

# Effects of Fermented Leachate of Food Waste (FLFW) and Temperature on Nutrient Removal in Sequencing Batch Reactor

Sung-Hee Roh, Young-Nam Chun<sup>1</sup>, Sook-Young Lee<sup>2</sup>, Hyeonsook Cheong<sup>3</sup>,  
Jae-Wook Lee, and Sun-Il Kim<sup>†</sup>

*Department of Chemical and Biochemical Engineering, Chosun University, Gwangju 501-759, Korea*

<sup>1</sup>*BK21 Team for Hydrogen Production · Department of Environmental Engineering, Chosun University, Gwangju 501-759, Korea*

<sup>2</sup>*Research Center for Proteinous Materials, Chosun University, Gwangju 501-759, Korea*

<sup>3</sup>*Department of Genetic Engineering, Chosun University, Gwangju 501-759, Korea*

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## Abstract

This study examined effects of the fermented leachate of food waste (FLFW) on nitrogen and phosphorous removal for domestic wastewater containing a low carbon-to-nitrogen (C/N) ratio in sequencing batch reactor (SBR). When the FLFW was not supplied in the process, release of phosphorus and excessive intake was not observed at both anaerobic and aerobic stages. On the other hand, when the FLFW was gradually added, active release of phosphorus and intake of phosphorus was noticed at an anaerobic stage and aerobic stage, respectively, resulting in improved phosphorus removal efficiency. The removal efficiency of nitrogen and phosphorus was increased from 75% and 37% (R-1, control test) to 97% and 80% (R-4, the highest substrate ratio test), respectively. In addition, although activity of the nitrogen oxidizing microorganisms was reduced when the reaction temperature was decreased to 10°C, the phosphorus removal efficiency was shown to increase with the addition of FLFW, indicating an independence from temperature. Overall, this study suggests that an efficient nutrients removal process can be successfully employed into a SBR when the FLFW is added to a wastewater which has a low C/N ratio.

**Keywords:** Food waste, Fermented leachate, Nitrogen removal, Phosphorus removal

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## 1. Introduction

The sequencing batch reactor (SBR) is a modified form of the activated sludge process, which enables the consecutive fill, reaction, aeration, precipitation and draw stage without requiring a secondary precipitation tank. Nitrification and denitrification occur during the aeration stage and the anoxic phase at the non-aeration stage, respectively. The SBR has the same dynamics force as a plug flow system. When operated with multiple SBR, it can achieve similar to efficiency that of a continuous flow stirred tank reactor (CFSTR).<sup>1)</sup>

Recently, the SBR has been widely used to remove the biological nutrients present in urban sewage, industrial wastewater and domestic wastewater.<sup>2-4)</sup> It is essential that the carbon-to-nitrogen (C/N) ratio of the influent is adequately maintained to obtain the satisfactory water-quality in the biological waste-

water treatment process. The low efficiency of the biological nutrients removal (BNR) process adopted in Korea has been attributed to the insufficient carbon source that is essential for the removal of nitrogen and phosphorus. In addition, most of the urban sewage does not contain enough dissolved organic matter such as acetic acid, propionic acid and butyric acid, which is a limiting factor for the biological advanced wastewater treatment processes. In the USA, practical technologies for the anoxic/oxic (A/O) process and its modified processes have been developed.<sup>5)</sup> In South Africa, sewage disposal plants are adopting various advanced biological wastewater treatment processes through the University of Cape Town (UCT).<sup>6)</sup> However, in Korea, supplementation with external carbon sources is essential when these foreign processes are used to remove biological nutrients from urban sewage with a low C/N ratio. Furthermore, extreme temperatures inhibit the growth rate of nitrogen reducing bacteria.<sup>7)</sup> More specifically, nitrification rates in wastewater become inhibited at water temperatures of about 10°C and rates drop rapidly at 6°C.<sup>8)</sup> Phosphorous removal is affected less because

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<sup>†</sup> Corresponding author

