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Comparison of sequencing batch reactor (SBR) and granular activated carbon-SBR (GAC-SBR) systems on treatment textile wastewater containing basic dye

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ABSTRACT

Efficiencies of SBR and granular activated carbon (GAC)-SBR systems with textile industrial wastewater (TIW) containing basic dyes (Basic Red 46 (BR46) and Basic Blue 41 (BB41)) at hydraulic retention times (HRTs) of 3.0, 5.0, and 7.5 d were investigated. The results showed that the basic dyes could be adsorbed onto bio-sludge but the adsorption yield depended on the molecular structure and weight of the basic dye. BR46 could be adsorbed onto the bio-sludge with higher yield than BB41. Also, the color adsorption yield of living bio-sludge was 22% higher than that of autoclaved bio-sludge (thermally treated bio-sludge). Moreover, the bio-sludge from a domestic wastewater treatment plant showed higher color adsorption yield than the bio-sludge from a textile wastewater treatment plant. The GAC-SBR system was more suitable than the SBR system to treat TIW. The highest color, COD, BOD_5, total Kjeldahl nitrogen (TKN), and total nitrogen (TN) removal efficiencies of the GAC-SBR system with TIW at HRT of 5 d (organic loading of 0.22 kg BOD_5/m^3 d and dye loading of 0.02 kg/m^3 d) were 68.3 ± 3.2, 88 ± 1, 90 ± 1, 80.6 ± 6.8, and 55.9 ± 3.2%, respectively. Moreover, its removal efficiency could be increased by adding organic matter (glucose). The color, COD, BOD_5, TKN, and TN removal efficiencies with TIW containing 0.87 g/L glucose at HRT of 5.0 d (organic loading of 0.25 kg BOD_5/m^3 d) increased up to 80.0 ± 0.7, 97 ± 1%, 98 ± 0, 83.3 ± 0.0, and 58.9 ± 0.2%, respectively. Moreover, it was the first study where nitrogen removal bacteria (nitrifying and denitrifying bacteria) were the main bacteria in basic dyes removing mechanism.

Keywords: Adsorption; Basic dye; Bio-sludge; Granular activated carbon; Sequencing batch reactor (SBR) system; Textile industrial wastewater

1. Introduction

Textile industry is one of the industries that generate large amounts of wastewater because of its high water consumption in comparison to other industries [1–3]. Moreover, TIW contains high concentrations of organic matter and dyes [1–4]. In the dyeing step of the textile coloring process, a part of the dye is adsorbed onto the fiber and the remaining dye is contained in the wastewater and discharged into the

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environment, which consequently becomes a serious environmental problem [1–3]. Normally, textile dye has large molecular weight, complicated structure and consists of an aromatic ring that is hardly biodegradable by normal micro-organisms under normal conditions [5,6]. In addition, textile dyes are toxic to the environment and organisms, especially micro-organisms [2,7–10]. Textile dyes have an environmental impact because when suspended in wastewater, they reduce light transmission yield [1,2]. Then, the amount of oxygen dissolved in wastewater decreases, resulting in a decrease in the number of types of organisms in the wastewater. Moreover, textile dyes are toxic to micro-organisms [2]. Popular and common textile wastewater treatment processes are chemical coagulation–flocculation and chemical adsorption [11,12]. However, the water-soluble dye is hardly removed by these processes [2,13–16]. Other disadvantages of these chemical treatment processes are high cost of chemical agents and large amounts of generated chemical waste [2,11,12,17–19]. Many researchers have suggested that bio-sludge from aerobic wastewater treatment system could be used as an adsorbent instead of chemical adsorbents or activated carbon [5,16,20–22]. Moreover, most textile dyes are hardly biodegradable organic matter; therefore, the conventional biological wastewater treatment system cannot be applied [2,16,23–27]. Modified biological wastewater treatment system to treat textile wastewater has been studied [15–17,26–28]. But, quantification of wastewater was one of the wastewater treatment system selection criteria. Then, an SBR system was selected for small and medium textile industrial factories [29]. Other advantages of the SBR system are easy operation and low energy consumption [2,6,17]. Moreover, this system can be operated under oxic-anoxic conditions which results in removing nitrogenous compounds by biological oxidation–reduction mechanisms. These characteristics show that the SBR system might be suitable for the treatment of textile wastewater containing basic dyes. However, the SBR system should be operated under highly mixed liquor suspended solids (MLSS); MLSS result in low excess of generated bio-sludge and high nitrogenous compounds removal yield. To increase MLSS of the system, Granular activated carbon (GAC) might be added into the reactor [2,6,10,26,30,31]. In this study, laboratory SBR and GAC-SBR systems were used. The experiments were carried out with raw textile industrial wastewater (TIW) and synthetic textile industrial wastewater (STIW). Hydraulic retention times (HRTs) of 3.0, 5.0, and 7.5 d were tested for the highest removal efficiency. The effects of supplemented organic matter (glucose) for increasing system efficiency with TIW were also investigated. Moreover, dyes adsorption ability of bio-sludge from biological wastewater treatment plant (autoclaved and living bio-sludge) and activated carbon were compared.

2. Materials and methods

2.1. Bio-sludge, dye adsorption test and SBR system

Two types of bio-sludge were used in this study; they were called bio-sludge type A and bio-sludge type B. Bio-sludge type A was collected from the Bangkok municipal central wastewater treatment plant (Sripaya sewage treatment plant: Extended activated sludge system, 28 d of bio-sludge age: SRT), Bangkok, Thailand. Bio-sludge type B was collected from a textile factory wastewater treatment plant (Conventional activated sludge system, 16 d of bio-sludge age: SRT) in Nonthaburi Province, Thailand. Both types of bio-sludge were used as the resting bio-sludge (living bio-sludge) after washing it twice with 0.1 M acetate buffer pH 6.0 (for cleaning up the bio-sludge without any effects to the microbial cells). The autoclaved bio-sludge (thermally treated bio-sludge) was prepared by autoclaving the resting bio-sludge at 110˚C for 10 min. All bio-sludge samples were kept at 4–8˚C to prevent any changes in the bio-sludge quality during the study.

2.2. Granular activated carbon (GAC)

GAC type CGC-11 from coconut charcoal (C. Gigan Co., Ltd, Thailand) with a mesh size of 8 × 10 mm, total surface area of 1,050–1,150 m^2/g and apparent density of 0.46–0.48 g/mL was used. GAC was used for dye adsorption tests and in the GAC-SBR system operation. GAC with a mesh size of 8 × 10 mm was used in the experiment resulted for the easy harvesting during operation in the SBR system (GAC-SBR system).

2.3. Dyes

Two types of basic dyes were selected for this study as Basic Blue 41: BB41 (trade name: Cationic Blue X-GRL300%) and Basic Red 46: BR46 (trade name: Cationic Red X-GRL300%) Chemical characteristics of BB41 were $C_{20}H_{26}N_4O_6S_2$ in molecular formula, 482.57 in molecular weight, 609 nm in maximum absorption wavelength and color index number 11,105. Chemical characteristics of BR46 were $C_{18}H_{21}BrN_6$ in molecular formula, 401.3 in molecular weight, 609 nm in maximum absorption wavelength, color index number 110,825 [32].

2.4. Wastewater samples

Two kinds of wastewater were used in this study as follows.

2.4.1. Textile industrial wastewater (TIW)

TIW was collected from the influent sump tank of the central wastewater treatment plant from a textile factory in Nonthaburi Province, Thailand. TIW was taken only once and stored at 4–8℃ to prevent any changes in the chemical quality before using in the experiments. Chemical properties and composition of TIW were shown in Table 1. TIW supplemented with 0.87 g/L glucose (final BOD_5 concentration of 1,235 ± 14 mg/L) was used as TIW + glucose according to our previous works [10,15,30]. Glucose was used as the organic matter for increasing BOD_5 concentration of TIW.

2.4.2. Synthetic textile industrial wastewater (STIW)

STIW was prepared according to the TIW characteristics as shown in Table 1. BOD_5 concentrations of STIW were about 1,000 ± 29 mg/L. Chemical composition and properties of STIW were described in Table 1.

2.5. Dye adsorption test

The dye adsorption test was carried out with resting and autoclaved bio-sludge with the jar test system (Rubin, 1978) using STIW containing 100 mg/L basic dye (Basic Blue 41: STIW + 100BB41 or Basic Red 46: STIW + 100BR46) for 1 h. The bio-sludge concentration in each jar test reactor was 1.0 g/100 mL. Dye adsorption yields of the bio-sludge (Section 2.1) were measured using Freundlich's adsorption isotherm equation [33].

2.6. Acclimatization of bio-sludge for the inoculums of SBR and GAC-SBR systems

Bio-sludge from the storage tank of the central domestic treatment plant of Bangkok Municipal, Thailand (Sripaya sewage treatment plant) was used as inoculums in the SBR and GAC-SBR systems. The bio-sludge was fed with STIW without basic dyes in the reactor and acclimatized for 1 week at HRT of 3.0 d and organic loading of 2.80 g BOD_5/d, as shown in Table 2.

