio-sludge performance. Also, the effect of heavy metals (Pb^{2+} and/or Ni^{2+}) concentration on the system efficiency and performance are obtained.

2. Materials and methods

2.1. Heavy metals

Two types of heavy metals were selected for use in this study, Pb^{2+} and Ni^{2+}. $PbCl_2$ and $NiCl_2{\cdot}6H_20$ were used as the sources of Pb^{2+} and Ni^{2+}, respectively, in both synthetic and real industrial estate wastewaters.

2.2. Wastewater samples

Two kinds of wastewater samples were used in this study: (1) industrial estate wastewater (IEWW) and (2) synthetic industrial estate wastewater (SIEWW). IEWW was collected from influent sump tank of central wastewater treatment plant of East-Bangkok industrial estate (Consisted of electronic automobile and food industrial factories), Thailand. The chemical properties of IEWW were described in Table 1. IEWW solutions were supplemented with glucose (final BOD_5 concentration of 550 ± 30 mg/L), $PbCl_2$ (final concentration of 5 ± 0.3 mg/L Pb^{2+}) $NiCl_2{\cdot}6H_20$ (final concentration of 5 ± 0.3 mg/L Ni^{2+}), $PbCl_2$ and $NiCl_2{\cdot}6H_20$ (final concentrations of 5 ± 0.3 mg/L Pb^{2+} and 5 ± 0.3 mg/L Ni^{2+}) and glucose, $PbCl_2$ and $NiCl_2{\cdot}6H_20$ (final concentrations of 550 ± 30 mg/L, 5 ± 0.3 mg/L Pb^{2+} and 5 ± 0.3 mg/L Ni^{2+}) were used as IEWW + glucose, IEWW + Pb^{2+}, IEWW + Ni^{2+}, IEWW + Pb^{2+} + Ni^{2+} and IEWW + glucose + Pb^{2+} + Ni^{2+}. The chemical compositions of all types of IEWW solutions were showed in Table 1. SIEWW was prepared according to IEWW properties. Two types of SIEWW as SIEWW containing various concentration of Pb^{2+} (SIEWW + Pb^{2+}) and SIEWW containing various concentration of Ni^{2+} (SIEWW + Ni^{2+}) were used in the experiment The SIEWW contained 720 mg/L glucose, 54 mg/L urea, 13 mg/L $FeSO_4{\cdot}7H_2O$, 22 mg/L KH_2PO_4 and various concentrations of heavy metals (Pb^{2+} or Ni^{2+}) of 5, 10, 15, 20, 30, 40 and 50 mg/L. The 6.7 mg/L $PbCl_2$ or 20.3 mg/L $NiCl_2{\cdot}6H_20$ were supplemented into SIEWW for the final Pb^{2+} or Ni^{2+} concentrations of 5 mg/L.

2.3. Acclimatization of bio-sludge for using in SBR system

Bio-sludge from the bio-sludge storage tank of central sewage treatment plant of Bangkok city, Thailand (Sripaya sewage treatment plant) was used as the inoculum of SBR system. The bio-sludge was fed with SIEWW without heavy metals in the SBR reactor and acclimatized for 1 week under hydraulic loading of 0.33 $m^3/(m^3\,d)$ before using as the inoculum of SBR system.

2.4. Sequencing batch reactor (SBR)

Six 10-L reactors, made from acrylic plastic (5 mm thick) as shown in Fig. 1, were used in the experiments. The dimension of each reactor was 18 cm-diameter and 40 cm-height, and the working volume was 7.5 L. Low speed gear motor (model P 630A-387, 100 V, 50/60 Hz, 1.7/1.3 A, Japan Servo Co. Ltd., Tokyo, Japan) was used for driving the paddle-shaped impeller. The speed of impeller was adjusted to 60 rpm for complete mixing. One set of air pump system, model EK-8000, 6.0 W (President Co. Ltd., Bangkok, Thailand) was used for supplying air for the 2 sets of reactor (the system had enough oxygen as evidenced by the dissolved oxygen in the system of about 2 ± 0.5 mg/L). The excess bio-sludge was drawn during draw and idle period to control mixed liquor suspended solids (MLSS) of the system as mentioned in Table 2.

2.5. Operation of SBR system

SBR system was operated at 1 cycle/day under a HRT of 3 days and various MLSS of 2000, 2500, 3000, 4000 and 4500 mg/L. A 1.4 L of 10 g/L of acclimatized sludge was inoculated in each reactor, and the IEWWs or SIEWWs were added (final volume of 7.5 L) within 1 h. During 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 removed (the removed volume of the supernatant was based on the operation program outlined in Table 2) within 0.5 h and the system was kept under idle condition for 0.5 h. After that, the reactor was filled with fresh wastewater

Table 2
The operating parameters of the SBR system used to treat SIEWW, modified SIEWW and IEWW.

Parameters	Types of wastewater											
	SIEWW					IEWW						
						IEWW	IEWW + glucose[a]	IEWW + Ni^{2+}	IEWW + Pb^{2+}	IEWW + glucose + Ni^{2+}	IEWW + glucose + Pb^{2+}	IEWW + glucose + Ni^{2+} + Pb^{2+}
MLSS (mg/L)	2000	2500	3000	4000	4500	3000	3000	3000	3000	3000	3000	3000
HRT (days)	3	3	3	3	3	3	3	3	3	3	3	3
Flow rate (mL/d)	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Hydraulic loading ($m^3/(m^3$ d))	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325
BOD_5 loading (g/d)	1.4	1.4	1.4	1.4	1.4	0.38	1.38	0.38	0.38	1.38	1.38	1.38
F/M ratio	0.093	0.074	0.062	0.046	0.042	0.017	0.061	0.017	0.017	0.061	0.061	0.061
Volumetric BOD_5 loading (kg/(m^3 d))	0.186	0.186	0.186	0.186	0.186	0.047	0.184	0.047	0.047	0.184	0.184	0.184
Pb^{2+} loading	b	b	b	b	b	0.0009	0.0011	0.0009	0.013	0.0009	0.013	0.013
Ni^{2+} loading	c	c	c	c	c	0.0011	0.0009	0.013	0.0011	0.013	0.0011	0.013

±: Standard deviation of 3 replicates.
[a] IEWW was added 500 mg/L glucose to increase BOD_5 concentration up to 500 mg/L.
[b] The Pb^{2+} loading of the SIEWW containing 5, 10, 20, 30, 40 and 50 mg/L of Pb^{2+} were 0.013, 0.026, 0.052, 0.078 and 0.130 g/L, respectively.
[c] The Ni^{2+} loading of the SIEWW containing 5, 10, 20, 30, 40 and 50 mg/L of Ni^{2+} were 0.013, 0.026, 0.052, 0.078 and 0.130 g/L, respectively.

