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Effects of Bio-sludge Concentration and Dilution Rate on the Efficiency of Sequencing Batch Reactor (SBR) System for Textile Wastewater Treatment

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Abstract

The color removal efficiency of a sequencing batch reactor (SBR) system with synthetic textile wastewater (STWW) containing 80 mg/L disperse dye increased with the increase of mixed liquor suspended solids (MLSS) or solids retention time (SRT). The color removal efficiency was over 98% at an MLSS of 4,000 mg/L and SRT of over 25 days. Also, the color removal efficiency decreased with the increase of dye concentration. Both disperse blue 60 and disperse red 60 repressed the growths and activities of both heterotrophic and denitrifying bacteria, but they did not show any effect on nitrifying bacteria. However, the SBR system did not show any change in color removal efficiency of both disperse red 60 and disperse blue 60. The SBR system showed quite low color, COD and BOD_5 removal efficiencies with raw textile wastewater (TWW). But, the system removal efficiencies could be increased by dilution of the TWW and supplementation with glucose. The color removal efficiency of the system with four times diluted-TWW containing 1.875 g/L glucose was 69.6±4.0%. Moreover, contaminated-NaCl in STWW could depress color adsorption yields of living as well as dead bio-sludge.

Keywords: disperse dye; disperse blue 60; disperse red 60; Sequencing Batch Reactor (SBR) system; textile wastewater

1. Introduction

Textile wastewater contains not only dyestuffs but also the organic substances which impact the environment and aquatic life (Chu, 2001; Department of Industrial Works, 2002). The amount of pollutants in the wastewater depends on type of the product and production process, especially, coloring and washing steps (Metcalf & Eddy, 2004; Hu, 1996; Wong and Yuen, 1996; Graca *et al*., 2001; Department of Industrial Works, 2002). Several types of dyestuffs such as disperse, vat, direct, acid, basic and reactive dyes are used in the textile industry. Disperse dyes are normally used to print or dye the typical Thai-textile products (cotton and silk). The Thai-textile factories normally belong to the small size factory group (home-made textile products) (Department of Industrial Works, 2002; Hu, 1996; Wong and Yuen, 1996; Graca *et al*., 2002). Chemical treatment processes such as adsorption, precipitation, coagulation and chemical oxidation are commonly used to remove dyestuffs from the textile wastewater (Janos *et al*., 2003; Meshko *et al*., 2001). Even though these chemical treatment processes are quite effective for dyestuffs removal, but they consume high energy and chemical agents. Chemical waste is also generated from those chemical processes and the effluent does not meet the permitted effluent standard levels (Department of Industrial works, 1992). However, the dyestuffs in the textile wastewater are refractory organic matter and can be biodegraded or utilized as carbon and energy sources for microorganisms (Metcalf & Eddy, 2004; Sirianuntapiboon *et al*., 2006; Yang *et al*., 2001; Kim *et al*., 2002). Nowadays, several researchers (Fu and Viraraghavan, 2001; Fongsatitkul *et al*., 2004; Basibuyuk *et al*., 2001; Nigam *et al*., 1995; Hu, 1996; Bromley-Challenor *et al*., 2000; Chen *et al*., 2003) have been focusing on the application of biological treatment processes to treat the textile wastewater due to low cost and absence of chemical wastes (chemical sludge). Several research studies on the biological removal of vat dyes have been reported in the literature (Nigam *et al*., 1995; Kapdan *et al*., 2000; Kapdan *et al*., 2003; Nigam *et al*., 1995; Lourenco *et al*., 2001), but only few on the biological removal of disperse dyes based on their properties such as water solubility and low adsorption yield onto activated carbon (Nilsson *et al*., 2006; Nigam *et al*., 1995; Lourenco *et al*., 2001). Nigam *et al*. (1995) reported that dyestuffs such as azo, diazo and reactive dyes could be adsorbed onto the surface of both dead and living microorganisms. Hu (1996) also reported that both gram negative and gram positive bacterial cells showed an ability to remove colorants or dyestuffs. Our previous work revealed that not only disperse dyes but also vat and direct dyes could be adsorbed onto the bio-sludge collected from activated sludge systems (Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon *et al*., 2007; Sirianunapiboon and Srisornsak, 2007) and the bio-sludge age affects dye removal capacity (both dye adsorption and degradation capacities) (Fu and Viraraghavan 2001; Hu 1996; Zaoyan *et al*., 1992; Walker and Weatherley, 2000; Khehra *et al*., 2005). However, a few researches working on the application of activated sludge system (AS) system to treat textile wastewater have been reported. Sequencing batch reactor (SBR) system is a fill and draw AS system was designed resulted to omit to clarifier and carried out the oxic and anoxic conditions in the same reactor. Form above results, SBR system might suitable for treatment the textile wastewater.

In this study, the SBR system was applied to treat both synthetic and raw textile wastewater containing disperse dyes (disperse blue 60 or/and disperse red 60) under various mixed liquor suspended solids (MLSS) and disperse dye concentrations. The effect of salt (NaCl) concentration on the dye removal efficiency of bio-sludge were also investigated as were the effects of dilution rates and glucose supplementation on the SBR system efficiency.

2. Materials and Methods

2.1. Dyes

Two types of disperse dyes were selected for use in this study viz., Disperse Red 60 (1-Amino-2-phenoxy-4-hydroxyanthraquinone: $C_{20}H_{13}NO_4$, Color index number: 60756, Maximum optical density at 580 nm) and disperse blue 60 (4,11-Diamino-2-(3-methoxypropyl)-1H-naphth(2,3-f)isoindole-1,3,5,10(2H)-tetrone: $C_{20}H_{17}N_3O_5$, color index No.61104, Maximum optical density at 548 nm) (Society of Dyes and Colourists, 1987) as shown in Fig. 1.

2.2. Textile Wastewaters

Two types of textile wastewaters, raw textile wastewater (TWW) and synthetic textile wastewater (STWW) were used in this study. TWW was collected from the influent sump tank of the central wastewater treatment plant of a textile factory in Samutprakarn Province, Thailand. TWW (the maximum optical density of TWW was detected at 573 nm) was taken only once and stored at 4-8^{o}C before using in the experiment to maintain the same wastewater quality. The chemical properties of TWW are described in Table 1. TWW was also diluted with distilled water at the ratio of 1:0, 1:1 and 1:2 to reduce toxicity before being used as the influent of SBR system (Table 1). The TWW and diluted-TWW solutions were supplemented with 1.875 g/L glucose to increase BOD_5 concentration as shown in Table 1 and also used as the influent of the SBR system. STWW was prepared according to the chemical properties of TWW. The STWW was composed of glucose 1,875 mg/L, urea 115 mg/L, $FeCl_2$ 3.5 mg/L, $NaHCO_3$ 675 mg/L KH_2PO_4 55 mg/L, $MgSO_4.7H_2O$ 42.5 mg/L and disperse dyes (Disperse blue 60 or/and disperse red 60) at 80, 160 or 320 mg/L. The chemical properties of STWW are described in Table 1.

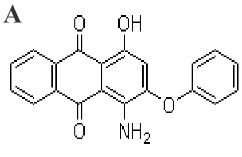
2.3. Acclimatization of bio-sludge for SBR system

Bio-sludge from the bio-sludge storage tank of the central sewage treatment plant of Bangkok Municipality (Sripaya sewage treatment plant) was used as the inoculum of the SBR system. The bio-sludge was fed with STWW without disperse dye in the SBR reactor and acclimatized for 1 week under HRT of 5 days as shown in Table 2.

