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Effect of anoxic:oxic ratio on the efficiency and performance of sequencing batch reactor (SBR) system for treatment of textile wastewater containing direct dye

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ABSTRACT

The effects of mixed liquor suspended solids (MLSS), hydraulic retention time (HRT) and anoxic:oxic ratio on the sequencing batch reactor (SBR) system efficiency with synthetic textile industrial wastewater (STIW) containing direct dyes were investigated. The results showed that the system had the highest removal efficiency at MLSS of up to 2,500 mg/L. Moreover, its efficiency was increased with the increase of HRT or decrease of organic loading rate. To increase the nitrogenous compounds removal efficiencies, the reaction step of SBR operation should be modified by adding the anoxic period. The optimal operation conditions of the SBR system for highest nitrogen and textile dye removal efficiencies were MLSS of 2,500 mg/L, HRT of 7.5 d (organic loading rate of 0.11 kg BOD_5/m^3-d) and anoxic:oxic ratio of 15:4. The system showed the highest direct red 23 and direct blue 15 removal efficiencies of 90.61% ± 2.14% and 83.82% ± 2.60%, respectively, resulting from the activity of denitrifying bacteria.

Keywords: Bio-sludge; Textile wastewater; Sequencing batch reactor (SBR); Direct dyes; Anoxic; Oxic

1. Introduction

The textile industry is one of the main industries in Thailand where its rapid growth year by year is dependent on the world market demand [1]. However, this industry produces a large volume of wastewater, which is an environmental problem [2,3]. Each step of textile processing generates large amounts of wastewater, especially during the dying step. Normally, the textile industrial wastewater (TIW) contains high concentrations of dye and organic matters. Almost all textile dyes are non-bio-degradable compounds due to their chemical structure such as the azo dye group [4,5]. The textile dye containing azo group compounds was most popularly used for coloring various types of textile fibers due to its properties [6]. However, azo dye causes cancer from the resulting aromatic amine (carcinogen) generated by bio-degradation of the azo group [7,8].

Nowadays, physical and chemical wastewater treatment processes such as chemical precipitation and adsorption by activated carbon are normally used to remove the color or dye from the TIW. However, their removal efficiency is in the low level and fluctuation due to their complicated chemical structure. The direct dye is classified as the disperse dye type that can be easily dissolved and desorbed into the water [9]. Therefore, it is difficult to remove by chemical precipitation and adsorption as mentioned above [10]. The other disadvantages are high chemical agent consumption and large amounts of chemical waste generation, which leads to high treatment costs. It is understood that the textile dye can be removed through a biological process [2,3,11]. This may be the most suitable method due to the low treatment operating cost and environmentally friendly process. Several researchers investigated the biological degradation process for removal or treatment of textile dye. It was reported that the textile wastewater can be treated by three processes as follows: Firstly, the wastewater was treated by a chemical process to remove the textile color, followed by a biological process to remove

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organic compounds. Secondly, it was treated by a biological process and followed by chemical treatment. Thirdly, it was treated by a physical and chemical process, then by a biological process. It was reported that the main mechanism of aerobic biological treatment of textile dye was adsorption, where the adsorption yield was dependent on the dye structure and the amount of substituent group. Moreover, the adsorption yield increased with the increase in dye molecule length. The system yield could be increased by adding the activated carbon in the reactor [3,12,13]. The activated carbon also improved sludge settling in the system. It was found that the most suitable biological system to treat textile wastewater containing reactive dye was firstly treating by anaerobic process, followed by aerobic process. The removal yield was over 98%. Panswad and Luangdilok [14] also reported that the reactive dye was removed with higher yield in the anoxic step of sequencing batch reactor (SBR) operation, where some of the dye particles were adsorbed onto the microbial cell. O'Neill et al. [15] reported that the wastewater color was reduced during anaerobic conditions. The anaerobic biological process was more suitable for treatment of the azo dye group, due to the degradation mechanism of the azo bond by azoreductase enzyme, which is generated by the anaerobic bacteria group. For the theoretical information, the azo bond was degraded by the bio-reduction reaction of azoreductase under anaerobic conditions [5]. Aromatic amine compounds were generated that could be degraded under aerobic biological conditions. O'Neill et al. [15] reported that the azo bond was degraded by anaerobe and the color density of the wastewater was rapidly reduced. The aromatic amine compounds generated were easily degraded by the aerobic biological process of textile wastewater containing direct dye. O'Neill et al. [15] reported on the biological degradation of Procion H-E7B by combined anaerobic and aerobic processes where the highest color removal efficiency of 63.9% was found in the anaerobic step while it was only 11.3% in the aerobic step. Kapdan and Oztekin [16] also confirmed that the reactive dye; remazol red (RR), was highly removed under anaerobic conditions (removal efficiency over 90%).

From the above information, it could be suggested that the bio-degradation of textile dyes occurs under combined aerobic–anaerobic conditions. In turn, the SBR system was selected in this study for treatment of textile wastewater containing direct dye. However, the bio-treatment under oxic and anaerobic conditions was quite difficult due to the difference in physiology and growing conditions. Therefore, the oxic-anoxic operation condition was applied, because it was very easy to operate. The system was suitable to be used for nitrogenous and phosphorus compound removal. In this study, the laboratory-scale SBR system was applied for treatment of synthetic textile wastewater containing direct red 23 (DR23) and direct blue 15 (DB15). The effects of various MLSS (1,500, 2,500, and 3,500 mg/L) and various hydraulic retention time (HRTs; 2.5, 5.0, and 7.5 d) on the system performance and efficiency were tested. In addition, the effect of anoxic and oxic ratio of reaction step of SBR operation on the system efficiency and performance was investigated, especially, the dye and nitrogen removal efficiencies. Moreover, the relationship of the oxic and anoxic conditions on the dye and nitrogen compound removal efficiencies were determined.

2. Materials and methods

2.1. Dyes

Two types of direct dyes were selected for use in this study: DB15 and DR23 [17]. The properties of both direct dyes are described in Table 1.

2.2. Synthetic textile industrial wastewater (STIW)

STIWs were prepared according to the TIW property [3]. The chemical oxygen demand (COD) and biological oxygen demand (BOD_5) concentrations of STIWs were about 1,999 ± 91 mg/L and 880 ± 45 mg/L, respectively. The dyes (DR23 and DB15) concentration was 0.04 g/L. The chemical compositions and properties of STIWs (STIW containing DR23: STIW+DR23, and STIW containing DB15: STIW+DB15) are described in Table 1.

2.3. Acclimatization of bio-sludge for the inoculums of SBR system

Bio-sludge from the storage tank of the central sewage treatment plant of Bangkok Municipal, Thailand (Sripaya sewage treatment plant) was used as the inoculum of the SBR systems. The characteristic of bio-sludge was shown in Table 2. The bio-sludge was acclimatized in the STIW without direct dye for 10 d for selection of the microbial group that was suitable for STIW.

2.4. SBR system reactor

Six 10-L reactors made from acrylic plastic (5 mm thick) were used in the experiments as shown in Fig. 1. The dimensions of each reactor were: 18 cm diameter and 40 cm height, and the working volume was 7.5 L. A low speed gear motor (model P 630A-387, 100 V, 50/60 Hz, 1.7/1.3 A, Japan Servo Co. Ltd., Japan) was used for driving the paddle-shaped impeller. The speed of impeller was adjusted to 50 rpm for complete mixing. One set of air compressor systems, model ACO-009, 120 W (Guangdong Hailea Group Co., Ltd, China), was used to supply air for six sets of reactors; this provided an adequate oxygen supply, as suggested by dissolved oxygen (DO) in the system of about 2 mg/L. Excess bio-sludge was drawn out during the draw and idle periods to control the level of mixed liquor suspended solids (MLSS) in the system as mentioned in Table 3.

2.5. Operation of SBR system

The operation procedure for SBR system was followed according to previous works [2,3,12]. A 1.4 L of acclimatized bio-sludge (10 g/L as dry basis) from section 2.4 was inoculated in each reactor, and STIW was added (final volume of 7.5 L) within 1 h. While feeding of the wastewater, the system had to be fully aerated. Then, the system was operated in the reaction step under oxic–anoxic condition for 19 h as shown in Table 4. After that, the system was shut down for 3 h, allowing the bio-sludge to settle. The supernatant was removed within 0.5 h, and the system was kept under idle conditions for 0.5 h (total of 3 h for anoxic condition). Then the fresh wastewater was pumped into the reactor to the final

Table 1
Chemical compositions and properties of synthetic textile wastewater containing direct dye (STIW+DR23 and STIW+DB15)

Chemical compositions	Concentration (g/L)	Chemical properties	
		Parameter	Value
Glucose	1.875	COD, mg/L	1,999 ± 91
Urea	0.115	BOD_5, mg/L	880 ± 45
$FeCl_2$	0.0035	TKN, mg/L	40.7 ± 0.7
$NaHCO_3$	0.675	–Org–N, mg/L	36.8 ± 0.4
KH_2PO_4	0.055	$–NH_4^+$, mg/L	3.9 ± 0.3
$MgSO_4{\bullet}7H_2O$	0.0425	NO_2^-, mg/L	1.2 ± 0.1
Direct dye[a]	0.04	NO_3^-, mg/L	0.3 ± 0.1
		pH	8.3

[a]Two kinds of direct dyes (direct red 23 [DR23] and direct blue 15 [DB15]) as follows:

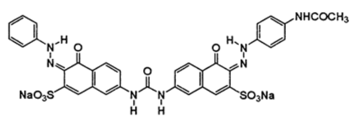
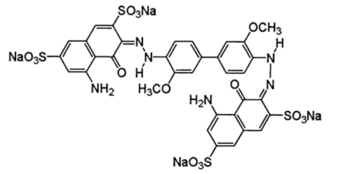
Trade name	Scientific name	Type	Color	Molecular formula	Molecular weight	CI No.	Maximum wavelength (nm)	Molecular structure
Direct red 4BS	Direct red 23	Direct, Diazo	Red	$C_{35}H_{25}N_7Na_2O_{10}S_2$	793.76	29160	500	
Direct sky blue 5B	Direct blue 15	Direct, Diazo	Blue	$C_{34}H_{24}N_6O_{16}S_4Na_4$	992.80	24400	607	

Table 2
Bio-sludge characteristic

Characteristic	Value
Source	Clarifier of central sewage treatment plant of Bangkok Municipal, Thailand (Sripaya sewage treatment plant)
Type of wastewater	Sewage (domestic wastewater)
Concentration (total solids), mg/L	10,000
MLVSS:MLSS	0.8
Bio-sludge age (SRT), d	15
pH	7.55

volume of 7.5 L, and the above operation was repeated. The system was operated for 30 d in each experiment. The experiments were carried out during April 2014–February 2015.