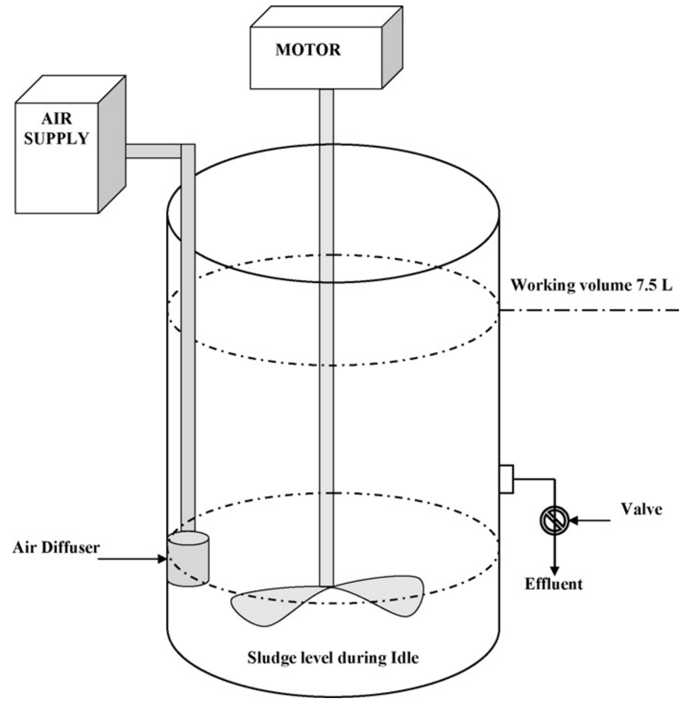

Fig. 1. The SBR reactor.

to the final volume of 7.5 L and the above operation repeated. The operation parameters of the SBR system with IEWW and SIEWW are described in Table 2.

2.6. Chemical analysis

The concentrations of chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total kjeldahl nitrogen (TKN), total nitrogen (TN), Pb^{2+}, Ni^{2+}, MLSS as well as the pH of influent and effluent and sludge volume index (SVI) of the SBR system were determined by using standard methods for the examination of water and wastewater [29]. The solid retention time (SRT) or bio-sludge age was determined as the ratio of total biomass (mixed liquor suspended solids: MLSS) of the system to the amount of excess bio-sludge wasted a day.

2.7. Statistical analysis method

Each experiment was repeated at least three times. All the data were subjected to two-way analysis of variance (ANOVA) using SAS Windows Version 6.12 [30]. Statistical significance was tested using least significant difference (L.S.D.) at the $p < 0.05$ level. The results shown are the mean ± the standard deviation.

3. Results

3.1. Effect of the bio-sludge concentrations on the efficiency of SBR with SIEWW containing 5 mg/L heavy metals (Pb^{2+} or Ni^{2+})

Two types of synthetic industrial estate wastewater, viz., SIEWW containing 5 mg/L Pb^{2+} (SIEWW + Pb^{2+}), SIEWW containing 5 mg/L Ni^{2+} (SIEWW + Ni^{2+}) were used in these experiments. The results showed that the removal efficiencies of SBR system were increased with the increase of MLSS as shown in Tables 3 and 4. The removal efficiency was increased up to the high level under the MLSS of up to 4000 mg/L as shown in Table 3. Moreover, Pb^{2+} and Ni^{2+} concentrations of 5 mg/L were not so significantly effects to heavy metals, COD and BOD_5 removal efficiencies. The COD and BOD_5 removal

Table 3
Effluent qualities and removal efficiencies of SBR system operated with SIEWW containing 5 mg/L of heavy metal (Ni^{2+} or Pb^{2+}) under HRT of 3 days and various MLSS of 2000, 2500, 3000, 4000 and 4500 mg/L.

Types of wastewater	MLSS of the system (mg/L)	F/M ratio	Chemical Properties							SS (mg/L)
			Heavy metals		COD		BOD_5		pH	
			Effluent (mg/L)	% removal	Effluent (mg/L)	% removal	Effluent (mg/L)	% removal		
SIEWW + Ni^{2+} [a]	2000	0.093	0.865 ± 0.008	82.74 ± 0.19	44 ± 1	93.2 ± 0.2	31 ± 2	93.9 ± 0.5	6.73 ± 0.5	66 ± 2
	2500	0.074	0.855 ± 0.004	82.93 ± 0.10	38 ± 0	94.2 ± 0.2	21 ± 2	95.9 ± 0.3	6.73 ± 0.3	61 ± 2
	3000	0.062	0.804 ± 0.002	83.95 ± 0.09	30 ± 0	95.3 ± 0.2	19 ± 1	96.4 ± 0.4	6.74 ± 0.2	33 ± 3
	4000	0.046	0.776 ± 0.002	84.52 ± 0.05	25 ± 0	96.2 ± 0.2	15 ± 2	97.1 ± 0.2	6.74 ± 0.1	10 ± 1
	4500	0.042	0.754 ± 0.003	84.95 ± 0.08	24 ± 0	96.3 ± 0.2	13 ± 1	97.5 ± 0.2	6.74 ± 0.1	6 ± 1
SIEWW + Pb^{2+} [b]	2000	0.093	0.795 ± 0.003	84.15 ± 0.09	40 ± 0	93.7 ± 0.1	32 ± 3	94.3 ± 0.5	7.34 ± 0.4	63 ± 6
	2500	0.074	0.784 ± 0.003	84.37 ± 0.05	33 ± 0	94.8 ± 0.1	29 ± 1	94.7 ± 0.1	7.38 ± 0.2	55 ± 5
	3000	0.062	0.743 ± 0.001	85.19 ± 0.09	27 ± 0	95.7 ± 0.1	19 ± 1	96.6 ± 0.3	7.40 ± 0.1	43 ± 6
	4000	0.046	0.724 ± 0.003	85.56 ± 0.11	25 ± 0	96.0 ± 0.1	14 ± 1	97.4 ± 0.2	7.40 ± 0.1	28 ± 3
	4500	0.042	0.705 ± 0.002	85.96 ± 0.09	23 ± 1	96.3 ± 0.2	10 ± 2	98.1 ± 0.2	7.40 ± 0.1	13 ± 6

±: Standard deviation of 3 replicates.
[a] SIEWW contained 5 mg/L Ni^{2+}.
[b] SIEWW contained 5 mg/L Pb^{2+}.