2.4. SBR system

Six 10-L reactors, made from acrylic plastic (5 mm thick) as shown in Fig. 2, were used in the experiments. The dimensions of each reactor were 18cm-diameter and 40 cm-height, and the working volume was 7.5 L. Low speed gear motor (model P 630A-387, 100V, 50/60 Hz, 1.7/1.3 A, Japan Servo Co. Ltd., Japan) was used for driving the paddle-shaped impeller. The speed of the impeller was adjusted to 60 rpm for complete mixing. One set of air pump system, model EK-8000, 6.0 W (President Co. Ltd., Thailand) was used for supplying air to each set of 2 reactors (The system had enough oxygen supply as evidenced by the dissolved oxygen of the system of about 2-3 mg/L). The excess bio-sludge was removed during draw and idle periods to control mixed liquor suspended solids (MLSS) of the system as mentioned in Table 2 (Metcalf & Eddy, 2004).

A



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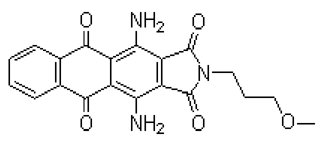

Figure 1. Molecular structure of Disperse dye A; Disperse red 60 B; Disperse blue 60

Table 1. Properties of various types of STWW, TWW and diluted-TWW solutions

Properties	STWW+ disperse blue 60 [a]	STWW+ Disperse red 60 [b]	STWW containing both disperse blue 60 and disperse red 60			TWW[f]	Diluted TWW		TWW containing glucose		
			STWW+ 40 disperse blue 60+ 40 disperse red 60 [c]	STWW+ 80 disperse blue 60+ 80 disperse red 60 [d]	STWW+ 160 disperse blue 60+ 160 disperse red 60 [e]		2 dil-TWW[g]	4 dil-TWW[h]	TWW+ glu[i]	2 dil-TWW + glu[j]	4 dil-TWW + glu[k]
COD, mg/L	1,900±40	1,900±40	1,950±50	1,950±60	1,950±60	2,600±180	1,300±90	700±50	2,800±150	2,000±140	1,200±40
BOD_5, mg/L	900±30	900±30	900±30	900±30	900±30	600±40	300±20	150±10	1,500±40	1,200±30	1050±20
TKN, mg/L	20.2±3.2	20.2±3.2	20.2±3.2	20.2±3.2	20.2±3.2	27.3±2.1	14.0±1.0	7.0±1.0	27.2±2.1	15.0±2.0	7.0±2.0
NH_4^+, mg/L	2.5±0.6	2.5±0.6	2.5±0.6	2.5±0.6	2.5±0.6	3.0±0.6	1.5±0.3	0.8±0.2	3.0±0.6	1.8±0.6	0.8±0.6
NO_2^-, mg/L	0.85±0.25	0.85±0.25	0.85±0.25	0.85±0.25	0.85±0.25	0.21±0.05	0.10±0.03	0.05±0.02	0.21±0.02	0.07±0.02	0.05±0.02
NO_3^-, mg/L	3.20±0.30	3.20±0.30	3.20±0.30	3.20±0.30	3.20±0.30	5.26±2.42	2.50±1.20	1.30±0.80	5.50±2.40	2.50±1.20	1.30±0.80
pH	7.8±0.2	7.8±0.2	7.8±0.2	7.8±0.2	7.8±0.2	8.8±0.2	8.5±0.2	8.5±0.2	8.8±0.2	8.3±0.2	8.3±0.2

a: STWW+disperse blue 60: STWW containing 80 mg/L disperse blue 60
b: STWW+disperse red 60: STWW containing 80 mg/L disperse red 60
c: STWW+40 disperse blue 60+ 40 disperse red 60: STWW containing 40 mg/L disperse blue 60 and 40 mg/L disperse red 60
d: STWW+80 disperse blue 60+ 80 disperse red 60: STWW containing 80 mg/L disperse blue 60 and 80 mg/L disperse red 60
e: STWW+160 disperse blue 60+ 160 disperse red 60: STWW containing 160 mg/L disperse blue 60 and 160 mg/L disperse red 60
f: TWW: Raw textile wastewater
g: 2 dil- TWW: The solution containing TWW and distilled water at the ratio of 1:1
h: 4 dil-TWW: The solution containing TWW and distilled water at the ratio of 1:2
i: TWW+ glu: Raw textile wastewater containing 1.875 g/L glucose
j: 2 dil-TWW +glu: The solution containing TWW and distilled water at the ratio of 1:1 and supplemented with 1.875 g/L glucose
k: 4 dil-TWW +glu: The solution containing TWW and distilled water at the ratio of 1:3 and supplemented with 1.875 g/L glucose

Table 2. The operating parameters of the SBR system used to treat various types of STWW, TWW and diluted-TWW solutions

Parameters	Types of wastewater													
	STWW+40 disperse blue 60+ 40 disperse red 60 [a]					STWW+40 disperse blue 60+40 disperse red 60 [a]	STWW+80 disperse blue 60+ 80 disperse red 60 [b]	STWW+160 disperse blue 60+160 disperse red 60 [c]	TWW [d]	2 dil-TWW [e]	2 dil-TWW [f]	TWW+ glu [g]	2 dil-TWW [h]	2 times diluted-TWW + glucose [i]
MLSS, mg/L	1,000	2,000	3,000	4,000	5,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
HRT, days	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Flow rate, mL/d	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Hydraulic loading, m^3/m^3-d	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
F/M ratio	1.28	0.64	0.43	0.32	0.26	0.38	0.46	0.50	0.30	0.21	0.14	0.52	0.47	0.46
BOD5 loading (g/d)	1.28	1.28	1.28	1.28	1.28	2.01	2.50	2.77	0.90	0.63	0.42	1.57	1.41	1.40
Volumetric BOD_5 loading (kg BOD_5/ m^3-d)	0.85	0.85	0.85	0.85	0.85	1.34	1.67	1.85	0.60	0.42	0.28	1.05	0.94	0.93
Dye loading (g/d)	0.12	0.12	0.12	0.12	0.12	0.12	0.24	0.48	N/A[j]	N/A[j]	N/A[j]	N/A[j]	N/A[j]	N/A**
Volumetric dye loading (kg/m^3-d)	0.08	0.08	0.08	0.08	0.08	0.08	0.16	0.32	N/A[j]	N/A[j]	N/A[j]	N/A[j]	N/A[j]	N/A**

a: STWW+40 disperse blue 60+ 40 disperse red 60: STWW containing 40 mg/L disperse blue 60 and 40 mg/L disperse red 60
b: STWW+80 disperse blue 60+ 80 disperse red 60: STWW containing 80 mg/L disperse blue 60 and 80 mg/L disperse red 60
c: STWW+160 disperse blue 60+ 160 disperse red 60: STWW containing 160 mg/L disperse blue 60 and 160 mg/L disperse red 60
d: TWW: Raw textile wastewater
e: 2 dil- TWW: The solution containing TWW and distilled water at the ratio of 1:1
f: 4 dil-TWW: The solution containing TWW and distilled water at the ratio of 1:2
g: TWW+ glu: Raw textile wastewater containing 1.875 g/L glucose
h: 2 dil-TWW +glu: The solution containing TWW and distilled water at the ratio of 1:1 and supplemented with 1.875 g/L glucose
i: 4 dil-TWW +glu: The solution containing TWW and distilled water at the ratio of 1:3 and supplemented with 1.875 g/L glucose
j: Cannot be calculated