2.6 Chemical analysis

COD, BOD_5, organic nitrogen (org–N), ammonia nitrogen (NH_4^+–N), nitrite nitrogen (NO_2^-–N), nitrate nitrogen (NO_3^-–N), and pH of the influent, effluent, MLSS, and sludge volume index (SVI) of the systems were determined using standard methods for the examination of water and wastewater [18]. Total nitrogen (TN) was the sum of org–N, NH_4^+–N, NO_2^-–N, and NO_3^-–N. Total Kjeldahl nitrogen (TKN) was the sum of org–N and NH_4^+–N. The color intensities of STIWs were determined by the absorbance at optimum wavelengths as shown in Table 1 after centrifugation at 6,000× g for 10 min. The bio-sludge age (solids retention time [SRT]) was determined as the ratio of total MLSS of the system to the amount of excess bio-sludge waste per day. SVI was the volume in milliliters occupied by 1 g of a suspension (dry basis) after 30 min settling [18].

2.7. Statistic analysis method

Each experiment was repeated at least 3 times. All the data was subjected to two-way analysis of variance (ANOVA) using SS Windows Version 6.12 [19,20]. Statistical significance was tested using the least significant difference (LSD) at the $p < 0.05$ level, and the results are shown as mean ± SD.

3. Results

3.1. Effects of MLSS on the efficiencies of SBR system with STIWs

The SBR system was operated with STIW+DR23 and STIW+DB15 at MLSS of 1,500, 2,500, and 3,500 mg/L and a HRT of 7.5 d. The results on the systems efficiencies and performances were shown as follows:

3.1.1. COD and BOD_5

The system with STIW+DR23 and STIW+DB15 showed quite high COD and BOD_5 removal efficiencies of about 95%–97% and 94%–96%, respectively, at various MLSS of 1,500–3,500 mg/L as shown in Table 5(a). The system with STIW+DR23 and STIW+DB15 at MLSS of 2,500 mg/L showed the highest COD, 97% ± 1% and 97% ± 1%, and BOD_5, 96% ± 1% and 95% ± 1%, removal efficiencies, respectively.

3.1.2. Direct dye

The system with STIW+DR23 and STIW+DB15 at MLSS of 2,500 mg/L showed the highest dye removal efficiencies of 92.0% ± 0.5% and 90.5% ± 0.5%, respectively, as shown in Table 5(a). DR23 was easier to remove than DB15. Also, the system with STIW+DR23 showed a higher stable dye removal efficiency than with STIW+DB15 as shown in Table 5(a) and Fig. 2. DR23 was rapidly decreased during first 2 weeks operation, after that the effluent dye was increased and became stable during 30 d of operation as shown in Fig. 2. While DB15 was slightly decreased during the first week of operation and the effluent DR23 fluctuated during operation.

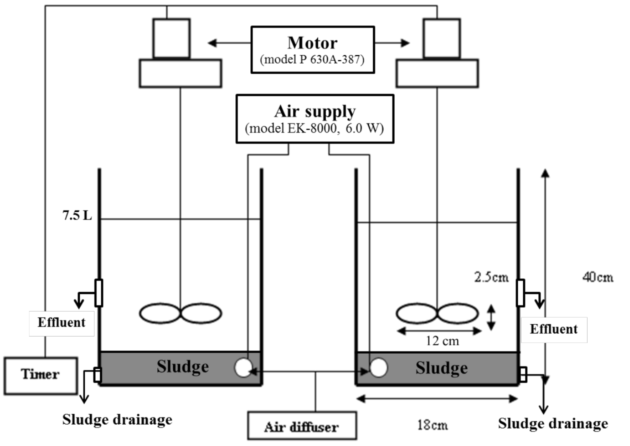


Fig. 1. Flow diagram of SBR systems.

Note: The physical operation controls were 60 rpm of impeller speed; full aeration with an air-pump system (one air pump system supplied air to two sets of reactor); and working volume of the reactor of 75% of total volume (7.5 L).

3.1.3. pH

The system could be operated around a stable alkaline pH condition without any chemical addition. The system pHs with STIW+DR23 and STIW+DB15 were about 8. In fact, the pH of the system with STIW+DR23 was around 8.3, while the system pH with STIW+DB15 was around 7.9 as shown in Table 5(a).

3.1.4. Nitrogenous compounds

The results of the nitrogenous compounds removal profiles are shown in Table 5(b) and Fig. 3. The system showed the same patterns with STIW+DR23 and STIW+DB15. TKN and org–N removal efficiencies were similar at all MLSS operations tested, and the value was around 90%. But the systems with DR23 and DB15 at MLSS of 2,500 mg/L (F/M ratio of 0.3 2 ± 0.04) had the highest TN, 70.2% ± 0.5% and 68.5% ± 1.2% and NH_4^+–N, 53.1% ± 2.7% and 51.8% ± 4.2% removal efficiencies, respectively. Moreover, the system with DR23 showed higher TN and NH_4^+–N removal efficiencies than that with DB15 as shown in Table 5(b). The effluent org–N was decreased with the increase of MLSS with both DR23 and DB15, but the effluent org–N with DR 23 was lower than that with DB15 in all MLSS operations tested. Effluents org–N of the system at MLSS of 2,500 mg/L with DR23 and DB15 were 1.8 ± 0.3 mg/L and 2.2 ± 0.1 mg/L, respectively. The effluents or–N, NH_4^+–N and NO_2^-–N were lower than influents org–N, NH_4^+–N and NO_2^-–N, while effluents NO_3^-–N were higher than influents NO_3^-–N in all experiments tested as shown in Table 5(b). For the effluents nitrogenous compounds profile observation, org–N and NH_4^+–N of STIW rapidly decreased during first week of

Table 3
The operating parameters of SBR system with STIW+DR23 and STIW+DB15 at various MLSS of 1,500, 2,500, and 3,500 mg/L and HRTs of 2.5, 5.0 and 7.5 d

Parameters	Operation conditions					
	MLSS (mg/L) at HRT of 7.5 d			HRT (d) at MLSS of 2,500 mg/L[a]		
HRT, d	7.5	7.5	7.5	2.5	5.0	7.5
MLSS, mg/L	1,500	2,500	3,500	2,500	2,500	2,500
Flow rate, mL/d	1,000	1,000	1,000	3,000	1,500	1,000
F/M ratio, mg BOD/mg MLSS/d	0.08	0.05	0.03	0.14	0.07	0.05
Hydraulic loading, m^3/m^3.d	0.13	0.13	0.13	0.40	0.20	0.13
Organic loading, kg BOD_5/m^3.d	0.11	0.11	0.11	0.34	0.17	0.11
Dye loading, kg/m^3.d	0.005	0.005	0.005	0.016	0.008	0.005

[a] Indicated that MLVSS was 2,000 mg/L (MLVSS was 80% of MLSS).

Table 4
The anoxic:oxic ratios of reaction step of SBR operation

Parameters	On the reaction step of SBR operation anoxic:oxic ratio (h)[a]				
	15:4	12:7	10:9	7:12	0:19
MLSS, mg/L	2,500	2,500	2,500	2,500	2,500
MLVSS, mg/L	2,000	2,000	2,000	2,000	2,000
HRT, d	7.5	7.5	7.5	7.5	7.5
Flow rate, mL/d	1,000	1,000	1,000	1,000	1,000
F/M ratio (mg BOD/mg MLSS/d)	0.05	0.05	0.05	0.05	0.05
Hydraulic loading, m^3/m^3.d	0.13	0.13	0.13	0.13	0.13
Volumetric BOD$_5$ loading, kg/m^3.d	0.11	0.11	0.11	0.11	0.11
Volumetric dye loading, kg/m^3.d	0.004	0.004	0.004	0.004	0.004

[a] Each operation cycle of SBR system was 24 h. Each cycle consisted of four steps as fill up step, reaction step, setting step, and draw and idle step, consecutively. The total period of reaction step of 19 h. On the reaction step, operation was controlled to be oxic and anoxic consecutively as below:

One cycle of operation (24 h) Step of operation (h)		On the reaction step of SBR operation: anoxic:oxic ratio (h)					Sampling point[a]
		15:4	12:7	10:9	7:12	0:19	
1: Fill		2	2	2	2	2	
2: React: The system was operated as anoxic and oxic condition consecutively.	Anoxic	5	4	3	2		
	Oxic	1	2	3	4		
	Anoxic	5	4	3	2		Sampling[a] (1st stage)
	Anoxic:oxic ratio of 1st stage	10:1	8:2	6:3	4:4		
	Oxic	1	2	3	4		
	Anoxic	5	4	3	3		
	Oxic	2	3	4	4		Sampling[a] (2nd stage)
	Anoxic:oxic ratio of 2nd stage	5:3	4:5	3:7	3:8	0:19	
3: Settling		2	2	2	2	2	
4: Draw and idle		1	1	1	1	1	

[a] The samples were taken after each operation step to determine the chemical properties. For the anioxic:oxic ratio of 0:19 experiment, samples were taken before feeding in the reactor (influent) and after setting step.