E-mail: sibkim@chosun.ac.kr

Tel: +82-62-230-7219, Fax: +82-62-230-7226

it is dominated by sediment adsorption as opposed to biological processes. Many treatment wastewaters in temperate climates often operate at a much lower level of nutrient removal efficiency in the colder months.<sup>7)</sup>

When an ordinary biological process is used to remove phosphorus, it is vital that an external carbon source should be supplied to maintain the adequate carbon-to-phosphorus (C/P) ratio to provide the optimal growth conditions of phosphorus removal microorganisms.<sup>9-12)</sup> The phosphorus removal organisms using the energy generated from the hydrolysis of intra-cellularly stored poly-P at the anaerobic stage can continually consume organic acid. They are also capable of transforming organic acid into poly- $\beta$ -hydroxyl butyrate (PHB) for energy storage within the cells. When they are in the aerobic phase, the released phosphorus is stored again in the form of poly-P, and the PHB generated in the anaerobic stage is hydrolyzed and utilized as energy. Therefore, the formation of PHB and poly-P is considered an important feature in the phosphorus removal mechanism.<sup>13)</sup> Recently, many studies have examined the possibility of using acetic acid and methanol as external carbon sources for removing biological nutrients. However, there is a difficulty in pH adjustment when using acetic acid. Methanol is also known to create problems in flexibility of sludge and slow denitrification.<sup>14-17)</sup>

Consequently, if the organic acid obtained from the fermentation of food waste is added as an alternative external carbon source during the processing of the urban sewage, it is expected that the food waste disposal problem can be solved effectively, allowing for the removal of biological nutrients at a lower cost. In addition, food waste can be fermented and dehydrated by the existing sludge process without additional cost, and the dehydrated low-salt sludge can also be used as a soil conditioner. Therefore, the combined treatment of food waste and wastewater can be considered an effective method for maximizing the use of organic waste while at the same time minimizing the level of environmental pollution. The aim of this study is to identify an external carbon source to remove biological nutrients in the SBR, and to determine the effects of the fermented leachate of food waste (FLFW) on the removal efficiency of organic matter, nitrogen and phosphorus, from the wastewater with a low C/N ratio as a function of the FLFW volumes.

## 2. Experimental Methods

### 2.1. FLFW and Wastewater

FLFW was made from the food waste collected from the restaurants at a university located in Gwang-Ju, South Korea.<sup>18)</sup> The food waste was fermented using a Bio G-8 batch top fermentation system (5 L) at Hanil R & D. The fermenter was operated under the following conditions: a temperature of 30°C ( $\pm 2^\circ\text{C}$ ) with constant stirring at 80 rpm for 10 days. The pH of the waste was not adjusted during this period. When the organic acid had reached the desired fermentation state, it was centrifuged for 10 min at 4000 rpm, and the supernatant was stored at 4°C in a refrigerator. For the experiment, the synthetic waste-

Table 1. Characteristics of the FLFW and influent used in the experiment

Components		FLFW	Wastewater
COD (mg/L)	Total	34,530	222
	Soluble	26,800	160
SS (mg/L)	Total	4,545	Not detected
	Soluble	3,920	Not detected
Nitrogen (mg/L)	TKN	1,680	85
	$\text{NH}_4^+\text{-N}$	665	50
Phosphorus (mg/L)	T-P	130	16
	$\text{PO}_4^{3-}\text{-P}$	32	10
VFAs as COD (mg/L)		9,802	Not detected
pH		$4.5 \pm 0.2$	$7.1 \pm 0.2$
Alkalinity as $\text{CaCO}_3$ (mg/L)		-	150

water was prepared. COD, N, P concentrations were analyzed to in order to retain the constant concentration of the target substances. The characteristics of the FLFW and influent used in the experiment are shown in Table 1.