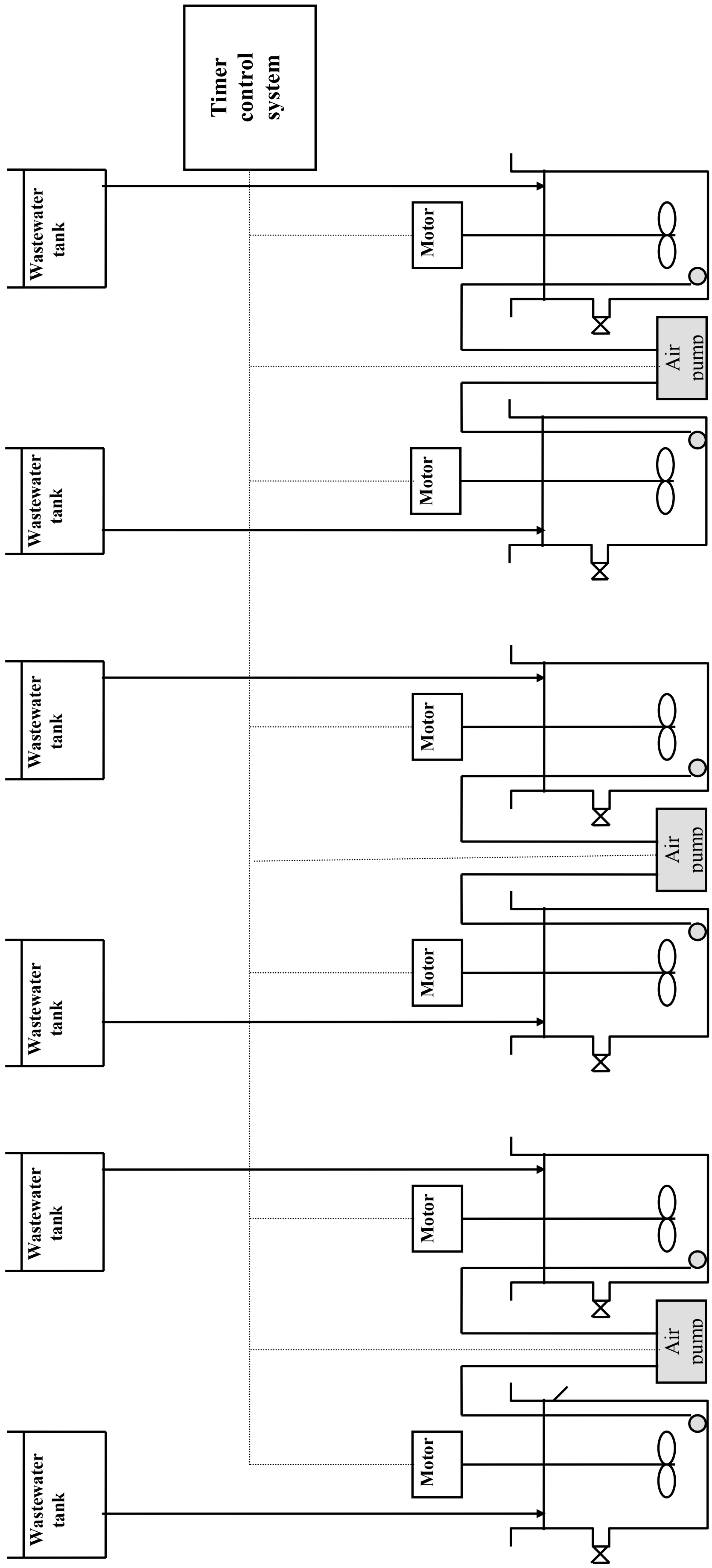

Figure 2. Flow diagram of SBR treatment system

2.5. Operation of SBR systems

1.4 L acclimatized bio-sludge (10 g/L as dry basic) from section 2.3 was inoculated in each reactor, and the TWW or STWW solutions were added (final volume of 7.5 L) within 1 h. During feeding the wastewater, the system had to be fully aerated and the aeration continued for 19 h. Aeration was then shut down for 3 h. After the bio-sludge was fully settled, the supernatant was removed within 0.5 h and the system kept under idle condition for 0.5 h (totally 4 h for anoxic step). Then, fresh wastewater was filled into the reactor to the final volume of 7.5 L and the above operation was repeated. The operation parameters of the SBR system are described in Table 2. The experiments were carried out for 12 months during January–December 2010.

2.6. Preparation of bio-sludge for dye adsorption test

Two types of bio-sludge, living (resting) and dead (autoclaved), were used in this experiment. Bio-sludge from the bio-sludge storage tank of Sripaya sewage treatment plant was cultivated with STWW without disperse dye for 1 week in SBR reactor under HRT of 5 days as shown in Table2. The cultivated bio-sludge was harvested and three times washed with 0.1 M phosphate buffer solution at pH 6.0. The washed bio-sludge was used as living bio-sludge. Half of the living bio-sludge was autoclaved twice for 10 min each at 110^{o}C and used as the dead bio-sludge.

2.7. Chemical analysis

Chemical oxygen demand (COD), biological oxygen demand (BOD_5), total kjeldahl nitrogen (TKN), and pH of influent and effluent, mixed liquor suspended solids (MLSS), sludge settled volume tested at 30 min. (SV_{30}) and sludge volume index (SVI) were determined using standard methods for the examination of water and wastewater (APHA, AWWA, WPCF, 1998). The color intensity of STWW and TWW was determined as the absorbance at the optimum wavelength as shown in section 2.1 and section 2.2 after centrifugation at 6,000 Xg for 10 min. SRT (solid retention time or bio-sludge age) was determined as the ratio of total MLSS of the system to the amount of excess bio-sludge wasted a day.

2.8. Statistical analysis method

Each experiment was repeated at least three times. All the data were subjected to two-way analysis of variance (ANOVA) using SAS Windows Version 6.12 (SAS Institute, 1996). Statistical significance was tested using the least significant difference (LSD) at the $p<0.05$ level and the results shown as the mean±the standard deviation.

3. Results

3.1. Effect of MLSS on the SBR system efficiency

The results on the effect of various MLSS concentrations on the removal efficiencies of the SBR system are shown in Tables 3-5. The COD and BOD_5 removal efficiencies were over 90% and 95%, respectively for all conditions of testing but, color and TKN removal efficiencies increased with the increase of MLSS or SRT as shown in Tables 3-5. Color and TKN removal efficiencies were over 98% and 85%, respectively at an MLSS of 4,000 mg/L and SRT of over 25 days as shown in Table 5. Effluent NO_3^- increased while effluent TKN decreased with the increase of MLSS operation as shown in Table 4. The NH_4^+ and TN removal efficiency decreased with the increase of MLSS as shown in Table 4. The COD, BOD_5, TKN and dye removal efficiencies of SBR system with STWW containing 80 mg/L disperse blue 60 were high at 93.3±1.0%, 97.2±0.5% and 98.2±0.5 %, respectively at an MLSS of 4,000 mg/L and HRT of 5 days as shown in Table 3 and Table 4. Also, the system showed high COD, BOD_5, TKN and dye removal efficiencies of 94.8±0.9%, 97.0±0.5%, 83.2±1.8% and 99.1±0.2%, respectively with STWW containing 80 mg/L disperse red 60 at an MLSS of 4,000 mg/L and HRT of 5 days. Moreover, the system did not show any significant difference in the color removal efficiency for both disperse blue 60 and disperse red 60. SVI of the system also increased with the increase of MLSS. However, SVI of the SBR system was in the range of 50-90 mL/g at MLSS of 1,000-3,000 mg/L as shown in Table 5. Also, SRT of the system increased with the increase of MLSS. SRT of the system with STWW at an MLSS of 3,000 mg/L was about 20 days as shown in Table 5.

From these results, the optimal operating of MLSS at 3, 000 mg/L was selected for further experiments.

3.2. Effect of the mixed-disperse dyes concentration on the SBR system efficiency

The results of the effects of mixed-dispersed dyes (mixture of disperse blue 60 and disperse red 60) concentration on the SBR system removal efficiencies are shown in Fig. 3 and Fig. 4. The COD, BOD_5 and color removal efficiencies of the system decreased with the increase of mixed-disperse dyes concentration. The COD, BOD_5 and dye removal efficiencies of the system with STWW containing high mixed-disperse

Table 3. Effluent qualities and removal efficiencies of SBR system with STWW containing 80 mg/L disperse dyes under various MLSS of 1,000, 2,000, 3,000, 4,000 and 5,000 mg/L and HRT of 5 days.