Table 4
Effluent qualities and nitrogen compounds removal efficiencies of SBR system with SIEWW containing 5 mg/L of heavy metal (Ni^{2+} or Pb^{2+}) under HRT of 3 days and various MLSS of 2000, 2500, 3000, 4000 and 4500 mg/L.

Types of heavy metal	MLSS (mg/L)	TKN (mg/L)		NH_4^+ (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	TN (mg/L)		% TN removal
		Effluent	% removal	Effluent	Effluent	Effluent	Influent	Effluent	
Ni^{2+}	2000	5.6 ± 0.0	79.3 ± 0.7	3.9 ± 0.0	0.4 ± 0.0	21.5 ± 0.8	27.7 ± 0.2	27.5 ± 0.8	0.6 ± 0.2
	2500	4.5 ± 0.0	83.4 ± 0.6	3.4 ± 0.0	0.4 ± 0.0	21.0 ± 0.9	277 ± 0.2	25.8 ± 0.9	6.8 ± 1.0
	3000	4.3 ± 0.0	83.9 ± 0.4	2.8 ± 0.0	0.3 ± 0.0	17.6 ± 0.2	27.7 ± 0.2	22.3 ± 0.2	19.4 ± 2.8
	4000	4.2 ± 0.0	84.6 ± 0.5	2.6 ± 0.0	0.3 ± 0.0	12.6 ± 0.3	27.7 ± 0.2	17.0 ± 0.3	38.4 ± 2.5
	4500	3.4 ± 0.0	87.6 ± 0.4	2.2 ± 0.0	0.3 ± 0.0	10.3 ± 0.9	27.7 ± 0.2	14.0 ± 0.9	49.6 ± 1.7
Pb^{2+}	2000	2.8 ± 0.0	89.4 ± 0.2	2.2 ± 0.0	0.3 ± 0.0	22.6 ± 0.1	27.1 ± 0.1	25.5 ± 0.2	5.7 ± 1.4
	2500	2.2 ± 0.0	91.5 ± 0.2	1.4 ± 0.0	0.2 ± 0.0	18.6 ± 0.4	27.1 ± 0.1	21.1 ± 0.3	22.0 ± 2.5
	3000	2.0 ± 0.0	92.4 ± 0.2	1.1 ± 0.0	0.2 ± 0.0	10.8 ± 0.0	27.1 ± 0.1	13.0 ± 0.1	52.0 ± 0.6
	4000	1.5 ± 0.0	94.4 ± 0.1	0.9 ± 0.0	0.1 ± 0.0	9.8 ± 0.0	27.1 ± 0.1	11.4 ± 0.1	58.1 ± 1.0
	4500	1.1 ± 0.0	95.8 ± 0.1	0.6 ± 0.0	0.1 ± 0.0	7.4 ± 0.1	27.1 ± 0.1	8.8 ± 0.3	67.7 ± 1.6

±: Standard deviation of 3 replicates.

efficiencies were almost stable and in the high level of higher than 90%. And the heavy metals removal efficiencies were higher than 80%. The effluent SS of the system was decreased with the increase of MLSS. For the determination of effluent nitrogen compounds, the effluent NH_4^+ was quite low of less than 4 mg/L in all case of MLSS operations. The effluent NO_3^- was decreased with the increase of MLSS as showed in Table 4. TN and TKN removal efficiencies were increased to 50–70% and 89–96%, respectively, with the increase of MLSS up to 4500 mg/L. And the effluent NO_3^- was lower than 10 mg/L. For the determination of bio-sludge quality, SVI was increased with the increase of MLSS concentration. However, SVI was less than 100 mL/g under the MLSS of not over 3000 mg/L as shown in Table 5. Also, SRT was increased with the increase of MLSS. SRT was increased to over 30 days with the increase of MLSS up to 4500 mg/L as shown in Table 5.

3.2. *Effect of heavy metals (Pb^{2+} or Ni^{2+}) concentrations on the SBR system efficiency*

The results on the effect of heavy metals (Pb^{2+} or Ni^{2+}) concentrations (5–50 mg/L) in SIEWW on the efficiency of SBR system were shown in Tables 6 and 7. The increase of Pb^{2+} or Ni^{2+} up to 50 mg/L was not significantly effect to both COD and BOD_5 removal efficiencies. The COD and BOD removal efficiencies of the system were reduced by only 7–5% and 5–4%, respectively, with the increase of heavy metals concentration from 5 to 50 mg/L. But it strongly affected to the heavy metals removal efficiencies. The heavy metals removal efficiencies were reduced by 20–30% with the increase of heavy metals concentrations from 5 to 50 mg/L. The increase of heavy metals concentration was also effect to the effluent nitrogen compounds. The effluent nitrate was increased up to 20–28 mg/L with the increase of heavy metals (Ni^{2+} or Pb^{2+}) up to 50 mg/L. Moreover, effluent NO_3^- of the system with SIEWW containing Ni^{2+} was higher than with SIEWW containing Pb^{2+} in all case of experiments. However, the effluent NH_4^+ was quite low of only 2–4 mg/L in all case of experiments. TKN and TN removal efficiencies were decreased with the increase of heavy metals concentrations as shown in Table 7. TKN and TN removal efficiencies of the system with SIEWW containing Ni^{2+} were lower than with SIEWW containing Pb^{2+} at the same heavy metals concentration as shown in Table 7. Effluent SS was increased up to more than 130 mg/L with the increase of heavy metals up to 50 mg/L as shown in Table 6. For the determination of bio-sludge performance, SVI was increased with the increase of heavy metals concentrations. The SVI was increased up to higher than 100 mL/g with the wastewater contained heavy metals of more than 20 mg/L as shown in Table 5. Also, SRT of the system was increased with the increase of heavy metals concentrations as shown in Table 5. Moreover, no excess bio-sludge was produced from the SBR system with wastewater containing Ni^{2+} of up to 30 mg/L.

