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Application of nitritation from ammonium nitrogen-rich wastewater using sequencing batch reactor process

Jiyeol Im[a], Kyungik Gil[b,*]

[a]*Department of Urban Policy Research, Goyang Research Istitute, Ilsandong-gu, Goyang, Gyeonggi-do, South Korea*
[b]*Department of Civil Engineering, Seoul National University of Science and Technology, Nowon-gu, Seoul 139-743, South Korea, email: kgil@seoultech.ac.kr*

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ABSTRACT

Recycle water containing high-load nitrogen returns to the main stream of a municipal wastewater treatment plant (MWTP) and causes increase of the nitrogen load in the main process. This study has evaluated economic, eco-friendly and energy-saving nitrogen process that uses nitritation in a sequencing batch reactor (SBR). The range of nitrogen removal efficiency was 70%–99%, and nitrite conversion efficiency was 0.5%–92.4% in a laboratory-scale SBR during overall operation days. The ammonium nitrogen removal efficiency was maintained at over 70% with various retention time conditions, but the nitrite conversion efficiency varied depending on the hydraulic retention time. Nitritation occurred at a short solids retention time (in case of this study it is 1 d) through the nitrite oxidizing bacteria washout in this SBR. The maximum ammonium nitrogen removal rate was 0.544 kg $N_{removed}/(m^3\ d)$, and the nitrite conversion rate was 0.49 kg $N_{removed}/(m^3\ d)$. Stable nitritation occurred at the influent ammonium nitrogen load ranging from 0.42 to 0.6 kg $N/(m^3\ d)$, which was similar or even higher compared with other nitrogen treatment processes that use nitritation. For the application of nitritation to recycle water treatment (RWT) process in MWTP, nitrite build-up is an important factor to be considered in the selection of an appropriate treatment process. According to the results, an SBR is suggested as a method to increase the applicability of nitritation to RWT process in MWTP.

Keywords: Nitritation; Recycle water; Sequencing batch reactor; Nitrogen; Wastewater treatment

1. Introduction

Nitrogen is the major cause of eutrophication and thus one of the most important parameters of water quality standards for municipal wastewater treatment plants (MWTPs). In particular, strict water quality standards for nitrogen are followed the United States in than South Korea and Table 1 shows the water quality standards for nitrogen in the United States and South Korea. Therefore, various nitrogen treatment technologies have been studied and developed using biological, chemical, and physical methods.

A biological nitrogen removal (BNR) process is the main process used for the treatment of nitrogen at MWTPs. A BNR is based on an oxidation–reduction reaction such as nitrification under aerobic conditions, and denitrification under anoxic conditions. Nitrification is a two-step oxidation process: the first step is the conversion of ammonium nitrogen to nitrite, and the second step is the conversion of nitrite to nitrate. However, nitritation is partial nitrification converting ammonium to nitrite with no further nitrification to nitrate: This process is cost-effective by saving energy compared with nitrification. Nitritation–denitritation uses

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* Corresponding author.

Table 1
Water quality standards for nitrogen in South Korea and the United States

Country	Area	Total nitrogen (mg/L)	Remarks
The United States	Chesapeake Bay Tributaries, Maryland	8	
	Puget Sound, Budd Inlet, Washington	4.01	
	Hookers Point WWTP, Florida	3	Annually average
	Reno-Sparks WWTP, Florida	5	Monthly average
	Palmetto WWTP, Florida	3	Monthly average
	Eastern Service Area WWTP, Florida	3.5	Monthly average
South Korea		20	

25% less oxygen than nitrification–denitrification [1,2]. Therefore, many studies have examined nitritation for the treatment of ammonium nitrogen-rich wastewater [3,4]. The sequencing batch reactor (SBR) process is well known for its advantages in treating wastewater such as stable performance under fluctuating influent pollutant loadings, high nitrogen removal efficiency and less space requirement for installation [5]. In an SBR process for nitritation, the sedimentation step and the aeration step are alternatively introduced at different time periods in the same reactor. Some researchers used SBR process for nitritation such as treatment of ammonium-rich wastewater, inducement of nitritation, analysis of effective parameters, etc. [5–7]. The results of advanced research using SBR process suggested it to be an effective process for nitritation. However, specific comparison on application of nitritation using SBR and other processes was not conducted.

In this study, a laboratory-scale nitritation SBR was operated for about 320 d and the effects of hydraulic retention time (HRT) and solids retention time (SRT) on the effluent concentrations of nitrite and nitrate were investigated. The operation results were analyzed for ammonium nitrogen removal efficiency (ARE, removed ammonium nitrogen/ammonium nitrogen in influent), nitrite conversion efficiency (NCE, nitrite in effluent/removed ammonium nitrogen), ammonium nitrogen removal rate (ARR, removed ammonium nitrogen load/d), nitrite conversion rate (NCR, removed ammonium nitrogen load/d) and comparison with other processes. The applicability of nitritation using SBR was evaluated through overall analysis.