Table 1
Characteristics of TIW, TIW + glucose and STIW

STIW			
		Characteristic	
Composition	Concentration	Parameter	Concentration
Glucose (mg/L)	1875	COD (mg/L)	1,926 ± 20
Urea (mg/L)	115	BOD_5 (mg/L)	1,122 ± 87
$FeCl_2$ (mg/L)	3.5	Organic-N (mg/L)	46 ± 1
$NaHCO_3$ (mg/L)	675	NH_4^+-N (mg/L)	6.7 ± 1.0
KH_2PO_4 (mg/L)	55	NO_2^--N (mg/L)	14.5 ± 0.2
$MgSO_4{\cdot}7H_2O$ (mg/L)	42.5	NO_3^--N (mg/L)	0.08 ± 0.01
Basic dye[a] (mg/L)	100	pH	8.03 ± 0.12
Characteristic		Types of raw textile wastewater (TIW)	
		TIW	TIW + glucose[b]
COD (mg/L)		532 ± 2	1,840 ± 10
BOD_5 (mg/L)		308 ± 11	1,235 ± 14
Organic-N (mg/L)		6.7 ± 0.0	6.72 ± 0.00
NH_4^+-N (mg/L)		4.5 ± 0.0	4.5 ± 0.00
NO_2^--N (mg/L)		4.2 ± 0.1	4.2 ± 0.1
NO_3^--N (mg/L)		0.04 ± 0.00	0.06 ± 0.01
pH		9.9 ± 0.1	9.9 ± 0.1

[a]Basic Red46 and Basic Blue41 were used for preparing STIWs.
[b]TIW + glucose: TIW was collected from the sump tank in a wastewater treatment plant from a textile industrial factory in Nonthaburi Province, Thailand. It was supplemented with 0.87 g/L glucose. The final BOD_5 of the TIW + glucose was approximately 1,200 mg/L.

Table 2
The operating parameters of SBR and GAC-SBR systems with STIW, TIW, and TIW + Glu at HRTs of 2.0, 3.0, 5.0, and 7.5 d

Parameters	Type of wastewater was tested					
	STIW			TIW		TIW + Glu
HRT (d)	3	5	7.5	2	5	5
MLSS (mg/L)	3,000	3,000	3,000	3,000	3,000	3,000
Flow rate (mL/d)	2,500	1,500	1,000	3,750	1,500	1,500
F/M	0.13	0.08	0.04	0.2	0.08	0.08
Hydraulic loading (m^3/m^2 d)	0.33	0.20	0.13	0.50	0.20	0.20
Organic loading (g BOD_5/d)	2.80	1.68	1.12	1.15	0.46	1.85
Volumetric organic loading (Kg BOD_5/m^3 d)	0.37	0.22	0.15	0.15	0.06	0.25
Dye loading (g/d)	0.25	0.15	0.1	N/A	N/A	N/A
Volumetric dye loading (kg/m^3 d)	0.03	0.02	0.01	N/A	N/A	N/A

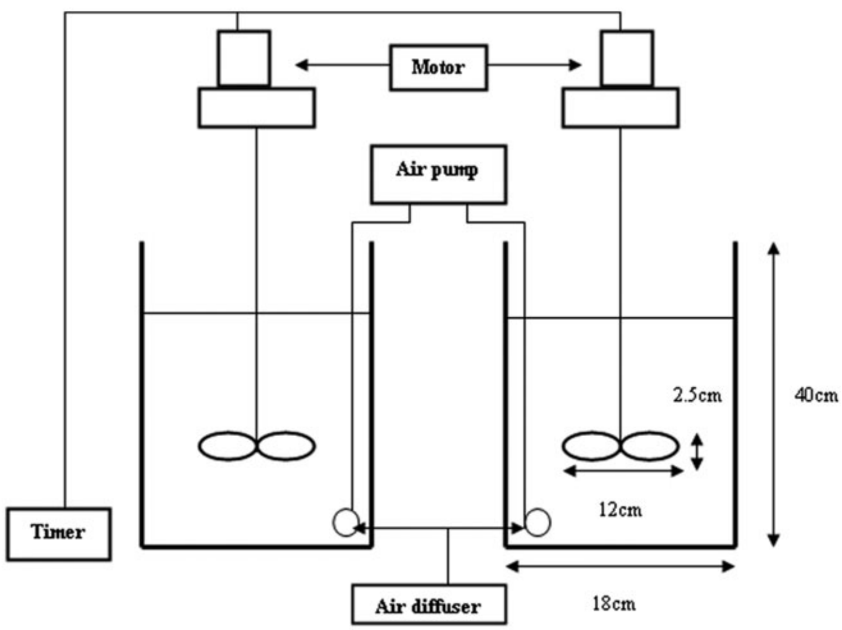

Fig. 1. Flow diagram of SBR and GAC-SBR systems. Physical conditions of operation were: 60 rpm of impeller speed; full aeration with an air-pump system (one air pump system supplied air to two sets of reactors) and working volume of the reactor which was 75% of total volume (7.5 L).

2.7. SBR and GAC-SBR system reactors

Ten 10-L reactors made from acrylic plastic (5 mm thick) were used in the experiments, as shown in Fig. 1. Dimensions of each reactor were 18 cm diameter and 40 cm height; 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. Speed of the impeller was adjusted to 60 rpm for complete mixing. One set of air pumps, model EK-8000, 6.0 W (President Co., Ltd, Thailand), was used to supply air to each set of two reactors; this provided an adequate oxygen supply, as evidenced by dissolved oxygen of about 2–3 mg/L in the system. Excess of bio-sludge was drawn out during the draw and idle period to control the level of MLSS in the system at 3,000 mg/L, as shown in Table 2.

2.8. Operation of SBR and GAC-SBR systems

Operation procedures for SBR and GAC-SBR systems followed the procedures from previous works [10,30,34]. In the SBR system, 1.4 L of acclimatized bio-sludge (10 g/L as dry basis of acclimatized bio-sludge) from Section 2.4 was inoculated in each reactor; then TIW or STIW were added (final volume of 7.5 L) within 1 h. During feeding the wastewater, the system had to be fully aerated for 19 h, and then shut down for 3 h. After the bio-sludge was fully settled, the supernatant was removed within 0.5 h and the system was kept under idle conditions for 0.5 h (totally 3 h for anoxic step). Then, the fresh wastewater was pumped into the reactor to the final volume of 7.5 L and the above-mentioned operation was repeated. The GAC-SBR system was operated similarly to the SBR system and 7,500 mg of GAC were added to each GAC-SBR reactor. Operation parameters of the SBR and GAC-SBR systems with various types of TIW and STIW are described in Table 2. Duration of operation of the SBR and GAC-SBR reactors with each type of wastewater was about 30 d. The experiments were carried out between April 2012 and February 2013.

2.9. Chemical analysis

COD, BOD_5, total Kjeldahl nitrogen (TKN), total nitrogen (TN), organic nitrogen (organic-N), ammonia nitrogen (NH_4^+-N), nitrite nitrogen (NO_2^--N), nitrate nitrogen (NO_3^--N), pH of the influent and effluent, MLSS and sludge volume index (SVI) of the systems were determined using standard methods for the examination of water and wastewater [35]. Color intensities of TIW and STIW were determined by the absorbance at optimum wavelengths, as shown in Section 2.2, 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 wasted per day.

2.10. Statistical analysis method

Each experiment was repeated at least three times. All the data were subjected to two-way analysis of variance using SS Windows Version 6.12 [36,37]. Statistical significance was tested using the least significant difference at the $p < 0.05$ level; the results are shown as the mean ± SD.

3. Results

3.1. Textile dye adsorption test

The experiments were performed with GAC, GAC (type CGC-11), and bio-sludge samples Sections 2.1 and 2.2. The results showed that BR46 was more easily adsorbed on the GAC and bio-sludge than BB41, as shown in Table 3. GAC type CGC-11 showed the maximum BR46 and BB41 adsorption yields of 80.0 and 69.9 mg/g, respectively. The bio-sludge type A gave higher dye adsorption yield than bio-sludge type B, as shown in Table 3. Moreover, the living bio-sludge showed higher dye adsorption yield than the autoclaved bio-sludge. The living bio-sludge type A showed the highest dye adsorption yield of 77.7 ± 0.1 mg BR46/g bio-sludge, as shown in Table 3.

3.2. Effects of HRT on the efficiencies of SBR and GAC-SBR systems with STIW

The SBR and GAC-SBR systems were operated with STIW at HRTs of 3.0, 5.0, and 7.5 d. The system efficiencies and performances were as follows.