3.3. *Application of SBR system with IEWW*

The result of application of SBR system with IEWW was shown in Table 5, Tables 8 and 9. The system showed high COD, BOD_5 and TKN removal efficiencies, but it showed quite low TN removal efficiency. The Pb^{2+}, Ni^{2+}, COD, BOD_5, TKN and TN removal efficiencies of the system with IEWW under MLSS of 3000 mg/L and HRT of 3 days (F/M of 0.017) were 57.22 ± 0.76%, 77.35 ± 0.95%, 89.0 ± 1.7%, 90.0 ± 1.3%, 87.9 ± 1.3% and 36.4 ± 12%, respectively. The effluent SS and NO_3^- were quite high of over 120 and 19 mg/L, respectively, while effluent NH_4^+ was quite low of 0.6 ± 0.0 mg/L as shown in Tables 8 and 9. SVI and SRT of the system were 90 mL/g and 7.8 ± 0.3 days (excess bio-sludge of 2880 ± 15 mg/d), respectively.

3.4. *Efficiency of SBR system with IEWW containing 5 mg/L Ni^{2+} and/or Pb^{2+}*

For the further application, the SBR system was operated with IEWW containing *5 mg/L Ni^{2+} or/and Pb^{2+}* under MLSS of 3000 mg/L and HRT of 3 days to determine the removal efficiency and performance. The system showed quite low organic removal efficiency with the IEWW containing heavy metals of up to 5 mg/L as shown in Tables 8 and 9. The COD removal efficiencies of the system with IEWW containing 5 mg/L Ni^{2+}, 5 mg/L Pb^{2+} and 5 mg/L Ni^{2+} and 5 mg/L Pb^{2+} were only 57.0 ± 1.4%, 79.0 ± 1.3% and 39.1 ± 0.1%, respectively. Also, the effluent SS of the systems were increased up to 140–170 mg/L. TN removal efficiency was only 10–12% while the TKN removal efficiency was about 79–85%. And the effluent nitrate was in the range of 25–28 mg/L. SVI and SRT of the system with IEWW + Ni^{+5}, IEWW + Pb^{2+} and IEWW + Ni^{+5} + Pb^{2+} were in the high level of over 100 mg/L and 15 days, respectively. Ni^{2+} was more effective than Pb^{2+} on the repression of the bio-sludge growth as shown in Table 5. The SRT of the system with IEWW + Ni^{2+} was 28.0 ± 0.4 days while it was only 15.0 ± 0.2 days with IEWW + Pb^{2+}. Moreover, no excess bio-sludge was produced with IEWW + Ni^{2+} + Pb^{2+} as shown in Table 5.

3.5. *Effect of BOD_5 on the efficiency of SBR system to treat IEWW*

The system efficiency with IEWW could be increase with the increase of BOD_5 loading or concentration (by glucose addition) as shown in Tables 8 and 9. The organic (COD and BOD_5) and heavy metals (Ni^{2+} and Pb^{2+}) removal efficiencies were increased by 10–15% and 10–20%, respectively, with the increase of organic loading from 0.047 to 0.184 mg $BOD_5/(m^3\,d)$. The Pb^{2+}, Ni^{2+}, COD, BOD_5 and TKN removal efficiencies of the system with IEWW + glucose + Ni^{2+} + Pb^{2+} were 85.68 ± 0.31%, 87.03 ± 0.21%, 86.0 ± 0.5%, 94.04 ± 0.4% and 90.5 ± 0.9%, respectively, but TN removal efficiency was only 37.6 ± 1.7%. Also, effluent NO_3^- and SS were reduced by 10–16% and 20–50%, respectively. The SRT of the system with IEWW + glucose + Ni^{2+} + Pb^{2+} was 44.7 ± 0.6 days.

4. Discussions

SBR system showed high organic and heavy metal (Ni^{2+} and Pb^{2+}) removal efficiencies with SIEWW containing 5 mg/L Ni^{2+} or Pb^{2+} under high MLSS of 3000–4000 mg/L and low F/M of 0.064. It could explain that the heavy metals (Ni^{2+} or Pb^{2+}) of SIEWW at the concentration of 5 mg/L might not significantly effect to the removal efficiency and bio-sludge quality [2,17,25,26]. Moreover, the system showed low excess bio-sludge producing under high MLSS of over 3000 mg/L. And the heavy metal removal efficiency of the system under MLSS of 2000–4500 mg/L was in the high level of more than 80% (it was only 2% increased when the MLSS was increased from 2000 to 4500 mg/L). This might be the advantage of the SBR system to treat SIEWW under high MLSS of 3000–4000 mg/L [2,27,31]. It could explain that heavy metals. However, the system showed the good bio-sludge performance under MLSS of 3000 mg/L (SVI of less than 100 mL/g). But SRT of the system was quite low of only 7.2 ± 0.2 days (high excess bio-sludge generation of 3200 ± 30 mg/d). Then, the excess bio-sludge wasting program had to be considered if the system was operated under MLSS of 3000 mg/L. Moreover, Ni^{2+} and Pb^{2+} concentrations of up to 50 mg/L were not significantly affected to COD and BOD_5 removal efficiencies even they effected to the growth of bio-sludge resulted by low excess bio-sludge production. However, the high concentration of Ni^{2+} and Pb^{2+} strongly repressed both TKN and TN removal efficiencies. Then, NH_4^+ and NO_3^- were accumulated in the system. This might be the effect of Ni^{2+} and Pb^{2+} to repress the

Table 5
The bio-sludge qualities of SBR system operated under HRT of 3 days and MLSS of 3000 mg/L with IEWW and modified IEWW.