### 2.2. Experimental Set-up for SBR

The reactor, which was made from acrylic materials and capable of holding a total volume of 5 L, was equipped with four cylindrical containers. Fig. 1 shows the sequencing batch reactor system. Each process reactor was equipped with an agitator and air diffuser to facilitate easy mixing and aeration, and also equipped with a timer in the control pump to allow the self operation of the influent and effluent. The activated sludge was prepared using the return sludge from the sewage treatment plant after acclimatized in the synthetic substrate for one month. The sludge was seeded in each reactor with a separate volume of MLSS 3000 mg/L. The effective volume of the reactor with a total volume of 5 L was set to 3 L, and 1.5 L of the sludge was filled and drained during each operation cycle. The hydraulic retention time (HRT) and the solid retention time (SRT) of the SBR were maintain at 48 hr and 20 days, respectively. The unit operation cycle of the SBR was completed in 24 hr (0.5 hr fill, 4.5 hr anaerobic, 8.5 hr 1<sup>st</sup> aerobic, 4 hr anoxic, 4 hr 2<sup>nd</sup> aerobic, 2 hr

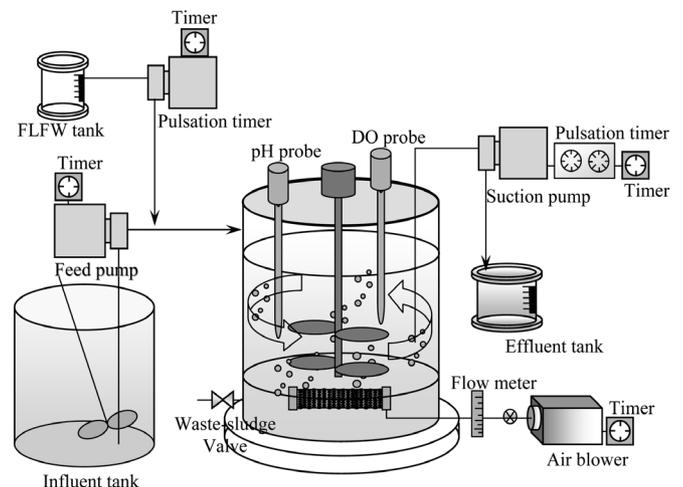


Fig. 1. Schematic diagram for the sequencing batch reactor system.

settling, and 0.5 hr draw). FLFW was added to each reactor with the exception of one control reactor at the early anoxic stage, maintaining a C/N ratio of the influence substrate at 3(R-1). The volume of FLFW was increased in stages commensurate with the C/N ratio of 6(R-2), 12(R-3), and 18(R-4), respectively, inside the reactor. Changes in DO, pH and nutrients at each operation stage under different conditions were observed with the addition of FLFW as an external carbon source. We recorded the removal characteristics of the organic matter and nutrients that depended on the changes in the dosage of FLFW and temperature at each reactor. Also, we investigated the removal efficiency of organic matter and nutrients under different reaction temperatures ranging from 10 to 30°C at each SBR as a function of the FLFW dosage.

### 2.3. Analytical Method

The initial 150 mL of the sample was circulated through the sample port in each reactor. All measurements were carried out according to the standard method.<sup>19)</sup> Table 2 shows the method and equipment used for analysis.

Table 2. Analytical method and instruments

Item	Method & Instrument
pH	pH meter (Conning pH meter 440)
DO	DO meter (Orion model 810)
COD	Closed reflux calorimetric method (Hach DR-2000)
TKN	Standard methods (UV spectrometer, Shimadzu)
NH <sub>4</sub> <sup>+</sup> -N	Standard methods (UV spectrometer, Shimadzu)
NO <sub>3</sub> <sup>-</sup> -N	Standard methods (UV spectrometer, Shimadzu)
T-P	Standard methods (UV spectrometer, Shimadzu)
PO <sub>4</sub> <sup>3-</sup> -P	Standard methods (UV spectrometer, Shimadzu)
VFAs	Chromatographic method (HPLC, Aminex HPX column)

