

Biological nutrient removal with volatile fatty acids from food wastes in sequencing batch reactor

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Abstract—Volatile fatty acids (VFAs) derived from food waste were used as an alternative carbon source in biological nutrient removal. The pH Profiles were monitored during the nutrient removal in an Na-acetate fed sequencing batch reactor (SBR) (C source). Effluent N, P and SCOD concentrations of 0.5 and 0.1 mg/L were achieved with 5.5 hour of HRT (hydraulic retention time) when influent concentrations of $\text{NH}_4^+\text{-N}$, PO_4^{3-} and SCOD were 42.5, 5.92 and 180 mg/L. Then the SBR was fed with four solutions of VFAs produced under different acidogenesis conditions of food wastes. VFAs-added SBR showed similar specific nitrification rates (3.0 to 3.9 mg-N/g MLSS·h) to that of acetate, but specific denitrification rates (3.2 to 4.2 mg $\text{NO}_3^-\text{-N/g MLSS·h}$) were slightly lower than with acetate of 4.67 mg $\text{NO}_3^-\text{-N/g MLSS·h}$. VFAs-introduced SBR efficiently removed phosphorus except when the SBR was fed with a VFA-solution containing high amounts of valerate and caproate.

Key words: Biological Nutrient Removal (BNR), Food Wastes, Sequencing Batch Reactor (SBR), Volatile Fatty Acids (VFAs)

INTRODUCTION

Nitrogen and phosphorus nutrient removal in wastewater can be made by means of various physicochemical methods [1,2]. However, these methods are expensive and create secondary pollution by adding chemicals to wastewater treatment systems. For this reason biological nutrient removal of nitrogen and phosphorus is favored over physicochemical methods. Many biological methods for N- and P-removal have been proposed and developed [3-7].

As an alternative to the conventional continuous flow activated sludge processes, sequencing batch reactor (SBR) systems have proved effective in biological nutrient removal (BNR) [8,12-14]. The SBR requires much less space since sedimentation and biodegradation occur in a single a reactor to remove nitrogen (ammonium and oxidized nitrogen) and phosphorus. In addition, the SBR can be operated with great flexibility to accommodate variations in conditions. The operation of the SBR consists of repeating cycles that each cycle has five basic operating steps: fill, reaction, settle, decant, and idle.

Optimization of the operation strategy of a biological process in treating wastewater contributes to improved effluent quality and/or cost savings. On-line or real time monitoring of pH has been shown to be a useful technique for controlling biological processes such as activated sludge process, sludge digestion, and BNR [13,15-17]. In the SBR system, pH profiles can show the end of nitrification through the identification of breakpoints [13,16]. Microbial reactions affect the pH value of a biological system and pH variation often reflects the ongoing biological reactions. Ammonification and denitrification cause an increase in pH, while nitrification results in a decrease in pH. In the nutrient removal cycle of SBR, monitor-

ing pH profiles would probably provide a further insight into the process dynamics.

Since the organic carbon present in the wastewater is often quite limited, a large amount of an external carbon source is required for the complete removal of nitrate from wastewaters that contain a high nitrogen concentration. Volatile fatty acids (VFAs) appear to be an attractive alternative source of carbon required for heterotrophic denitrification [8-11,18].

VFAs can be produced on-site via anaerobic acidogenesis of organic wastes such as food wastes [3,8,19]. Recently, Chang et al. [10] established a method for manufacturing anaerobic fermentation broth with VFAs having different compositions by changing the fermentation conditions of pH, temperature, organic loading rate and hydraulic retention time [10].

Although pH and ORP have been reported to be useful as control parameters for BNR [17,20,21], their effectiveness in an SBR system for BNR using VFAs as carbon sources has not been reported. In this study, pH profiles were monitored as control strategies for BNR in an SBR system that was fed with VFAs produced from anaerobic acidogenesis of food wastes. In Korea about four million tons of food wastes are generated each year and collected separately from the household solid wastes. Thus this can be easily converted to VFAs. The purpose of this study is to investigate whether the VFAs from the foodwastes are useful or not in the denitrification of wastewater as a valuable carbon source with no or little cost.