Types of wastewater	Heavy metal		Organic loading (kg $BOD_5/(m^3 d)$)	Controlled MLSS (mg/L)	Excess bio-sludge (mg/d)	SRT (days)	SVI (mL/g)
	Type	Concentration (mg/L)					
SIEWW	Ni^{2+}	5	0.186	2000	8200 ± 50	2.0 ± 0.2	62
		5	0.186	2500	4200 ± 30	4.5 ± 0.3	78
		5	0.186	3000	3200 ± 30	7.2 ± 0.2	81
		5	0.186	4000	1500 ± 20	20.0 ± 0.4	120
		5	0.186	4500	1110 ± 10	30.2 ± 0.4	143
SIEWW	Pb^{2+}	5	0.186	2000	8340 ± 20	2.0 ± 0.3	83
		5	0.186	2500	4800 ± 20	4.0 ± 0.3	93
		5	0.186	3000	3350 ± 20	6.7 ± 0.4	95
		5	0.186	4000	1660 ± 10	18.0 ± 0.4	145
		5	0.186	4500	940 ± 10	35.8 ± 0.6	153
SIEWW	Ni^{2+}	5	0.186	3000	3050 ± 10	7.4 ± 0.2	82
		10	0.186	3000	2880 ± 12	7.8 ± 0.3	85
		20	0.186	3000	2380 ± 10	9.5 ± 0.5	104
		30	0.186	3000	–	–	117
		40	0.186	3000	–	–	153
		50	0.186	3000	–	–	83
SIEWW	Pb^{2+}	5	0.186	3000	2880 ± 10	7.8 ± 0.1	94
		10	0.186	3000	2780 ± 12	8.1 ± 0.2	108
		20	0.186	3000	2560 ± 10	8.8 ± 0.2	114
		30	0.186	3000	2510 ± 13	9.0 ± 0.2	119
		40	0.186	3000	2400 ± 20	9.4 ± 0.2	120
		50	0.186	3000	1120 ± 10	19.9 ± 0.3	116
IEWW	Ni^{2+}, Pb^{2+}	0.41, 0.35	0.047	3000	2880 ± 15	7.8 ± 0.3	90
IEWW + glucose[a]	Ni^{2+}, Pb^{2+}	0.41, 0.35	0.184	3000	3550 ± 10	6.4 ± 0.2	70
IEWW + Ni^{2+}[b]	Ni^{2+}, Pb^{2+}	5, 0.35	0.184	3000	800 ± 10	28.0 ± 0.4	100
IEWW + Pb^{2+}[c]	Ni^{2+}, Pb^{2+}	0.41, 5	0.184	3000	1500 ± 10	15.0 ± 0.2	95
IEWW + glucose + Ni^{2+}[d]	Ni^{2+}, Pb^{2+}	5,5	0.184	3000	2220 ± 10	10.0 ± 0.2	72
IEWW + glucose + Pb^{2+}[e]	Ni^{2+}, Pb^{2+}	0.41,5	0.184	3000	2100 ± 10	10.7 ± 0.2	84
IEWW + Ni^{2+} + Pb^{2+}[f]	Ni^{2+}, Pb^{2+}	5,5	0.047	3000	–	–	120
IEWW + glucose + Ni^{2+} + Pb^{2+}[g]	Ni^{2+},Pb^{2+}	5,5	0.184	3000	500 ± 15	44.7 ± 0.6	100

±: Standard deviation of 3 replicates.
[a] IEWW + glucose: IEWW was supplemented with 500 mg/L glucose (final BOD_5 concentration was 500 mg/L).
[b] IEWW + Ni^{2+}: IEWW was supplemented with 20.3 mg/L $NiCl_2 \cdot 6H_2O$ (final Ni^{2+} concentration was 5 mg/L).
[c] IEWW + Pb^{2+}: IEWW was supplemented with 6.7 mg/L $PbCl_2$ (final Pb^{2+}concentration was 5 mg/L).
[d] IEWW + glucose + Ni^{2+}: IEWW was supplemented with 500 mg/L glucose and 20.3 mg/L $NiCl_2 \cdot 6H_2O$ (final BOD_5 and Ni^{2+} concentration were 500 and 5 mg/L, respectively).
[e] IEWW + glucose + Pb^{2+}: IEWW was supplemented with 500 and 6.7 mg/L $PbCl_2$ (final BOD_5 and Pb^{2+}concentration were 500 and 5 mg/L, respectively).
[f] IEWW + Ni^{2+} + Pb^{2+}: IEWW was supplemented with 20.3 mg/L $NiCl_2 \cdot 6H_2O$ and 6.7 mg/L $PbCl_2$ (final Ni^{2+} and Pb^{2+} concentration were 5 and 5 mg/L, respectively).
[g] IEWW + glucoses + Ni^{2+} + Pb^{2+}: IEWW was supplemented with 500 mg/L glucose, 20.3 mg/L $NiCl_2 \cdot 6H_2O$ and 6.7 mg/L $PbCl_2$ (final BOD_5 Ni^{2+} and Pb^{2+} concentration were 500, 5 and 5 mg/L, respectively).

Table 6
Effluent qualities and removal efficiencies of SBR system operated under HRT of 3 days and MLSS of 3000 mg/L with SIEWW containing various concentrations of heavy metals (Ni^{2+}or Pb^{2+}) of 5, 10, 20, 30, 40 and 50 mg/L.

