*Desalination and Water Treatment*
www.deswater.com


doi: 10.1080/19443994.2012.719470

50 (2012) 206–219
December

Taylor & Francis
Taylor & Francis Group

# Effects of some operating parameters on the efficiency of a sequencing batch reactor system for treatment of textile wastewater containing acid dyes

Suntud Sirianuntapiboon[a,*], Kanidta Chairattanawan[b]

[a]*Department of Environmental Technology, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi, Thungkru, Bangkok 10140, Thailand*
*Tel. +66 2 470 8656; Fax: +66 2 470 8660; email: suntud.sir@kmutt.ac.th*
[b]*Department of Applied Science, Office of General Education, Sripatum University, Phahonyothin Road, Chatuchak, Bangkok 10900, Thailand*

Received 7 December 2011; Accepted 1 July 2012

ABSTRACT

The purpose of this research was to find the optimal treatment conditions of a sequencing batch reactor (SBR) system for treatment of various types of textile wastewater (TWW) and synthetic textile wastewater containing acid red 18 and acid blue 9 dyes. Experiments were carried out under various $BOD_5$:TN ratios of 100:5, 100:10, 100:15, and 100:20, with mixed liquor suspended solids of 3,000 mg/L, and at hydraulic retention times (HRT) of 5, 7.5, and 10 d in order to determine the highest removal efficiency. Also, glucose, starch industrial wastewater (SWW), and noodle industrial wastewater were tested for their suitability as a carbon source. The results showed that mixed acid dyes had no significant effect on heterotrophic bacteria, but strongly repressed denitrifying bacteria activity. The SBR system with two times diluted TWW containing 1,480 mg/L glucose demonstrated high removal efficiencies for color, chemical oxygen demand (COD), biochemical oxygen demand ($BOD_5$), and TN ($75.9 \pm 2.1$, $89 \pm 7$, $92 \pm 1$, and $90.9 \pm 2.8$%, respectively). Regarding the effect of nitrogen concentration and HRT, the highest color, COD, $BOD_5$, and TN removal efficiencies ($91.1 \pm 0.3$, $96 \pm 1$, $97 \pm 3$, and $86.9 \pm 0.4$%, respectively) were observed with one time diluted TWW containing 1,480 mg/L glucose and 344 mg/L urea ($BOD_5$:TN of 100:10) at HRT of 10 d. For future applications, noodle or SWWs could be used as a carbon source instead of glucose, without any significant difference in color removal efficiency. This study suggests that the SBR system could be applied for treatment of TWW after one-time dilution with water and supplemented with carbon and nitrogen sources at organic loading and $BOD_5$:TN ratio of 0.17–0.23 kg $BOD_5/m^3$ d and 100:10, respectively.

*Keywords:* Acid dye; Noodle industrial wastewater; Sequencing batch reactor (SBR); Starch industrial wastewater; Textile wastewater

## 1. Introduction

Textile industry is divided into three groups, according to the type of fiber used: cellulose (cotton), protein (wool), and synthetic (nylon and polyester) [1]. Acid dyes are suitable for both protein fibers and synthetic fibers; in this case, the industrial wastewater contains not only dyestuffs but also organic substances which adversely impact the environment and aquatic life. The amount of pollutants produced

*Corresponding author.

depends on the production process, especially the coloring and washing steps [1,2]. Moreover, textile factories which use synthetic fibers and protein fibers as raw materials are categorized as “large size” factories [3–5]. For this reason, selecting the most efficient type and process of wastewater treatment system for these textile factories is of great importance. Chemical treatment processes such as adsorption, precipitation, coagulation, and oxidation–reduction have been commonly used to remove dyestuffs from textile wastewaters (TWWs) [6,7]. Although these chemical treatment processes are mostly effective for dyestuff removal, they consume a high amount of energy and use a large quantity of chemical agents. These processes consequently generate a high volume of chemical wastes whose effluent properties exceed the permitted standard [8]. Then, the biological treatment process was introduced for treatment of the TWW. The dyestuffs are a type of refractory organic matter, and can be biodegraded or utilized as carbon and energy sources for micro-organisms [2,9–13]; hence, a biological wastewater treatment system should be utilized [2]. Many researchers [3,14–19] have attempted to select special microbial strains that are able to biologically degrade or decolorize dyestuffs; the optimal conditions for biological dyestuff degradation have been investigated as well. But the application of a biological process for treatment of textile industrial wastewater has thus far been restricted to the laboratory, but the optimal conditions for biological dyestuff removal have not been precisely determined [3,19–23]. Our previous studies found that various types of textile dye could be removed by bio-sludge collected from a conventional activated sludge system [24,25]. It has also been shown that a sequencing batch reactor (SBR) system could be applied to treat various types of TWWs, with the added advantage of being able to operate under either oxic or anoxic conditions [2,12,24,25]. But the efficiency of such a system is affected by the age of the bio-sludge, as well as various physical and chemical conditions [3,18,26–29]. Moreover, raw TWW has a very low content of organic matter, and some of these organic compounds are not easily biodegradable [2,12,24,25]. To improve the removal efficiency, external organic matter should be added in order to increase the growth and activity of bio-sludge [12,30].

In this study, a SBR system was carried out with various types of TWWs and synthetic textile wastewaters (STWWs) under various hydraulic retention time (HRT) to observe the highest removal efficiency. Additional of a nitrogen source (urea), was tested for SBR system efficiency and performance for both TWW and STWW. Also, the effects of various types of carbon sources (glucose, starch industrial wastewater (SWW), and noodle industrial wastewater [NWW]) on the SBR system efficiency for TWW were determined.

## 2. Materials and methods

### 2.1. Dyes

Two types of acid dyes were selected for use in this study, as shown in Fig. 1: acid red 18 (trisodium (E)-7-hydroxy-8-((4-sulfonatonaphthalen-1-yl)diazenyl) naphthalene-1, 3-disulfonat), $C_{20}H_{11}N_2Na_3O_{10}S_3$, color index No. 16255, molecular weight 604.47 and acid blue 9 (N-Ethyl-N-[4-[[4-[ethyl[(3-sulfophenyl)methyl] amino]phenyl](2-sulfophenyl)methylene]-2,5-cyclohexa dien-1-ylidene]-3-sulfo-benzenemethanaminium inner salt diammonium salt), $C_{37}H_{34}N_2Na_2O_9S_3$, color index No. 42090, molecular weight 792.84 [31].

### 2.2. Textile wastewaters

Raw TWW and STWW were used in this study. TWW was collected from the influent sump tank of a wastewater treatment plant of a textile factory in Samut Prakan province, Thailand. The factory used only acid red 18 and acid blue 9 for dyeing step. Wastewater contaminated with acid red 18 and acid

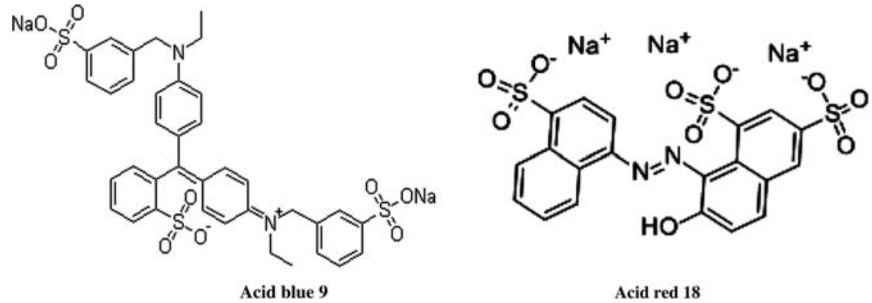


Fig. 1. Molecular structure of acid blue 9 and acid red 18.