EXPERIMENT

1. SBR System

The SBR system consisted of a reactor, controller (time, solenoid valve, pH), pumps, ion selective electrodes (pH), and tanks as described previously [8]. The reactor was made of an acrylic plastic cylinder with a 6 L working volume. Solenoid valves adjusted the

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gas flow for each cycle according to a time sequence. The controller controlled the duration of each condition within one cycle. The pH electrode was located at the reactor side.

2. SBR Operation

During the operation of the SBR, the volumes of sludge and treated water were kept at 1 and 5 L, respectively. The reactor was operated at 26 °C. The SBR had a 20-day solid retention time (SRT). The operational cycle for the SBR included 10 min of fill, 3 h of an anaerobic period with mix, 3 h of aeration with mix, 2 h of an anoxic period with mix, 25 min of settle followed by 20 min of decant, and 5 min of idle. This operational cycle was changed in the reduced HRT (hydraulic retention time) study according to the monitoring results of pH profiles. Shaft speed was high enough to produce a homogeneous activated sludge suspension, but not so high as to induce shearing of the flocs. Samples were taken every 1 h and analyzed after filtering with a glass fiber filter. In this study, synthetic wastewater was used (Table 1). Concentrations of $\text{NH}_4^+\text{-N}$, $\text{PO}_4^{3-}\text{-P}$ and SCOD were 42.5, 5.92, and 180 mg/L, respectively. Carbon source for the BNR was sodium acetate or VFA solutions. VFA solutions were obtained from anaerobic acidogenesis of food wastes. The carbon source was separately added to the SBR system.

Fermentation broths (VFA solutions) were produced by anaerobic acidogenesis of food wastes as described previously [8]. VFA solutions were added to the SBR in two steps. In the SBR with anaerobic (2 h) - aerobic (3 h) - anoxic (2 h) cycles, the fermentation broth of organic wastes was first added under anaerobic condition and another fermentation broth under anoxic condition, respectively. There was no other carbon source except for the fermentation broth in the BNR system. Table 2 shows the characteristics of the VFA solutions used in this study.

3. Analytical Methods

Effluent samples were immediately filtered through a glass fiber filter (Whatman GF/C) and used for analysis. NO_2^- , NO_3^- , NH_4^+ and

PO_4^{3-} concentrations and COD were determined with a Hach DR/2010 spectrophotometer system (Hach, Loveland, Co., USA) pre-programmed with the calibration data needed to perform a range of assays using Hach reagents. MLSS was measured by the methods described in *Standard Methods* [22].

RESULTS AND DISCUSSION

1. Track Studies

Fig. 1 shows the typical profiles pH, nutrient (nitrogen and phosphorus) concentration during the process over three (3 h anaerobic, 3 h aerobic, and 2 h anoxic) consecutive phases in the SBR system. Once in the anaerobic stage, rapid phosphate release occurred; within 90 min, the supernatant concentration reached 44 mg-P/L. Thereafter, $\text{PO}_4^{3-}\text{-P}$ remained essentially the same. This result indicates that the anaerobic stage could be shortened. The pH rose slightly during the anaerobic stage.