Types of disperse dye	MLSS of the system (mg/L)	F/M ratio	Chemical Properties						pH	SS
			Color		COD		BOD_5			
			Effluent (mg/L)	% removal	Effluent (mg/L)	% removal	Effluent (mg/L)	% removal		
Disperse blue 60	1,000	1.28	7.5±0.7	87.8±1.6	215±8	88.4±0.9	31±3	96.2±0.6	8.42±0.6	31±2
	2,000	0.64	4.5±0.7	92.7±1.2	162±11	91.3±0.6	28±1	96.5±0.7	8.23±0.4	29±3
	3,000	0.43	2.6±0.7	95.5±1.0	158±18	91.5±0.4	24±2	97.0±0.5	8.56±0.8	27±3
	4,000	0.32	1.1±0.2	98.2±0.5	146±18	92.2±1.0	24±1	97.0±0.1	8.21±0.4	24±2
	5,000	0.26	1.0±0.4	98.4±0.7	119±16	93.4±0.9	21±3	97.4±0.1	8.16±0.4	21±2
Disperse red 60	1,000	1.28	5.4±1.1	92.4±0.7	123±7	93.4±0.5	29±2	96.6±0.4	8.32±0.4	32±9
	2,000	0.64	3.7±0.9	94.8±0.9	102±7	94.5±0.8	28±1	96.8±0.5	8.12±0.3	31±4
	3,000	0.43	2.8±0.7	96.0±0.8	100±5	94.6±0.6	27±1	96.9±0.5	8.43±0.2	16±3
	4,000	0.32	0.7±0.1	99.1±0.2	96±5	94.8±0.9	26±1	97.0±0.5	8.62±0.2	14±4
	5,000	0.26	0.4±0.1	99.5±0.2	88±2	95.2±0.8	22±2	97.5±0.3	8.33±0.4	12±3

Table 4. Effluent qualities and nitrogen compounds removal efficiencies of SBR system with STWW containing 80 mg/L disperse dyes under various MLSS of 1,000, 2,000, 3,000, 4,000 and 5,000 mg/L and HRT of 5 days.

Types of disperse dye	MLSS of the system (mg/L)	TKN		NH_4^+ (mg/L)		NO_2^- (mg/L)		NO_3^- (mg/L)		TN (mg/L)		% TN removal
		Effluent (mg/L)	% removal	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	
Disperse blue 60	1,000	4.5±0.8	77.7±3.4	2.5±0.6	1.9±0.6	0.85±0.25	0.50±0.08	3.20±0.30	5.57±0.54	24.3±3.4	10.6±0.9	56.5±2.1
	2,000	4.1±0.6	79.7±2.8	2.5±0.6	1.9±0.6	0.85±0.25	0.62±0.09	3.20±0.30	13.16±0.66	24.3±3.4	17.9±0.8	26.4±1.8
	3,000	3.4±0.6	83.2±2.7	2.5±0.6	1.9±0.6	0.85±0.25	0.67±0.19	3.20±0.30	15.32±0.78	24.3±3.4	19.4±0.8	20.2±1.6
	4,000	3.0±0.6	85.1±2.6	2.5±0.6	2.2±.0.6	0.85±0.25	0.79±0.18	3.20±0.30	17.35±0.85	24.3±3.4	21.1±0.9	13.0±1.3
	5,000	3.0±0.5	85.1±2.2	2.5±0.6	2.6±0.6	0.85±0.25	0.93±0.23	3.20±0.30	18.33±0.68	24.3±3.4	23.8±0.8	8.4±1.1
Disperse red 60	1,000	5.3±0.8	73.8±3.3	2.5±0.6	1.7±0.6	0.85±0.25	2.37±0.73	3.20±0.30	4.05±0.84	24.3±3.4	11.7±0.9	51.8±2.3
	2,000	5.2±1.3	74.3±2.7	2.5±0.6	1.9±0.6	0.85±0.25	2.96±0.73	3.20±0.30	6.26±0.73	24.3±3.4	14.4±1.0	40.7±2.0
	3,000	5.2±0.6	74.3±2.1	2.5±0.6	2.1±0.6	0.85±0.25	3.87±0.57	3.20±0.30	10.12±0.65	24.3±3.4	19.2±0.9	21.0±1.5
	4,000	3.4±0.6	83.2±2.0	2.5±0.6	2.4±0.6	0.85±0.25	4.36±0.71	3.20±0.30	13.21±0.55	24.3±3.4	20.9±0.9	13.7±1.2
	5,000	2.5±0.6	87.6±1.8	2.5±0.6	2.4±0.5	0.85±0.25	4.39±0.42	3.20±0.30	15.15±1.45	24.3±3.4	22.0±0.8	9.3±0.9

Table 5. The bio-sludge qualities of SBR system operated with various types of STWW solution under various MLSS of 1,000, 2,000, 3,000, 4,000 and 5,000 mg/L and HRT of 5 days.

Types of wastewater	Types of Disperse dye	Initial dye concentration (mg/L)	MLSS (mg/L)	Excess sludge (mg/d)	SRT (d)	SV30 (mL/L)	SVI (mL/g)
STWW	Disperse blue 60	80	1,000	3,095±195	3±1	88±6	47±7
			2,000	1,505±254	11±1	124±9	51±2
			3,000	1,248±114	20±1	374±15	88±2
			4,000	1,322±318	25±2	552±35	126±3
			5,000	983±137	38±4	862±15	184±3
	Disperse red 60	80	1,000	2,828±198	4±1	75±6	50±3
			2,000	1,997±162	10±1	138±7	54±5
			3,000	1,132±175	20±1	290±28	90±9
			4,000	1,000±140	32±3	477±49	114±10
			5,000	886±178	44±4	880±8	168±4
	Mixture of Disperse red 60 and Disperse blue 60	80	3,000	965±209	24±6	182±8	78±2
		160		1023±149	22±5	178±13	80±4
		320		1008±181	23±7	198±14	89±6

dye of 320 mg/L were 75.8±4.4%, 87.7±2.5% and 47.2±4.6%, respectively. However, the mixed-disperse dyes concentration of up to 160 mg/L did not show any significant effect to the TKN and TN removal efficiencies. TKN and TN removal efficiencies of the system with STWW containing 160 mg/L mixed disperse dyes were 77.2±2.0% and 24.7±2.2%, respectively. But, the TN removal efficiency was reduced by 50% with the increase of mixed-disperse dye concentration from 160 mg/L to 320 mg/L. The effluent NO_3^- was increased by about 23% as shown in Fig. 4(a). The effluent SS was almost stable at 33-34 mg/L at mixed disperse dye concentration of 80-320 mg/L as shown in Fig. 4(b). For the bio-sludge performance investigation, the mixed-disperse dyes concentration in the range of 80-320 mg/L did not show any significant effect to the bio-sludge quality as shown in Table 5. SRT of the system was about 22-24 days and SVI was less than 90 ml/g as shown in Table 5.