Table 1
Chemical properties of SWW, NWW, TWWs and STWWs

| Chemical properties | | | | | |
|---|---|---|---|---|---|
| Parameters | SWW | NWW | TWW | TWW + Glu | STWW |
| COD (mg/L) | 240,000 ± 125 | 325,000 ± 150 | 1,200 ± 14 | 2,700 ± 22 | 2,700 ± 34 |
| $BOD_5$ (mg/L) | 155,000 ± 75 | 195,000 ± 110 | 150 ± 11 | 1,700 ± 30 | 1,800 ± 24 |
| Organic-N (mg/L) | 8.9 ± 0.5 | 8.5 ± 0.9 | 5.6 ± 0.5 | 9.9 ± 0.8 | 8.4 ± 0.0 |
| $NH_4^+$–N (mg/L) | 2.8 ± 0.2 | 3.3 ± 0.4 | – | 3.4 ± 0.5 | 3.2 ± 0.6 |
| $NO_2^-$–N (mg/L) | 0.1 ± 0.0 | – | 0.1 ± 0.0 | 3.0 ± 0.3 | 2.7 ± 0.3 |
| $NO_3^-$–N (mg/L) | – | – | – | 0.6 ± 0.1 | 0.5 ± 0.1 |
| TN (mg/L) | 9.0 ± 0.5 | 8.5 ± 0.9 | 5.7 ± 0.5 | 17.0 ± 2.1 | 14.8 ± 3.2 |
| Color intensity (units/mL) | – | – | 1.324 ± 0.2 ($OD_{603nm}$)[a] | 1.324 ± 0.2 ($OD_{603nm}$)[a] | 0.924 ± 0.2 ($OD_{532nm}$)[b] |
| SS (mg/L) | 387,560 ± 1,587 | 22,1,610 ± 984 | 270 ± 31 | 270 ± 31 | 23 ± 3 |
| pH | 6.7 ± 0.2 | 6.3 ± 0.1 | 8.3 ± 0.2 | 8.0 ± 0.2 | 8.4 ± 0.1 |

[a,b]Color intensity of the TWWs and STWWs are represented as the optical density at wavelengths of 603 and 532 nm, respectively.

blue 9 was dark in color; the maximum optical density of TWW was detected at a wavelength of 573 nm. A TWW sample was taken only once, and stored at 4–8˚C before being used, in order to ensure that the same wastewater properties were maintained throughout the experiments. The chemical properties of TWWs are described in Table 1. TWW was diluted with distilled water at ratios of 1:0, 1:1, and 1:2 (TWW, 1dil-TWW, and 2dil-TWW, respectively) and was supplemented with 1,480 mg/L glucose (TWW + Glu, 1dil-TWW + Glu, and 2dil-TWW + Glu, respectively) before being used as the influent for SBR treatment (Table 2). SWW and NWW were added to 1dil-TWW instead of glucose (1dil-TWW + SWW and 1dil-TWW + NWW, respectively), resulting in increased $BOD_5$ of up to 1,700 mg/L, similar to $BOD_5$ of the TWWs + Glu (Table 2). Moreover, various concentrations of urea (172, 344, 516, and 688 mg/L) were added to 1dil-TWW to increase the ratio of $BOD_5$:TN (total nitrogen) to 100:5, 100:10, 100:15, and 100:20, respectively. STWWs were prepared corresponding to the chemical properties of TWWs. The chemical compositions of STWWs are shown in Table 2. Three types of STWW were prepared: STWW (containing 160 mg/L mixed acid dyes), 1dil-STWW (containing 80 mg/L mixed acid dyes), and 2dil-STWW (containing 40 mg/L mixed acid dyes), as shown in Table 2. The maximum optical density of the STWW solutions was detected at a wavelength of 603 nm. Also, 516 mg/L urea was added to 1dil-STWW to increase the $BOD_5$:TN ratio to 100:15 (1dil-STWW + 15 N) (Table 2).

### 2.3. *Starch industrial wastewater*

A SWW sample was collected from the sump tank of a wastewater treatment plant at a starch factory in Nakhon Pathom province, and stored at 4–8˚C to prevent any change in chemical properties. The chemical oxygen demand (COD) and biochemical oxygen demand ($BOD_5$) of SWW were 240,000 ± 125 mg/L and 155,000 ± 75 mg/L, respectively (Table 1).

### 2.4. *Noodle industrial wastewater*

A NWW sample was collected from the sump tank of a wastewater treatment plant at a rice noodle factory in Nakhon Pathom province, and stored at 4–8˚C to prevent any change in chemical properties. The COD and $BOD_5$ of NWW were 325,000 ± 150 and 195,000 ± 110 mg/L, respectively (Table 1).

### 2.5. *Acclimatization of bio-sludge for the SBR system*

Bio-sludge from the bio-sludge storage tank of the central sewage treatment plant of Bangkok, Thailand (Sripaya sewage treatment plant) was used as the inoculum of the SBR system. The bio-sludge was fed with STWW without acid dyes in the SBR reactor, and acclimatized for one week at HRT of 7.5 d (Table 3).

### 2.6. *SBR system*

Six 10-L reactors made from acrylic plastic (5 mm thick) were used in the experiments (Fig. 2). The dimensions of each reactor were 18 cm diameter and

Table 2
Chemical composition of TWWs and STWWs

| Chemical composition | Type of textile wastewater | |
|---|---|---|
| | STWW[a] | TWW[b] |
| Glucose (mg/L) | 1,530 | 1,480 |
| Urea[c] (mg/L) | 182 | 0, 172, 344, 516, 688 |
| $FeCl_2$ (mg/L) | 3.5 | |
| $NaHCO_3$ (mg/L) | 675 | |
| $KH_2PO_4$ (mg/L) | 55 | |
| $MgSO_4.7H_2O$ (mg/L) | 42.5 | |

[a]Various types of synthetic textile wastewaters: STWW containing 160 mg/L mixed acid dyes (STWW), STWW containing 80 mg/L mixed acid dyes (1dil-STWW), and STWW containing 40 mg/L mixed acid dyes (2dil-STWW).
[b]Various types of textile wastewaters: TWW (containing 0 mg/L glucose), and TWW + Glu, 1dil-TWW + Glu and 2dil-TWW + Glu (all containing 1,480 mg/L glucose).
[c]Various concentrations of urea (172, 344, 516 and 688 mg/L) were added to TWWs and STWWs to adjust the $BOD_5$:TN ratios to 100:5, 100:10, 100:15 and 100:20, respectively.

Table 3
Operating parameters of the SBR system

| Parameter | HRT | | |
|---|---|---|---|
| | 5 | 7.5 | 10 |
| MLSS (mg/L) | 3,000 | 3,000 | 3,000 |
| Volume of reactor (L) | 7.5 | 7.5 | 7.5 |
| Volume of influent (L/d) | 1.5 | 1.0 | 0.75 |
| Volume of effluent (L/d) | 1.5 | 1.0 | 0.75 |
| Cycle of system (h) | 24 | 24 | 24 |
| Fill (h) | 1 | 1 | 1 |
| React (h) | 19 | 19 | 19 |
| Settle (h) | 3 | 3 | 3 |
| Draw and idle (h) | 1 | 1 | 1 |

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 the impeller was adjusted to 60 rpm for complete mixing. One air pump system, 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 in the system of about 2–3 mg/L. Excess bio-sludge was removed during the draw and idle periods to control the level of mixed liquor suspended solids (MLSS).

### 2.7. Operation of the SBR system

Acclimatized bio-sludge (1.4 L; 10 g/L dry basis) was inoculated into each reactor, and then TWWs or STWWs were added (to a final volume of 7.5 L) within 1 h. During the wastewater feeding period, the system had to be fully aerated; aeration continued for 19 h, and was then shutdown for 3 h. After the bio-sludge had fully settled, the supernatant was removed within 0.5 h and the system kept in an idle condition for another 0.5 h (for a total of 4 h under anoxic conditions). Then fresh wastewater was pumped into the reactor (final volume, 7.5 L) and the above operation was repeated. The system was operated with MLSS of 3,000 mg/L and at HRT of 5, 7.5, and 10 d, as shown in Table 3. The duration of operation of the SBR reactor with each textile wastewater was about 40 days. The experiments were carried out for 12 months, during July 2010–June 2011.