3.2.1. COD and BOD_5

COD and BOD_5 removal efficiencies of the SBR and GAC-SBR systems increased with the increase in HRT (decrease in organic and dye loadings), as shown in Table 4. The SBR and GAC-SBR systems with STIW + BB41 at the HRT of 7.5 d (organic loading of 0.15 kg BOD_5/m^3 d and dye loading of 0.01 kg/m^3 d) showed the highest COD and BOD_5 removal efficiencies of 98 ± 1 and 98 ± 1%, and 97 ± 1 and 98 ± 1%, respectively. Also, the systems with STIW + BR46 at the HRT of 7.5 d (organic loading of 0.15 kg BOD_5/m^3 d and dye loading of 0.01 kg/m^3 d) showed the highest COD and BOD_5 removal efficiencies of 97 ± 1 and 98 ± 1%, and 97 ± 1 and 99 ± 1%, respectively. Moreover, the effluent COD and BOD_5 of the systems with STIW + BB41 and STIW + BB41 at HRTs operations were almost stable during 30 d of operation, as shown in Fig. 2. Moreover, effluent COD and BOD_5 of the GAC-SBR system were lower and more stable than those of SBR system at the same HRT of operation tested, as shown in Table 4 and Fig. 3.

3.2.2. Basic dyes

The results showed that BR46 could be removed more easily than BB41 by SBR and GAC-SBR systems, as shown in Table 4. The color removal yield increased with the increase of the SRT. Moreover, the GAC-SBR system was more suitable than the SBR system for removing the basic dyes from wastewater. With the same removal efficiency, the GAC-SBR system could be operated with a shorter HRT than the SBR system, as shown in Table 4. The GAC-SBR system with STIW + BB41 and STIW + BR46 had the

Table 3
Maximum dye adsorption yields of the bio-sludge and activated carbon

Granular activated carbon (GAC) CGC-11 type		Bio-sludge			
Basic dye	Adsorbed dye (mg/g GAC)	Basic dye	Type	Treatment	Adsorbed dye (mg/g bio-sludge)
Basic Red 46	80.0		A[a]	Resting[c]	77.7 ± 0.1
Basic Blue 41	69.9	Basic Red 46		Autoclaved[d]	56.0 ± 0.2
			B[b]	Resting	68.4 ± 0.1
				Autoclaved	53.1 ± 0.8
		Basic Blue 41	A	Resting	70.6 ± 0.2
				Autoclaved	54.7 ± 0.1
			B	Resting	66.2 ± 0.3
				Autoclaved	50.1 ± 0.4

Notes: Resting: the living bio-sludge of A and B type bio-sludge was washed with sterile distilled water three times before using in the experiment.

Autoclaved: the dead bio-sludge of A and B type bio-sludge; the living bio-sludges were autoclaved at 110°C for 10 min to kill the microbes without cell autolysis.

[a]Bio-sludge type A; the bio-sludge was collected from the sludge storage tank of Bangkok municipal central wastewater treatment plant, Thailand.

[b]Bio-sludge type B; the bio-sludge was collected from the sludge storage tank of textile wastewater treatment plant, Nonthaburi Province, Thailand.

highest color removal yields of about 99% at the HRT of 5 d (organic loading of 0.22 kg BOD_5/m^3 d and dye loading of 0.02 kg/m^3 d), while the SBR system with STIW + BB41 and STIW + BR46 had the highest dye removal yields of about 99% at the HRT of 7.5 d (organic loading of 0.15 kg BOD_5/m^3 d and dye loading of 0.01 kg/m^3 d). Moreover, the effluent color of the systems with BB41 and BR46 was almost stable during the operation, as shown in Fig. 3. Moreover, color removal efficiencies of the GAC-SBR system were higher and more stable than those of the SBR system at HRT of not more than 5.0 d (BOD_5 loading of not more than 0.22 kg/m^3 d).

3.2.3. Nitrogenous compounds

Profiles of nitrogenous compounds removal are shown in Table 5, Figs. 4–6. They had the same patterns in both SBR and GAC-SBR systems. TKN and TN removal efficiencies of the SBR and GAC-SBR systems increased with the increase in HRT (decrease in BOD_5 and dye loadings), as shown in Table 5. The TKN removal efficiencies of SBR and GAC-SBR systems with STIW + BB41 and STIW + BR46 at HRT of 7.5 d (organic loading of 0.15 kg BOD_5/m^3 d and dye loading of 0.01 kg/m^3 d) were 95.1 ± 0.1 and 95.6 ± 1.1%, and 92.8 ± 3.3 and 95.9 ± 1.1%, respectively. Effluent organic-N and NH_4^+-N were lower than influent organic-N and NH_4^+-N in all experiments, as shown in Fig. 4. However, effluents NO_3^--N were higher than influents NO_3^--N in all experiments. Moreover, the effluent NO_3^--N decreased with the increase in HRT (decrease in BOD_5 and dye loadings). Effluents NO_3^--N of the GAC-SBR system were lower than those of the SBR system in all experiments, as shown in Table 5. Moreover, NO_2^--N in all types of wastewater were almost completely removed by both SBR and GAC-SBR systems at all tested HRTs of the operation.

3.2.4. SS

Effluent SS in the SBR and GAC-SBR systems decreased with the increase of HRT (decrease of BOD_5 and dye loadings), as shown in Table 4. Also, effluent SS in the GAC-SBR system were lower than those in the SBR system in all experiments. Moreover, the systems with STIW + BB41 and STIW + BR46 did not show any significant differences in regard to effluent SS in all experiments, as shown in Table 4.

3.2.5. Bio-sludge performance

SBR and GAC-SBR systems showed interesting results in terms of bio-sludge performance under various operation conditions, as shown in Table 4. SRT of the systems increased with the increase in HRT (decrease in BOD_5 and dye loadings). The GAC-SBR system had longer SRT than the SBR system under all tested operation conditions, as shown in Table 4. SRTs of the systems with STIW + BB41

Table 4
Effluent qualities and removal efficiencies of SBR and GAC-SBR systems with STIWs at HRTs of 3.0, 5.0, and 7.5 d, respectively

Type of textile dye	Type of wastewater treatment	HRT (d)	Organic loading (kg BOD_5/m^3 d)	Color intensity		BOD_5		COD		SS	Bio-sludge qualities	
				Effluent (mg/L)	Removal (%)	Effluent (mg/L)	Removal (%)	Effluent (mg/L)	Removal (%)	Effluent (mg/L)	SRT (d)	SVI (mL/g)
Basic Blue 41	SBR	3	0.37	3.8 ± 0.1	96.3 ± 0.1	117 ± 7	93 ± 1	106 ± 6	91 ± 1	59 ± 9	6 ± 1	60 ± 4
		5	0.22	2.4 ± 0.1	97.7 ± 0.1	90 ± 8	95 ± 1	46 ± 2	96 ± 1	49 ± 12	10 ± 0	53 ± 1
		7.5	0.15	1.2 ± 0.1	98.8 ± 0.1	55 ± 13	97 ± 1	30 ± 0	98 ± 1	30 ± 6	15 ± 1	40 ± 1
	GAC-SBR	3	0.37	1.6 ± 0.1	98.5 ± 0.1	86 ± 13	97 ± 1	55 ± 5	95 ± 1	47 ± 10	9 ± 2	67 ± 3
		5	0.22	1.2 ± 0.1	98.8 ± 0.1	56 ± 11	97 ± 1	36 ± 2	97 ± 1	35 ± 7	13 ± 2	58 ± 6
		7.5	0.15	1.1 ± 0.2	98.9 ± 0.1	35 ± 9	98 ± 1	24 ± 4	98 ± 1	18 ± 5	19 ± 2	51 ± 1
Basic Red 46	SBR	3	0.37	2.2 ± 0.1	97.9 ± 0.2	89 ± 7	95 ± 1	100 ± 8	92 ± 1	67 ± 8	7 ± 2	64 ± 6
		5	0.22	1.4 ± 0.1	98.7 ± 0.1	63 ± 7	97 ± 1	58 ± 6	95 ± 1	44 ± 9	11 ± 2	60 ± 2
		7.5	0.15	0.9 ± 0.1	99.2±0.1	39 ± 5	97 ± 1	38 ± 8	97 ± 1	33 ± 3	16 ± 2	46 ± 4
	GAC-SBR	3	0.37	1.4 ± 0.1	98.7 ± 0.1	54 ± 5	97 ± 1	73 ± 8	95 ± 1	50 ± 6	9 ± 2	73 ± 8
		5	0.22	1.0 ± 0.1	99.1 ± 0.1	40 ± 4	98 ± 1	46 ± 8	97 ± 1	31 ± 3	13 ± 2	63 ± 3
		7.5	0.15	0.8 ± 0.1	99.2 ± 0.1	25 ± 4	99 ± 1	22 ± 8	98 ± 1	20 ± 6	22 ± 3	54 ± 7