Table 5(a)
Effluent qualities and removal efficiencies of SBR system with STIW+DR23 and STIW+DB15 at HRT of 7.5 d, anoxic:oxic ratio of 0:19 and various MLSS operations of 1,500, 2,500, and 3,500 mg/L

Types of STIW	MLSS (mg/L)	Chemical properties							Sludge properties	
		Direct dye		COD		BOD$_5$		pH	SRT (d)	SVI
		Effluent (mg/L)	% Removal	Effluent (mg/L)	% Removal	Effluent (mg/L)	% Removal			
STIW+DR23	1,500	4.7 ± 0.3	88.5 ± 0.7	82 ± 7	96 ± 1	48 ± 2	95 ± 1	8.3 ± 0.1	6 ± 2	68 ± 3
	2,500	3.2 ± 0.2	92.0 ± 0.5	67 ± 5	97 ± 1	38 ± 1	96 ± 1	8.3 ± 0.3	12 ± 2	75 ± 3
	3,500	4.2 ± 0.2	89.8 ± 0.5	78 ± 11	96 ± 1	49 ± 2	94 ± 1	8.3 ± 0.1	20 ± 3	70 ± 3
STIW+DB15	1,500	5.0 ± 0.3	89.8 ± 1.4	86 ± 6	95 ± 1	46 ± 1	95 ± 1	7.9 ± 0.2	7 ± 1	87 ± 3
	2,500	3.9 ± 0.2	90.5 ± 0.5	65 ± 5	97 ± 1	43 ± 2	95 ± 1	7.9 ± 0.1	12 ± 1	74 ± 3
	3,500	4.6 ± 0.8	88.6 ± 1.8	74 ± 3	95 ± 1	46 ± 1	94 ± 1	7.9 ± 0.2	22 ± 2	75 ± 3

operation and became stable after 30 d operation as shown in Fig. 3. On the other hand, NO$_3^-$–N was rapidly increased during first 2 weeks of operation and became stable in the high level as shown in Fig. 3. The effluent NO$_3^-$–N was lowest at about 8 mg/L at an MLSS of 2,500 mg/L as shown in Table 5(b) and Fig. 3.

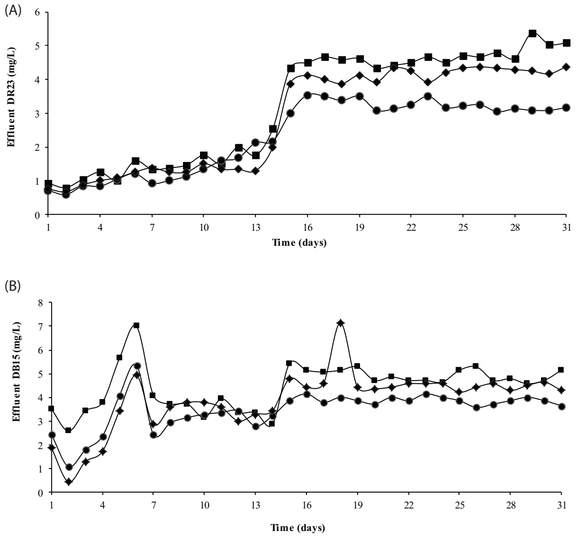


Fig. 2. Effluents DR23 and DB15 profiles of SBR system with STIW+DR23 (A) and STIW+DB15 (B) at MLSS operation of 1,500 (■), 2,500 (●), and 3,500 (♦) mg/L and HRT of 7.5 d.

3.1.5. *Sludge performance*

The system SRT was increased with the increase of MLSS (decrease of F/M ratio) as shown in Table 5(a). Moreover, the system with DR23 and DB15 did not show any significant difference on the SRT in all experiments tested. The system with DR23 and DB15 at the highest MLSS operation of 3,500 mg/L (F/M ratio of 0.25 ± 0.04) showed the longest SRT of 20 and 22 d, respectively. However, the system at MLSS of 2,500 mg/L (F/M ratio of 0.32 ± 0.04) with DR23 and DB15 was about 12 d. For the bio-sludge quality determination, SVI, the system with DR23 and DB15 showed good SVI values of less than 90 mL/g in all MLSS operations tested. Finally, the system with DR23 gave lower SVI values than that with DB15 in each MLSS operations tested as shown in Table 5(a).

3.2. *Effects of HRT on the efficiencies of SBR system with STIWs*

The system was operated with STIW+DR23 and STIW+DB15 at various HRTs of 2.5, 5.0, and 7.5 d and MLSS of 2,500 mg/L. The results of system efficiency and performance were as follows.

3.2.1. *COD and BOD$_5$*

The system with DR23 and DB15 showed the same patterns on the COD and BOD$_5$ removal efficiencies as shown in Table 6(a). COD and BOD$_5$ removal efficiencies increased with the increase of HRT or decrease of organic loading. The system with DR23 and DR15 at HRT of 7.5 d (organic loading of 0.11 kg BOD$_5$/m^3.d) gave the highest COD, 98% ± 1% and 96% ± 1%, and BOD$_5$, 97% ± 1% and 96% ± 1%, removal efficiencies, respectively, as shown in Table 6(a).

3.2.2. *Direct dye*

The effluent dyes increased with the increase of organic loading or decrease of HRT as shown in Table 6(a) and Fig. 4. The system with DR23 and DB15 showed the highest dye removal efficiency of 90.6% ± 2.1% and 83.8% ± 2.6% at HRT of 7.5 d (organic loading of 0.11 kg BOD$_5$/m^3.d) as shown in Table 6(a). Moreover, the system with DR23 showed a higher dye removal efficiency compared with DB15 at each HRT or organic loading operation tested. For the effluent dye profile observation, the system showed fluctuations at the lowest HRT of 2.5 d (organic loading of 0.34 kg BOD$_5$/m^3.d), and the effluent dye became stable when the HRT was increased as shown in Fig. 5.

3.2.3. *pH*

The systems were in alkaline condition during operation at various HRT operations tested as shown in Table 5(a). The systems pH with STIW+DR23 and STIW+DB15 were in the range of 7.8–8.7 without any chemical addition during operations as shown in Table 6(a). But, the effluent pH of the system with DR23 was higher than with DB15. The highest pH of 8.7 ± 0.3 and 7.8 ± 0.1 were detected with DR23 and DB15, respectively, at a HRT of 5 d (organic loading of 0.17 kg BOD$_5$/m^3.d).

3.2.4. *Nitrogenous compounds*

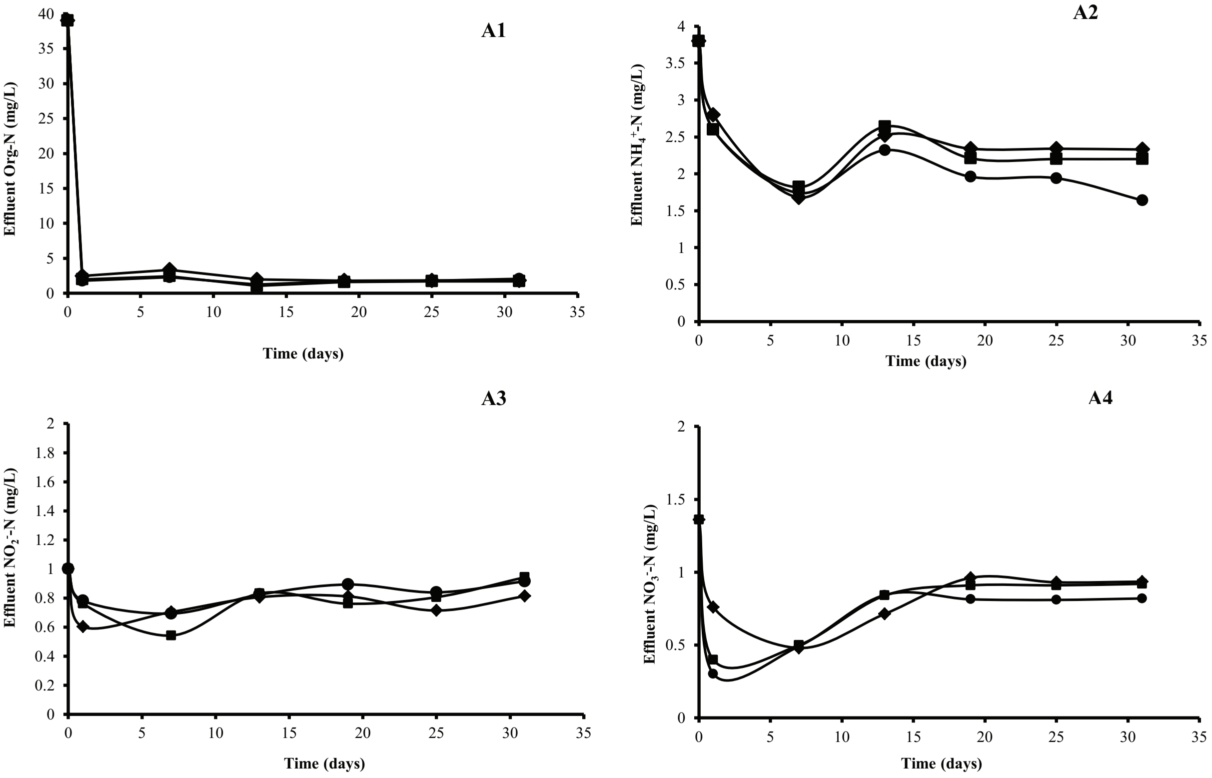
The results on the effect of HRTs (organic loadings) on the nitrogenous compounds removal profiles are shown in Table 6(b) and Fig. 6. The results showed the same patterns with DR23 and DB15. TN, TKN, org–N, and NH_4^+–N removal efficiencies of SBR system increased with the increase of HRT or organic loading. Systems detected with DR23 and DB15 at HRT of 7.5 d or lowest organic loading 0.11 kg BOD$_5$/m^3.d showed the highest TN, TKN, org–N, and NH_4^+–N removal efficiencies of 69.7% ± 3.2% and 68.1% ± 3.1%, 91.2% ± 0.1% and 91.3% ± 0.4%, 92.7% ± 0.4% and 91.3% ± 0.5%, and 35.0% ± 0.2% and 51.2% ± 0.2%, respectively. Moreover, the system with DR23 showed higher TN and NH_4^+–N removal efficiencies than that with DB15 as shown in Table 6(b). Additionally, the system with DR23 at the highest HRT of 7.5 d or lowest organic loading 0.11 kg BOD$_5$/m^3.d showed an NH_4^+–N removal efficiency of about 30% higher than with DB15. However, the effluents NO_3^-–N were higher than influents NO_3^-–N in all experiments tested as shown in Table 5(b). The effluent NO_3^-–N with DR23 and DB15 decreased with the increase of HRT or decrease of organic loading. For the effluents nitrogenous compounds profiles determination, the effluent org–N, NH_4^+–N, and NO_2^-–N rapidly decreased during the first week of operation; then, they became stable. While, the effluent NO_3^-–N rapidly increased, then became stable in the high level after 1 week of operation as shown in Fig. 6.