## 3. Results and Discussion

### 3.1. Behaviors of pH and DO

For the simultaneous removal of nitrogen and phosphorus in the SBR, it is essential to maintain an adequate DO and pH under different operation conditions. In the biological nutrients removal process, it is also necessary that the concentration of DO be maintained below 0.3 mg/L in order for the phosphorus removal bacteria to achieve an easy release of phosphorus at the anaerobic stage, while for limiting the denitrification reaction the DO concentration at the anoxic stage should be kept below 0.2 mg/L.<sup>20,21)</sup> Fig. 2 shows the behavior of DO at each operation stage during the unit cycle under different conditions. It was found that oxygen is not an impeding factor in the phosphorus release and the denitrification mechanism because the stable DO concentration at the early reaction stage was maintained at < 0.1 mg/L at the anaerobic and the anoxic stages see the cases of R-1 without FLFW and R-3 with FLFW. The changes of pH during the unit cycle under the different conditions showed that the pH of R-1 without FLFW had decreased from pH 7.3 at the early aerobic stage to pH 6.5 immediately at the end of the aerobic stage. In the case of R-3 with FLFW, the pH

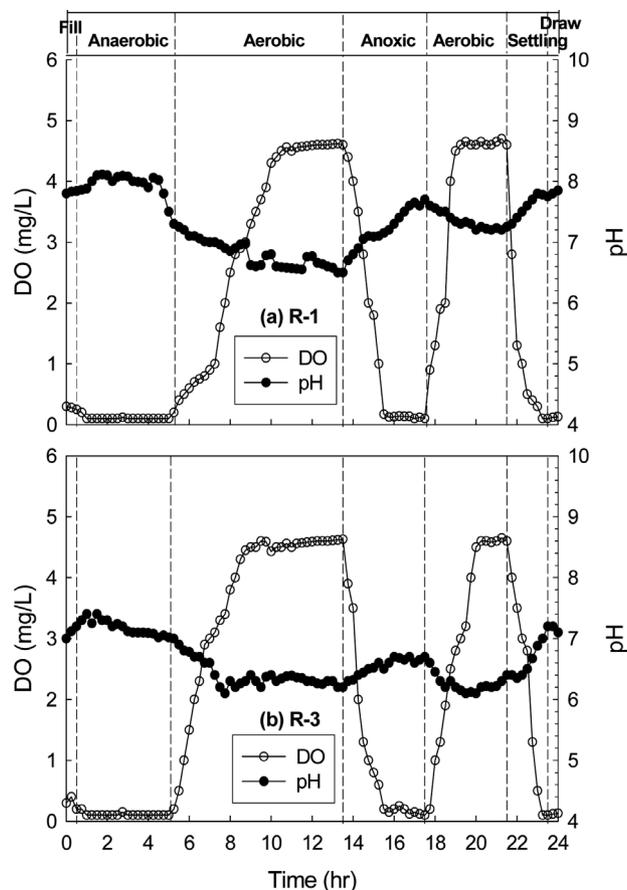


Fig. 2. Temporal variation DO and pH in a cycle; (a) R-1, (b) R-3.

decreased from pH 7.0 to pH 6.2. All these changes in pH are attributed to a decrease in pH caused by the generation of H<sup>+</sup> during the nitrification reaction at the aerobic stage. An increase in pH as a result of denitrification at the early anaerobic stage was followed by a decrease in pH because of the generation of volatile fatty acids (VFAs). For R-2 and R-4 with FLFW, the behaviors of pH and DO at each operation stage during the unit cycle were similar to that in the case of R-3. Therefore, it is believed that pH is an important factor in the nutrient removal process of wastewater with a high concentration of nitrogen sources.