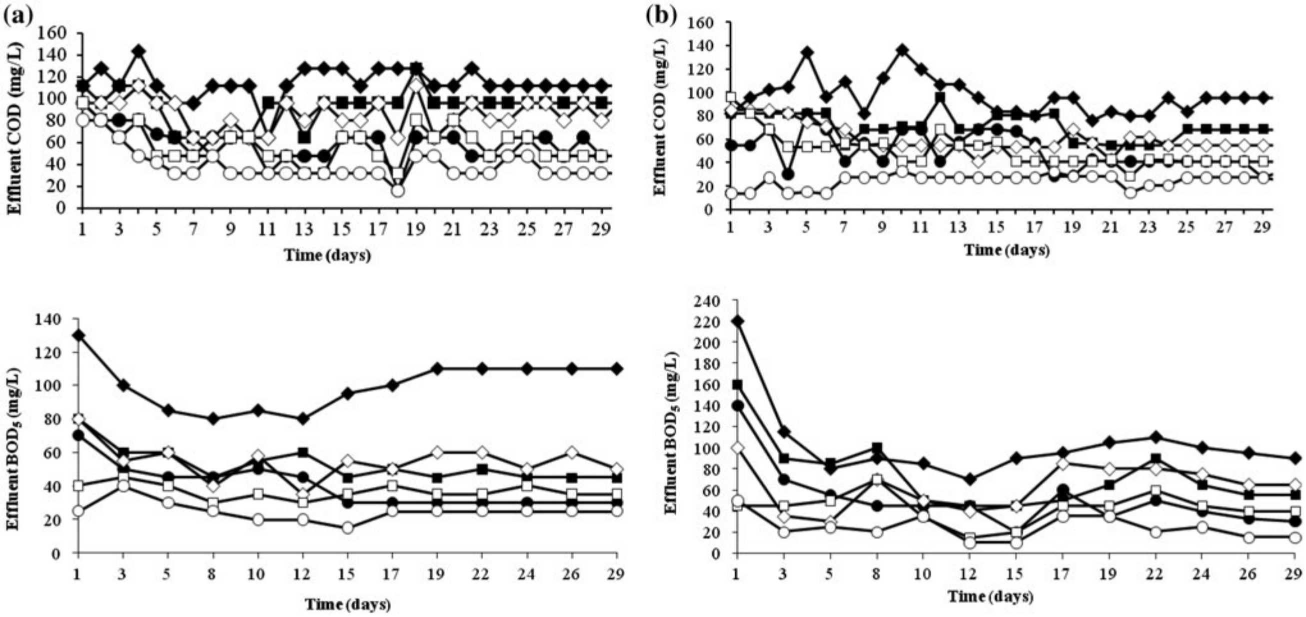

Fig. 2. Effluents COD and BOD_5 profiles of SBR and GAC-SBR systems operated with STIW containing 100 mg/L Basic Blue 41 (a) and Basic Red 46 (b) at HRT of 3.0, 5.0, and 7.5 d.
Symbols: For SBR system: ♦: HRT of 3.0 d, ■: HRT of 5.0 d and ●: HRT of 7.5 d. For GAC-SBR system: ◇: HRT of 3.0 d, □: HRT of 5.0 d and ○: HRT of 7.5 d.

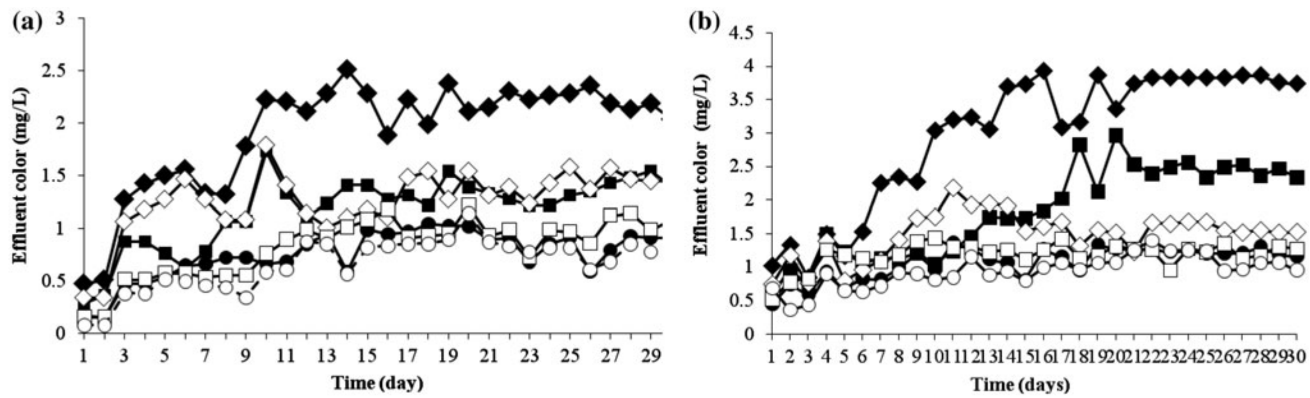

Fig. 3. Effluent color intensity profiles of SBR and GAC-SBR systems operated with STIW containing 100 mg/L Basic Blue 41 (a) and Basic Red 46 (b) at various HRTs of 3.0, 5.0, and 7.5 d.
Symbols: For SBR system: ♦: HRT of 3.0 d, ■: HRT of 5.0 d and ●: HRT of 7.5 d. For GAC-SBR system: ◇: HRT of 3.0 d, □: HRT of 5.0 d and ○: HRT of 7.5 d.

were shorter than those of the systems with STIW + BR46, as shown in Table 4. Observation of bio-sludge quality showed that SVI decreased with the increase in HRT (decrease of BOD_5 and dye loadings). However, SVIs of the systems were lower than 75 mL/g in all experiments.

3.3. Application of SBR and GAC-SBR systems for the treatment of TIW and TIW + Glu

SBR and GAC-SBR systems were tested with TIW and TIW + Glu at HRTs of 2.0–5.0 d. Their efficiencies and performances were as follows.

Table 5
Nitrogenous compounds removal efficiencies of the SBR and GAC-SBR systems with STIWs at HRTs of 3.0, 5.0, and 7.5 d, respectively

Types of textile dye	Types of wastewater treatment	HRT (d)	Organic loading (kg BOD_5/m^3 d)	Organic-N Influent (mg/L)	Organic-N Effluent (mg/L)	NH_4^+-N Influent (mg/L)	NH_4^+-N Effluent (mg/L)	NO_2^--N Influent (mg/L)	NO_2^--N Effluent (mg/L)	NO_3^--N Influent (mg/L)	NO_3^--N Effluent (mg/L)	Removal efficiency TKN (%)	Removal efficiency TN (%)
Basic Blue 41	SBR	3	0.37	40.9 ± 0.0	3.5 ± 0.6	6.7 ± 0.0	5.2 ± 1.3	9.8 ± 0.4	1.2 ± 0.3	0.2 ± 0.0	10.0 ± 0.4	81.1 ± 0.6	64.3 ± 0.4
		5	0.22	40.9 ± 0.0	0.8 ± 0.6	6.7 ± 0.0	3.2 ± 0.4	9.8 ± 0.4	0.8 ± 0.1	0.2 ± 0.0	7.2 ± 0.7	91.2 ± 1.2	78.4 ± 0.4
		7.5	0.15	40.9 ± 0.0	0.2 ± 0.1	6.7 ± 0.0	2.7 ± 0.8	9.8 ± 0.4	0.8 ± 0.1	0.2 ± 0.0	5.1 ± 1.0	95.1 ± 0.1	83.8 ± 0.2
	GAC-SBR	3	0.37	40.9 ± 0.0	2.6 ± 0.1	6.7 ± 0.0	4.3 ± 0.4	9.8 ± 0.4	0.9 ± 0.1	0.2 ± 0.0	8.9 ± 0.5	84.9 ± 1.0	80.3 ± 0.4
		5	0.22	40.9 ± 0.0	0.8 ± 0.5	6.7 ± 0.0	2.8 ± 0.6	9.8 ± 0.4	0.6 ± 0.1	0.2 ± 0.0	6.9 ± 0.7	92.2 ± 1.0	70.1 ± 0.3
		7.5	0.15	40.9 ± 0.0	0.3 ± 0.5	6.7 ± 0.0	1.7 ± 0.6	9.8 ± 0.4	0.4 ± 0.1	0.2 ± 0.1	6.0 ± 0.7	95.6 ± 1.1	84.9 ± 0.2
Basic Red 46	SBR	3	0.37	40.9 ± 0.0	5.1 ± 0.4	4.9 ± 0.5	3.6 ± 1.3	14.5 ± 0.2	1.2 ± 0.2	0.1 ± 0.0	14.9 ± 1.3	75.8 ± 9.5	75.9 ± 14.9
		5	0.22	40.9 ± 0.0	1.3 ± 0.5	4.9 ± 0.5	2.9 ± 1.2	14.5 ± 0.2	0.7 ± 0.2	0.1 ± 0.0	12.7 ± 0.4	85.0 ± 8.5	79.4 ± 12.7
		7.5	0.15	40.9 ± 0.0	0.2 ± 0.5	4.9 ± 0.5	2.9 ± 1.0	14.5 ± 0.2	0.6 ± 0.2	0.1 ± 0.0	12.7 ± 0.9	92.8 ± 3.3	80.5 ± 12.0
	GAC-SBR	3	0.37	40.9 ± 0.0	5.0 ± 0.6	4.9 ± 0.6	2.8 ± 0.8	14.5 ± 0.2	0.7 ± 0.1	0.1 ± 0.0	13.3 ± 1.0	81.9 ± 5.4	79.5 ± 12.7
		5	0.22	40.9 ± 0.0	1.7 ± 0.9	4.9 ± 0.6	2.5 ± 0.9	14.5 ± 0.2	0.4 ± 0.1	0.1 ± 0.0	12.0 ± 1.0	89.4 ± 4.3	78.4 ± 13.3
		7.5	0.15	40.9 ± 0.0	0.4 ± 0.5	4.9 ± 0.6	1.7 ± 0.6	14.5 ± 0.2	0.2 ± 0.1	0.1 ± 0.0	10.6 ± 1.0	95.9 ± 1.1	82.8 ± 10.6