3.2.5. *Sludge performance*

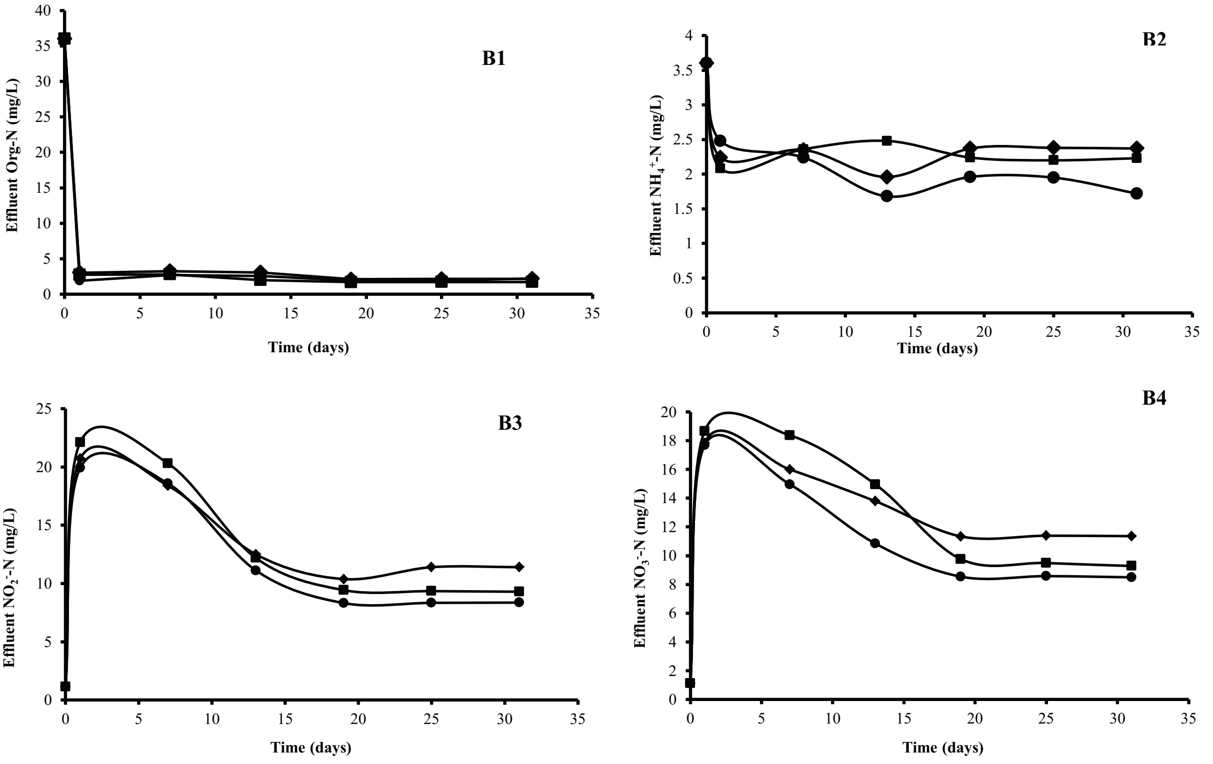
SRT of the systems with STIW+DR23 and STIW+DB15 increased with the increase of HRT or decrease of organic loading as shown in Table 5(a). SRT with DR23 and DB15 at the highest HRT of 7.5 d or lowest organic loading of 0.11 kg BOD$_5$/m^3.d was 17 ± 2 d and 22 ± 1 d, respectively. For the bio-sludge quality determination, SVI, they decreased with the increase of HRT or decrease of organic loading as shown

Table 5(b)
Effluents nitrogen compounds and their removal efficiencies of SBR system with STIW+DR23 and STIW+DB15 at HRT of 7.5 d, anoxic:oxic ratio of 0:19 and various MLSS operations of 1,500, 2,500, and 3,500 mg/L

Types of STIW	MLSS (mg/L)	TN			TKN			Org–N			NH_4^+–N			NO_2^-–N		NO_3^-–N	
		Inf. (mg/L)	Eff. (mg/L)	% removal	Inf. (mg/L)	Eff. (mg/L)	% removal	Inf. (mg/L)	Eff. (mg/L)	% removal	Inf. (mg/L)	Eff. (mg/L)	% removal	Inf. (mg/L)	Eff. (mg/L)	Inf. (mg/L)	Eff. (mg/L)
STIW+DR23	1,500	43.4 ± 0.7	14.1 ± 0.2	67.6 ± 0.5	40.7 ± 0.6	3.9 ± 0.1	90.5 ± 0.1	36.8 ± 0.4	1.8 ± 0.3	90.5 ± 0.1	3.9 ± 0.3	2.2 ± 0.0	43.8 ± 3.4	1.3 ± 0.1	0.8 ± 0.1	1.4 ± 0.1	9.4 ± 0.1
	2,500	43.4 ± 0.7	12.9 ± 0.1	70.2 ± 0.5	40.7 ± 0.6	3.7 ± 0.1	90.9 ± 0.1	36.8 ± 0.4	1.8 ± 0.3	90.9 ± 0.1	3.9 ± 0.3	1.8 ± 0.2	53.1 ± 2.7	1.3 ± 0.1	0.9 ± 0.1	1.4 ± 0.1	8.3 ± 0.0
	3,500	43.4 ± 0.7	16.0 ± 0.6	63.2 ± 1.1	40.7 ± 0.6	4.1 ± 0.1	89.8 ± 0.1	36.8 ± 0.4	2.2 ± 0.1	89.8 ± 0.1	3.9 ± 0.3	2.3 ± 0.0	40.4 ± 3.6	1.3 ± 0.1	0.8 ± 0.1	1.4 ± 0.1	11.1 ± 0.6
STIW+DB15	1,500	42.1 ± 0.8	14.4 ± 0.2	65.9 ± 1.3	39.2 ± 1.9	3.9 ± 0.1	89.9 ± 0.5	35.3 ± 1.6	2.1 ± 0.0	89.9 ± 0.5	3.9 ± 0.3	2.2 ± 0.0	42.8 ± 4.3	1.4 ± 0.1	0.9 ± 0.1	1.5 ± 0.1	9.5 ± 0.1
	2,500	42.1 ± 0.8	12.3 ± 0.1	68.5 ± 1.2	39.2 ± 1.9	3.9 ± 0.1	90.0 ± 0.5	35.3 ± 1.6	2.2 ± 0.1	90.0 ± 0.5	3.9 ± 0.3	1.9 ± 0.1	51.8 ± 4.2	1.4 ± 0.1	0.8 ± 0.1	1.5 ± 0.1	8.5 ± 0.0
	3,500	42.1 ± 0.8	16.8 ± 0.1	60.0 ± 1.5	39.2 ± 1.9	4.5 ± 0.1	88.5 ± 0.5	35.3 ± 1.6	2.6 ± 0.0	88.5 ± 1.6	3.9 ± 0.3	2.4 ± 0.0	39.0 ± 3.9	1.4 ± 0.1	0.9 ± 0.1	1.5 ± 0.1	11.4 ± 0.6



(A) DR23



(B) DB15

Fig. 3. Effluents nitrogenous compounds (1: Org-N, 2: NH_4^+–N, 3: NO_2—N, and 4: NO_3—N) profiles of SBR system with STIW+DR23 (A) and STIW+DB15 (B) at MLSS operation of 1,500 (■), 2,500 (●), and 3,500 (♦) mg/L and HRT of 7.5 d.

Table 6(a)
Effluent qualities and removal efficiencies of SBR system with STIW+DR23 and STIW+DB15 at MLSS of 2,500 mg/L, anoxic:oxic ratio of 0:19, and various HRTs operations of 2.5, 5, and 7.5 d

Types of STIW	HRT (d)	Organic loading (kgBOD$_5$/m^3·d)	Chemical properties							Sludge properties	
			Direct dye		COD		BOD$_5$		pH	SRT (d)	SVI (mL/g)
			Effluent (mg/L)	% removal	Effluent (mg/L)	% removal	Effluent (mg/L)	% removal			
STIW+DR23	2.5	0.34	16.5 ± 3.5	77.1 ± 4.7	76 ± 8	96 ± 1	60 ± 9	93 ± 1	8.6 ± 0.4	6 ± 1	74 ± 3
	5.0	0.17	8.1 ± 2.0	88.7 ± 2.8	64 ± 6	97 ± 1	47 ± 8	95 ± 1	8.7 ± 0.3	9 ± 1	67 ± 3
	7.5	0.11	6.8 ± 1.5	90.6 ± 2.14	48 ± 9	98 ± 1	37 ± 6	96 ± 1	8.6 ± 0.4	17 ± 2	55 ± 3
STIW+DB15	2.5	0.34	10.9 ± 1.9	72.3 ± 5.2	89 ± 15	95 ± 1	63 ± 6	93 ± 1	7.8 ± 0.1	6.0 ± 0.8	77 ± 3
	5.0	10.7	8.4 ± 1.5	78.5 ± 4.4	75 ± 11	96 ± 1	50 ± 7	94 ± 1	7.8 ± 0.1	10.0 ± 1.7	67 ± 3
	7.5	0.11	6.4 ± 1.0	83.8 ± 2.6	56 ± 13	97 ± 1	39 ± 8	96 ± 1	7.8 ± 0.1	22.0 ± 1.2	53 ± 3