Phosphate uptake and nitrification occurred immediately at the

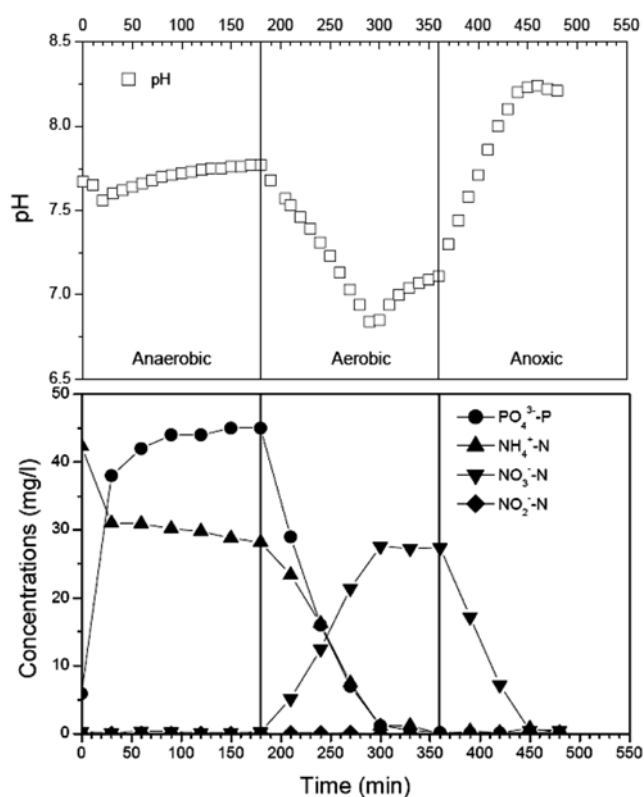


Fig. 1. Performance of the SBR operated with the HRT 8 h. The SBR was fed with sodium acetate as a carbon source for denitrification.

Table 1. Composition of synthetic wastewater used for the SBR

Component	Concentration (mg/L)
SCOD*	180
$\text{NH}_4^+\text{-N}$	42.5
$\text{PO}_4^{3-}\text{-P}$	5.93
$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	50
$\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$	3.75
CaCl_2	2.5
$\text{MnSO}_4 \cdot \text{H}_2\text{O}$	5
NaHCO_3	102.5

*Carbon source was sodium acetate or VFA solutions. VFA solutions were produced from anaerobic acidogenesis of food wastes.

Table 2. Characteristics of VFA solutions added into the SBR

VFA solution	Fermentation condition			TVFA, g/L	VFA composition (% SCOD)				
	Temp., °C	pH	HRT, days (OLR, g/L·d)		Acetate	Propionate	Butyrate	Valerate	Caproate
A	35	5.5	12 (5)	21	15	36	17	19	0
B	35	5.5	8 (9)	24	21	25	24	17	5
C	35	6.0	8 (9)	25	33	23	25	7	0
D	45	5.5	8 (9)	20	29	3	17	7	29

onset of the aerobic stage and both PO_4^{3-} and NO_3^- concentrations leveled off within 130 min of the stage. Aerobic stage also found to be over lasted in this SBR, at least in the wastewater composition investigated. The ammonium valley [23] in the pH profile, corresponding to the end of nitrification (point A), was clearly observed.

The anoxic stage supplemented with 100 mg/L ThOD of sodium acetate was used for denitrification. In this stage, the nitrate decreased rapidly near to zero in a period of approximately 90 min due to denitrification. The pH curve rapidly increased due to alkalinity produced from denitrification, and a subsequent decrease. The bending-point on the pH curve has been termed the 'nitrate apex' [24].

Ammonium was essentially exhausted at point A on the pH profiles in the aerobic phase (Fig. 1). In the anoxic phase, the concentration of nitrate was reduced close to zero at the breakpoint B on the pH curves. These points A and B are important control points because they indicate the end of nitrification and denitrification, the disappearance of ammonium and nitrate, in the aerobic and the anoxic stages, respectively. This implies that the anoxic phase should start at point A and terminate at point B.

2. Performance of the SBR at Decreased HRT

Based on the above results, HRT of 5.5 h consisting of the sequence of anaerobic (1.5 h) - aerobic (2.5 h) - anoxic (1.5 h) phases was tested for the system operation. Influent wastewater compositions were the same as those of HRT of 8 h. In anoxic stage, 100 mg/L (ThOD) of sodium acetate was added as a carbon source for denitrification.

A typical release and over-uptake of phosphorous by the micro-organisms occurred and phosphorous was removed very efficiently (Fig. 2). The phosphorous concentration in the effluent wastewater was kept consistently below 0.1 mg/L. The specific phosphorus release rates of 12-17 mg-P/g MLSS·h in this study were relatively high. A value of 3 mg-P/g MLSS·h was attained by Shin et al. [12] with an SBR system operated for more than 80 days. Specific phos-

phate uptake rate observed ranged from 4.5 to 6 mg-P/g MLSS·h.