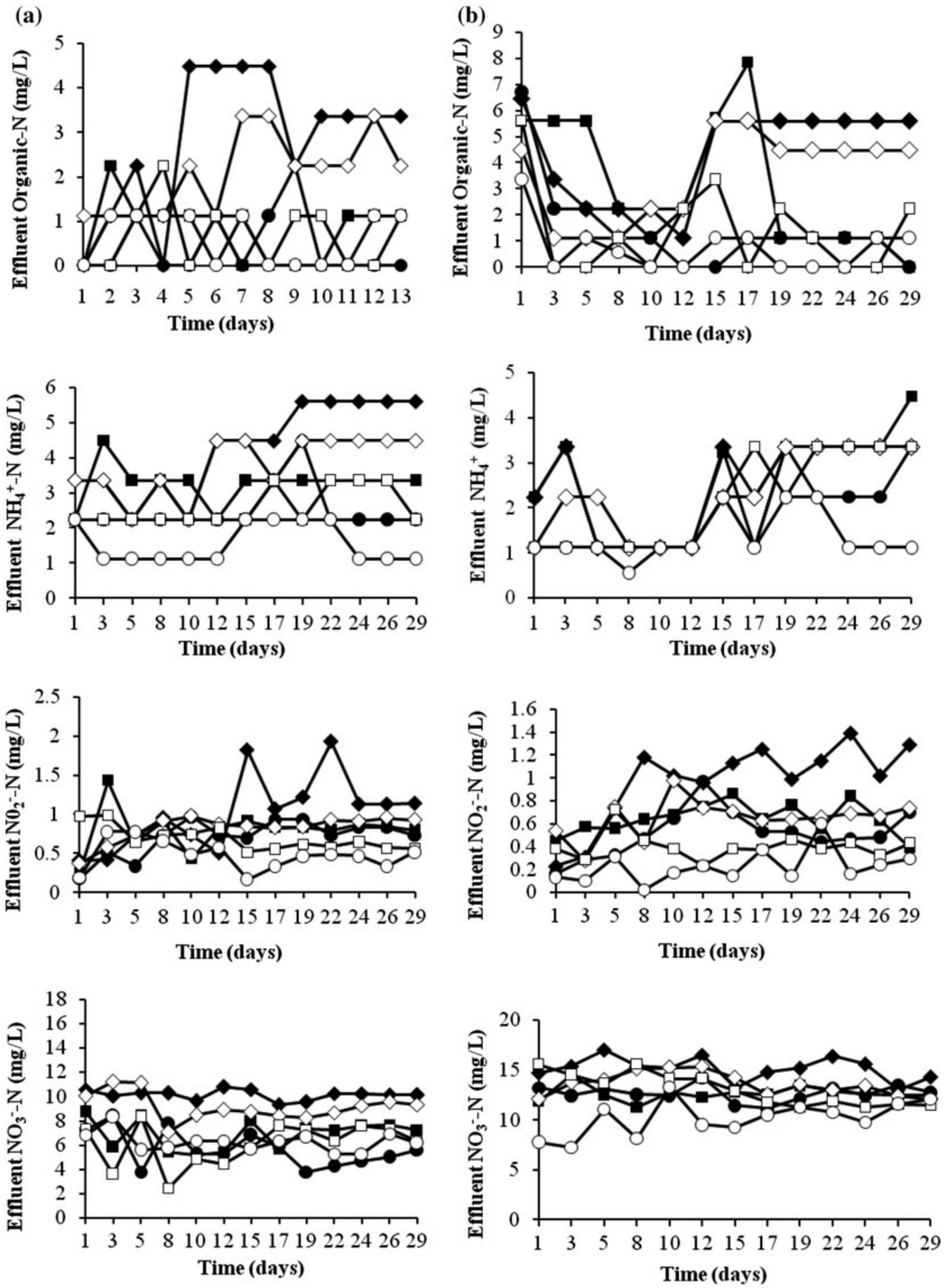

Fig. 4. Effluent nitrogen compounds profiles of SBR and GAC-SBR systems operated with STIW containing 100 mg/L Basic Blue 41 (a) and Basic Red 46 (b) at HRTs 3.0, 5.0, and 7.5 d.

Symbols: For SBR system: ♦: HRT of 3.0 d, ■: HRT of 5.0 d and ●: HRT of 7.5 d. For GAC-SBR system: ◇: HRT of 3.0 d, □: HRT of 5.0 d and ○: HRT of 7.5 d.

3.3.1. COD and BOD_5

COD and BOD_5 removal efficiencies of the SBR and GAC-SBR systems with TIW increased with the increase in HRT (decrease in BOD_5 and dye loadings). COD and BOD_5 removal efficiencies of the GAC-SBR system were higher than those of the SBR system, as shown in Table 6. The highest COD and BOD_5 removal yields of the GAC-SBR system with TIW at HRT of 5 d (organic loading of 0.06 kg BOD_5/m^3 d) were 88 ± 1–90 ± 1%, respectively. However, removal efficiencies of the systems could be increased by adding organic matter (glucose). The highest COD and BOD_5 removal efficiencies of the GAC-SBR system with TIW + Glu at HRT of 5 d (organic loading of 0.25 kg BOD_5/m^3 d) were 97 ± 1–98 ± 0%, respectively, as shown in Table 6. Observation of the COD and BOD_5 removal efficiencies profiles showed that effluent COD and BOD_5 became stable after 5–7 d of operation, as shown in Fig. 5. Moreover, GAC had an advantage in the COD and BOD_5 removal efficiency of the system; the GAC-SBR system showed higher COD and BOD_5 removal efficiencies than the SBR system at the same HRT of operation, as shown in Table 6. Also, effluent COD and BOD_5 of the GAC-SBR system were lower and more stable than those of the SBR system at the same HRT of the operation, as shown in Table 6 and Fig. 5.

3.3.2. Basic dyes

The results showed that color removal efficiencies of the SBR and GAC-SBR systems with TIW increased with the increase in HRT (decrease of organic loading), as shown in Table 6. Also, the GAC-SBR system with TIW showed higher color removal efficiency than the SBR system. Moreover, the color removal efficiency increased with the increase of organic loading, as shown in Table 6. The highest color removal efficiencies of the SBR and GAC-SBR systems with TIW + Glu at the HRT of 5 d (organic loading of 0.25 kg BOD_5/m^3 d) were 71.1 ± 0.6–80.0 ± 0.7%, respectively, as shown in Table 6. In terms of effluents' color intensity profiles of the systems with TIW and TIW + Glu at HRTs of 2–5 d, they became stable after 9–10 d of the operation and maintained stability for 30 d of the operation, as shown in Fig. 6. Moreover, GAC had an advantage in terms of color removal efficiency in the SBR system; effluent color intensity in the GAC-SBR system was more stable and lower than that of the SBR system at the same HRT of operation, as shown in Table 6 and Fig. 6.

3.3.3. Nitrogenous compounds

The SBR and GAC-SBR systems showed almost the same patterns of nitrogenous compounds removal efficiencies (Table 7). TKN and TN removal efficiencies of the systems increased with the increase in HRT or decrease in BOD_5 loading, as shown in Table 7. TKN and TN removal efficiencies of the SBR and GAC-SBR systems with TIW at the HRT of 5 d were 55.6 ± 8.6 and 43.6 ± 0.7% and 80.6 ± 6.8 and 55.9 ± 0.2%, respectively. Effluent organic-N and NH_4^+-N of the systems were lower than influent organic-N and NH_4^+-N in all experiments, as shown in Table 7. TKN and TN removal efficiencies of the systems could be increased by supplementation of organic matter (glucose). TKN and TN removal efficiencies of the SBR and GAC-SBR systems with TIW + Glu after 5 d were 69 ± 6.3 and 57.1 ± 0.3%, and 83.3 ± 0.0 and 58.9 ± 0.2%, respectively, as shown in Table 7. Moreover, NO_2^--N in TIW and TIW + Glu were almost completely removed in both SBR and GAC-SBR system at all tested HRTs of operation. However, effluent NO_3^--N was higher than influent NO_3^--N at all tested HRTs of operation, as shown in Table 7.

3.3.4. SS

Effluent SS decreased with the increase in HRT or organic loading. Moreover, the GAC-SBR system with TIW showed lower effluent SS than the SBR system. GAC-SBR system with TIW at HRT of 5 d showed the lowest effluent SS of 29 ± 2 mg/L, as shown in Table 7. However, effluent SS of the systems with TIW increased by supplementation of organic matter (glucose), as shown in Table 7.