Types of heavy metals	Heavy metals concentration (mg/L)	Volumetric heavy metals loading (kg/(m^3 d))	Chemical Properties							SS (mg/L)
			Heavy metal		COD		BOD_5		pH	
			Effluent (mg/L)	% removal	Effluent (mg/L)	% removal	Effluent (mg/L)	% removal		
Ni^{2+}	5	0.0125	0.9 ± 0.0	83.1 ± 0.5	24 ± 1	96.3 ± 0.2	12 ± 1	97.9 ± 0.2	7.26 ± 0.2	35 ± 7
	10	0.0250	2.0 ± 0.1	81.0 ± 2.6	27 ± 1	96.3 ± 0.1	13 ± 1	97.8 ± 0.2	7.26 ± 0.2	74 ± 5
	20	0.0500	4.3 ± 1.1	76.4 ± 4.0	35 ± 1	95.2 ± 0.2	18 ± 1	96.9 ± 0.1	7.23 ± 0.2	99 ± 5
	30	0.0750	8.5 ± 1.8	69.3 ± 3.5	51 ± 1	93.0 ± 0.2	23 ± 1	96.0 ± 0.2	7.23 ± 0.2	114 ± 3
	40	0.1000	14.6 ± 2.1	61.4 ± 2.4	57 ± 0	92.2 ± 0.2	29 ± 1	95.0 ± 0.2	7.23 ± 0.2	125 ± 4
	50	0.1250	22.8 ± 3.5	53.7 ± 1.2	59 ± 0	91.8 ± 0.2	37 ± 1	93.6 ± 0.3	7.23 ± 0.2	138 ± 3
Pb^{2+}	5	0.0125	0.7 ± 0.0	85.3 ± 0.5	11 ± 3	98.3 ± 0.5	10 ± 1	98.3 ± 0.3	7.35 ± 0.2	38 ± 3
	10	0.0250	1.5 ± 0.3	84.7 ± 2.6	26 ± 1	96.5 ± 0.2	12 ± 1	98.0 ± 0.1	7.35 ± 0.2	47 ± 3
	20	0.0500	3.6 ± 0.8	80.2 ± 1.5	35 ± 1	95.3 ± 0.2	14 ± 1	97.5 ± 0.1	7.35 ± 0.2	62 ± 3
	30	0.0750	6.3 ± 1.5	76.9 ± 0.7	49 ± 1	93.3 ± 0.2	18 ± 0	96.9 ± 0.1	7.34 ± 0.2	67 ± 3
	40	0.1000	10.1 ± 1.7	73.7 ± 1.8	54 ± 1	92.6 ± 0.3	22 ± 1	96.2 ± 0.1	7.34 ± 0.2	83 ± 3
	50	0.1250	15.2 ± 1.2	69.0 ± 0.5	61 ± 1	91.7 ± 0.3	27 ± 1	95.4 ± 0.3	7.34 ± 0.2	92 ± 3

±: Standard deviation of 3 replicates.

Table 7
Effluent qualities and nitrogen compounds removal efficiencies of SBR system operated under HRT of 3 days and MLSS of 3000 mg/L with SIEWW containing various concentrations of heavy metals (Ni^{2+} or Pb^{2+}) of 5, 10, 20, 30, 40 and 50 mg/L.

Types of heavy metals	Initial heavy metals concentration (mg/L)	TKN(mg/L)		NH_4^+ (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	TN (mg/L)		% TN removal
		Effluent	% removal	Effluent	Effluent	Effluent	Influent	Effluent	
Ni^{2+}	5	4.6 ± 0.0	83.4 ± 0.0	2.9 ± 0.0	0.3 ± 0.0	17.7 ± 0.0	27.6 ± 0.0	22.6 ± 0.0	18.2 ± 0.1
	10	5.3 ± 0.0	80.3 ± 0.0	3.1 ± 0.0	0.3 ± 0.0	17.9 ± 0.0	27.6 ± 0.0	23.5 ± 0.0	14.7 ± 0.1
	20	5.9 ± 0.0	78.6 ± 0.0	3.3 ± 0.0	0.3 ± 0.0	18.9 ± 0.0	27.6 ± 0.0	25.1 ± 0.0	9.1 ± 0.1
	30	6.4 ± 0.0	76.8 ± 0.0	3.5 ± 0.0	0.3 ± 0.0	19.1 ± 0.0	27.6 ± 0.0	25.8 ± 0.0	6.6 ± 0.0
	40	6.5 ± 0.0	76.4 ± 0.0	3.6 ± 0.0	0.3 ± 0.0	19.3 ± 0.3	27.6 ± 0.0	26.1 ± 0.0	5.5 ± 0.1
	50	6.7 ± 0.0	75.7 ± 0.0	3.7 ± 0.0	0.2 ± 0.0	20.5 ± 0.0	27.6 ± 0.0	27.4 ± 0.0	0.5 ± 0.1
Pb^{2+}	5	2.2 ± 0.0	91.8 ± 0.0	1.4 ± 0.0	0.2 ± 0.0	9.1 ± 0.0	27.5 ± 0.0	11.6 ± 0.0	58.0 ± 0.0
	10	2.7 ± 0.0	90.2 ± 0.0	1.7 ± 0.0	0.2 ± 0.0	11.6 ± 2.2	27.5 ± 0.0	13.5 ± 0.3	50.9 ± 1.2
	20	2.8 ± 0.0	89.7 ± 0.0	1.8 ± 0.0	0.3 ± 0.0	11.9 ± 2.4	27.5 ± 0.0	13.9 ± 0.8	49.5 ± 2.7
	30	3.1 ± 0.0	88.6 ± 0.0	2.1 ± 0.0	0.3 ± 0.0	14.8 ± 2.8	27.5 ± 0.0	17.1 ± 0.3	38.1 ± 1.2
	40	3.9 ± 0.0	85.6 ± 0.1	2.2 ± 0.0	0.4 ± 0.0	15.1 ± 1.0	27.5 ± 0.0	19.0 ± 0.3	31.0 ± 1.0
	50	4.4 ± 0.0	83.8 ± 0.1	2.5 ± 0.0	0.4 ± 0.0	15.8 ± 0.6	27.5 ± 0.0	20.4 ± 0.2	25.8 ± 0.9

±: Standard deviation of 3 replicates.

Table 8
Effluent qualities and removal efficiencies of SBR system operated under HRT of 3 days and MLSS of 3000 mg/L with IEWW and modified IEWW.