3.3. Application of SBR system for treatment of TWW

Experiments were carried out in SBR system with TWW and diluted-TWW (2 and 4 times diluted-TWW)

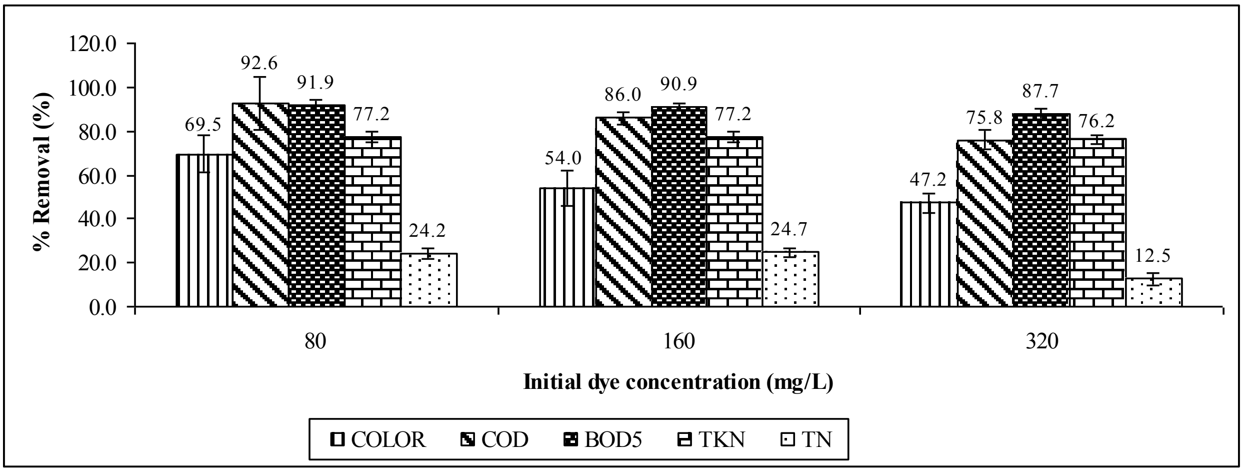

Figure 3. Removal efficiencies of SBR system with STWW containing various mixed-disperse dyes (mixture of disperse blue 60 and disperse red 60) concentrations of 80, 160 and 320 mg/L under MLSS of 3,000 mg/L and HRT of 5 days.

solutions, supplemented with and without 1.875 g/L glucose, to determine the system efficiency and performance as follows:

3.3.1. Effect on the dilution times of TWW

The results of the system efficiency and performance with TWW and diluted-TWW solutions are shown in Figs. 5-7. The system with raw TWW (influent BOD_5 of about 600±40 mg/L) showed quite low COD, BOD_5 and color removal efficiencies of only 56.1±10.6%, 60.0±5.6% and 22.4±8.3% respectively and high TKN and TN removal efficiencies of 84.2±3.6% and 55.4±4.2%, respectively. However, the system with 4 times diluted-TWW solution (BOD_5 of 150±10 mg/L) showed high COD, BOD_5, and color removal efficiencies of 77.6±2.9%, 72.7±3.5% and 57.6±4.4, respectively, and low TKN and TN removal efficiencies of 65.7±3.8% and 2.9±0.7%, respectively. Moreover effluent NO_3^- was higher than influent NO_3^- in all cases of experiment tested. SRT of the system decreased with the increase of dilution times of TWW as shown in Fig. 7. The SRT and SVI of the system with 4 times diluted-TWW were 26 days and less than 100 mL/g, respectively.

3.3.2. Effect of glucose supplementation on the SBR system efficiency

The effect of glucose on the SBR system removal efficiency with TWW and diluted-TWW solutions are shown in Figs. 5-7. The COD, BOD_5 and color removal efficiencies increased while the TKN and TN removal efficiencies decreased when glucose was added to TWW and diluted-TWW (BOD_5 was in the range of 1,000-1,500 mg/L). The COD, BOD_5, color, TKN and TN removal efficiencies of the system with 4 times diluted-TWW solution containing 1.875 mg/L glucose were 89.3±2.6%, 96.0±2.6%, 69.6±4.0%, 51.4±2.7% and 6.6±0.9%, respectively. The NO_3^- concentration

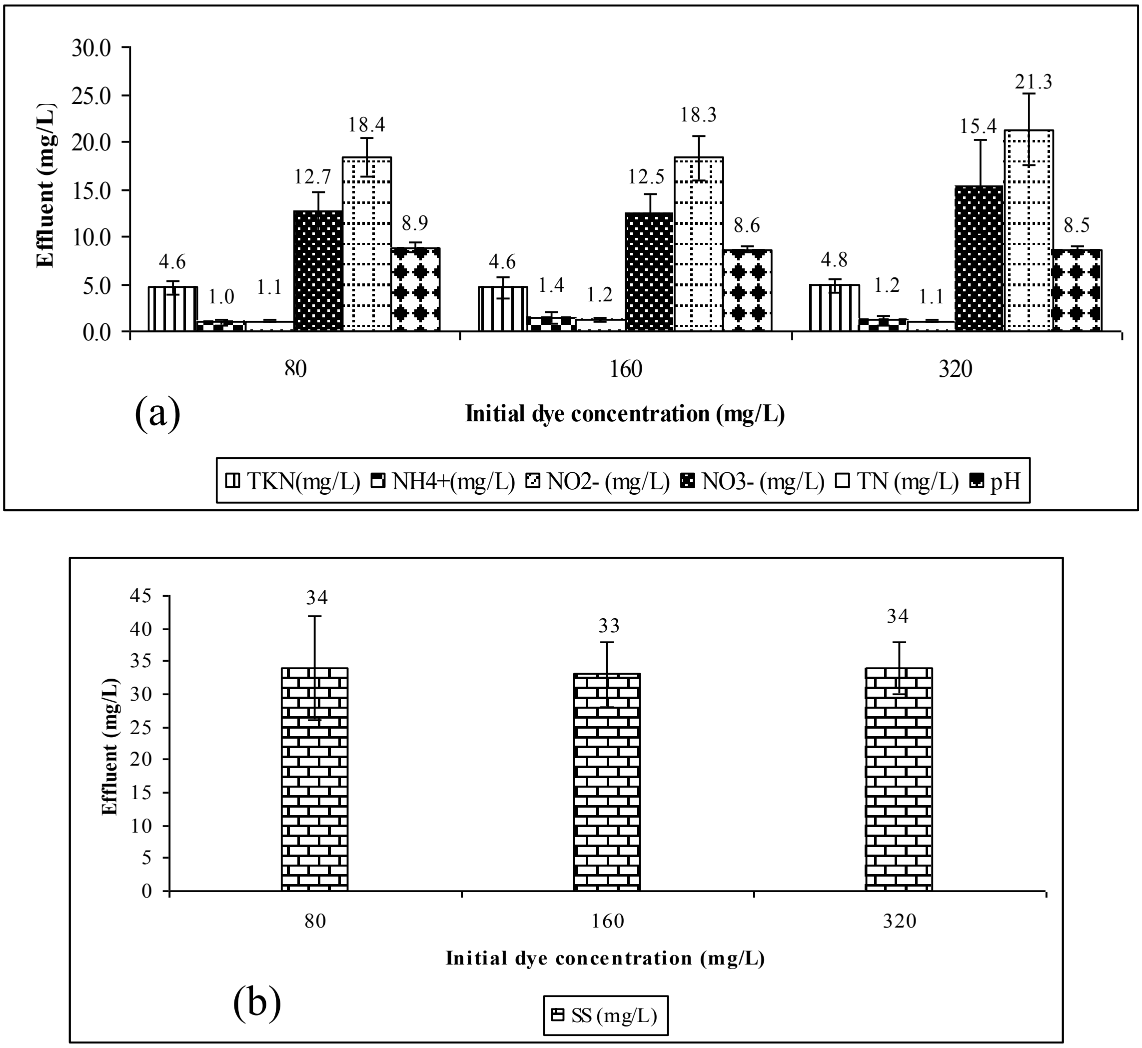

Figure 4. Effluent qualities (a: TKN, NH_4^+, NO_2^-, NO_3^-, TN and pH and b: SS) of SBR system with STWW containing various mixed-disperse dyes (mixture of disperse blue 60 and disperse red 60) concentrations of 80, 160 and 320 mg/L under MLSS of 3,000 mg/L and HRT of 5 days. Remark: Influent TKN = 20.2±3.2 mg/L

of the wastewater was increased after treatment in all cases. SRT of the system with both TWW and diluted-TWW solutions was reduced by the addition of 1.875 mg/L glucose. SRT of the system with 4 times diluted-TWW containing 1.875 mg/L glucose was 20±5 days. SVI of the system was less than 100 mL/g in all cases of experiment tested.