3.3.5. Bio-sludge performance

Excess bio-sludge in the system with TIW at HRT of 2–5 d (organic loadings of 0.06–0.15 kg BOD_5/m^3 d, respectively) could not be detected, as shown in Table 6. Also, SVIs of the systems with TIW at HRTs of 2–5 d (organic loadings of 0.15 and 0.06 kg BOD_5/m^3 d) were less than 60 mL/g. However, the excess bio-sludge in the systems with TIW could be detected by adding organic matter, especially glucose. SRTs of the SBR and GAC-SBR systems with TIW + Glu at the HRT of 5 d (organic loading of 0.25 kg BOD_5/m^3 d) were 12 ± 2 and 21 ± 1 d, respectively. Moreover, SVIs of the systems were about 61–67 mL/g in all experiments, as shown in Table 6.

Table 6
Effluents qualities and removal efficiencies of SBR and GAC-SBR systems with TIW and TIW + Glu at HRTs of 2.0–5.0 d

Type of wastewater	System	HRT	Organic loading (kg BOD_5/m^3 d)	Color intensity Effluent (mg/L)	Color intensity Removal (%)	BOD_5 Effluent (mg/L)	BOD_5 Removal (%)	COD Effluent (mg/L)	COD Removal (%)	SS Effluent (mg/L)	Bio-sludge qualitiy SRT (d)	Bio-sludge qualitiy SVI (mL/g)
TTW	SBR	2	0.15	0.15 ± 0.0	50.9 ± 2.2	110 ± 13	64 ± 6	79 ± 3	85 ± 1	55 ± 2	–	53 ± 2
	GAC-SBR	2	0.15	0.13 ± 0.0	57.1 ± 1.0	77 ± 3	75 ± 1	50 ± 3	91 ± 1	34 ± 2	–	58 ± 3
	SBR	5	0.06	0.13 ± 0.01	57.1 ± 4.2	74 ± 4	86 ± 1	72 ± 3	77 ± 2	39 ± 3	–	57 ± 2
	GAC-SBR	5	0.06	0.10 ± 0.00	68.3 ± 3.2	54 ± 4	90 ± 1	38 ± 3	88 ± 1	29 ± 2	–	60 ± 2
TTW + Glu[a]	SBR	5	0.25	0.09 ± 0.00	71.1 ± 0.6	62 ± 4	97 ± 0	59 ± 2	95 ± 1	51 ± 6	12 ± 2	61 ± 3
	GAC-SBR	5	0.25	0.06 ± 0.00	80.0 ± 0.7	46.66 ± 4	98 ± 0	40 ± 4	97 ± 1	34 ± 2	21 ± 1	67 ± 4

[a]TTW + Glu: TTW containing 870 mg/L glucose.

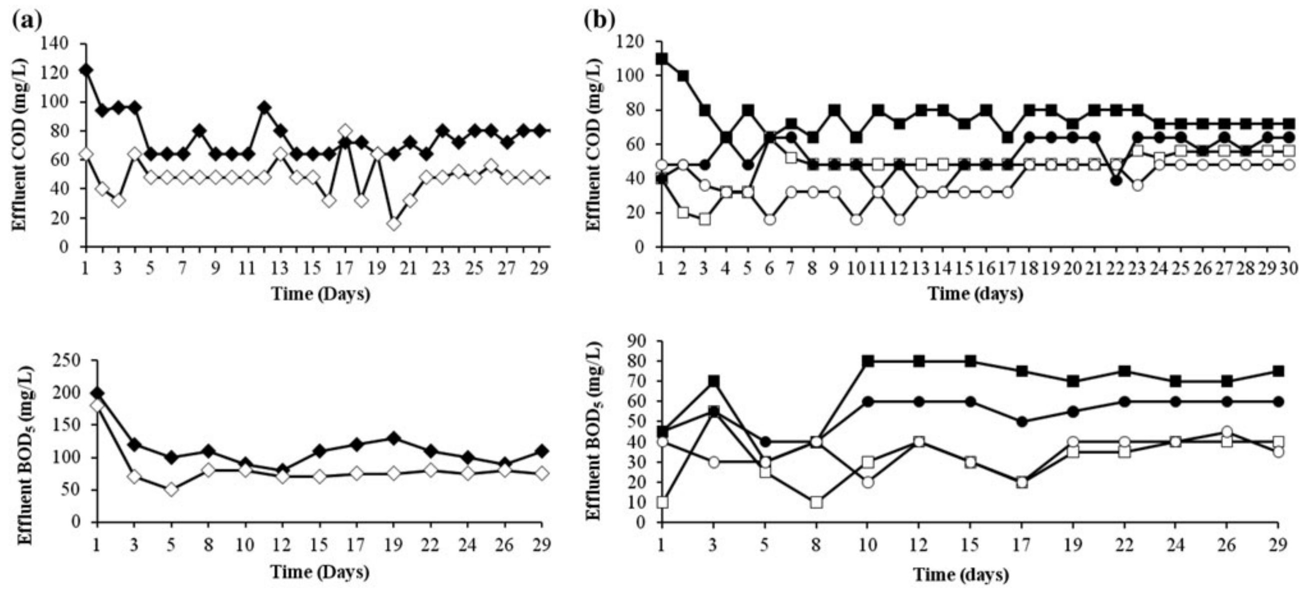

Fig. 5. Effluent COD and BOD_5 of SBR and GAC-SBR systems operated with TIW and TIW + Glu at HRT 2.0–5.0 d.
Symbols: For HRT 2.0 d (a): ♦: TIW of SBR system, ◊: TIW of GAC-SBR system. For HRT 5.0 d (b): ●: TIW of SBR system, ■: TIW+Glu of SBR system. ○: TIW of GAC-SBR system, □: TIW+Glu of GAC-SBR system.

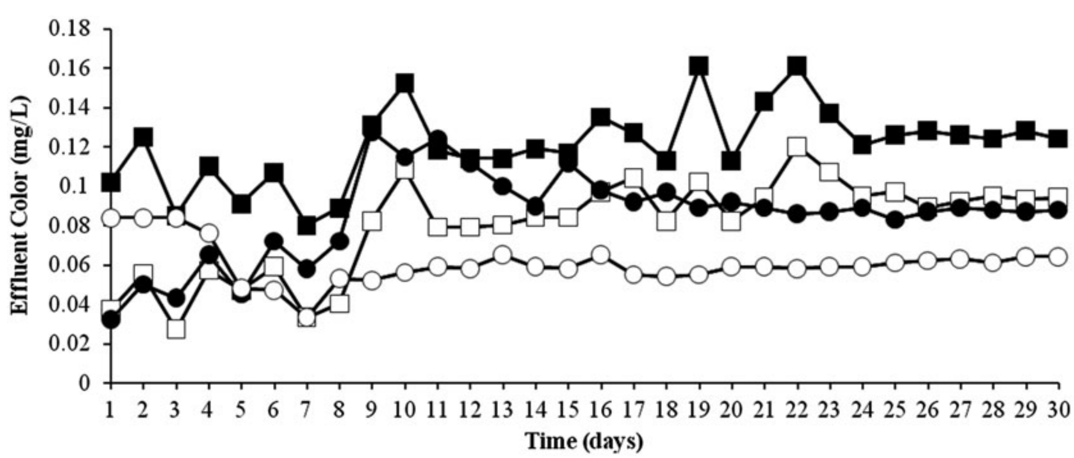

Fig. 6. Effluent color intensity profiles of SBR and GAC-SBR systems operated with TIW and TIW + Glu at HRT of 2.0–5.0 d.
Symbols: For HRT of 2.0 d (a): ♦: TIW of SBR system, ◊: TIW of GAC-SBR system. For HRT of 5.0 d (b): ●: TIW of SBR system, ■: TIW+Glu of SBR system. ○: TIW of GAC-SBR system, □: TIW+Glu of GAC-SBR system.

4. Discussion

SBR and GAC-SBR systems were applied for the treatment of TIW and investigating the efficiencies and performances of the systems. In the investigation of color adsorption capacity by GAC and bio-sludge, it was found that GAC could be used as an adsorbent for removing color (textile dye) from textile wastewater [2,7,12,15,16,22,34]. However, from the theoretically information, the powdered activated carbon (PAC) give more adsorption yield than GAC because PAC had more surface area than GAC. But, the harvesting of GAC during operation in SBR system was easier than that of PAC [30,34]. Then, GAC was used in the experiment. Moreover, color adsorption yield of GAC depended on the type and structure of a textile dye [12]. This was reported in previous works on the application of the GAC-SBR system for removal of

Table 7
Nitrogenous compounds removal efficiencies of the SBR and GAC-SBR systems with TIW and TIW + Glu at HRTs of 2.0–5.0 d