Type of IEWW	Chemical Properties									SS (mg/L)
	Heavy metals				COD		BOD_5		pH	
	Effluent Ni^{2+} (mg/L)	% Ni^{2+} removal	Effluent Pb^{2+} (mg/L)	% Pb^{2+} removal	Effluent (mg/L)	% removal	Effluent (mg/L)	% removal		
IEWW	0.18 ± 0.00	57.22 ± 0.76	0.08 ± 0.00	77.35 ± 0.95	23 ± 4	89.0 ± 1.7	16 ± 2	90.0 ± 1.3	7.57 ± 0.2	128 ± 10
IEWW + glucose[a]	0.17 ± 0.01	58.54 ± 0.71	0.07 ± 0.00	79.79 ± 0.52	27 ± 3	96.0 ± 0.5	19 ± 1	96.0 ± 0.2	7.43 ± 0.2	80 ± 5
IEWW + Ni^{2+}[b]	1.65 ± 0.03	84.22 ± 0.33	0.08 ± 0.00	77.17 ± 0.83	95 ± 3	57.0 ± 1.4	32 ± 1	80.0 ± 1.2	6.73 ± 0.5	150 ± 6
IEWW + glucose + Ni^{2+}[c]	1.57 ± 0.01	84.98 ± 0.11	0.086 ± 0.01	81.63 ± 0.45	76 ± 3	88.0 ± 0.7	21 ± 2	96.0 ± 0.3	6.79 ± 0.2	90 ± 8
IEWW + Pb^{2+}[d]	0.35 ± 0.01	19.12 ± 2.25	1.46 ± 0.04	85.93 ± 0.36	46 ± 3	79.0 ± 1.3	22 ± 1	86.0 ± 0.7	7.38 ± 0.3	140 ± 10
IEWW + glucose + Pb^{2+}[e]	0.26 ± 0.09	30.57 ± 3.77	0.82 ± 0.02	92.10 ± 0.16	47 ± 3	93.0 ± 0.6	16 ± 2	97.0 ± 0.4	7.43 ± 0.2	65 ± 10
IEWW + Ni^{2+} + Pb^{2+}[f]	1.78 ± 0.16	83.33 ± 0.17	1.90 ± 0.06	81.66 ± 0.54	134 ± 1	39.1 ± 0.1	34 ± 1	78.0 ± 1.3	6.78 ± 1.3	170 ± 10
IEWW + glucose + Ni^{2+} + Pb^{2+}[g]	1.74 ± 0.02	85.68 ± 0.31	1.34 ± 0.01	87.03 ± 0.12	72 ± 2	86.0 ± 0.5	33 ± 2	94.0 ± 0.4	7.05 ± 0.1	150 ± 6

±: Standard deviation of 3 replicates.
[a] IEWW + glucose: IEWW was supplemented with 500 mg/L glucose (final BOD_5 concentration was 500 mg/L).
[b] IEWW + Ni^{2+}: IEWW was supplemented with 20.3 mg/L $NiCl_2{\cdot}6H_2O$ (final Ni^{2+} concentration was 5 mg/L).
[c] IEWW + Pb^{2+}: IEWW was supplemented with 6.7 mg/L $PbCl_2$ (final Pb^{2+}concentration was 5 mg/L).
[d] IEWW + glucose + Ni^{2+}: IEWW was supplemented with 500 mg/L glucose and 20.3 mg/L $NiCl_2{\cdot}6H_2O$ (final BOD_5 and Ni^{2+} concentration were 500 and 5 mg/L, respectively).
[e] IEWW + glucose + Pb^{2+}: IEWW was supplemented with 500 and 6.7 mg/L $PbCl_2$ (final BOD_5 and Pb^{2+}concentration were 500 and 5 mg/L, respectively).
[f] IEWW + Ni^{2+} + Pb^{2+f}: IEWW was supplemented with 20.3 mg/L $NiCl_2{\cdot}6H_2O$ and 6.7 mg/L $PbCl_2$ (final Ni^{2+} and Pb^{2+} concentration were 5 and 5 mg/L, respectively).
[g] IEWW + glucoses + Ni^{2+} + Pb^{2+}: IEWW was supplemented with 500 mg/L glucose, 20.3 mg/L $NiCl_2{\cdot}6H_2O$ and 6.7 mg/L $PbCl_2$ (final BOD_5 Ni^{2+} and Pb^{2+} concentration were 500, 5 and 5 mg/L, respectively).

Table 9
Effluent qualities and nitrogen compounds removal efficiencies of SBR system SBR system operated under HRT of 3 days and MLSS of 3000 mg/L with IEWW and modified IEWW.

Types of heavy metals	Chemical properties							
	TKN (mg/L)		NH_4^+ (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	TN (mg/L)		
	Effluent	% removal	Effluent	Effluent	Influent	Influent	Effluent	% removal
IEWW	2.8 ± 0.0	87.9 ± 1.3	0.6 ± 0.0	0.1 ± 0.0	19.3 ± 0.2	34.9 ± 0.6	22.2 ± 0.2	36.4 ± 1.2
IEWW + glucose[a]	1.7 ± 0.0	95.8 ± 0.1	0.6 ± 0.0	0.2 ± 0.0	18.5 ± 1.0	34.9 ± 0.9	20.4 ± 1.0	41.5 ± 2.6
IEWW + Ni^{2+}[b]	5.0 ± 0.0	78.3 ± 2.3	1.7 ± 0.0	0.2 ± 0.0	25.4 ± 1.1	34.9 ± 0.6	30.6 ± 0.1	12.2 ± 1.6
IEWW + glucose + Ni^{2+}[c]	4.2 ± 0.2	89.3 ± 0.4	1.6 ± 0.0	0.2 ± 0.0	23.8 ± 0.4	45.6 ± 0.9	28.1 ± 0.5	38.4 ± 1.2
IEWW + Pb^{2+}[d]	2.8 ± 0.0	87.9 ± 1.3	0.7 ± 0.3	0.2 ± 0.0	27.6 ± 0.6	34.9 ± 0.6	31.3 ± 0.6	10.32 ± 2.4
IEWW + glucose + Pb^{2+}[e]	3.0 ± 0.2	92.4 ± 0.3	0.6 ± 0.0	0.2 ± 0.0	22.6 ± 0.2	45.6 ± 0.9	25.8 ± 0.3	43.3 ± 1.6
IEWW + Ni^{2+} + Pb^{2+}[f]	3.4 ± 0.0	85.5 ± 1.5	1.7 ± 0.0	0.2 ± 0.0	27.4 ± 1.2	34.9 ± 0.6	31.0 ± 1.2	11.2 ± 3.2
IEWW + glucose + Ni^{2+} + Pb^{2+}[g]	3.8 ± 0.4	90.5 ± 0.9	1.7 ± 0.0	0.4 ± 0.0	24.6 ± 0.2	45.6 ± 0.8	28.4 ± 0.5	37.6 ± 1.7