In the case of nitrogen, ammonium was completely oxidized into nitrate and no accumulation of nitrite was observed in the aerobic phase. The specific nitrification rates varied between 3.0 and 3.6 mg-N/g MLSS·h, as compared with the 1.7-5.1 mg-N/g MLSS·h nitrification rates of an SBR system [25]. An external carbon source was added during the anoxic phase because of the exhaust of organic components during the anaerobic stage, and then nitrate was reduced to nitrogen gas which was then released. In this study, the calculated specific denitrification rate observed when sodium acetate was used as the carbon source was around 4.67 mg NO_3^- -N/g MLSS·h. Such a value is comparable to a study carried out by Jones et al. [26] in an SBR system with the specific denitrification rate between 3 and 4 mg NO_3^- -N/g MLSS·h.

The phosphorus and nitrogen concentrations were maintained within 0.5 mg/L by the addition of a suitable amount of a carbon source. From these results, it is evident that the shortened HRT was enough for an appropriate level of removal rate under the conditions used in this study.

3. Use of VFAs from Acidogenesis of Food Wastes for Denitrification

Fig. 3 shows the concentration profiles during the experiment using VFA solutions as carbon source for BNR. The VFA solutions A-D (Table 2) used in this study were produced under different conditions of anaerobic acidogenesis. They contained TVFA in the range of 20-25 g/L and showed different amounts (% SCOD) of major VFAs. Major VFAs showing high amounts were as follows: VFA solution A, propionate (36%); VFA solution B, acetate (21%), propionate (25%), and butyrate (24%); VFA solution C, acetate (33%); VFA solution D, acetate (29%) and caproate (29%).

Ammonium was completely removed without accumulation of nitrite. The specific nitrification rates varied between 3.0 and 3.9 mg-N/g MLSS·h, as compared with the 3.0-3.6 mg-N/g MLSS·h nitrification rates of the SBR system using acetate as a carbon source. VFA solution was added during the anoxic phase with an average ratio of 3.6 mg SCOD for each mg of NO_3^- -N, in accordance with what was used in the SBR system supplemented with sodium acetate. With the four different VFA-solutions, the SBR showed similar denitrification efficiencies. The calculated specific denitrification rates ranged from 3.2 to 4.2 mg NO_3^- -N/g MLSS·h. This range was relatively lower than the specific denitrification rate of 4.67 mg NO_3^- -N/g MLSS·h observed in the SBR supplemented with sodium acetate. In addition, experimental ratios of SCOD to NO_3^- -N ranged from 4.8 to 5.2, resulting in effluent concentrations of 6.7-9.8 mg NO_3^- -N/L. However, these concentrations were still permissible.

The SBR systems supplemented with the VFA solutions A-C showed efficient removal of phosphorus, keeping phosphorous concentration in the effluent below 0.25 mg/L. However, when the VFA solution D was the carbon source SCOD remained in the reactor even at the end of anaerobic phase, and P removal was not achieved (Fig. 3d). This result is partly explained by the fact that the VFA solution D contained high COD percentages of acetate and caproate (Table 2). When acetate and caproate were used as carbon sources for P removal, VFA uptake rates were very low. These low VFA uptake rates led to the existence of VFA in the aerobic phase, which could be detrimental for P-uptake [27,28]. The best result was obtained with VFA solution C that contained the highest content of

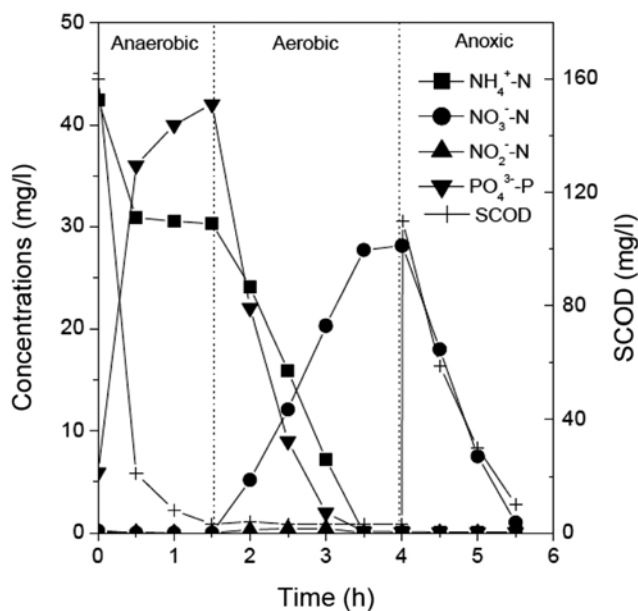


Fig. 2. Performance of the SBR operated with the shortened HRT, 5.5 h. The SBR was fed with sodium acetate as a carbon source for denitrification.