				Organic-N		NH_4^+-N		NO_2^--N		NO_3^--N		Removal efficiency	
Type of wastewater	System	HRT	Organic loading (kg BOD_5/m^3 d)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	TKN (%)	TN (%)
	SBR	2	0.15	3.4 ± 0.0	3.2 ± 0.5	4.5 ± 0.0	2.6 ± 06	4.1 ± 0.0	0.3 ± 0.0	0.1 ± 0.0	3.3 ± 0.1	52.8 ± 6.8	40.7 ± 1.2
	GAC-SBR	2	0.15	3.4 ± 0.0	2.4 ± 0.5	4.5 ± 0.0	4.5 ± 0.0	4.1 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	2.6 ± 0.2	63.9 ± 6.8	52.2 ± 0.7
TTW	SBR	5	0.06	3.4 ± 0.0	0.7 ± 0.6	4.5 ± 0.0	2.2 ± 0.0	4.1 ± 0.0	0.2 ± 0.1	0.1 ± 0.0	2.6 ± 0.2	55.6 ± 8.6	43.6 ± 0.7
	GAC-SBR	5	0.06	3.4 ± 0.0	0.3 ± 0.5	4.5 ± 0.0	1.1 ± 0.2	4.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	3.5 ± 0.1	80.6 ± 6.8	55.9 ± 0.2
TTW + Glu[a]	SBR	5	0.25	3.4 ± 0.0	0.6 ± 0.6	4.5 ± 0.0	1.7 ± 0.6	4.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	7.0 ± 0.8	69.1 ± 6.3	57.1 ± 0.3
	GAC-SBR	5	0.25	3.4 ± 0.0	0.4 ± 0.2	4.5 ± 0.0	0.8 ± 0.2	4.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	7.8 ± 0.6	83.3 ± 0.0	58.9 ± 0.2

[a]TTW + Glu: TTW containing 870 mg/L glucose.

direct dyes [10,26,30,34]. It was confirmed that BR46 was more easily adsorbed onto GAC than BB 41. This could be explained by the fact that BB41 had larger molecular weight and molecular size than BR46, which resulted in obstruction of the adsorption site of GAC [5,11]. In previous work, color removal efficiency of the SBR system could be increased by adding GAC, which was the result of the increase in the amount of MLSS or MLVSS (increasing in the bio-sludge age or SRT) [2,30,34]. It was informed that the bio-sludge in aerobic wastewater treatment system could be used as an adsorbent for color and organic and inorganic matter, such as BOD_5, COD or heavy metals [24]. Then, two types of bio-sludge, bio-sludge type A and bio-sludge type B, were tested for color adsorption ability. Bio-sludge type A had higher color adsorption yield than bio-sludge type B. This could explain why some adsorption sites of bio-sludge type B were filled up with textile dye particles, resulting in a reduced color adsorption ability [16,38,39]. This was confirmed in our previous work on the application of SBR and GAC-SBR for treating wastewater containing vat and disperse dyes [15,16]. For the observation of the bio-sludge characteristics, it was found that bio-sludge type A (short SRT of 16 d) was the older bio-sludge (long SRT of 28 d). It was previously reported that shorter SRT bio-sludge (younger bio-sludge) had lower color removal yield than longer SRT bio-sludge (older bio-sludge) [30]. And, the older bio-sludge of the activated sludge system contained large number of nitrifying and denitrifying bacteria and they play the main role for color removal ability [2,10,40]. This might be the first report where nitrogen removal bacteria (both nitrifying and denitrifying bacteria groups) showed higher textile dye adsorption ability than heterotrophic bacteria [10,40]. Also, bio-sludge showed higher color adsorption yield on BB41 than on BR46, similarly to the GAC phenomenon, as explained previously. Moreover, color adsorption yield of the living (resting) bio-sludge was 20% higher than that of the autoclaved bio-sludge. This might be an advantage of applying the biological treatment process for treating textile wastewater containing basic dyes because the bio-sludge could show both adsorption and degradation mechanisms in the SBR and GAC-SBR systems [5,7,16,30,34]. However, GAC in the SBR system had two advantages: color adsorption activity and increase in the number of microbes (increasing bio-sludge mass), which resulted in the increase of SRT of the bio-sludge. The other advantage of the use of GAC in the SBR system (biological treatment system) was that GAC was bio-regenerated by the bio-sludge of the system [30,34]. Then, GAC that added into the SBR system (GAC-SBR system) could be used during operation without replacement. Therefore, the GAC-SBR system was more suitable than the SBR system for the treatment of textile wastewater containing basic dyes. Moreover, the observation of HRT effects on the efficiencies of SBR and GAC-SBR systems with the STIW was carried out to determine the highest removal efficiency. The results showed that the GAC-SBR system at the HRT of 7.5 d (organic loading of 0.15 kg BOD_5/m^3 d and dye loading of 0.01 kg/m^3 d) was most suitable [2,10,40]. Another advantage of the GAC-SBR system at the longest HRT of 7.5 d (lowest organic loading of 0.15 kg BOD_5/m^3 d and dye loading of 0.01 kg/m^3 d) was the fact that it was suitable for nitrogen removal bacteria. As the theoretically information, the system was operated at high HRT could stimulate the growth and activity of nitrogen removal bacteria (both nitrifying and denitrifying bacteria) [2]. It was confirmed that the TKN and TN removal efficiencies of the GAC-SBR system with STIW were over 95 and 82%, respectively, as shown in Table 7. The SBR and GAC-SBR systems were easy to operate under oxic-anoxic conditions, resulting in an increase in nitrification–denitrification activity [2]. The above-mentioned results and discussion confirmed that the GAC-SBR system was the most suitable for the treatment of textile wastewater because the system was easy to operate for increasing the number of nitrifying and denitrifying bacterial groups. This might be the first report where nitrogen removal bacteria (nitrifying and denitrifying bacteria) were the main bacteria for basic dyes removing mechanism [10,40]. However, effluents NO_3^--N of the systems were still higher than influents NO_3^--N in all experiments. This means that the anoxic period was the shortest and lasted only 0.5 h (idle step of SBR operation). To decrease the effluent NO_3^--N concentration, duration of the anoxic period in the idle step should be increased, resulting in an increased denitrification activity. From these results, it can be concluded that the SBR and GAC-SBR systems could be applied for treating TIW, but the GAC-SBR system was the most suitable system due to its higher efficiency. Anyways, the application of GAC-SBR system still had some disadvantages as no excess of bio-sludge generated during operation caused a washing out problem [2,30]. This might be caused by the low contents of organic matter and high contents of basic dyes in TIW of 308 ± 11 mg BOD_5/L and 100 mg/L, respectively. To increase efficiency of the systems and bio-sludge quality, the organic content as BOD_5 in wastewater should be increased [2,10,40]. To increase the BOD_5 concentration of wastewater, glucose was supplemented. It could be confirmed by the results from Tables 6 and 7 that efficiency and performance of the system were improved by increasing organic matter concentration (addition of glucose) in the wastewater. Moreover, SRT of the GAC-SBR system with TIW + Glu was 21 d, which was similar to the quality of bio-sludge type A that was used in the dye adsorption test section. This reconfirmed that the older bio-sludge showed higher color removal yield than younger bio-sludge; it depended on the type of microbes in the bio-sludge, as mentioned above. The older bio-sludge consisted of high population of nitrogen removal bacteria resulted to give the higher color and nitrogen removal yield than that of younger bio-sludge.

5. Conclusion

The GAC-SBR system was the most suitable to be applied for the treatment of textile wastewater containing basic dyes. GAC had two advantages: it was a dye adsorbent and a medium for bio-sludge attachment which resulted in an increase in the bio-sludge mass. Moreover, the bio-sludge showed both dye adsorption and degradation mechanisms. The optimal operation conditions for the GAC-SBR system with STIW containing BB41 or BR46 were MLSS of 3,000 mg/L and HRT of 7.5 d. The highest COD, BOD_5, color, TKN, and TN removal efficiencies of the GAC-SBR system with STIW + BB41 and STIW + BR46 at MLSS of 3,000 mg/L and HRT of 7.5 d were 98 ± 1 and 98 ± 1%, 97 ± 1 and 99 ± 1%, 98.8 ± 0.1 and 98.2 ± 0.1, 95.1 ± 0.1 and 95.9 ± 1.1 and 83.8 ± 0.2% and 82.8 ± 10.6%, respectively. Applying the GAC-SBR system for the treatment of raw TIW, the excess of bio-sludge could not be generated (no excess bio-sludge) which resulted in poor operation with stable conditions. To operate the GAC-SBR system with raw TIW stability, the excess bio-sludge should be generated to prevent the washout problem. Therefore, the organic loading should be increased, which results in an increase in the amount of excess bio-sludge. Glucose, as a simple organic carbon source, was used to confirm this suggestion. Another advantage of the GAC-SBR system was the fact that during operation of the GAC-SBR system, the number of nitrogen removal bacterial groups and denitrifying bacteria groups as well as their activities increased by increasing duration of the anoxic period in the system.

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Nomenclature

BOD_5	— biochemical oxygen demand
BR46	— basic red 46
COD	— chemical oxygen demand
GAC	— granular activated carbon
GAC-SBR	— granular activated carbon-sequencing batch reactor
HRT	— hydraulic retention time
NH_4^+-N	— ammonium nitrogen
NO_3^--N	— nitrate
NO_2^--N	— nitrite
Organic-N	— organic nitrogen
SBR	— sequencing batch reactor
SRT	— solids retention time
SS	— suspended solids
STIW	— synthetic textile industrial wastewater
TIW	— textile industrial wastewater
TIW-Glu	— textile industrial wastewater supplemented with glucose
TKN	— total Kjeldahl nitrogen
TN	— total nitrogen
BB41	— basic blue 41
STIW-BB41	— synthetic textile industrial wastewater containing Basic Blue 41
STIW-BR46	— synthetic textile industrial wastewater containing Basic Red 46

References

[1] Department of Industrial Works (Thailand), Industrial Statistics in Thailand 2002, Ministry of Industry, Bangkok, Thailand, 1992.