### 3.2. Effect of FLFW Addition on Organic Matter Removal

The components of SCOD in the effluent treated by the biological treatment process are not the partial residue of the biodegradable organic matter, but they are either nonbiodegradable organic matter or regenerated during the metabolic process of the microorganisms.<sup>22,23)</sup> Fig. 3 shows the changes in the SCOD concentration as a function of the distribution time per cycle at each SBR depending on the dosage of FLFW. The average SCOD concentration at each SBR of R-1, R-2, R-3 and R-4 at the early anaerobic stage are 56 mg/L, 58 mg/L, 60 mg/L and 63 mg/L, respectively, while the effluent after the aerobic stage are 28 mg/L, 29 mg/L, 31 mg/L and 36 mg/L, respectively. This indicates that the SCOD concentration of the effluent increased in proportion to the FLFW dosage. This also implies that the

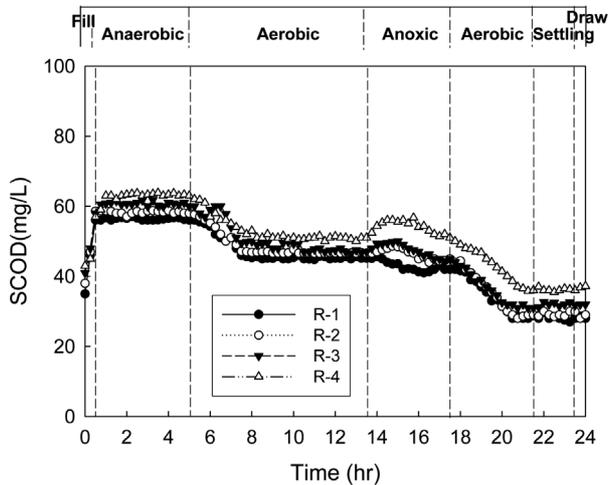


Fig. 3. Temporal variation in the SCOD concentration in a cycle.

nonbiodegradable organic matter present in FLFW increase with the increase in FLFW dosage. It is also thought that insufficient time for aeration after the anoxic stage is the cause of the incomplete decomposition of the organic matter resulting in the increase in the SCOD concentration of the effluent. In the case of R-4, it was found that the addition of FLFW with a high C/N ratio contributes to the increase in the SCOD concentration at the anoxic stage. This suggests that the FLFW contains a large amount of nonbiodegradable organic matter.

### 3.3. Effect of FLFW Addition on Nutrient Removal

In the biological process, the removal of nitrogen is achieved through the processes of nitrification and denitrification. Previous studies suggest that cellular metabolism of micro organisms, pH, DO, temperature, SRT, C/N ratio, concentration of  $\text{NO}_x\text{-N}$  and the species of carbon sources are the dominant factors affecting nitrification and denitrification.<sup>24)</sup> Fig. 4 shows the behavior of  $\text{NO}_3^-\text{-N}$  and  $\text{NH}_4^+\text{-N}$  as a function of the distribution time of unit cycle in each SBR in proportion to the FLFW dosage. The concentration of  $\text{NO}_3^-\text{-N}$  decreased with an increasing FLFW dosage in the anoxic stage (Fig. 4(a)). The concentration of  $\text{NH}_4^+\text{-N}$  was high at the anaerobic stage, but the initiation of aeration-induced nitrification increased the removal efficiency of  $\text{NH}_4^+\text{-N}$ . At each SBR of R-1, R-2, R-3 and R-4, the average  $\text{NH}_4^+\text{-N}$  concentrations at the anaerobic stage were 20 mg/L, 23 mg/L, 26 mg/L and 28 mg/L, respectively, and 11 mg/L, 8 mg/L, 2 mg/L and 2 mg/L after the aerobic stage, respectively (Fig. 4(b)). It is suggested that the high removal efficiency of  $\text{NH}_4^+\text{-N}$  at the aerobic stage is attributed to nitrification and the cellular metabolism.