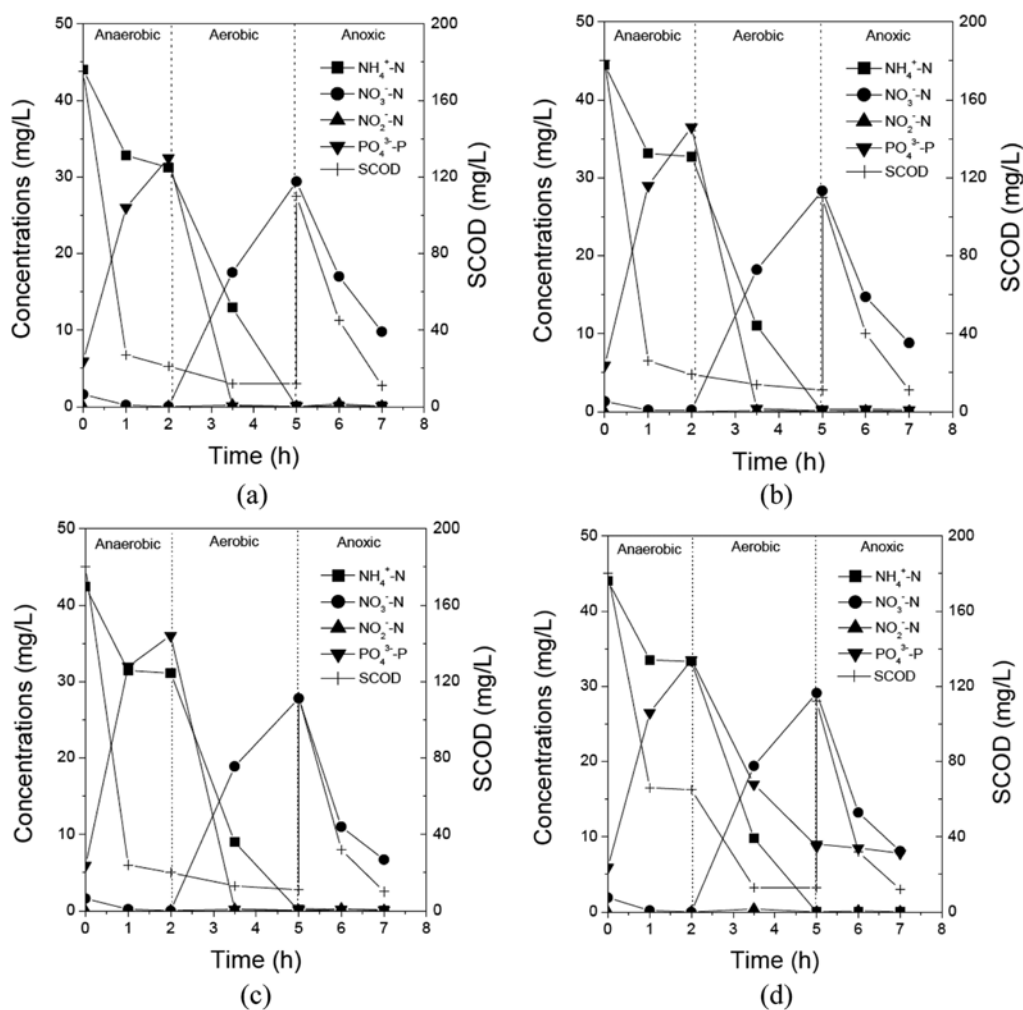


Fig. 3. Performance of the SBR fed with VFA solution (carbon source) obtained from anaerobic acidogenesis of food wastes. The SBR operated with the HRT 7 h. VFA solutions used were as follows: (a) A; (b) B; (c) C; and (d) D.