±: Standard deviation of 3 replicates.
[a] IEWW + glucose: IEWW was supplemented with 500 mg/L glucose (final BOD_5 concentration was 500 mg/L).
[b] IEWW + Ni^{2+}: IEWW was supplemented with 20.3 mg/L $NiCl_2{\cdot}6H_2O$ (final Ni^{2+} concentration was 5 mg/L).
[c] IEWW + Pb^{2+}: IEWW was supplemented with 6.7 mg/L $PbCl_2$ (final Pb^{2+}concentration was 5 mg/L).
[d] IEWW + glucose + Ni^{2+}: IEWW was supplemented with 500 mg/L glucose and 20.3 mg/L $NiCl_2{\cdot}6H_2O$ (final BOD_5 and Ni^{2+} concentration were 500 and 5 mg/L, respectively).
[e] IEWW + glucose + Pb^{2+}: IEWW was supplemented with 500 and 6.7 mg/L $PbCl_2$ (final BOD_5 and Pb^{2+}concentration were 500 and 5 mg/L, respectively).
[f] IEWW + glucoses + Ni^{2+} + Pb^{2+}: IEWW was supplemented with 500 mg/L glucose, 20.3 mg/L $NiCl_2{\cdot}6H_2O$ and 6.7 mg/L $PbCl_2$ (final BOD_5 Ni^{2+} and Pb^{2+} concentration were 500, 5 and 5 mg/L, respectively).

growth of both nitrification and denitrification bacteria. Lee et al. [32] also reported that Ni^{2+} and Cu^{2+} could repress the growth of nitrification bacteria. But, there has been no report on the effect of heavy metals on the repression of denitrification bacteria growth in SBR system. This might be the first finding that heavy metals especially, Ni^{2+} and Pb^{2+} could repress the growth of denitrification bacteria. Also, Ni^{2+} was more effective than Pb^{2+} to repress the growth of nitrification and denitrification bacteria. Form above results, it could conclude that the total nitrogen removal efficiency was decreased with the increase of heavy metals concentrations or loadings [2,32–35]. Also, the effluent SS of the system was increased with the increase of heavy metal concentration or loading. This might be the effects of heavy metals to kill and repress the growth of bio-sludge of the system resulted by low excess bio-sludge production or high SRT. It is therefore recommended that further research regarding the determination of the effect of types and concentrations of heavy metals to the types of microbe of bio-sludge (heterotrophic, nitrification and denitrification bacteria) have to be conducted to provide a better understanding of the toxicity of heavy metal on the bio-sludge. For the treatment of IEWW by SBR system, the removal efficiency and bio-sludge quality were quite low even the IEWW contained low Ni^{2+} and Pb^{2+} concentrations of only 0.41 and 0.36 mg/L, respectively. It could explain that IEWW might contain hardly biodegradable organic compounds and/or toxic substances [8,36,37]. Therefore, the further experiments degrading the determination of types of organic compound and toxic substance of IEWW and effect of toxic substances on the growth of bio-sludge should be conducted to confirm the above suggestions. However, both organic and heavy metal removal efficiencies could be increased with the increase of organic loading or concentration (adding glucose into the IEWW). This might be the effect of the bio-sludge growth [2,27,31]. Several researchers reported that the main heavy metal removal mechanism of the bio-sludge under SBR system was adsorption [17,38–43]. Then, the heavy metals adsorption yield was increased with the increase of bio-sludge production: growth association mechanism [7,11,12,17,23,44–46]. Also, the organic (COD or BOD_5) removal rate was increased with the increase of bio-sludge generation rate [2]. Form above results, it could suggest that MLSS was the one of major operation parameters of SBR system to control the system efficiency. Moreover, the SBR system could be applied to treat IEWW containing 5 mg/L heavy metals (Ni^{2+} and/or Pb^{2+}), but the removal efficiency and excess bio-sludge production were quite low according to the effects of both low organic content and toxicity of heavy metal [2,17,25]. Also, the effluent $NO_3{}^+$ was in the high level. To increase both organic and heavy metals removal efficiencies, the organic loading or concentration of the wastewater should be increased [17,25,26]. Also, the bio-sludge quality of the system could be improved (SVI value was decreased and the excess bio-sludge was generated) by increasing the organic loading. This phenomenon was similar to above results on the operation of SBR system with SIWW containing various concentrations of heavy metals. It could explain that IEWW might contain hardly biodegradable organic compounds and some other toxic substances as mentioned above. To increase both removal efficiency and bio-sludge quality, the suitable biodegradable organic compounds such as glucose (simple carbon source) should be added resulted to simulated and increase the bio-sludge growth [2,27,31]. However, the addition of glucose as the carbon source into the wastewater resulted to increase the removal efficiency might be disadvantage, because the wastewater should be treated under low cost [2]. Then, the low cost carbon source such as molasses, starch industrial wastewater or domestic wastewater should be considered to be used instead of pure glucose. It is therefore recommended that further research regarding the determination of the effect types and concentrations of carbon source on the efficiency and performance of the system have to be conducted for selection of the low and suitable carbon source.

5. Conclusions

SBR system with high MLSS operation was found to be suitable to treat the wastewater containing both organic matters and heavy metals especially Pb^{2+} and Ni^{2+}, because, bio-sludge could remove both organic matter and heavy metal form the wastewater with high efficiency. Pb^{2+} or Ni^{2+} of SIEWW at concentration of up to 50 mg/L was not significantly effect to the BOD_5 and COD removal efficiencies, but they were effected to the nitrogen removal efficiency. This might be the effect of heavy metals to repress the growth of both nitrification and denitrification bacteria. Then, both $NH_4{}^+$ and $NO_3{}^+$ were accumulated in the SBR system. Ni^{2+} was more effective than Pb^{2+} to repress the growth of bio-sludge of the system. The system could also apply to treat the IEWW, but the efficiency and bio-sludge quality were quite low. The removal efficiency and bio-sludge could be increased by adding the suitable organic compounds resulted to increase the bio-sludge production.

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