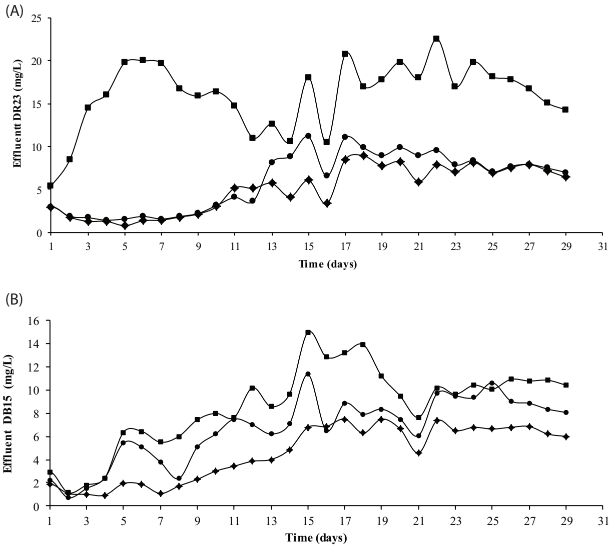


Fig. 4. Effluents DR23 and DB15 profiles of SBR system with STIW+DR23 (A) and STIW+DB15 (B) at various HRTs of 2.5 (■), 5 (●), and 7.5 (♦) d and MLSS of 2,500 mg/L.

in Table 5(a). Moreover, the systems showed good SVI values of less than 77 mL/g in all HRT or organic loading operations tested. The system with DR23 and DB15 at a HRT of 7.5 d or 0.11 kg BOD$_5$/m^3.d gave the lowest SVI values of 55 ± 3 mL/g and 53 ± 3 mL/g, respectively, as shown in Table 6(a).

3.3. *Effect of various anoxic:oxic ratios of reaction step of SBR system operation on the system performance and efficiency*

The SBR systems were tested with STIW+DR23 and STIW+DB15 at HRT of 7.5 d and MLSS of 2,500 mg/L (F/M of 0.05 and organic loading of 0.11 kg BOD$_5$/m^3.d), and the anoxic:oxic ratios of the reaction step were controlled as shown in Table 4. The samples were collected during operation for chemical analysis; the resulting system performance and efficiency were as follows.

3.3.1. *Dissolved oxygen (DO)*

The system with STIW+DR23 and STIW+DB15 showed the same DO pattern as shown in Tables 7(a) and (b). DO of the systems after the 1st aeration step were 0.04–0.06 mg/L while they were 6.00–6.25 mg/L after the 2nd reaction step as shown in Tables 7(a) and (b).

3.3.2. *COD and BOD$_5$*

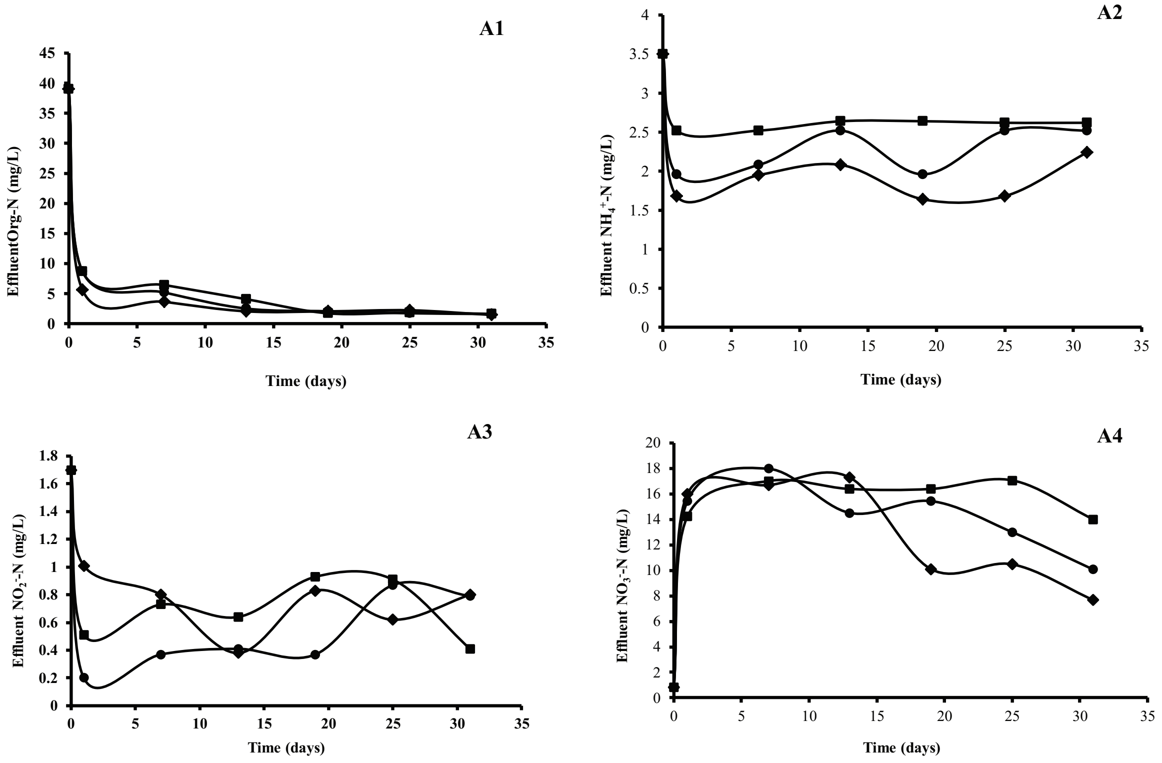
The system with STIW+DR23 and STIW+DB15 showed the same COD and BOD$_5$ removal efficiency patterns as shown in Tables 7(a) and (b). The COD and BOD$_5$ removal efficiencies increased with the increase of oxic period in the reaction step. The system with STIW+DR23 and STIW+DB15 at anoxic:oxic ratio of 7:12 showed the highest COD, 98.7% ± 0.1% and 95.6% ± 0.4%, and BOD$_5$, 98.7% ± 0.1% and 95.7% ± 0.6%, removal efficiencies, respectively. Moreover, the COD and BOD$_5$ were rapidly and highly removed at the 1st aeration step as shown in the Tables 7(a) and (b). Also, the removal efficiencies of the system at the 2nd reaction step increased with the increase of oxic period as shown in Tables 7(a) and (b).

3.3.3. *Direct dyes*

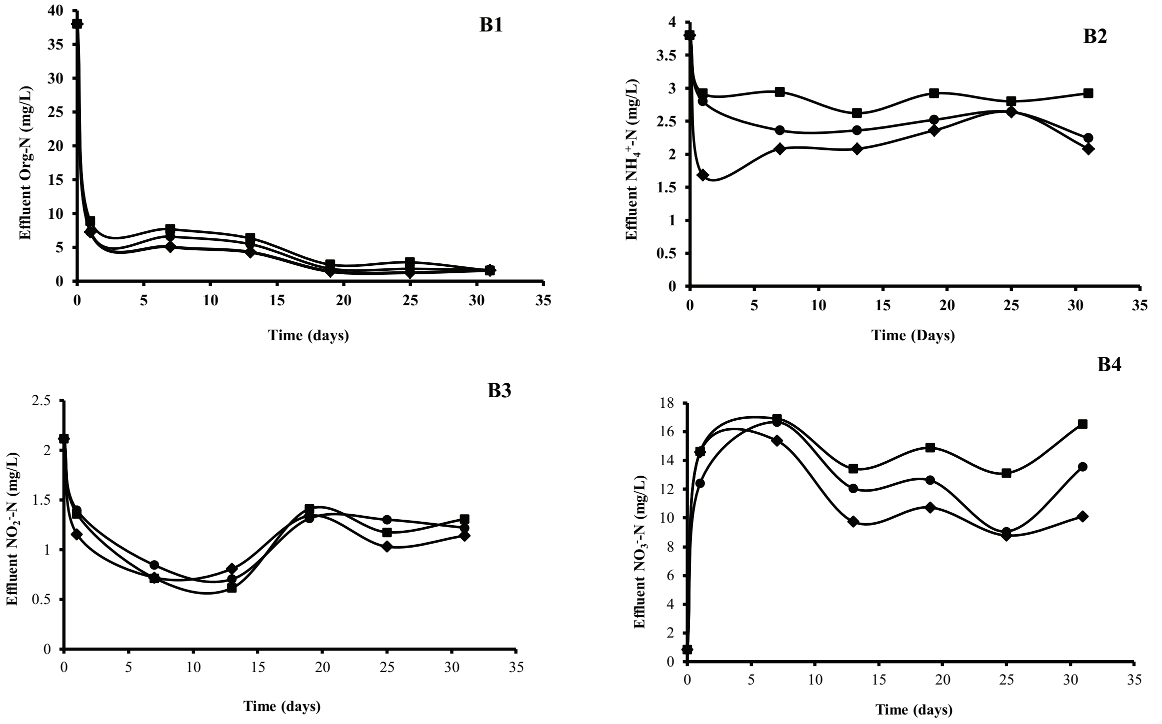
The system STIW+DR23 and STIW+DB15 showed the highest dye removal efficiencies of 93.9% ± 0.9% and 93.4% ± 0.6%, respectively, at anoxic:oxic ratio of 15:4, and the removal ability was shown in the 1st reaction step as shown in Tables 7(a) and (b). Moreover, the effluents dye concentrations increased in the 2nd step, and it was increased with the increase of oxic period of the 2nd reaction step. The highest effluents dye concentration of 8.1 ± 0.4 mg/L and 8.0 ± 0.5 mg/L were detected with DR23 and DB15, respectively, at anoxic:oxic ratio of 7:12 as shown in Tables 7(a) and (b). For the effluents dye profiles observations, during operation at the higher anoxic:oxic ratio, it was more stable than at lower anoxic:oxic ratio as shown in Fig. 6.