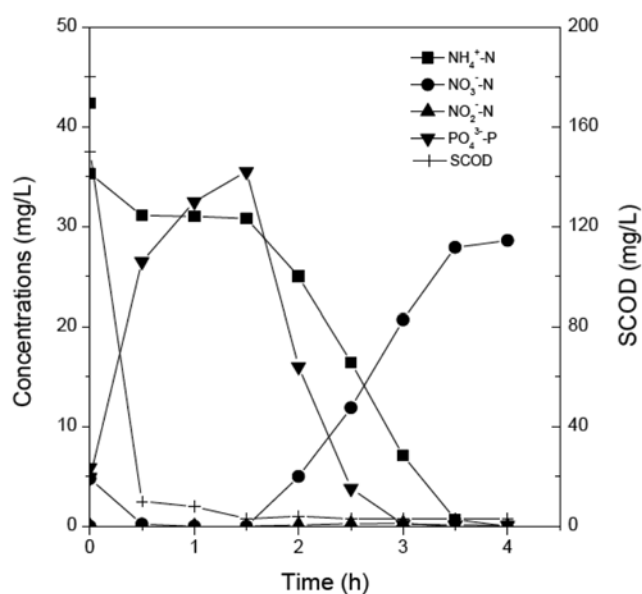


Fig. 4. Performance of the SBR fed with VFA solution C. The SBR operated with the HRT 5.5 h.

acetate without caproate. The effluent concentrations of $\text{NO}_3^-\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ were 6.70 and 0.08 mg/L, respectively. Although there was ammonium nitrogen and phosphate in the fermentation broth, it did not affect the overall removal efficiency.

Reduced HRT was tested for the BNR system supplemented with the VFA solution C. Other experimental conditions were the same as those of the above investigations. Nitrogen, phosphorus, and SCOD concentrations are shown in Fig. 4. The effluent concentrations of nitrogen and phosphorus were 9.5 and 0.15 mg/L, respectively. This result indicates that the shortened HRT is applicable to the BNR system using VFA solution as a carbon source, while the removal efficiency is not affected by it.

Several studies have been published regarding nitrogen compound removal in a packed bed external loop airlift bioreactor and in a sequencing batch reactor [29,30]. Also, the use of chemical engineering principles has been increasing steadily to the solution of biological problems such as H_2S gas removal, drinking water, bacterial cellulose production, biodiesel production, steam gasification of biomass and water filter carbon [31-33]. These efforts are quite encouraging since as far as chemical and biological process engineering is concerned, chemical engineering principles are the key to the econom-

ical solution of many impending environmental biotechnology problems.

CONCLUSION

1. Hydraulic residence time (HRT) in a model acetate fed-SBR system for biological nutrient was optimized from 8 h to 5.5 h by monitoring a pH profile in the SBR system when influent concentrations of $\text{NH}_4^+\text{-N}$, PO_4^{3-} and SCOD were 42.5, 5.92 and 180 mg/L, respectively.

2. Four different VFA compositions were prepared by varying temperature, pH, hydraulic residence time and organic loading rate. The VFAs-added SBR showed similar specific nitrification rates (3.0 to 3.9 mg-N/g MLSS·h) to that of acetate, but the specific denitrification rates (3.2 to 4.2 mg NO_3^- -N/g MLSS·h) were slightly lower than with acetate of 4.67 mg NO_3^- -N/g MLSS·h.

3. The VFAs-introduced SBR efficiently removed phosphorus except when the SBR was fed with a VFA-solution containing high amount of valerate and caproate.

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NOMENCLATURE

BNR : biological nutrient removal
 COD : chemical oxygen demand
 DO : dissolved oxygen
 HRT : hydraulic retention time
 SBR : sequencing batch reactor
 SCOD : soluble chemical oxygen demand
 SRT : solid retention time
 TVFAs: total volatile fatty acids
 VFAs : volatile fatty acids

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