### 2.8. Chemical analysis

COD, $BOD_5$, organic nitrogen (organic-N), ammonia nitrogen ($NH_4^+$–N), nitrate nitrogen ($NO_3^-$–N), nitrite nitrogen ($NO_2^-$–N), and pH of the influent and effluent, as well as MLSS and sludge volume index (SVI), were determined using standard methods for the examination of water and wastewater [32]. The color intensities of STWWs and TWWs were determined by the absorbance at the optimum wavelengths of 603 and 573 nm, respectively, after centrifugation at 6,000 × g for 10 min. Bio-sludge age was determined as the ratio of total MLSS of the system to the amount of excess bio-sludge wasted per day.

### 2.9. Statistical analysis

Each experiment was repeated at least three times. All data were subjected to two-way analysis of variance using statistical analysis system (SAS) for Windows, version 6.12 [33]. Statistical significance was tested using the least significant difference at $p < 0.05$; results were shown as mean standard deviation.

## 3. Results

### 3.1. Effects of dilution rates on SBR system efficiency and performance

Experiments were carried out with TWWs and STWWs containing glucose content of 1,480 and 1,530 mg/L (respectively) at HRT of 7.5 d, in order to observe the effect of mixed acid dye concentrations on the efficiency and performance of the SBR system (Tables 4 and 5).

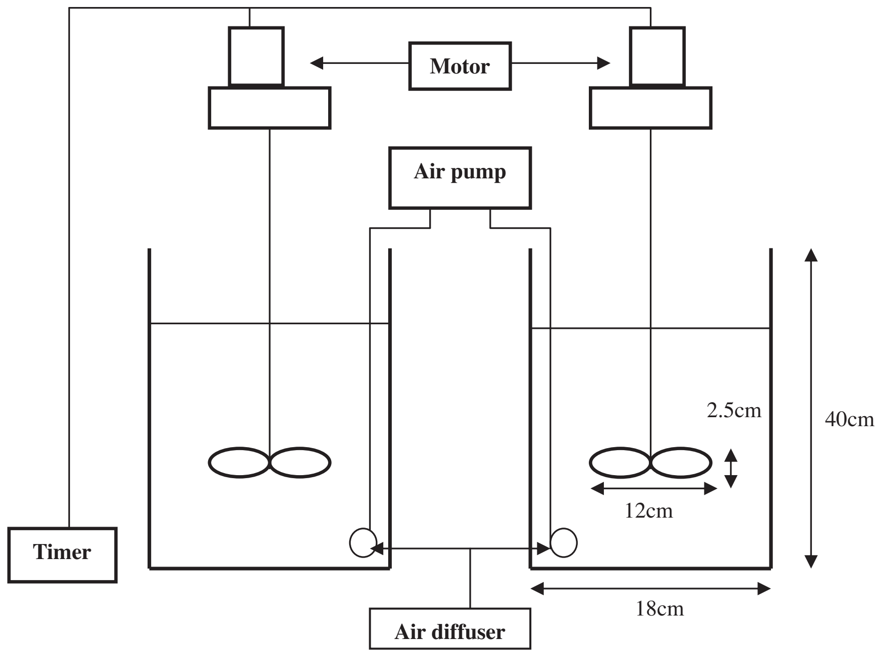


Fig. 2. Flow diagram of the SBR treatment system. The physical operation controls were: 60 rpm of impeller speed; full aeration with an air-pump system (one air pump system supplied air to two sets of reactors); and a working volume of the reactor of 75% of total volume (7.5 L).

*3.1.1. COD and $BOD_5$*

The COD and $BOD_5$ removal efficiencies increased with a decrease of mixed acid dye concentration. The highest COD and $BOD_5$ removal efficiencies, 89 ± 7 and 92 ± 1% and 91 ± 2 and 94 ± 1%, were observed with 2dil-TWW + Glu and 2dil-STWW + Glu, respectively. Moreover, the system with STWWs + Glu showed higher COD and $BOD_5$ removal efficiencies than that with TWWs + Glu (Table 4).

*3.1.2. Nitrogen compounds*

TN removal efficiency increased with a decrease in mixed acid dye concentration; TN removal efficiencies with 2dil-TWWs + Glu and 2dil-STWW were 90.9 ± 2.8 and 94.3 ± 2.2%, respectively. Organic-N, $NH_4^+$–N, and $NO_2^-$–N were almost completely removed from the influents; the effluent $NO_3^-$–N of the systems with TWWs + Glu and STWWs were quite low, in the ranges of 0.2–0.6 and 3.8–8.2 mg/L, respectively (Table 5).

*3.1.3. Color intensity*

Color removal efficiencies with TWW + Glu and STWW were quite low, only 55.4 ± 2.6 and 65.4 ± 2.2%, respectively. But color removal efficiency could be increased by decreasing mixed dye concentration; color removal efficiencies of the system with 2dil-TWW + Glu and 2dil-STWW were 75.9 ± 2.1 and 87.1 ± 2.4%, respectively (Table 4).

*3.1.4. Suspended solids*

Effluent suspended solids (SS) decreased with a decrease of mixed acid dye concentration. The system with 2dil-TWW + Glu and 2dil-STWW resulted in a low effluent SS of only 36 ± 3 and 33 ± 3 mg/L, respectively. SS content in STWWs effluents were about 10–15% lower than with TWWs + Glu (Table 4).

*3.1.5. Bio-sludge performance*

SVI also increased in a decrease of mixed acid dye concentration. SVI with TWW + Glu and STWW were 84 ± 4 and 90 ± 3 mL/g, respectively. Also, bio-sludge age decreased with a decrease of mixed acid dye concentration (Table 4). The bio-sludge ages of the system with 2dil-TWW + Glu and 2dil-STWW were 25 ± 1 and 23 ± 1 d, respectively.

*3.2. Effects of TN supplementation on SBR system efficiency and performance*

The results from the TN addition on the SBR system efficiency and performance with TWWs + Glu + 15 N and STWWs + Glu + 15 N at HRT of 7.5 d are shown in Tables 4 and 5, and as follows.

Table 4
Effluent qualities and removal efficiencies of the SBR system with TWWs and STWWs