3.3.4. *Nitrogenous compounds*

The results on the effect of various anoxic:oxic ratios on the nitrogenous compounds removal efficiencies are shown in Tables 7(a) and (b). TN removal efficiency with DR23 and DB15 increased with the increase of anoxic period in the reaction step and the highest TN removal efficiencies of 80.3% ± 0.5% and 80.3% ± 0.3%, respectively, were detected



(A) DR23



(B) DB15

Fig. 5. Effluents nitrogenous compounds (1: Org–N, 2: NH_4^+–N, 3: NO_2^-–N, and 4: NO_3^-–N) profiles of SBR system with STIW+DR23 (A) and STIW+DB15 (B) at various HRT of 2.5 (■), 5 (●), and 7.5 (♦) d and MLSS of 2,500 mg/L.

Table 6(b)
Effluent nitrogen compounds and their removal efficiencies of SBR system with STIW+DR23 and STIW+DB15 at MLSS of 2,500 mg/L, anoxic:oxic ratio of 0:19, and various HRTs operations of 2.5, 5, and 7.5 d

Types of STIW	HRT (d)	TN			TKN			Org–N			NH_4^+–N			NO_2^-–N		NO_3^-–N	
		Inf. (mg/L)	Eff. (mg/L)	% removal	Inf. (mg/L)	Eff. (mg/L)	% removal	Inf. (mg/L)	Eff. (mg/L)	% removal	Inf. (mg/L)	Eff. (mg/L)	% removal	Inf. (mg/L)	Eff. (mg/L)	Inf. (mg/L)	Eff. (mg/L)
STI-W+DR23	2.5	46.0 ± 1.5	20.9 ± 2.0	54.5 ± 4.0	42.9 ± 1.7	4.4 ± 0.1	89.8 ± 0.3	39.1 ± 1.5	4.1 ± 0.1	89.6 ± 0.9	3.8 ± 0.1	2.6 ± 0.0	20.7 ± 0.2	2.3 ± 0.2	0.8 ± 0.3	0.8 ± 0.1	15.8 ± 1.6
	5.0	46.0 ± 1.5	17.7 ± 2.5	61.6 ± 5.7	42.9 ± 1.7	4.1 ± 0.1	90.4 ± 0.1	39.1 ± 1.5	3.6 ± 0.2	90.7 ± 0.9	3.8 ± 0.1	2.3 ± 0.3	32.1 ± 0.2	2.3 ± 0.2	0.7 ± 0.3	0.8 ± 0.1	12.8 ± 2.7
	7.5	46.0 ± 1.5	13.9 ± 1.5	69.7 ± 3.2	42.9 ± 1.7	3.8 ± 0.1	91.2 ± 0.1	39.1 ± 1.5	2.8 ± 0.4	92.7 ± 0.4	3.8 ± 0.1	1.9 ± 0.3	35.0 ± 0.2	2.3 ± 0.2	0.8 ± 0.1	0.8 ± 0.1	9.4 ± 1.5
STI-W+DB15	2.5	46.6 ± 1.1	21.3 ± 1.1	54.3 ± 3.5	43.7 ± 1.1	5.2 ± 0.6	88.2 ± 1.3	40.0 ± 1.2	5.0 ± 0.6	87.6 ± 1.6	3.6 ± 0.3	2.9 ± 0.1	30.9 ± 0.2	2.0 ± 0.1	1.3 ± 0.1	0.9 ± 0.1	14.9 ± 1.4
	5.0	46.6 ± 1.1	17.3 ± 2.1	62.9 ± 5.2	43.7 ± 1.1	4.3 ± 0.3	90.3 ± 0.7	40.0 ± 1.2	4.1 ± 0.1	89.4 ± 0.3	3.6 ± 0.3	2.5 ± 0.2	38.6 ± 0.2	2.0 ± 0.1	1.3 ± 0.1	0.9 ± 0.1	11.8 ± 2.4
	7.5	46.6 ± 1.1	14.9 ± 1.0	68.1 ± 3.1	43.7 ± 1.1	3.8 ± 0.1	91.3 ± 0.4	40.0 ± 1.2	3.5 ± 0.2	91.3 ± 0.5	3.6 ± 0.3	2.4 ± 0.3	51.2 ± 0.2	2.0 ± 0.1	1.2 ± 0.2	0.9 ± 0.1	9.9 ± 1.0

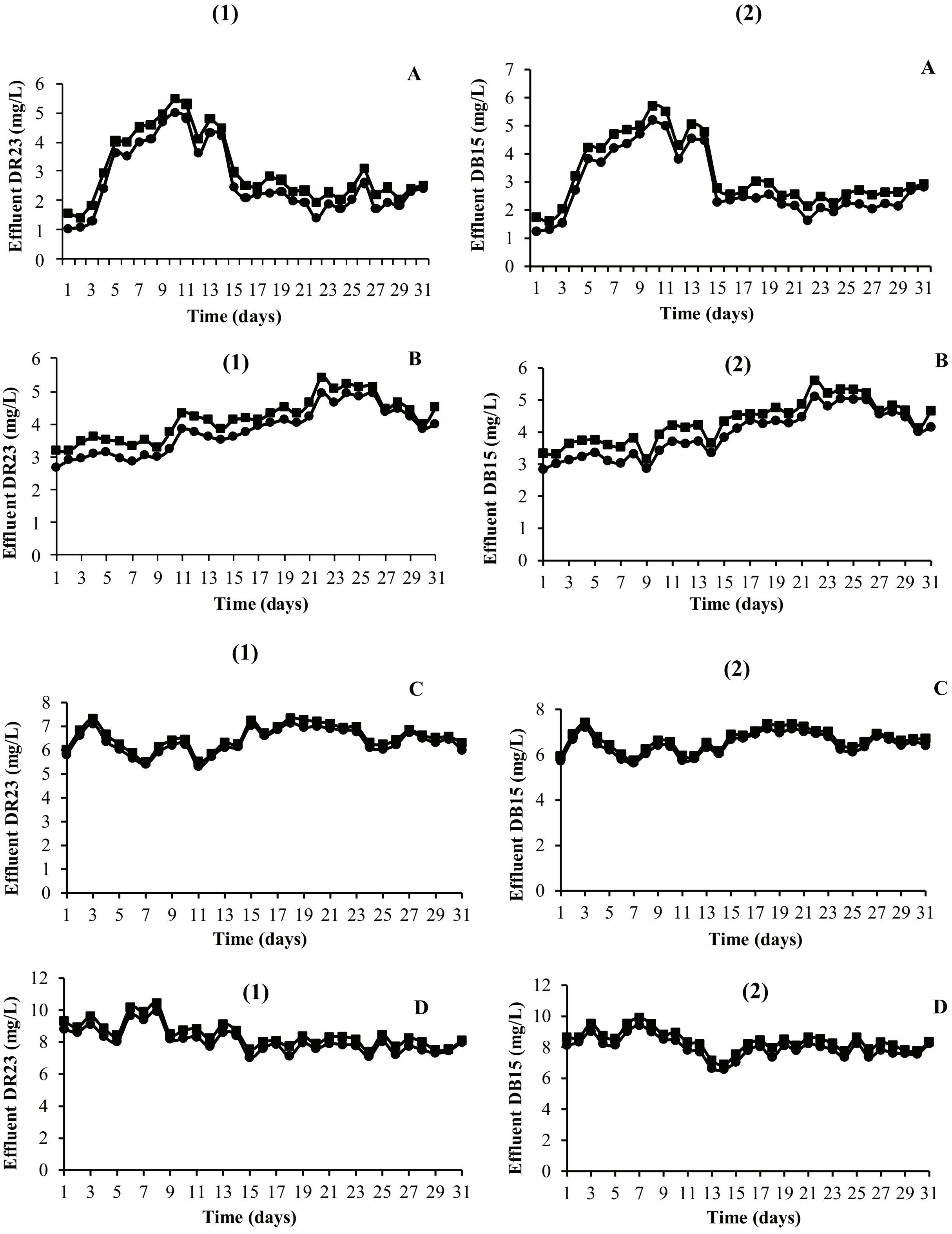


Fig. 6. Effluent DR23 and DB15 profiles that were collected after anoxic (■) and oxic (●) period reaction step of SBR system operation with STIW+DR23 (1) and STIW+DB15 (2) at anoxic:oxic ratio of 15:4 (A), 12:7 (B), 10:9 (C), and 7:12 (D).
Note: The system was operated following the SBR operation procedure as shown in Table 4.

Table 7(a)
Effluent qualities and removal efficiencies of SBR system with STIW+DR23 at MLSS of 2,500 mg/L, HRT of 7.5 d, and various anoxic:oxic ratio of 15:4, 12:7, 10:9, and 7:12