Fig. 5 shows the behavior of phosphorus with the distribution time at the unit cycle in the SBR as a function of the FLFW dose. R-1 without FLFW did not show any phosphorus release or excessive intake at the anaerobic and aerobic stages, but R-2, R-3 and R-4 with FLFW showed active biological removal, which increased with FLFW volume. The C/P ratios of the substrate used in each SBR of R-1, R-2, R-3 and R-4 were 15, 30, 60 and 90, respectively, and the increase in the C/P ratio induced

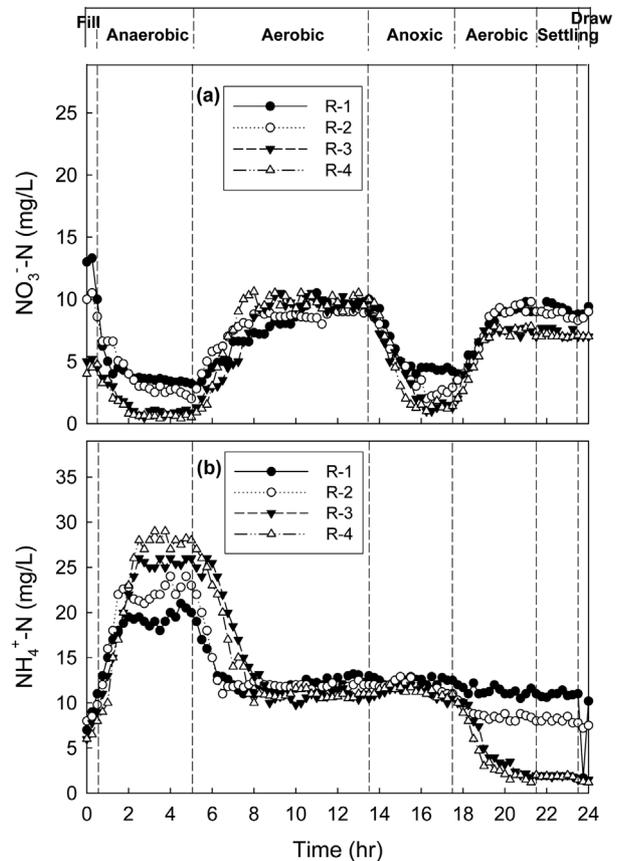


Fig. 4. Temporal variation in the  $\text{NO}_3^-\text{-N}$  concentration and  $\text{NH}_4^+\text{-N}$  concentration in a cycle; (a)  $\text{NO}_3^-\text{-N}$ , (b)  $\text{NH}_4^+\text{-N}$ .

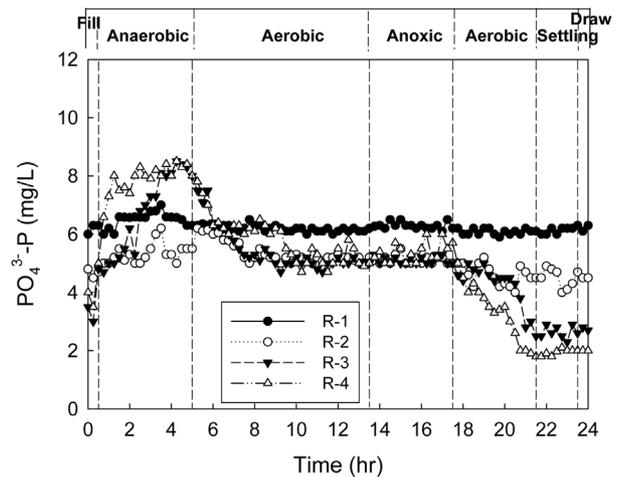


Fig. 5. Temporal variation in the  $\text{PO}_4^{3-}\text{-P}$  concentration in a cycle.

the active release of phosphorus at the anaerobic stage. In addition, the intake of phosphorus at the aerobic stage improved the phosphorus removal efficiency but decreased the average phosphorus concentration of the effluent to 6.3 mg/L, 4.5 mg/L, 2.7 mg/L and 2.0 mg/L, respectively. This suggests that, since the biological release of phosphorus is performed by the intake of biodegradable COD (BDCOD) at the anaerobic stage, BDCOD is essential for achieving an effective release of phosphorus. Moreover, a higher C/P ratio improves the phosphorus removal efficiency, which concurs with the results reported by Meinhold