| Type of wastewater | Added urea (g/L) | $BOD_5$:TN | Organic loading (kg $BOD_5$ /$m^3$ d) | Color intensity | | $BOD_5$ | | COD | | Effluent qualities | Bio-sludge qualities | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Effluent (unit/mL)[m] | Removal (%) | Effluent (mg/L) | Removal (%) | Effluent (mg/L) | Removal (%) | Effluent SS (mg/L) | Sludge age (days) | SVI (mg/L) |
| TWW + Glu[a] | – | 100:1 | 0.23 | 0.59 ± 0.02 | 55.4 ± 2.6 | 102 ± 3 | 88 ± 1 | 189 ± 5 | 86 ± 3 | 44 ± 3 | 35 ± 2 | 84 ± 4 |
| 1dli-TWW + Glu[b] | – | 100:0.5 | 0.23 | 0.20 ± 0.01 | 70.4 ± 2.3 | 85 ± 3 | 90 ± 1 | 149 ± 4 | 89 ± 2 | 40 ± 6 | 29 ± 3 | 87 ± 4 |
| 2dil-TWW + Glu[c] | – | 100:0.3 | 0.23 | 0.08 ± 0.00 | 75.9 ± 2.1 | 68 ± 3 | 92 ± 1 | 149 ± 6 | 89 ± 7 | 36 ± 3 | 25 ± 1 | 90 ± 5 |
| TWW + Glu + 15N[d] | 0.516 | 100:15 | 0.23 | 0.32 ± 0.01 | 76.0 ± 2.3 | 85 ± 2 | 90 ± 1 | 150 ± 6 | 89 ± 3 | 39 ± 3 | 22 ± 2 | 89 ± 4 |
| 1dil-TWW + Glu + 15N[e] | 0.516 | 100:15 | 0.23 | 0.06 ± 0.01 | 89.6 ± 2.1 | 43 ± 2 | 95 ± 1 | 68 ± 2 | 95 ± 2 | 35 ± 3 | 19 ± 1 | 96 ± 5 |
| 2dil-TWW + Glu + 15N[f] | 0.516 | 100:15 | 0.23 | 0.03 ± 0.00 | 90.9 ± 2.2 | 25 ± 2 | 97 ± 1 | 54 ± 5 | 96 ± 2 | 31 ± 3 | 18 ± 1 | 108 ± 6 |
| STWW[g] | 0.182 | 100:1 | 0.24 | 0.32 ± 0.02 | 65.4 ± 2.2 | 77 ± 2 | 91 ± 4 | 150 ± 6 | 89 ± 2 | 40 ± 3 | 30 ± 2 | 90 ± 3 |
| 1dil-STWW[h] | 0.182 | 100:1 | 0.24 | 0.08 ± 0.01 | 82.9 ± 2.1 | 60 ± 3 | 93 ± 1 | 136 ± 4 | 90 ± 1 | 35 ± 3 | 25 ± 2 | 96 ± 5 |
| 2dil-STWW[i] | 0.182 | 100:1 | 0.24 | 0.03 ± 0.00 | 87.1 ± 2.4 | 52 ± 3 | 94 ± 1 | 121 ± 4 | 91 ± 2 | 33 ± 3 | 23 ± 1 | 104 ± 4 |
| STWW + 15N[j] | 0.546 | 100:15 | 0.24 | 0.15 ± 0.02 | 83.8 ± 4.4 | 60 ± 1 | 93 ± 0 | 136 ± 5 | 90 ± 3 | 40 ± 3 | 16 ± 2 | 110 ± 4 |
| 1dil-STWW + 15N[k] | 0.546 | 100:15 | 0.24 | 0.02 ± 0.00 | 93.6 ± 4.2 | 34 ± 3 | 96 ± 2 | 68 ± 2 | 95 ± 1 | 38 ± 3 | 16 ± 3 | 120 ± 6 |
| 2dil-STWW + 15N[l] | 0.546 | 100:15 | 0.24 | 0.01 ± 0.00 | 95.9 ± 3.1 | 25 ± 1 | 97 ± 1 | 53 ± 3 | 96 ± 1 | 37 ± 3 | 16 ± 2 | 130 ± 6 |

[a]TWW + Glu: TWW containing 1,480 mg/L glucose.
[b]1dil-TWW + Glu: one time diluted-TWW containing 1,480 mg/L glucose.
[c]2dil-TWW + Glu: two times diluted-TWW containing 1,480 mg/L glucose.
[d]TWW + Glu + 15 N: TWW containing 1,480 mg/L glucose and 516 mg/L urea.
[e]1dil-TWW + Glu + 15 N: one time diluted-TWW containing 1,480 mg/L glucose and 516 mg/L urea.
[f]2dil-TWW + Glu + 15 N: two times diluted-TWW containing 1,480 mg/L glucose and 516 mg/L urea.
[g]STWW: STWW containing 160 mg/L mixed acid dyes.
[h]1dil-STWW: STWW containing 80 mg/L mixed acid dyes.
[i]2dil-STWW: STWW containing 40 mg/L mixed acid dyes.
[j]STWW + 15 N: STWW containing 182 mg/L urea.
[k]1dil-STWW + 15 N: 1dil-STWW containing 546 mg/L urea.
[l]2dil-STWW + 15 N: 2dil-STWW containing 546 mg/L urea.
[m]Color intensity of TWWs and STWWs are represented as the optical density at wavelengths of 603 and 532 nm, respectively.

Table 5
Nitrogenous compound removal efficiency of the SBR system with TWWs and STWWs at HRT of 7.5 d

| Type of wastewater | Added urea (g/L) | $BOD_5$: TN | Organic loading | Organic-N (mg/L) | | $NH_4^+$–N (mg/L) | | $NO_2^-$–N (mg/L) | | $NO_3^-$–N (mg/L) | | Total nitrogen | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (kg $BOD_5$/$m^3$ d) | Influent | Effluent | Influent | Effluent | Influent | Effluent | Influent | Effluent | Effluent (mg/L) | Removal (%) |
| TWW + Glu[a] | – | 100:1 | 0.23 | 10.0 ± 0.1 | 1.0 ± 0.1 | 3.4 ± 0.1 | 0.5 ± 0.1 | 3.0 ± 0.1 | 0.0 ± 0.0 | 0.6 ± 0.1 | 0.6 ± 0.1 | 2.1 ± 0.3 | 82.0 ± 2.1 |
| 1dli-TWW + Glu[b] | – | 100:0.5 | 0.23 | 5.0 ± 0.1 | 0.4 ± 0.1 | 1.7 ± 0.1 | 0.3 ± 0.1 | 1.6 ± 0.1 | 0.0 ± 0.0 | 0.6 ± 0.1 | 0.2 ± 0.0 | 0.9 ± 0.2 | 90.4 ± 1.2 |
| 2dil-TWW + Glu[c] | – | 100:0.3 | 0.23 | 3.0 ± 0.1 | 0.2 ± 0.1 | 1.0 ± 0.1 | 0.0 ± 0.0 | 0.8 ± 0.1 | 0.0 ± 0.0 | 0.6 ± 0.1 | 0.2 ± 0.0 | 0.5 ± 0.1 | 90.9 ± 2.8 |
| TWW + Glu + 15N[d] | 0.516 | 100:15 | 0.23 | 81.6 ± 3.6 | 11.5 ± 2.1 | 66.4 ± 2.0 | 6.3 ± 1.2 | 8.8 ± 1.3 | 2.1 ± 0.1 | 8.8 ± 1.2 | 37.7 ± 4.2 | 57.6 ± 7.1 | 65.2 ± 7.6 |
| 1dil-TWW + Glu + 15N[e] | 0.516 | 100:15 | 0.23 | 81.3 ± 4.3 | 7.3 ± 1.8 | 65.9 ± 2.4 | 3.6 ± 0.8 | 8.7 ± 1.3 | 1.5 ± 0.0 | 8.8 ± 0.8 | 36.5 ± 4.1 | 48.9 ± 6.8 | 70.3 ± 7.0 |
| 2dil-TWW + Glu + 15N[f] | 0.516 | 100:15 | 0.23 | 79.6 ± 4.8 | 7.5 ± 1.4 | 66.1 ± 2.8 | 8.2 ± 1.2 | 8.2 ± 1.3 | 1.0 ± 0.0 | 8.7 ± 0.9 | 33.5 ± 3.1 | 45.1 ± 5.6 | 72.3 ± 6.5 |
| STWW[g] | 0.182 | 100:5 | 0.24 | 40.2 ± 3.4 | 3.5 ± 0.8 | 33.2 ± 4.6 | 1.3 ± 0.3 | 4.7 ± 0.3 | 0.0 ± 0.0 | 4.5 ± 0.1 | 8.2 ± 1.9 | 13.0 ± 0.9 | 84.3 ± 3.2 |
| 1dil-STWW[h] | 0.182 | 100:5 | 0.24 | 40.0 ± 2.5 | 1.1 ± 0.1 | 33.1 ± 3.6 | 0.0 ± 0.0 | 4.5 ± 0.4 | 0.0 ± 0.0 | 4.5 ± 0.3 | 5.3 ± 1.3 | 6.4 ± 0.7 | 92.2 ± 2.2 |
| 2dil-STWW[i] | 0.182 | 100:5 | 0.24 | 40.7 ± 2.5 | 0.9 ± 0.1 | 32.7 ± 3.9 | 0.0 ± 0.0 | 4.5 ± 0.7 | 0.0 ± 0.0 | 4.5 ± 0.1 | 3.8 ± 0.7 | 4.7 ± 0.6 | 94.3 ± 2.2 |
| STWW + 15N[j] | 0.546 | 100:15 | 0.24 | 81.3 ± 4.7 | 5.5 ± 1.3 | 65.5 ± 1.7 | 0.9 ± 0.1 | 8.7 ± 0.9 | 0.0 ± 0.0 | 8.8 ± 1.2 | 38.5 ± 3.4 | 44.9 ± 3.4 | 72.7 ± 7.7 |
| 1dil-STWW + 15N[k] | 0.546 | 100:15 | 0.24 | 82.4 ± 4.8 | 4.1 ± 0.9 | 65.2 ± 1.9 | 1.0 ± 0.1 | 8.4 ± 1.1 | 0.0 ± 0.0 | 8.7 ± 1.1 | 30.4 ± 2.9 | 35.6 ± 2.9 | 78.4 ± 6.6 |
| 2dil-STWW + 15N[l] | 0.546 | 100:15 | 0.24 | 81.6 ± 0.6 | 3.6 ± 0.7 | 64.8 ± 1.8 | 0.9 ± 0.1 | 8.6 ± 1.3 | 0.0 ± 0.0 | 8.8 ± 1.0 | 24.3 ± 2.4 | 28.8 ± 2.3 | 82.4 ± 6.8 |