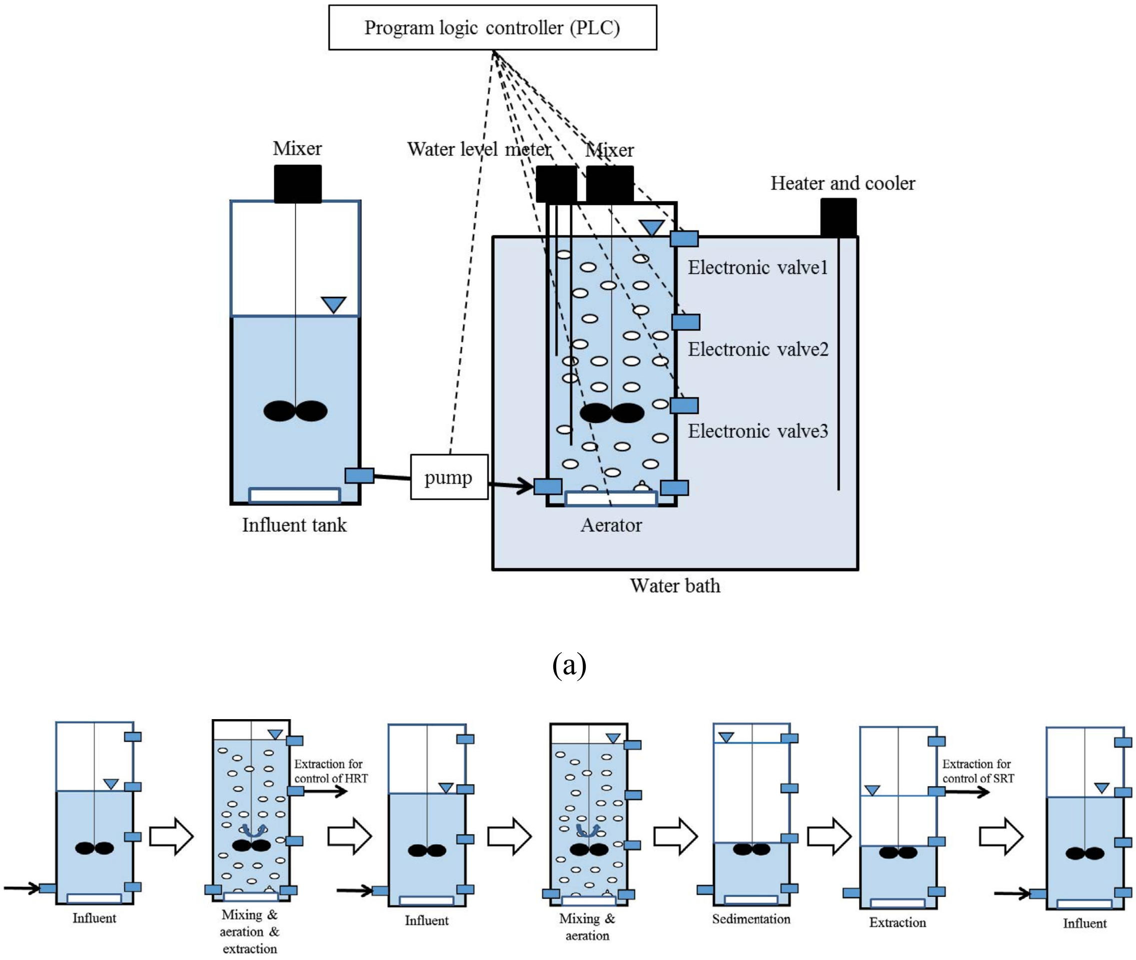
2. Materials and methods

Fig. 1 shows a schematic diagram of the laboratory-scale nitritation SBR process. The SBR was operated on a cycle (influent – mixing and aeration and extraction (for HRT control) – influent – mixing and aeration – sedimentation – extraction (for SRT control) – influent) using a programmable logic controller (PLC). HRT was controlled by extraction during mixing and aeration and extraction and SRT was controlled by extraction after sedimentation. The influent electric control valve, effluent electric control valve_1, effluent electric control valve_2, aerator, mixer, water level meter, and the pumps for adjusting HRTs and SRTs were controlled by the PLC. The water jacket was composed of a heater, cooler, and temperature controller. The temperature of the SBR was maintained at 35°C ± 0.5°C using a water bath. The influent wastewater was anaerobic digester supernatant from an MWTP in Seoul, South Korea. The ammonium nitrogen concentration of the influent was 220–280 mg/L, and the alkalinity/ammonium nitrogen ratio was 7.1–7.4. Table 2 shows the characteristics of the influent anaerobic digester supernatant. Pollutants chemical oxygen demand (COD, ammonium nitrogen, nitrite, nitrate and alkalinity) were analyzed in accordance with standard methods (APHA [8]).