3.4. Effect of sodium concentration on the color adsorption capacity of bio-sludge

The effect of NaCl concentration on the color adsorption capacity of bio-sludge is shown in Table 6. The color adsorption yields of both dead and living bio-sludge were decreased with the increase of NaCl concentration. The dye adsorption yield was decreased by 15-20% with the increase of NaCl concentration of STWW from 0 to 30 mg/L.

4. Discussion

Our previous studies showed that both SBR and granular activated carbon-SBR systems could be applied to treat textile wastewater containing various types of dyestuffs (Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon *et al*., 2007; Sirianuntapiboon and Sriaornsak, 2007; Sirianuntapiboon and Sansak, 2008). Granular activated carbon-SBR (GAC-SBR) system showed a higher color removal efficiency than SBR system because the former could be operated under a high total bio-sludge concentration resulting from the bio-film mass (Metcalf & Eddy, 2004; Kapdan *et al*, 2000; Sirianuntapiboon *et al*., 2007; Sirianutnapiboon and Srisornsak, 2007; Sirianuntapiboon and Sansak, 2008; Sirianuntapiboon and Saengow, 2004). According to the high bio-sludge concentration operation, the bio-sludge was in the early stationary or late log phase giving the high color adsorption and degradation yields (Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon *et al*., 2007; Sirianuntapiboon and Srisornsak, 2007; Kapdan and Kargi, 2002). However, to operate GAC-SBR system under constant bio-sludge concentration was quite difficult due to the bio-film on GAC (Sirianuntapiboon *et al*., 2007; Sirianuntapiboon and Srisornsak). Then, the SBR system, operated with high MLSS, was applied. It was found that the color removal efficiency of the system with STWW containing 80 mg/L disperse dye was over 98% at an MLSS of 4,000 mg/L. Also, COD and BOD_5 and TKN removal efficiencies were high in the range of 93.4±0.9%, 97.0±0.1% and 85.1±2.6%, respectively. This might be the increasing of MLSS resulted in decrease of food/microbe ratio (F/M). Then, the bio-sludge of the system was in the late log phase or early stationary phase and could show high color and organic removal efficiencies (bio-sludge was controlled as the high SRT of over 25 days) (Metcalf & Eddy, 2004; Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon *et al*., 2007; Sirianuntapiboon and Srisornsak, 2007). This phenomenon was similar to our previous observations where bio-sludge of GAC-SBR system with long SRT, showed high vat dye removal efficiency (Metcalf & Eddy, 2004; Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon and Srisornsak, 2007).

Moreover, the SBR system did not show any significant different on color removal efficiency for both disperse blue 60 and disperse red 60 because the chemical structure of both dyes are quite similar (Metcalf & Eddy, 2004; Society of Dyes and Colourists, 1987). But the system, operated at an MLSS of up to 4,000 mg/L, showed poor bio-sludge quality (SVI of over 100 mL/g). Moreover, effluent NO_3^- and TKN removal efficiency increased with the increase of MLSS due to the increase of the number of nitrifying bacteria (Nitrifying bacteria transform organic nitrogen and ammonia nitrogen to NO_3^-) (Metcalf & Eddy, 2004). Unfortunately, TN removal efficiency was relatively low but the effluent NO_3^- increased. This might be the effect of dispersed dye to repress the growth and activity of both heterotrophic and denitrifying bacteria, but it did not give any effect to nitrifying bacteria (Metcalf & Eddy, 2004; Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon *et al*., 2007; Sirianuntapiboon and Srisornsak, 2007). To increase TN removal efficiency and decrease the effluent NO_3^- concentration, the chemical composition of the wastewater and operating conditions of the SBR should be optimized to increase the number and activity of denitrifying bacteria (Metcalf & Eddy, 2004; Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon *et al*., 2007; Sirianuntapiboon and Srisornsak, 2007). TWW might be diluted to reduce some toxic substances and glucose added to increase the BOD concentration at the suitable level for the growth of denitrifying bacteria. As mentioned in the materials and methods section, the system was operated with 19 hrs for the aeration step of each cycle; thus the growth of both heterotrophic and nitrifying bacteria was stimulated (Metcalf & Eddy, 2004; Sirianuntapiboon and Sansak, 2008). To increase the growth and activity of denitrifying bacteria, the anoxic period should be increased (Metcalf & Eddy, 2004; Sirianuntapiboon and Sansak, 2008). The system also showed the same removal efficiency and performance patterns with the STWW containing mixed-disperse dyes. TKN removal efficiency was not affected by the increase of mixed-disperse dyes concentration of up to 320 mg/L. Moreover, the effluent NO_3^- increased with the increase of mixed-disperse dyes concentration. From the above results, it can be concluded that the organic nitrogen

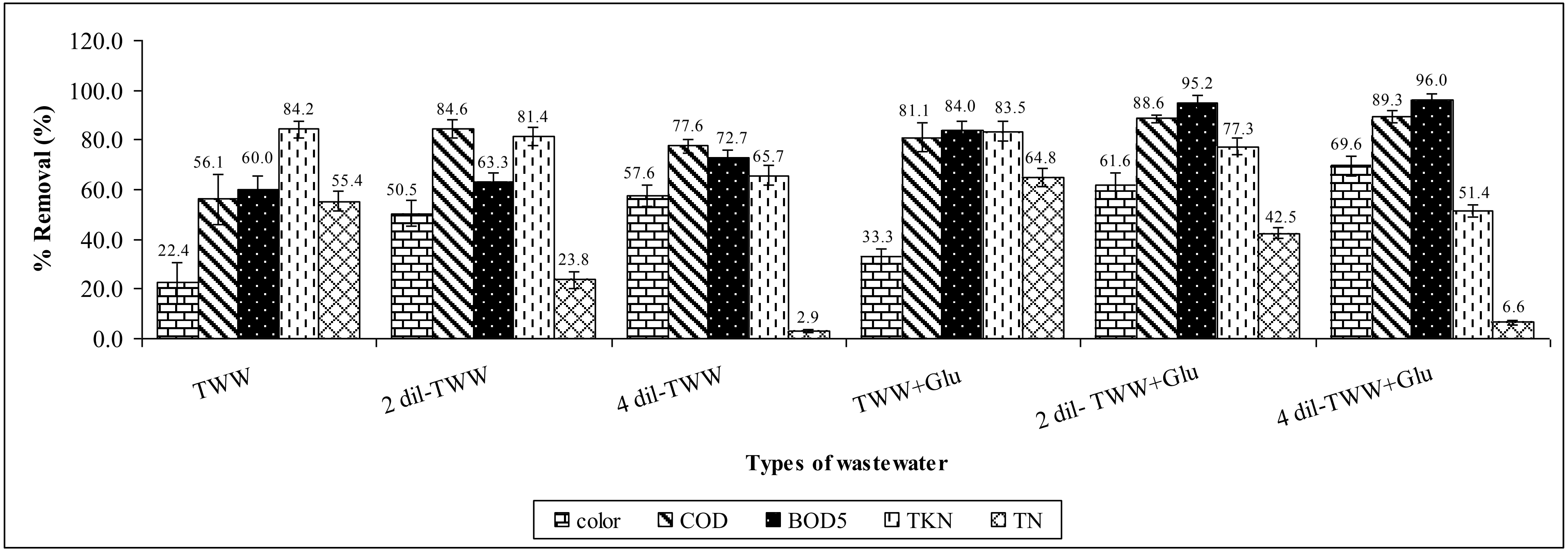

Figure 5. Effluent qualities of SBR system with TWW and TWW+glucose solutions under MLSS of 3,000 mg/L and HRT of 5 days.