[a] TWW + Glu: TWW containing 1,480 mg/L glucose.
[b] 1dil-TWW + Glu: one time diluted-TWW containing 1,480 mg/L glucose.
[c] 2dil-TWW + Glu: two times diluted-TWW containing 1,480 mg/L glucose.
[d] TWW + Glu + 15 N: TWW containing 1,480 mg/L glucose and 516 mg/L urea.
[e] 1dil-TWW + Glu + 15 N: one time diluted-TWW containing 1,480 mg/L glucose and 516 mg/L urea.
[f] 2dil-TWW + Glu + 15 N: two times diluted-TWW containing 1,480 mg/L glucose and 516 mg/L urea.
[g] STWW: STWW containing 160 mg/L mixed acid dyes.
[h] 1dil-STWW: STWW containing 80 mg/L mixed acid dyes.
[i] 2dil-STWW: STWW containing 40 mg/L mixed acid dyes.
[j] STWW + 15 N: STWW containing 182 mg/L urea.
[k] 1dil-STWW + 15 N: 1dil-STWW containing 546 mg/L urea.
[l] 2dil-STWW + 15 N: 2dil-STWW containing 182 mg/L urea.

#### 3.2.1. COD and $BOD_5$

COD and $BOD_5$ removal efficiencies were increased by the 516 mg/L urea additions ($BOD_5$:TN of 100:15). However, the system with TWWs + Glu + 15 N and STWWs + 15 N did not show any significant difference in the COD and $BOD_5$ removal efficiencies. The system with 2dil-TWW + Glu + 15 N and 2dil-STWW + 15 N showed high $BOD_5$ and COD removal efficiencies of 98 ± 2 and 96 ± 2%, and 98 ± 1 and 96 ± 1%, respectively (Table 4).

#### 3.2.2. Nitrogen compounds

TN removal efficiency was decreased by urea supplementation. The system with TWW + Glu and STWW showed high TN removal efficiencies of 82.2 ± 2.1 and 84.3 ± 3.2%, while they were only 65.2 ± 7.6 and 72.7 ± 7.7% with 2dil-TWW + Glu + 15 N and 2dil-STWW + 15 N, respectively. More than 90% of organic-N, $NH_4^+$–N, and $NO_2^-$–N were removed from the influents; but $NO_3^-$–N contents of the effluents with TWWs + Glu + 15 N and STWWs + 15 N were 3–4 times higher than influent $NO_3^-$–N (Table 5).

#### 3.2.3. Color intensity

Color removal efficiency was increased by urea supplementation. Moreover, the color removal efficiencies of the system with STWWs + 15 N were 5–10% higher than with TWWs + Glu + 15 N. The color removal efficiencies of the system with 2dil-TWW + Glu + 15 N and 2dil-STWW + 15 N were 90.9 ± 2.2% and 95.9 ± 3.1%, respectively (Table 4).

#### 3.2.4. Suspended solids

Effluent SS decreased by urea addition. SS content of the effluents with 2dil-TWWs + Glu + 15 N and 2dil-STWWs + 15 N were 31 ± 3 and 29 ± 3 mg/L, respectively, while they were 39 ± 3 and 32 ± 3 mg/L with TWW + Glu + 15 N and STWW + 15 N, respectively. However, the increase of $BOD_5$:TN from 100:5 to 100:15 did not show any significant effect on the effluent SS (Table 4).

#### 3.2.5. Bio-sludge performance

SVI increased by urea additions ($BOD_5$:TN of 100:15). SVI with 2dil-TWW + Glu + 15 N and 2dil-STWW + 15 N was 108 ± 6 and 130 ± 6 mL/g, respectively. Bio-sludge age with 2dil-TWW + Glu + 15 N was only 18 ± 1 d, but it was 22 ± 2 d with TWW + Glu + 15 N. However, with STWW + 15 N, 1dil-STWW + 15 N, and 2dil-STWW + 15 N, there was no significant difference in bio-sludge age (Table 4).

### 3.3. Effects of $BOD_5$:TN ratios on the efficiency and performance of the SBR system with 1dil-TWW

The SBR system was tested with 1dil-TWW + Glu containing various urea concentrations of 172, 344, 516, and 688 mg/L at HRT of 7.5 d (Table 1). The effects of various $BOD_5$:TN ratios on the system efficiency and performance are shown in Tables 6 and 7.

#### 3.3.1. COD and $BOD_5$

The system showed the highest COD and $BOD_5$ removal efficiencies (94 ± 1 and 95 ± 2%, respectively) with $BOD_5$:TN of more than 100:10 (Table 6).

#### 3.3.2. Nitrogen compounds

TN removal efficiency decreased with an increase in effluent TN (urea) concentration. The system with 1dil-TWW + Glu + 5 N gave the highest TN removal efficiency of 90.2 ± 2.1%, with the lowest TN removal efficiency (61.3 ± 3.3%) in 1dil-TWW + Glu + 20 N. Organic-N, $NH_4^+$–N, and $NO_2^-$–N in the effluents were rapidly removed, with high efficiencies of over 90%. The effluents' $NO_3^-$–N was increased with an increase of TN (urea) concentration. Effluent $NO_3^-$–N in the 1dil-TWW + Glu + 20 N ($BOD_5$:TN of 100:20) treatment was 69.3 ± 6.2 mg/L, as shown in Table 7.

#### 3.3.3. Color intensity

The system with 1dil-TWW + Glu + 10 N resulted in the highest color removal efficiency of 88.2 ± 2.3%. Unfortunately, the system did not show any significant increase in color removal efficiency with $BOD_5$:TN higher than 100:10 (Table 6).

#### 3.3.4. Suspended solids

In the system with 1dil-TWW at various $BOD_5$:TN ratios of 100:5–100:20, there was no significant difference in effluent SS (less than 30 mg/L) (Table 6).