Parameter		Influent	Various anoxic:oxic ratio operation of reaction step											
			15:4			12:7			10:9			7:12		
			Sampling after			Sampling after			Sampling after			Sampling after		
			1st stage	2nd stage	Total	1st stage	2nd stage	Total	1st stage	2nd stage	Total	1st stage	2nd stage	Total
DO	Effluent (mg/L)	–	0.04 ± 0.01	6.25 ± 0.03	–	0.04 ± 0.02	6.16 ± 0.02	–	0.05 ± 0.01	6.04 ± 0.02	–	0.06 ± 0.01	5.97 ± 0.02	–
DR23	Effluent (mg/L)	39.9 ± 0.8	2.1 ± 0.3	2.5 ± 0.3	2.5 ± 0.3	4.3 ± 0.4	4.6 ± 0.4	4.6 ± 0.4	6.6 ± 0.4	6.7 ± 0.4	6.7 ± 0.4	7.7 ± 0.4	8.1 ± 0.4	8.1 ± 0.4
	% removal	–	94.8 ± 0.8	–	93.9 ± 0.9	89.3 ± 1.1	–	88.5 ± 1.1	83.4 ± 0.9	–	83.0 ± 0.9	80.9 ± 0.8	–	80.0 ± 0.8
BOD_5	Effluent (mg/L)	845 ± 40	113 ± 8	73 ± 4	73 ± 4	105 ± 5	53 ± 2	–	103 ± 5	51 ± 3	51 ± 3	107 ± 5	37 ± 2	37 ± 2
	% removal	–	87 ± 1	37 ± 8	91 ± 1	88 ± 1	50 ± 2	94 ± 1	88 ± 1	50 ± 5	94 ± 1	87 ± 1	66 ± 1	96 ± 1
COD	Effluent (mg/L)	1,993 ± 15	74 ± 4	54 ± 3	54 ± 3	71 ± 5	49 ± 3	–	52 ± 3	36 ± 2	36 ± 2	37 ± 2	26 ± 1	26 ± 1
	% removal	–	96 ± 1	28 ± 1	97 ± 0	96 ± 0	30. ± 1	98 ± 0	97 ± 0	31 ± 2	98 ± 0	98 ± 0	31 ± 2	99 ± 0
TN	Effluent (mg/L)	45.7 ± 1.1	25.4 ± 1.0	9.0 ± 0.1	9.0 ± 0.1	24.8 ± 0.5	11.7 ± 0.4	11.7 ± 0.4	25.5 ± 0.1	11.3 ± 0.2	11.3 ± 0.2	25.4 ± 0.2	14.2 ± 0.1	14.2 ± 0.1
	% removal	–	44.4 ± 2.7	64.6 ± 0.9	80.3 ± 0.5	45.7 ± 2.5	52.9 ± 1.1	74.4 ± 1.3	44.1 ± 1.6	55.6 ± 0.9	75.2 ± 0.8	44.3 ± 1.8	44.1 ± 0.9	68.9 ± 0.5
TKN	Effluent (mg/L)	43.7 ± 1.1	24.4 ± 1.0	6.7 ± 0.2	6.7 ± 0.2	23.7 ± 0.6	5.8 ± 0.4	5.8 ± 0.4	24.3 ± 0.1	5.1 ± 0.2	5.1 ± 0.2	24.1 ± 0.2	4.7 ± 0.1	4.7 ± 0.1
	% removal	–	44.1 ± 2.9	72.6 ± 0.6	84.7 ± 0.5	45.8 ± 2.6	75.3 ± 1.3	86.6 ± 1.1	44.3 ± 1.7	79.1 ± 0.9	88.3 ± 0.7	44.9 ± 1.9	80.37 ± 0.6	89.2 ± 0.1
Org–N	Effluent (mg/L)	39.9 ± 0.8	20.6 ± 1.0	4.6 ± 0.2	4.6 ± 0.2	21.1 ± 0.4	4.1 ± 0.4	4.1 ± 0.4	21.2 ± 0.1	3.0 ± 0.2	3.0 ± 0.2	21.3 ± 0.2	3.1 ± 0.1	3.1 ± 0.1
	% removal	–	48.4 ± 2.6	77.6 ± 1.0	88.4 ± 0.4	47.2 ± 2.4	80.4 ± 0.8	89.7 ± 1.1	46.8 ± 1.6	85.9 ± 1.0	92.5 ± 0.8	46.5 ± 1.7	85.6 ± 0.9	92.3 ± 0.4
NH_4^+–N	Effluent (mg/L)	3.7 ± 0.1	3.1 ± 0.0	2.3 ± 0.01	2.3 ± 0.01	2.9 ± 0.0	2.2 ± 0.0	2.2 ± 0.0	2.8 ± 0.0	2.0 ± 0.0	2.0 ± 0.0	2.6 ± 0.0	1.9 ± 0.0	1.9 ± 0.0
	% removal	–	18.5 ± 1.5	23.4 ± 0.7	37.6 ± 1.0	23.6 ± 1.2	24.9 ± 0.8	42.6 ± 1.2	25.5 ± 1.8	28.0 ± 0.4	46.3 ± 1.0	29.8 ± 1.3	26.7 ± 0.1	48.5 ± 1.0
NO_2^-–N	Effluent (mg/L)	0.8 ± 0.0	0.1 ± 0.0	0.4 ± 0.0	0.4 ± 0.0	0.1 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.1 ± 0.0	0.6 ± 0.0	0.6 ± 0.0	0.2 ± 0.0	0.7 ± 0.0	0.7 ± 0.0
NO_3^-–N	Effluent (mg/L)	1.2 ± 0.0	0.9 ± 0.0	1.9 ± 0.0	1.9 ± 0.0	1.0 ± 0.0	4.3 ± 0.0	4.3 ± 0.0	1.1 ± 0.0	5.7 ± 0.0	5.7 ± 0.0	1.1 ± 0.0	8.8 ± 0.0	8.8 ± 0.0
SRT	d	–	–		34 ± 5	–	–	19 ± 4	–	–	15 ± 3	–	–	13 ± 2
SVI	mL/g	–	–		44 ± 4	–	–	46 ± 5	–	–	48 ± 5	–	–	54 ± 4

Table 7(b)
Effluent qualities and removal efficiencies of SBR system and STIW+DB15 at MLSS of 2,500 mg/L, HRT of 7.5 d, and various anoxic:oxic ratios of 15:4, 12:7, 10:9, and 7:12

Parameter		Influent	Various anoxic:oxic ratio operation of reaction step											
			15:4			12:7			10:9			7:12		
			Sampling after			Sampling after			Sampling after			Sampling after		
			1st stage	2nd stage	Total	1st stage	2nd stage	Total	1st stage	2nd stage	Total	1st stage	2nd stage	Total
DO	(mg/L)	–	0.04 ± 0.01	6.23 ± 0.03	–	0.04 ± 0.02	6.14 ± 0.02	–	0.05 ± 0.02	6.03 ± 0.03	–	0.06 ± 0.01	5.98 ± 0.03	–
DB15	Effluent (mg/L)	39.9 ± 0.7	2.3 ± 0.3	2.6 ± 0.3	2.6 ± 0.3	4.5 ± 0.4	4.8 ± 0.4	4.8 ± 0.4	6.7 ± 0.3	6.8 ± 0.3	6.8 ± 0.3	7.7 ± 0.5	8.0 ± 0.5	8.0 ± 0.5
	% removal	–	94.3 ± 0.7	–	93.4 ± 0.6	88.7 ± 1.0	–	87.9 ± 1.0	83.2 ± 0.6	–	82.8 ± 0.6	80.5 ± 0.8	–	79.6 ± 0.8
BOD_5	Effluent (mg/L)	852 ± 49	111 ± 2	71 ± 5	71 ± 5	100 ± 9	52 ± 5	52 ± 5	98 ± 8	53 ± 4	53 ± 4	102 ± 9	37 ± 4	37 ± 4
	% removal	–	87 ± 1	36 ± 5	92 ± 1	88 ± 1	48 ± 1	93 ± 1	88 ± 1	46 ± 5	94 ± 1	88 ± 1	64 ± 2	96 ± 1
COD	Effluent (mg/L)	1,996 ± 16	55 ± 3	55 ± 2.76	55 ± 3	70 ± 4	49 ± 2	49 ± 2	52 ± 3	36 ± 2.23	36 ± 2	36 ± 3	25 ± 2	25 ± 2
	% removal	–	96 ± 0	28 ± 1	97 ± 0	97 ± 0	30 ± 1	98 ± 0	97 ± 0	31 ± 2	98 ± 0	98 ± 0	31 ± 1	99 ± 0
TN	Effluent (mg/L)	45.8 ± 1.2	25.8 ± 0.2	9.0 ± 0.3	9.0 ± 0.3	24.6 ± 0.5	10.8 ± 0.3	10.8 ± 0.3	25.2 ± 0.5	11.3 ± 0.2	11.3 ± 0.2	25.4 ± 0.2	14.1 ± 0.1	14.1 ± 0.1
	% removal	–	43.8 ± 1.2	64.9 ± 1.01	80.3 ± 0.3	46.3 ± 2.3	56.1 ± 0.5	76.4 ± 1.1	44.0 ± 1.4	55.3 ± 1.6	75.4 ± 0.8	44.5 ± 1.1	44.5 ± 0.5	69.2 ± 0.6
TKN	Effluent (mg/L)	43.9 ± 1.2	24.9 ± 0.2	6.7 ± 0.3	6.7 ± 0.3	23.6 ± 0.5	6.0 ± 0.3	6.0 ± 0.3	24.1 ± 0.4	5.0 ± 0.2	5.0 ± 0.2	24.1 ± 0.2	4.7 ± 0.1	4.7 ± 0.1
	% removal	–	43.3 ± 1.3	72.9 ± 1.1	84.7 ± 0.4	46.2 ± 2.4	74.7 ± 0.8	86.4 ± 1.0	45.1 ± 1.5	79.1 ± 1.3	88.5 ± 0.6	45.1 ± 1.1	80.7 ± 0.5	89.4 ± 0.3
Org–N	Effluent (mg/L)	40.1 ± 0.8	21.8 ± 0.2	4.4 ± 0.3	4.4 ± 0.3	20.7 ± 0.3	3.8 ± 0.3	3.8 ± 0.3	21.2 ± 0.4	3.0 ± 0.2	3.0 ± 0.2	21.4 ± 0.2	2.7 ± 0.1	2.7 ± 0.1
	% removal	–	45.6 ± 1.1	79.8 ± 0.8	89.0 ± 1.0	48.4 ± 2.2	81.5 ± 1.0	90.5 ± 0.7	47.1 ± 1.4	85.8 ± 0.9	92.5 ± 1.1	46.5 ± 1.0	87.4 ± 0.9	92.3 ± 0.4
NH_4^+–N	Effluent (mg/L)	3.8 ± 0.1	3.0 ± 0.0	19.2 ± 1.1	19.2 ± 1.1	2.9 ± 0.0	24.1 ± 0.7	24.1 ± 0.7	2.8 ± 0.0	24.8 ± 0.8	24.8 ± 0.8	2.7 ± 0.0	29.5 ± 1.2	29.5 ± 1.2
	% removal	–	2.3 ± 0.0	23.3 ± 0.2	38.1 ± 0.6	2.1 ± 0.0	25.1 ± 0.6	43.2 ± 1.0	2.0 ± 0.0	28.7 ± 0.6	46.3 ± 1.0	1.9 ± 0.0	26.7 ± 1.0	48.4 ± 0.6
NO_2^-–N	Effluent (mg/L)	0.8 ± 0.0	0.1 ± 0.0	0.4 ± 0.0	0.4 ± 0.0	0.2 ± 0.0	0.5 ± 0.0	0.5 ± 0.0	0.1 ± 0.0	0.6 ± 0.0	0.6 ± 0.0	0.2 ± 0.0	0.7 ± 0.0	0.7 ± 0.0
NO_3^-–N	Effluent (mg/L)	1.2 ± 0.0	0.9 ± 0.0	1.9 ± 0.0	1.9 ± 0.0	1.0 ± 0.0	4.3 ± 0.0	4.3 ± 0.0	1.1 ± 0.01	5.7 ± 0.0	5.7 ± 0.0	1.1 ± 0.0	8.8 ± 0.0	8.8 ± 0.0
SRT	d	–	–	–	28 ± 2	–	–	20 ± 1	–	–	15 ± 1	–	–	13 ± 1
SVI	mL/g	–	–	–	43 ± 3	–	–	47 ± 2	–	–	48 ± 3	–	–	55 ± 4