Remark: **TWW:** Raw textile wastewater
2 dil-TWW: The solution containing TWW and distilled water at the ratio of 1:1
4 dil-TWW: The solution containing TWW and distilled water at the ratio of 1:2
TWW+glu: Raw textile wastewater containing 1.875 g/L glucose
2 dil-TWW+glu: The solution containing TWW and distilled water at the ratio of 1:1 and supplemented with 1.875 g/L glucose
4 dil-TWW+glu: The solution containing TWW and distilled water at the ratio of 1:3 and supplemented with 1.875 g/L glucose

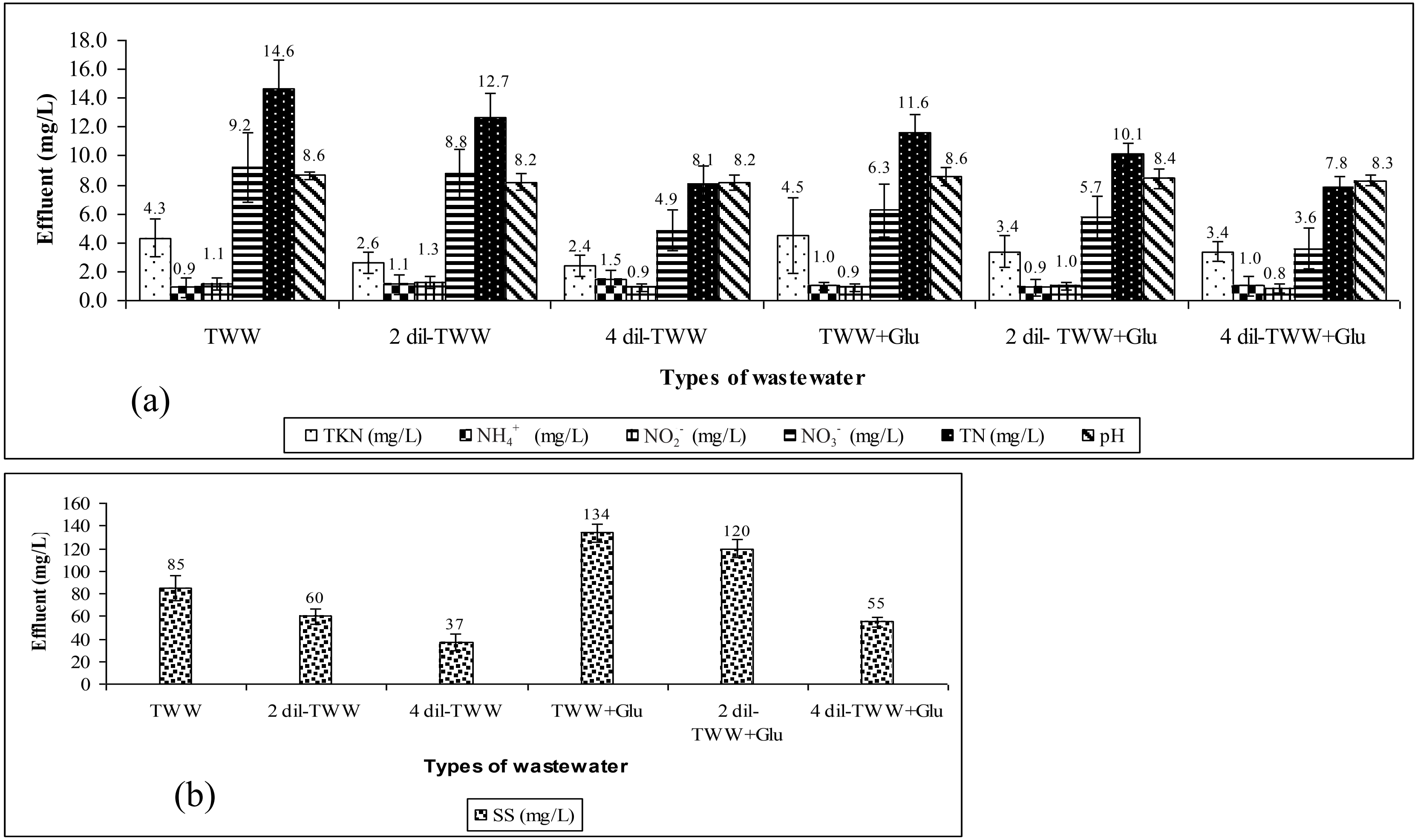

Figure 6. Effluent qualities (a: TKN, NH_4^+, NO_2^-, NO_3^-, TN and pH and b: SS) of SBR system with TWW and TWW+glucose solutions under MLSS of 3,000 mg/L and HRT of 5 days.

Remark: TWW: Raw textile wastewater, **2 dil-TWW:** The solution containing TWW and distilled water at the ratio of 1:1, **4 dil-TWW:** The solution containing TWW and distilled water at the ratio of 1:2, **TWW+glu:** Raw textile wastewater containing 1.875 g/L glucose, **2 dil-TWW+glu:** The solution containing TWW and distilled water at the ratio of 1:1 and supplemented with 1.875 g/L glucose, **4 dil-TWW+glu:** The solution containing TWW and distilled water at the ratio of 1:3 and supplemented with 1.875 g/L glucose

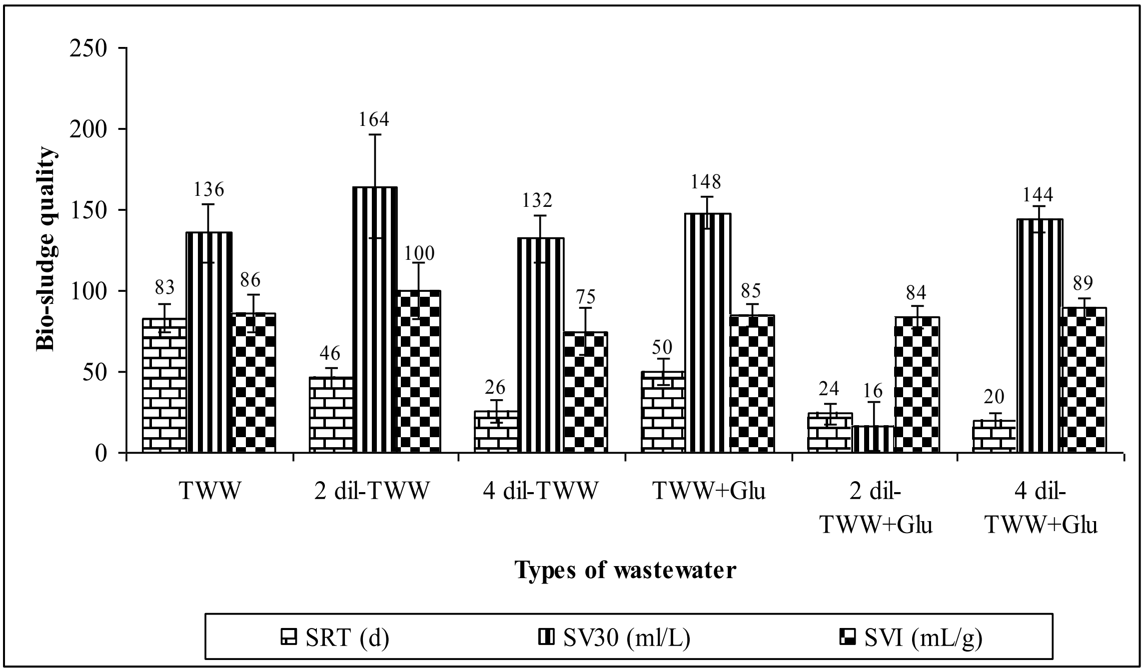

Figure 7. The bio-sludge qualities of SBR system operated with TWW and diluted-TWW+glucose solutions under MLSS of 3,000 mg/L and HRT of 5 days.