#### 3.3.5. Bio-sludge performance

SVI of less than 100 mL/g was observed in $BOD_5$:TN of $\leq$100:15. Bio-sludge age of the system decreased with an increase in the ratio of $BOD_5$:TN;

Table 6
Removal efficiencies and performances of the SBR system with 1dil-TWW containing various types of carbon sources (glucose, noodle industrial wastewater and starch industrial wastewater), at various $BOD_5$:TN ratios (100:5, 100:10, 100:15, and 100:20), and at HRT of 5, 7.5, and 10 d

| Type of wastewater | HRT (days) | $BOD_5$:TN | Organic loading | Color intensity | | $BOD_5$ | | COD | | Effluent qualities | Bio-sludge qualities | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (kg $BOD_5$/$m^3$ d) | Effluent (unit/ml)[g] | Removal (%) | Effluent (mg/L) | Removal (%) | Effluent (mg/L) | Removal (%) | Effluent SS (mg/L) | Sludge age (days) | SVI (mg/L) |
| 1dil-TWW + Glu + 5N[a] | 7.5 | 100:5 | 0.23 | 0.13 ± 0.01 | 80.1 ± 2.3 | 85 ± 7 | 90 ± 3 | 149 ± 2 | 89 ± 2 | 33 ± 6 | 29 ± 3 | 87 ± 4 |
| 1dil-TWW + Glu + 10N[b] | 7.5 | 100:10 | 0.23 | 0.08 ± 0.01 | 88.2 ± 2.3 | 43 ± 5 | 95 ± 2 | 81 ± 4 | 94 ± 1 | 29 ± 2 | 20 ± 1 | 90 ± 3 |
| 1dil-TWW + Glu + 15N[c] | 7.5 | 100:15 | 0.23 | 0.07 ± 0.01 | 89.6 ± 2.1 | 43 ± 2 | 95 ± 1 | 68 ± 2 | 95 ± 2 | 35 ± 3 | 19 ± 1 | 96 ± 5 |
| 1dil-TWW + Glu + 20N[d] | 7.5 | 100:20 | 0.23 | 0.07 ± 0.01 | 90.2 ± 3.1 | 35 ± 1 | 96 ± 1 | 67 ± 3 | 95 ± 2 | 38 ± 3 | 17 ± 1 | 102 ± 3 |
| 1dil-TWW + Glu + 10N | 7.5 | 100:10 | 0.23 | 0.08 ± 0.01 | 88.2 ± 2.3 | 51 ± 5 | 94 ± 2 | 95 ± 2 | 93 ± 1 | 29 ± 2 | 20 ± 1 | 90 ± 3 |
| 1dil-TWW + NWW + 10N[e] | 7.5 | 100:10 | 0.23 | 0.09 ± 0.01 | 87.2 ± 2.1 | 68 ± 3 | 92 ± 2 | 175 ± 6 | 87 ± 3 | 32 ± 5 | 21 ± 1 | 93 ± 5 |
| 1dil-TWW + SWW + 10N[f] | 7.5 | 100:10 | 0.23 | 0.09 ± 0.01 | 87.4 ± 2.4 | 68 ± 3 | 92 ± 2 | 189 ± 8 | 86 ± 2 | 34 ± 3 | 22 ± 1 | 91 ± 5 |
| 1dil-TWW + Glu + 10N | 5.0 | 100:10 | 0.34 | 0.09 ± 0.01 | 85.7 ± 0.6 | 68 ± 2 | 92 ± 2 | 136 ± 2 | 90 ± 1 | 35 ± 3 | 17 ± 1 | 110 ± 7 |
| 1dil-TWW + Glu + 10N | 7.5 | 100:10 | 0.23 | 0.08 ± 0.01 | 88.2 ± 2.3 | 52 ± 5 | 94 ± 2 | 95 ± 4 | 93 ± 1 | 29 ± 2 | 20 ± 1 | 90 ± 3 |
| 1dil-TWW + Glu + 10N | 10.0 | 100:10 | 0.17 | 0.06 ± 0.01 | 91.1 ± 0.3 | 26 ± 1 | 97 ± 3 | 54 ± 3 | 96 ± 1 | 25 ± 2 | 22 ± 1 | 80 ± 3 |

[a]1dil-TWW + Glu + 5 N: one time diluted-TWW containing 1,480 mg/L glucose and 172 mg/L urea.
[b]1dil-TWW + Glu + 10 N: one time diluted-TWW containing 1,480 mg/L glucose and 344 mg/L urea.
[c]1dil-TWW + Glu + 15 N: one time diluted-TWW containing 1,480 mg/L glucose and 516 mg/L urea.
[d]1dil-TWW + Glu + 20 N: TWW containing 1,480 mg/L glucose and 688 mg/L urea.
[e]1dil-TWW + NWW + 10 N: one time diluted-TWW containing noodle industrial wastewater ($BOD_5$ of about 1,700 mg/L) and 344 mg/L urea.
[f]1dil-TWW + SWW + 10 N: one time diluted-TWW containing starch industrial wastewater ($BOD_5$ of about 1,700 mg/L) and 344 mg/L urea.
[g]Color intensity of TWWs and STWWs are represented as the optical density at wavelengths of 603 and 532 nm, respectively.

Table 7
Nitrogenous compound removal efficiencies of the SBR system with 1dil-TWW containing various types of carbon sources (glucose, noodle industrial wastewater, and starch industrial wastewater), at various $BOD_5$:TN ratios (100:5, 100:10, 100:15, and 100:20), and at HRT of 5, 7.5, and 10 d

| Type of wastewater | HRT (days) | $BOD_5$: TN | Organic loading (kg $BOD_5$/m$^3$ d) | Organic-N (mg/L) | | $NH_4^+$–N (mg/L) | | $NO_2^-$–N (mg/L) | | $NO_3^-$–N (mg/L) | | Total nitrogen | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Influent | Effluent | Influent | Effluent | Influent | Effluent | Influent | Effluent | Effluent (mg/L) | Removal (%) |
| 1dil-TWW + Glu + 5N[a] | 7.5 | 100:5 | 0.23 | 41.1 ± 2.4 | 1.4 ± 0.4 | 34.7 ± 3.7 | 0.2 ± 0.0 | 4.4 ± 0.2 | 0.0 ± 0.0 | 4.2 ± 0.0 | 6.7 ± 1.0 | 8.3 ± 0.2 | 90.2 ± 2.1 |
| 1dil-TWW + Glu + 10N[b] | 7.5 | 100:10 | 0.23 | 61.5 ± 4.9 | 3.2 ± 0.8 | 47.4 ± 4.4 | 1.1 ± 0.3 | 6.6 ± 0.2 | 0.0 ± 0.0 | 6.9 ± 0.5 | 13.6 ± 3.0 | 17.9 ± 3.0 | 85.4 ± 3.2 |
| 1dil-TWW + Glu + 15N[c] | 7.5 | 100:15 | 0.23 | 79.9 ± 5.8 | 6.5 ± 1.7 | 65.0 ± 4.5 | 1.2 ± 0.4 | 8.4 ± 1.3 | 0.0 ± 0.0 | 8.5 ± 1.2 | 38.6 ± 4.1 | 46.3 ± 7.2 | 71.4 ± 7.2 |
| 1dil-TWW + Glu + 20N[d] | 7.5 | 100:20 | 0.23 | 121.2 ± 5.3 | 18.7 ± 2.3 | 93.2 ± 5.4 | 3.9 ± 0.5 | 13.3 ± 2.2 | 1.0 ± 0.2 | 12.8 ± 1.2 | 69.3 ± 6.2 | 93.1 ± 9.2 | 61.3 ± 3.3 |
| 1dil-TWW + Glu + 10N | 7.5 | 100:10 | 0.23 | 61.1 ± 5.6 | 3.1 ± 0.4 | 44.6 ± 0.4 | 1.1 ± 0.2 | 6.2 ± 0.1 | 0.0 ± 0.0 | 6.9 ± 0.5 | 13.4 ± 2.2 | 17.6 ± 2.3 | 85.3 ± 3.5 |
| 1dil-TWW + NWW + 10N[e] | 7.5 | 100:10 | 0.23 | 62.2 ± 4.8 | 6.8 ± 0.8 | 47.9 ± 0.3 | 1.7 ± 0.2 | 6.8 ± 0.2 | 0.0 ± 0.0 | 6.4 ± 0.1 | 21.8 ± 2.7 | 30.3 ± 1.2 | 75.4 ± 5.5 |
| 1dil-TWW + SWW + 10N[f] | 7.5 | 100:10 | 0.23 | 62.9 ± 6.3 | 4.0 ± 0.7 | 46.2 ± 0.3 | 0.7 ± 0.1 | 6.5 ± 0.1 | 0.0 ± 0.0 | 6.3 ± 0.1 | 19.5 ± 1.9 | 24.1 ± 1.8 | 80.2 ± 4.2 |
| 1dil-TWW + Glu + 10N | 5.0 | 100:10 | 0.34 | 61.0 ± 2.3 | 6.1 ± 0.8 | 45.9 ± 0.6 | 4.1 ± 0.4 | 6.8 ± 0.3 | 1.0 ± 0.2 | 6.7 ± 0.5 | 24.9 ± 1.1 | 36.1 ± 1.8 | 70.0 ± 0.8 |
| 1dil-TWW + Glu + 10N | 7.5 | 100:10 | 0.23 | 60.5 ± 3.9 | 3.8 ± 0.7 | 46.1 ± 0.4 | 0.4 ± 0.0 | 6.8 ± 0.4 | 0.0 ± 0.0 | 6.2 ± 0.3 | 13.4 ± 0.6 | 17.6 ± 1.2 | 85.3 ± 1.2 |
| 1dil-TWW + Glu + 10N | 10.0 | 100:10 | 0.17 | 60.8 ± 2.2 | 4.0 ± 0.5 | 46.1 ± 0.5 | 1.2 ± 0.1 | 6.8 ± 0.4 | 0.0 ± 0.0 | 6.2 ± 0.2 | 10.5 ± 0.3 | 15.7 ± 0.7 | 86.9 ± 0.4 |