Table 3. Nutrient removal efficiencies of various carbon sources

Carbon source	Nitrogen Removal efficiency (%)	Phosphorus Removal efficiency (%)	Reference
Centrifugal decanter	90.1	-	Kim <sup>26)</sup>
Mixture (50/50) of glucose and acetate	87	90	Kargi et al. <sup>27)</sup>
Hydrolyzed molasses	91.6±1.6	-	Quan et al. <sup>28)</sup>
Methanol	85.3±2.0 70.37	- -	Quan et al. <sup>28)</sup> Tam et al. <sup>29)</sup>
Fermented swine wastes	90	89	Lee et al. <sup>24)</sup>
Condensate of food waste	81	91	Chae et al. <sup>30)</sup>
FLFW	97	80	* This study

et al.<sup>25)</sup> Despite the sufficiently high C/P ratio of 90 for R-4, however, the effluent concentration was similar to the C/P ratio of 60 for R-3. This shows that PHB formation by organic matter was impeded at the anaerobic stage. The results of this study were summarized and compared to the results of previous studies (Table 3). The nutrient removal using FLFW was comparable to the values achieved with various carbon source as reported by previous researchers.<sup>24,26-30)</sup>

### 3.4. Effect of Reaction Temperature on Organic Matter Removal

As shown in Fig. 6, R-1 without FLFW achieved a SCOD removal efficiency of 72% at a reaction temperature of 20~30°C, and a slight decrease to 70% at 10°C. In the cases of R-2, R-3 and R-4 with FLFW, the SCOD removal efficiency remained at 71%, 69% and 65% at 20~30°C, respectively, and slightly decreased to 69%, 68% and 63% at 10°C, respectively. This indicates that a decrease in the reaction temperature suppresses the activities of the microorganisms resulting in a lower SCOD removal efficiency.

### 3.5. Effect of Reaction Temperature on Nutrient Removal

As shown in Fig. 7, the removal efficiencies of  $\text{NH}_4^+\text{-N}$  in each SBR of R-1, R-2, R-3 and R-4 depending on the FLFW volume were 75%, 91%, 96% and 97%, at 20~30°C, respectively, but considerably decreased to 50%, 55%, 60% and 65%, respectively, at 10°C. This indicates that the biological release of nitrogen is largely dependent on the reaction temperature. This result is in accordance with Eckenfelder et al.,<sup>31)</sup> who suggests that nitrification is achieved at temperatures ranging from 5~45°C, and the optimum temperature range for nitrification is 25~35°C.

As shown in Fig. 8, R-1 without FLFW achieved a dissolved phosphorus removal efficiency of 37% at 20~30°C, and decreased to 32% at 10°C, while the dissolved phosphorus removal efficiency of R-2, R-3 and R-4 with FLFW increased to 55%, 75% and 80% at 20~30°C, respectively, in proportion to the FLFW dosage, and 51%, 72% and 77% at 10°C, respectively. This shows that the removal of phosphorus is relatively independent of temperature. Therefore, it is evident that FLFW, as

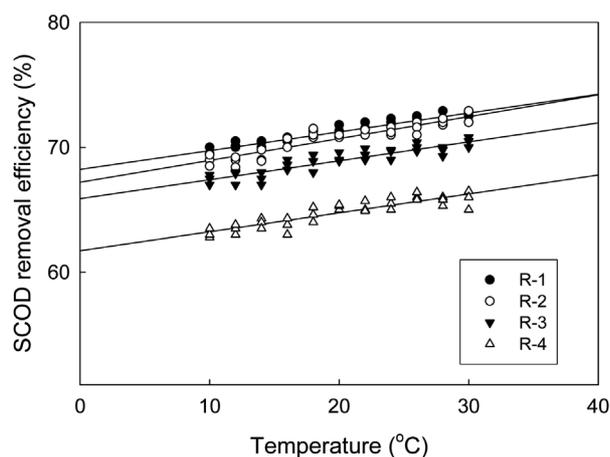


Fig. 6. Variations in the SCOD removal efficiency according to the operating temperature.