at anoxic:oxic ratio of 15:4. On the other hand, DR23 and DB15 systems at anoxic:oxic ratio of 7:12 showed an increase in removal efficiency with an increase of oxic period in the reaction step where TKN, org–N, and NH_4^+–N efficiency values were 89.2% ± 0.1%, 92.3% ± 0.4%, and 48.5% ± 1.0%; and 89.4% ± 0.3%, 92.3% ± 0.4%, and 48.4% ± 0.6%, respectively, Moreover, their removal efficiencies in the 1st reaction step were lower than that in the 2nd reaction step as shown in Tables 7(a) and (b). Also, the effluents NO_2^-–N and NO_3^-–N increased with the increase of oxic period in the reaction step. The effluents NO_2^-–N and NO_3^-–N of the 1st reaction step were lower than that of the 2nd reaction step as shown in Tables 7(a) and (b).

3.3.5. Sludge performance

Interesting results were observed on the system where the SRT (sludge age) increased with the increase of anoxic period in the reaction step as shown in Tables 7(a) and (b). The SRT of the systems with DR23 and DB15 at the highest anoxic period of reaction step of 15 h (anoxic:oxic ratio of 15:4) was 34 ± 5 d and 28 ± 2 d, respectively, while they were only 13 ± 2 d and 13 ± 2 d, respectively, at the shortest anoxic period of 7 h (anoxic:oxic ratio of 7:12). For the bio-sludge quality determination, SVI with DR23 and DB15 decreased with the increase of oxic period in the reaction step as shown in Tables 7(a) and (b). However, SVI with DR23 and DB15 was lower than 55 mL/g in all experiments tested.

4. Discussion

The system with STIW+DR23 and STIW+DB15 at MLSS of 2,500 mg/L and aeration period of reaction step of 19 h (oxic:anoxic ratio of reaction step of 19:0) showed the highest COD, BOD_5, direct dye, and TN removal efficiencies of 96.63% ± 0.21% and 95.71% ± 0.26%, 96.64% ± 0.14% and 94.93% ± 0.28%, 92.04% ± 0.47% and 90.47% ± 0.54%, and 70.2% ± 0.5% and 68.5% ± 1.2%, respectively. But, it did not show any significant different on the TKN and NH_4^+–N removal efficiencies at the MLSS operation of 1,500–3,500 mg/L. This might suggest that the system was operated under above condition resulted to stimulate the bio-sludge to be in the late log phase state of the growth curve [21]. In conclusion, the system would show the highest removal efficiency at the optimal bio-sludge age (SRT) of about 12 d and organic loading of 0.13 kg BOD_5/m^3-d. Moreover, the system at MLSS of 3,500 mg/L still gave the high removal efficiencies, especially, nitrogenous compounds and textile dyes, resulted by the stimulation of nitrogen removal microorganism with high MLSS operation [21]. From the theoretical information, the bio-sludge of the system at long SRT operation contained a higher nitrogen removal bacteria population than that at short SRT operation [21–24]. The heterotrophic bacteria play a part in the main mechanism for the COD and BOD_5 removal activities while nitrogenous compounds removal bacteria play the role for nitrogenous compounds removal activity [22–24]. From the above results, it could be that the textile removal activity is related to the population of nitrogenous compounds removal bacteria [21]. To increase system removal efficiency, HRT of the system should be increased [12,25,26]. It was confirmed that the removal efficiency increased with the increase of HRT or decrease of organic loading. The highest COD, BOD_5, TKN, and direct dye removal efficiencies of 97.6% ± 0.5%, 97.2% ± 0.7%, 95.7% ± 0.6%, and 95.5% ± 0.7%; and 91.21% ± 0.12%, 91.28% ± 0.24%, 90.61% ± 2.14%, and 83.82% ± 2.60%, respectively, were detected with STIW+DR23 and STIWW+DB15 at HRT of 7.5 d or organic loading rate of 0.11 kg BOD_5/m^3-d [3,12]. Moreover, to increase the HRT or decrease organic loading, the direct dye removal efficiency was increased. According to the information above, it could be suggested that the system shows high removal efficiency at HRT of 7.5 d or organic loading of 0.11 kg BOD_5/m^3-d. But, the nitrogenous compound removal mechanism is mainly concerned by nitrifying and denitrifying bacteria (oxidation–reduction mechanism) where both types of bacteria are different and operate the condition requirements with the BOD_5 removal microbe (heterotrophy) [27,28]. Nitrifying bacteria or autotrophic bacteria required oxic conditions, while denitrifying bacteria or heterotrophic bacteria required anoxic conditions [27,29,30]. To increase the nitrogenous compound removal efficiency, the reaction step of the SBR system should be modified. The anoxic conditions should be added in the reaction step of the SBR operation program [21]. From the conventional operation pattern of SBR system, the ratio of fill:reaction (aeration):setting:draw and idle were 2:19:2:1 [4,16,21,31]. Then, the aeration period of reaction step was modified to increase the nitrogenous compound removal efficiency as shown in Table 3. Various anoxic:oxic ratios of 15:4, 12:7, 10:9, and 7:12 were investigated. It was found that the COD and BOD_5 removal efficiencies increased with the increase of aeration period but unfortunately TN removal efficiency decreased. However, the COD and BOD_5 removal efficiencies of the system at anoxic:oxic ratios of 15:4 to 7:12 were still over 90%. From above information, it could conclude that, to increase the nitrogen removal yield, the number of nitrogen removal bacteria (nitrifying and denitrifying bacteria) should be increased. To increase the number of nitrogen removal bacteria, the SRT of the system should be increased according to the low specific growth rate of nitrogen removal bacteria. Moreover, the nitrogen removal mechanism consisted of nitrification and denitrification; then the oxic and anoxic conditions were required. Moreover, it was found that the direct dye removal efficiency increased with the increase of anoxic period of reaction step [22,32,33]. The direct dye removal efficiencies of the system with STIW+DR23 and STIW+DB15 at highest anoxic:oxic ratio of 15:4 were 93.9% ± 0.9% and 93.4% ± 0.6%, respectively. It could suggest that carbonaceous compounds were mainly removed by the aerobic heterotrophic bacteria, while the nitrogenous compounds were removed by assimilation mechanism with aerobic heterotrophic, nitrifying and denitrifying bacteria [23,34] and oxidation and reduction mechanisms with nitrogen removal bacteria (nitrifying and denitrifying bacteria). However, the mainly nitrogenous compounds removal mechanism was the oxidation and reduction mechanism. Then, the addition of anoxic period in the reaction step was most important to convert NO_3^-–N to N_2 [35]. Moreover, the system showed the highest DR23 and DB15 removal efficiencies of 94.8% ± 0.8% and 94.3% ± 0.7%, respectively, at a anoxic:oxic ratio of 15:4. This could be due to the activity of the denitrifying bacteria to remove the direct dyes. In that denitrifying bacteria is the main microbial group to play the direct dye removal mechanism of the SBR system. This might be the first finding in this paper.

5. Conclusion

SBR system showed the highest removal efficiency at MLSS of 2,500 mg/L and HRT of 7.5 d. All contaminants in the wastewater were removed by different types of microbes of bio-sludge. COD and BOD_5 were mainly removed by the aerobic heterotrophic bacteria, while the main nitrogenous removal activity was the oxidation–reduction mechanism that occurred with nitrifying and denitrifying bacteria. Then, to increase the nitrogen removal yield, the anoxic period was added in the reaction step to increase the denitrification efficiency. The system showed the highest TN removal efficiencies at an anoxic:oxic ratio of 15:4. Moreover, the system showed the other advantage on the highest DR23 and DB15 removal yields of 94.8% ± 0.8% and 94.3% ± 0.7% with STIW+DR23 and STIW+DB15, respectively. It could be suggested that the nitrogen removal bacteria showed the dye removal ability. This might be the first report on the direct dye removing by nitrogen removal bacteria, especially, denitrifying bacteria.

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Symbols

BOD_5	—	Biochemical oxygen demand
DB15	—	Direct blue 15
DR23	—	Direct red 23
COD	—	Chemical oxygen demand
HRT	—	Hydraulic retention time
MLSS	—	Mixed liquor suspended solids
MLVSS	—	Mixed liquor volatile suspended solids
NH_4^+–N	—	Ammonium nitrogen
NO_3^-–N	—	Nitrate
NO_2^-–N	—	Nitrite
Org–N	—	Organic nitrogen
SBR	—	Sequencing batch reactor
SRT	—	Solids retention time
SS	—	Suspended solids
STIW	—	Synthetic textile industrial wastewater
TIW	—	Textile industrial wastewater
TKN	—	Total Kjeldahl nitrogen
TN	—	Total nitrogen
STIW–DB15	—	Synthetic textile industrial wastewater containing direct blue 15
STIW–DR23	—	Synthetic textile industrial wastewater containing direct red 23

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