[a] 1dil-TWW + Glu + 5 N: one time diluted-TWW containing 1,480 mg/L glucose and 172 mg/L urea.
[b] 1dil-TWW + Glu + 10 N: one time diluted-TWW containing 1,480 mg/L glucose and 344 mg/L urea.
[c] 1dil-TWW + Glu + 15 N: one time diluted-TWW containing 1,480 mg/L glucose and 516 mg/L urea.
[d] 1dil-TWW + Glu + 20 N: TWW containing 1,480 mg/L glucose and 688 mg/L urea.
[e] 1dil-TWW + NWW + 10 N: one time diluted-TWW containing noodle industrial wastewater ($BOD_5$ of about 1,700 mg/L) and 344 mg/L urea.
[f] 1dil-TWW + SWW + 10 N: one time diluted-TWW containing starch industrial wastewater ($BOD_5$ of about 1,700 mg/L) and 344 mg/L urea.

the system with 1dil-TWW + Glu + 20 N ($BOD_5$:TN of 100:20) was 17 ± 1, as shown in Table 6. These results suggest that 1dil-TWW + Glu + 10 N might be a suitable treatment in a SBR system; however, the use of glucose to increase $BOD_5$ might be costly and impractical, so other types of carbon sources should be investigated further.

### 3.4. Effect of types of carbon source on SBR system efficiency and performance

Three types of carbon sources—glucose, SWW, and NWW—were used; the experiments were carried out in the SBR system at HRT of 7.5 d with 1dil-TWW containing the above three types of carbon source (final $BOD_5$ concentration of 1,700 ± 30 mg/L) and 344 mg/L urea (to adjust the $BOD_5$:TN to 100:10). The results are shown in Tables 6 and 7, and as follows.

#### 3.4.1. COD and $BOD_5$

The system with 1dil-TWW + Glu + 10 N showed the highest COD and $BOD_5$ removal efficiencies of 93 ± 1 and 94 ± 2%, respectively; while with 1dil-TWW + NWW + 10 N and 1dil-TWW + SWW + 10 N, they were 87 ± 3 and 92 ± 2% and 86 ± 2 and 92 ± 2%, respectively, as shown in Table 6. However, there was no significant difference among the three types of carbon sources on COD and $BOD_5$ removal efficiencies.

#### 3.4.2. Nitrogen compounds

TN removal efficiencies of the system with 1dil-TWW + Glu + 10 N, 1dil-TWW + NWW + 10 N, and 1dil-TWW + SWW + 10 N were 85 ± 3.5, 75.4 ± 5.5, and 80.2 ± 4.2%, respectively. About 95% of organic-N, $NH_4^+$–N, and $NO_2^-$–N were removed from the influents. $NO_3^-$–N in the effluents was about 2–3.5 times higher than influent $NO_3^-$–N. The system showed the lowest effluent $NO_3^-$–N of 13.4 ± 2.2 mg/L with 1dil-TWW + Glu + 10 N, while it was 21.8 ± 2.7 mg/L with 1dil-TWW + NWW + 10 N (Table 7).

#### 3.4.3. Color intensity

There was no significant difference in color removal efficiency of the SBR system with 1dil-TWW + 10 N containing various types of carbon sources, as shown in Table 6; the color removal efficiencies with 1dil-TWW + Glu + 10 N, 1dil-TWW + NWW + 10 N, and 1dil-TWW + SWW + 10 N were 88.2 ± 2.3, 87.2 ± 2.1, and 87.4 ± 2.4%, respectively.

#### 3.4.4. Suspended solids

Effluent SS with 1dil-TWW + Glu + 10 N was the lowest (29 ± 2 mg/L), followed by 1dil-TWW + NWW + 10 N and 1dil-TWW + SWW + 10 N at 32 ± 5 and 34 ± 3 mg/L, respectively (Table 6). However, there were no significant differences among the three types of carbon sources.

#### 3.4.5. Bio-sludge performance

The system did not show any significant difference in bio-sludge quality based on the type of carbon source. SVI with 1dil-TWW + Glu + 10 N, 1dil-TWW + NWW + 10 N, and 1dil-TWW + SWW + 10 N were 87 ± 8, 89 ± 5, and 90 ± 15 mL/g, respectively. Moreover, the SVI of the system with 1dil-TWW + SWW + 10 N fluctuated during operation, resulting in high ± SD of about 15%. The bio-sludge age of the system with 1dil-TWW + Glu + 10 N was the shortest (17 ± 1 d), while it was longest with 1dil-TWW + SWW + 10 N (20 ± 1 d) (Table 6).

### 3.5. Effects of HRT on the efficiency and performance of SBR system with 1dil-TWW+Glu+10N

The experiments were carried out with 1dil-TWW + Glu + 10 N at various HRTs of 5.0, 7.5, and 10.0 d (organic loading of 0.34, 0.23, and 0.17 kg $BOD_5/m^3$ d, respectively). The results are shown in Tables 6 and 7, and as follows.

#### 3.5.1. COD and $BOD_5$

The system with 1dil-TWW + Glu + 10 N at HRT of 10 d (organic loading of 0.17 kg $BOD_5/m^3$ d) demonstrated the highest COD and $BOD_5$ removal efficiencies (96 ± 1 and 97 ± 3%). $BOD_5$ and COD of the effluents were 26 ± 1 and 54 ± 3 mg/L, respectively (Table 6).

#### 3.5.2. Nitrogen compounds

TN removal efficiency increased with an increase in HRT. The system showed the lowest TN removal efficiency (70.0 ± 0.8%) at HRT of 5.0 d (organic loading of 0.34 kg $BOD_5/m^3$ d), while it was highest (86.9 ± 0.4%) at HRT of 10.0 d (0.17 kg $BOD_5/m^3$ d); more than 90% of the influents' organic-N, $NH_4^+$–N, and $NO_2^-$–N were removed. However, the effluent $NO_3^-$–N of the system increased with a decrease in HRT; effluent $NO_3^-$–N levels at HRT of 5.0 and 10.0 d were 24.9 ± 1.1 and 10.5 ± 0.3 mg/L, respectively (Table 7).

*3.5.3. Color intensity*

Color removal efficiency at the shortest HRT of 5.0 d (organic loading of 0.34 kg $BOD_5/m^3$ d) was 85.7 ± 0.6%, while it was 91.1 ± 0.3% at the longest HRT of 10.0 d (organic loading of 0.17 kg $BOD_5/m^3$ d) (Table 6).

*3.5.4. Suspended solids*

The effluent SS of the system decreased with an increase in HRT. Effluent SS levels at HRTs of 5.0 and 10.0 d (organic loading of 0.34 and 0.17 kg $BOD_5/m^3$ d, respectively) were 35 ± 3 and 25 ± 2 mg/L, respectively (Table 6).