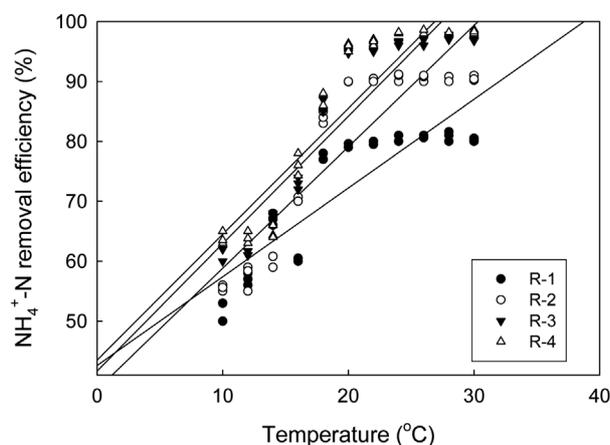


Fig. 7. Variations in the  $\text{NH}_4^+\text{-N}$  removal efficiency according to the operating temperature.

an external carbon source, can be effectively utilized to remove the organic matter and nutrients, and temperature has a larger effect on the nitrification bacteria rather than the denitrification bacteria. Thus, it is concluded that the phosphorus removal efficiency is strongly affected by the changes in the SRT or BDCOD concentration.<sup>24)</sup>

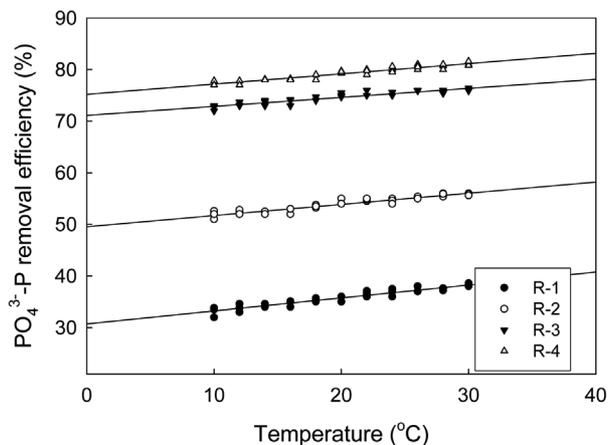


Fig. 8. Variations in the  $\text{PO}_4^{3-}\text{-P}$  removal efficiency according to the operating temperature.

#### 4. Conclusions

This study examined the removal efficiency of organic matter, nitrogen and phosphorus in the SBR as a function of FLFW dosage and reaction temperature. Each SBR was dependent on the FLFW dosage. The concentration of SCOD of the effluent increased with the increasing level of the nonbiodegradable organic matter present in FLFW. The  $\text{NO}_3^- \text{-N}$  concentration decreased with an increase of FLFW dosage at the anoxic stage. The  $\text{NH}_4^+ \text{-N}$  concentration increased at the anaerobic stage, but the removal efficiency of  $\text{NH}_4^+ \text{-N}$  increased during the process of nitrification after the start of aeration. This suggests that the high removal efficiency of  $\text{NH}_4^+ \text{-N}$  at the aerobic stage is attributed to the nitrification and the cellular metabolism. When the FLFW was not supplied in the process, the release of phosphorus and the excessive intake was not observed at the anaerobic and aerobic stages. However, the active release of phosphorus at the anaerobic stage and the intake of phosphorus at the aerobic stage was noticed when FLFW was added, resulting in an improved phosphorus removal efficiency. The removal efficiency of SBR was dependent on the reaction temperature. The nitrification bacteria were more sensitive to low temperatures at 10°C than the denitrification bacteria, which led to the suppression of the bacterial activities. On the other hand, the SCOD and phosphorus removal efficiency were barely affected by the reaction temperature, indicating that they are more dependent on the SRT or the BDCOD concentration than the reaction temperature.

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