Remark: TWW: Raw textile wastewater, **2 dil-TWW:** The solution containing TWW and distilled water at the ratio of 1:1, **4 dil-TWW:** The solution containing TWW and distilled water at the ratio of 1:2, **TWW+glu:** Raw textile wastewater containing 1.875 g/L glucose, **2 dil-TWW+glu:** The solution containing TWW and distilled water at the ratio of 1:1 and supplemented with 1.875 g/L glucose, **4 dil-TWW+glu:** The solution containing TWW and distilled water at the ratio of 1:3 and supplemented with 1.875 g/L glucose

compounds were removed by both heterotrophic bacteria and nitrifying bacteria similar to the results of SBR system with STWW containing disperse dye. The mixed-disperse dyes of STWW might affect the growth of the heterotrophic bacteria resulting in decrease of the nitrogen assimilation yield (Metcalf & Eddy, 2004). But, they did not affect the growth of nitrifying bacteria which resulted in increasing of NO_3^- concentration of wastewater after SBR system treatment (Metcalf & Eddy, 2004). Moreover, the growth and activity of denitrifying bacteria were repressed by the increase of mixed-disperse dyes concentration of STWW (Metcalf & Eddy, 2004; Sirianuntapiboon and Sansak, 2008).

For the application of the SBR system to treat TWW containing mixed-disperse dyes, the system showed quite low COD, BOD_5 and dye removal efficiencies, but high TKN and TN removal efficiencies. This might be the effect of low organic matter (BOD_5 of 600±40 mg/L for TWW), high toxic substances and high disperse dye concentration resulting in the decrease of the heterotrophic bacteria (Metcalf & Eddy, 2004; Sirianuntapiboon and Sansak, 2008; Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon and Srisornsak, 2007). But it did not affect the growth and activity of nitrifying bacteria. The results were similar to the case of SBR system with STWW containing single and mixed-disperse dyes. This confirms that the organic (COD and BOD_5) removal efficiency increased with the increase of the diluted rate of TWW. The organic (COD and BOD_5) removal efficiency also increased by adding glucose (BOD_5) which was confirmed by the increasing of excess bio-sludge production (SRT of the system was shorten). Unfortunately, the TN removal efficiency was decreased. This could be because the system was operated under short SRT (high excess bio-sludge production by increasing BOD_5 concentration) which could stimulate heterotrophic bacteria to be dominant due to the high specific growth rate and reduce the number of both nitrifying and denitrifying bacteria due to low specific growth rate (Metcalf & Eddy, 2004; Sirianuntapiboon and Sansak, 2008; Sirianuntapiboon and Saengow, 2004; Sirianuntapiboon and Srisornsak, 2007). It was also found that the dye adsorption yields of both living and dead bio-sludge were repressed by NaCl because, the dye adsorption sites on the surface of bio-sludge were filled with Na^+ (Sirianuntapiboon and Sansak, 2008; Sirianuntapiboon and Hongsrisuwan, 2006). To increase the dye adsorption yield, Na^+ on the adsorption sites of bio-sludge and in the solution should be eluted and eliminated, respectively.

From the above results, it can be suggested that the biological treatment process especially, SBR system

Table 6. Color adsorption capacity of resting (living) and autoclaved (dead) bio-sludge with disperse dyes (disperse blue 60 and disperse red 60) solutions containing various concentration of NaCl.

Conc. of NaCl (g/L)	Adsorption capacity (mg/g bio-sludge)				%Relative adsorption			
	Disperse blue 60		Disperse red 60		Disperse blue 60		Disperse red 60	
	Resting Bio-sludge	Autoclaved Bio-sludge	Resting Bio-sludge	Autoclaved Bio-sludge	Resting Bio-sludge	Autoclaved Bio-sludge	Resting Bio-sludge	Autoclaved Bio-sludge
0	34.4±1.3	30.9±0.7	37.8±1.1	29.8±5.1	90.9±0.7	80.9±0.8	100.0±0.0	77.7±10.5
5	32.6±1.3	31.4±0.3	36.2±1.4	30.7±3.8	85.7±0.6	82.3±1.9	95.6±0.7	80.1±7.1
10	31.8±1.6	29.5±0.3	33.8±1.8	29.6±3.8	83.5±1.6	77.2±2.6	88.7±1.8	77.1±7.2
15	31.7±1.8	28.1±1.9	33.1±2.5	28.9±4.9	83.5±1.9	73.3±2.6	86.9±3.7	75.6±9.4
20	31.4±1.8	26.3±3.2	32.6±2.6	28.3±5.3	82.5±1.9	68.6±5.9	85.5±3.9	73.6±10.9
25	30.4±2.2	24.9±3.9	31.9±3.2	27.9±6.1	79.9±3.2	64.8±7.9	83.9±5.6	72.6±13.2
30	29.4±2.4	23.0±5.3	31.4±4.7	26.0±9.8	77.3±3.6	59.7±11.4	82.2±9.4	67.7±22.4

under high MLSS operation could be applied to treat TWW containing disperse dyes, but the disperse dye removal efficiency was quite low. However, the dye removal efficiency could be increased by adding organic matter such as glucose. The consequent increase of influent BOD_5 might reduce the number of both nitrifying and denitrifying bacteria in the system due to low specific growth rate of both strains (Metcalf & Eddy, 2004; Sirianuntapiboon *et al*., 2007; Sirianuntapiboon and Srisornsak, 2007). Also, the operating program of the SBR system should be considered accordingly to increase the growth and activity of nitrifying and denitrifying bacteria (to increase TN removal yield). The ratio of oxic and anoxic periods should be controlled to stimulate and optimize the growth and activity of heterotrophic, nitrifying and denitrifying bacteria. Moreover, the concentration of contaminant salt (NaCl) in TWW should be reduced before biological treatment by SBR system, otherwise the removal efficiency is reduced

5. Conclusion

SBR system under high MLSS operation can treat textile wastewater containing disperse dyes. The observed color removal efficiency with STWW was over 98% at an MLSS of 4,000 mg/L. The system did not show any difference in the color removal efficiency for both disperse blue 60 and disperse red 60. Moreover, the removal efficiency decreased with the increase of disperses dye concentration. However, the organic (COD and BOD_5) and color removal efficiencies were increased while TN and TKN removal efficiencies decreased by increasing BOD_5 loading or concentration. Both disperse blue 60 and disperse red 60 could repress the growth of heterotrophic and denitrifying bacteria, but they did not show any effect on the growth and activity of nitrifying bacteria. Moreover, the contaminant NaCl could repress the dye adsorption yield of both living and dead bio-sludge. Thus, NaCl in TWW should be reduced or eliminated before biological treatment by SBR system to obtain a highest removal efficiency.

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Nomenclature

BOD_5:	Biochemical oxygen demand
COD:	Chemical oxygen demand
F/M:	Food (BOD5 loading)/ Microbe (total Bio-sludge)
HRT:	Hydraulic retention time
MLSS:	Mixed liquor suspended solids
SBR:	Sequencing batch reactor
SRT:	Solid retention time
SS:	Suspended solids
STWW:	Synthetic textile wastewater
SVI:	Sludge volume index
SV30:	Sludge settled volume at 30 min
TWW:	Textile wastewater
TKN:	Total kjeldahl nitrogen

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