[2] Metcalf & Eddy, Wastewater Engineering: Treatment Disposal and Reuse, fourth ed., McGraw-Hill, New York, NY, 2004.

[3] S. Vajnhandl, J.V. Valh, The status of water reuse in European textile sector, J. Environ. Manage. 141 (2014) 29–35.

[4] I. Nilsson, A. Möller, B. Mattiasson, M.S.T. Rubindamayugi, U. Welander, Decolorization of synthetic and real textile wastewater by the use of white-rot fungi, Enzyme Microb. Technol. 38 (2006) 94–100.

[5] I.M. Banat, P. Nigam, D. Singh, R. Marchant, Microbial decolorization of textile-dyecontaining effluents: A review, Bioresour. Technol. 58 (1996) 217–227.

[6] Y.K. Zaoyan, S. Ke, S. Guangliang, Y. Fan, D. Jinsha, M. Huanian, Anaerobic-aerobic treatment of a dye wastewater by combination of RBC with activated sludge, Water Sci. Technol. 26 (1992) 2093–2096.

[7] K.C. Chen, J.Y. Wu, D.J. Liou, S.C.J. Hwang, Decolorization of the textile dyes by newly isolated bacterial strains, J. Biotechnol. 101 (2003) 57–68.

[8] A.S Cleder, L.S. Edésio, L.B. Sávio, W. Alberto, M.R. Claudemir, Use of ozone in a pilot-scale plant for textile wastewater pre-treatment: Physico-chemical efficiency, degradation by-products identification and environmental toxicity of treated wastewater, J. Hazard. Mater. 175 (2010) 235–240

[9] H. Kroiss, H. Müller, Development of design criteria for highly efficient biological treatment of textile wastewater, Water Sci. Technol. 40 (1999) 399–407.
[10] S. Sirianuntapiboon, K. Chairattanawan, Effects of some operating parameters on the efficiency of a sequencing batch reactor system for treatment of textile wastewater containing acid dyes, Desalin. Water Treat. 50 (2012) 206–219.
[11] P. Janos, H. Buchtova, M. Ryznarova, Sorption of dyes from aqueous solutions onto fly ash, Water Res. 37 (2003) 4938–4944.
[12] V. Meshko, L. Markovska, M. Mincheva, A.E. odrigues, Adsorption of basic dyes on granular acivated carbon and natural zeolite, Water Res. 35 (2001) 3357–3366.
[13] F.M. Amaral, M.T. Kato, L. Florêncio, S. Gavazza, Color, organic matter and sulfate removal from textile effluents by anaerobic and aerobic processes, Bioresour. Technol. 163 (2014) 364–369.
[14] K.C.A. Bromley-Challenor, J.S. Knapp, Z. Zhang, N.C.C. Gray, M.J. Hetheridge, M.R. Evans, Decolorization of an azo dye by unacclimated activated sludge under anaerobic conditions, Water Res. 34 (2000) 4410–4418.
[15] S. Sirianuntapiboon, K. Chairattanawan, S. Jungphungsukpanich, Some properties of a sequencing batch reactor system for removal of vat days, Bioresour. Technol. 97 (2006) 1243–1252.
[16] S. Sirianuntapiboon, P. Srisornsak, Removal of disperse dyes from textile wastewater using bio-sludge, Bioresour. Technol. 98 (2007) 1057–1066.
[17] C.S.D. Rodrigues, L.M. Madeira, R.A.R. Boaventura, Synthetic textile dyeing wastewater treatment by integration of advanced oxidation and biological processes—Performance analysis with costs reduction, J. Environ. Chem. Eng. 2 (2014) 1027–1039.
[18] D.R. Manenti, A.N.A. Módenes, P.A. Soares, F.R. Espinoza-Quiñones, R.A.R. Boaventura, R. Bergamasco, V.J.P. Vilar, Assessment of a multistage system based on electrocoagulation, solar photo-Fenton and biological oxidation processes for real textile wastewater treatment, Chem. Eng. J. 252 (2014) 120–130.
[19] S. Ledakowicz, M. Gonera, Optimisation of oxidants dose for combined chemical and biological treatment of textile wastewater, Water Res. 33 (1999) 2511–2516.
[20] M. Basibuyuk, T. Yilmaz, B. Kayranli, A. Yuceer, C.F. Forster, The use of waterworks sludge for the treatment of dye wastes, Environ. Technol. 23 (2001) 345–351.
[21] I.K. Kapdan, F. Kargi, Simultaneous biodegradation and adsorption of textile dyestuff in an activated sludge unit, Process Biochem. 37 (2002) 973–981.
[22] M.S. Khehra, H.S. Saini, D.K. Sharma, B.S. Chadha, S.S. Chimni, Decolorization of various azo dyes by bacterial consortium, Dyes Pigm. 67 (2005) 55–61.
[23] D. Heri, Y. Yanto, S. Tachibana, K. Itoh, Biodecolorization of textile dyes by immobilized enzymes in a vertical bioreactor system, Procedia Environ. Sci. 20 (2014) 235–244.
[24] Z. Fu, Y. Zhang, X. Wang, Textiles wastewater treatment using anoxic filter bed and biological wriggle bed-ozone biological aerated filter, Bioresour. Technol. 102 (2011) 3748–3753.
[25] A.M. Lotito, U. Fratino, G. Bergna, C.D. Iaconi, Integrated biological and ozone treatment of printing textile wastewater, Chem. Eng. J. 195–196 (2006) 261–269.
[26] F. Nakajima, K. Fukushi, Bioaugmented membrane bioreactor (MBR) with a GAC-packed zone for high rate textile wastewater treatment, Water Res. 45(6) (2011) 2199–2206.
[27] F.I. Hai, K. Yamamoto, K. Fukushi, Hybrid treatment systems for dye wastewater, Crit. Rev. Environ. Sci. Technol. 37 (2007) 315–377.
[28] F.I. Hai, K. Yamamoto, F. Nakajima, K. Fukushi, Development of a submerged membrane fungi reactor for textile wastewater treatment, J. Membr. Sci. 325(1) (2008) 395–403.
[29] I.K. Kapdan, M. Tekol, F. Sengul, Decolorization of simulated textile wastewater in an anaerobic-aerobic sequential treatment system, Process Biochem. 38 (2003) 1031–1037.
[30] S. Sirianuntapiboon, J. Sansak, Treatability studies with granular activated carbon (GAC) and sequencing batch reactor (SBR) system for textile wastewater containing direct dyes, J. Hazard. Mater. 159 (2008) 404–411.
[31] F.I. Hai, K. Yamamoto, F. Nakajima, K. Fukushi, Application of a GAC-coated hollow fiber module to couple enzymatic degradation of dye on membrane to whole cell biodegradation within a membrane bioreactor, J. Membr. Sci. 389 (2012) 67–75.
[32] Society of Dyes and Colurists, Color Index, V.8. the Society of Dyes and colorists, the American Association of Textile Chemists and Colorists, third ed., Society of Dyes and Colourists, England, Bradford, 1987.
[33] A.J. Rubin, Chemistry of Wastewater Technology. Ann Arbor Science Publishers Inc., 230 Colingwood, P.O. Box 1425, Ann Arbor, Michigan, 1987
[34] S. Sirianuntapiboon, O. Sadahiro, P. Salee, Some properties of a granular activated carbon-sequencing batch reactor (GAC-SBR) system for treatment of textile wastewater containing direct dyes, J. Environ. Manage. 85 (2007) 162–170.
[35] APHA, AWWA, WPCF, Standard Method for the Examination of Water and Wastewater, twenty-first ed., Washington, DC, 2005, pp. 4–35.
[36] T. Hill, P. Lewicki, Statistics: Methods and Applications, first ed., Statsoft, Inc., Tulsa OK, 2005.
[37] SAS Institute, The SAS System for Windows, Version 6.12, SAS Campus Drive Cary, Cary, NC, 1996.
[38] S. Sirianuntapiboon, T. Hongsrisuwan, Removal of Zn^{2+} and Cu^{2+} by a sequencing batch reactor (SBR) system, Bioresour. Technol. 98 (2007) 808–818.
[39] S. Sirianuntapiboon, O. Ungkaprasatcha, Removal of Pb^{2+} and Ni^{2+} by bio-sludge in sequencing batch reactor (SBR) and granular activated carbon-SBR (GAC-SBR) systems, Bioresour. Technol. 98 (2007) 2749–2757.
[40] S. Sirianuntapiboon S. Maneewan, Effects of bio-sludge concentration and dilution rate on the efficiency of sequencing batch reactor (SBR) system for textile wastewater treatment, Environ. Asia 5(1) (2012) 36–52.