*3.5.5. Bio-sludge performance*

SVI at HRT of 5.0 and 10.0 d (organic loading of 0.34 and 0.17 kg $BOD_5/m^3$ d, respectively) was 36 ± 7 and 58 ± 7 mL/g, respectively. Also, the bio-sludge age of the system increased with an increase in HRT or a decrease in organic loading. Bio-sludge age at the shortest HRT of 5.0 d (organic loading of 0.34 kg $BOD_5/m^3$ d) was only 17 ± 1 d, while it was 22 ± 1 d at the longest HRT of 10.0 d (organic loading of 0.17 kg $BOD_5/m^3$ d) (Table 6).

## 4. Discussion

TWW collected from Samut Prakan province contained acid red 9 and acid blue 18. Its color intensity was measured as an absorbance of 1.324 units/mL at 603 nm. According to our previous reports [11,12,30], a biological treatment process, especially a SBR system, could be used for treatment of TWW. However, the removal efficiencies are quite low due to low organic matter content [2,11,17,24,34,35]. It was confirmed that the organic matter content, especially $BOD_5$, of TWW was only 150 ± 11 mg/L. Moreover, it has been shown that TWW containing a high concentration of mixed acid dyes of more than 160 mg/L (color intensity of 1.324 units/mL at 603 nm) might repress the activity and growth of bio-sludge in a SBR system [2,9,10,17,30,35]. Also, some chemical agents contained in TWW might be toxic to bio-sludge [2,30]. Further experiments on the treatment of TWW and STWW containing various concentrations of mixed acid dyes (mixture of acid red 9 and acid blue 18) were then carried out in a SBR system in order to confirm the above observation. Also, various types of carbon sources—glucose, SWW, and NWW—were tested. The results showed that a mixed acid dye concentration of 160 mg/L did not have any significant effect on $BOD_5$ and COD removal efficiencies; however, it could reduce the color and TN removal efficiencies. Moreover, the bio-sludge age of the system decreased with a decrease in mixed acid dye concentration. The above results were similar to our previous findings that SBR system removal efficiencies with TWW containing disperse dyes or direct dyes decreased with an increase of dye concentration [11,12,25,30]. These results suggest that acid dye has a strong effect on denitrifying bacteria, but does not affect heterotrophic bacteria [24,27,30]. The color and TN removal efficiencies of the system with TWWs were lower than with STWWs, but there was no significant difference in COD and $BOD_5$ removal efficiencies. This could be explained by the presence of toxic substances in TWW which might repress the growth and activities of nitrifying and denitrifying bacteria, which are the main microbial groups responsible for color removal [12,25,30]. This suggests that for efficient application of a SBR system, TWW must be diluted and supplemented with carbon and nitrogen sources before treatment. In addition, it has been found that system efficiency increases with an increase in TN concentration [10,17,18,22,23,30]. Unfortunately, the SVI of the system with STWWs was higher than that with TWWs as a result of shorter bio-sludge age (the bio-sludge of the system with STWW was in the log phase or early stationary phase) [2]. TN removal efficiencies for TWWs with low concentrations of TN (BOD:TN $\leqslant$ 100:10) were higher than 80%; also, more than 90% of organic-N, $NH_4^+$–N, and $NO_2^-$–N were removed, with low $NO_3^-$–N accumulation. This indicates that acid dye may be more effective in repressing the growth and activity of denitrifying bacteria than of nitrifying bacteria [12,30]. Also, the color removal capacity increased with a decrease in bio-sludge age (growth association mechanism). This strongly confirmed that the color removal yield was decreased by the increase of $BOD_5$:TN [2,3,16,22,36]. Unfortunately, the effluent $NO_3^-$–N with 1 dil-TWW + Glu + 20 N was 10 times higher than with 1 dil-TWW + Glu + 5 N. The existing theory indicates that influent TN is removed by assimilation and oxidation–reduction mechanisms. The increase of influent TN can stimulate or increase the number of nitrifying and denitrifying bacteria; organic-N and $NH_4^+$–N are converted to $NO_3^-$–N by nitrifying bacteria under oxic conditions, and $NO_3^-$–N is converted to $N_2$ by denitrifying bacteria under anoxic conditions. Thus, to reduce the effluent $NO_3^-$–N of the SBR system, the HRT of the system (or the anoxic step) should be increased where would result in an increase in the number and activity of denitrifying bacteria [2,36–40]. Moreover, increasing the number of nitrifying and denitrifying bacteria would provide other advantages since the reduction of SVI results in an increase of bio-sludge age. This was confirmed by the results of the system with 1dil-TWW + Glu + 20 N at 5 and 7 d, which showed bio-sludge ages of only 17 ± 1 and 22 ± 1 d, respectively. This suggests that the system with 1dil-TWW + Glu + 10 N should operate at a HRT of 7.5–10 d (organic loadings of 0.17–0.23 kg $BOD_5/m^3$ d). However, the use of glucose as a supplemented carbon source might be costly and impractical. Therefore, other carbon sources—especially starch and NWW—were investigated. The results showed that both SWW and NWW could be used as a carbon source instead of glucose, without any significant effect on color removal efficiency; however, TN removal efficiencies of the system with 1dil-TWW + NWW + 10 N and 1dil-TWW + SWW + 10 N were about 15% lower than with 1dil-TWW + Glu + 10 N.

## 5. Conclusions

A biological treatment process, especially a SBR system, could be used for treatment of TWW after one fold dilution, and supplementing with carbon and nitrogen sources. This treatment would be required since the bio-sludge of the system could be adversely affected by the high acid dye concentration (the color intensity of TWW is represented by an optical density of 1.324 ± 0.2 units/mL at 603 nm) and low $BOD_5$ of 150 ± 11 mg/L. The system with 1dil-TWW + Glu + 10 N at 10 d HRT (organic loading of 0.17 kg $BOD_5/m^3$ d) showed optimal COD, $BOD_5$, TN, and color removal efficiencies of 96 ± 1, 97 ± 3, 86.9 ± 0.4, and 91.1 ± 0.3%, respectively, with a good quality of bio-sludge (SVI of 80 ± 3 mL/g and bio-sludge age of 22 ± 1 d). Mixed acid dyes of up to 160 mg/L strongly affected denitrifying bacteria, but they did not have any significant effect on heterotrophic bacteria. Moreover, SWW and NWW could be used as carbon sources instead of glucose, resulting in a reduction of the operating cost. For efficient application of SBR to treat textile wastewater containing acid dyes, careful consideration should be given to selection of the optimal HRT, organic loading, and nitrogen content. The system should operate at an HRT of $\geq$7.5 d or organic loading of $\leq$0.23 kg $BOD_5/m^3$ d. In conclusion, this study showed that the SBR system could be applied for treatment textile wastewater containing mixed acid dyes at the concentration of $\leq$80 mg/L under the organic loading of 0.17–0.23 kg $BOD_5/m^3$ d and $BOD_5$: TN ratio of 100:10 with high removal efficiency.

## Acknowledgment

This work was supported by the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission. Also, sincere thanks is given to the National Research Council of Thailand, and to the Department of Environmental Technology, School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi, for research equipment.

## Nomenclature

| | | |
|---|---|---|
| $BOD_5$ | — | biochemical oxygen demand |
| COD | — | chemical oxygen demand |
| HRT | — | hydraulic retention time |
| Glu | — | glucose |
| N | — | nitrogen |
| $NH_4^+$–N | — | ammonia |
| $NO_2^-$–N | — | nitrite |
| $NO_3^-$–N | — | nitrate nitrogen |
| NWW | — | noodle industrial wastewater |
| Organic-N | — | organic nitrogen |
| SBR | — | sequencing batch reactor |
| SRT | — | solid retention time |
| SS | — | suspended solids |
| STWW | — | synthetic textile wastewater |
| STWWs | — | various types of synthetic textile wastewater |
| SVI | — | sludge volume index |
| TN | — | total nitrogen |
| TWW | — | textile wastewater |
| TWWs | — | various types of textile wastewater |
| SWW | — | starch industrial wastewater |

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