3. Results and discussion

Fig. 2a shows the alkalinity and ammonium nitrogen concentrations with respect to operation days and Fig. 2b is the inorganic nitrogen compound concentration with respect to operation days; these show a summary of the operation results in the laboratory-scale nitritation SBR after attaining a stable state. The concentration of the influent ammonium nitrogen ranged at 200–280 mg/L, and the median value was 260 mg/L during the study period. Operational periods were separated according to different conditions of HRT and SRT. The operating HRT was in the range 0.5–2 d, and the operating SRT was in the range 1–4 d. In the operation results, the nitrite and nitrate in the effluent varied depending on the conditions of HRT and SRT. Table 3 shows the summary of operation result. In Table 3, stable ARE was obtained during overall operation days; however, stable NCE was obtained when SRT 1 d condition. Mixed liquor suspended solid (MLSS) ranged 5,940 mg/L (HRT 1 d and SRT 4 d) ~ 9,890 mg/L (HRT 2 d and SRT 4 d) and MLSS maintained similar median value showed during overall operation days.

Fig. 3 shows the ammonium nitrogen loading during operating periods in the SBR. The ammonium nitrogen loading ranged 0.42–0.60 kg N/(m^3 d). It seemed that ARE and NCE were unaffected by the ammonium nitrogen loading during operation period. Thus, the SBR process is a stable method for changing the influent of ammonium nitrogen loading in the range 0.42–0.60 kg N/(m^3 d). Commonly, the BNR efficiency and the activity of microorganisms are affected by the influent ammonium nitrogen shock loading. SBR has an advantage that it is less affected by influent ammonium nitrogen shock loading compared with continuous flow reactor. In this study, the laboratory-scale SBR achieved 80% ARE and stable NCE with an influent ammonium nitrogen loading range of 0.42–0.60 kg N/(m^3 d). The nitritation using the SBR process



(a)

(b)

Fig. 1. (a) Schematic diagram and (b) operation periods of laboratory-scale nitritation sequencing batch reactor.

Table 2
Characteristics of anaerobic digester supernatant

Parameters	Range	Median
pH	7.3~7.8	7.6
COD (mg/L)	1,830~5,740	3,875
NH_4^+-N (mg/L)	210~300	260
Alkalinity (mg/L as $CaCO_3$)	1,510~2,320	1,860
Alkalinity/NH_4^+–N ratio	7.1~7.4	7.2

can be beneficial as it attenuates the rapid changing of the ammonium nitrogen loading. Thus, the SBR is one of the effective methods for the control of HRT and SRT. Hence, SBR has the advantage of application for the nitritation process in MWTP.

Fig. 4a compares the ARR and ARE with previous research results such as moving bed, completely stirred tank reactor (CSTR)+SBR_1, CSTR+SBR_2, membrane bioreactor (MBR), and SBR in this study [9–12]. The highest ARR was shown by MBR+MBR, and the lowest ARR was shown by CSTR+SBR_2. The highest ARE was shown by SBR, and the lowest ARE was shown by moving bed. Through Fig. 4a, SBR showed higher ARE and ARR than the other processes. Fig. 4b compares NCE in steady states with previous research results such as MBR [13], SBR [14], SBR_pilot scale [7], CSTR [6], and SBR in this study. As a result, the MBR and CSTR processes were shown to be approximately 80% of NCE. However, SBR-processed NCE was shown at about 90%, even for the pilot scale. Thus, the NCE shows the higher efficiency in the SBR process than the MBR and CSTR process. In Fig. 4, the SBR process in this study is shown to be an effective process for the treatment of nitrogen using nitritation.

Fig. 5 shows the ARR, NCR, HRT, and SRT during operating days in the SBR. The maximum ARR was 0.544 kg $N_{removed}/(m^3$ d) at HRT = 0.5 d and SRT = 1 d, and the minimum ARR was 0.09 kg $N_{removed}/(m^3$ d) at HRT = 2 d and SRT = 4 d. The maximum NCR was 0.49 kg $N_{removed}/(m^3$ d) at HRT = 0.5 and SRT = 1 d, and the minimum NCR was 0.0005 kg $N_{removed}/(m^3$ d) at HRT = 2 d and SRT = 4 d. At the same SRT condition, ARR and NCR were decreased as HRT increased. Because influent flow was decreased as HRT increased. Fig. 6 shows ARE and NCE in a laboratory-scale nitritation SBR. ARE was maintained at

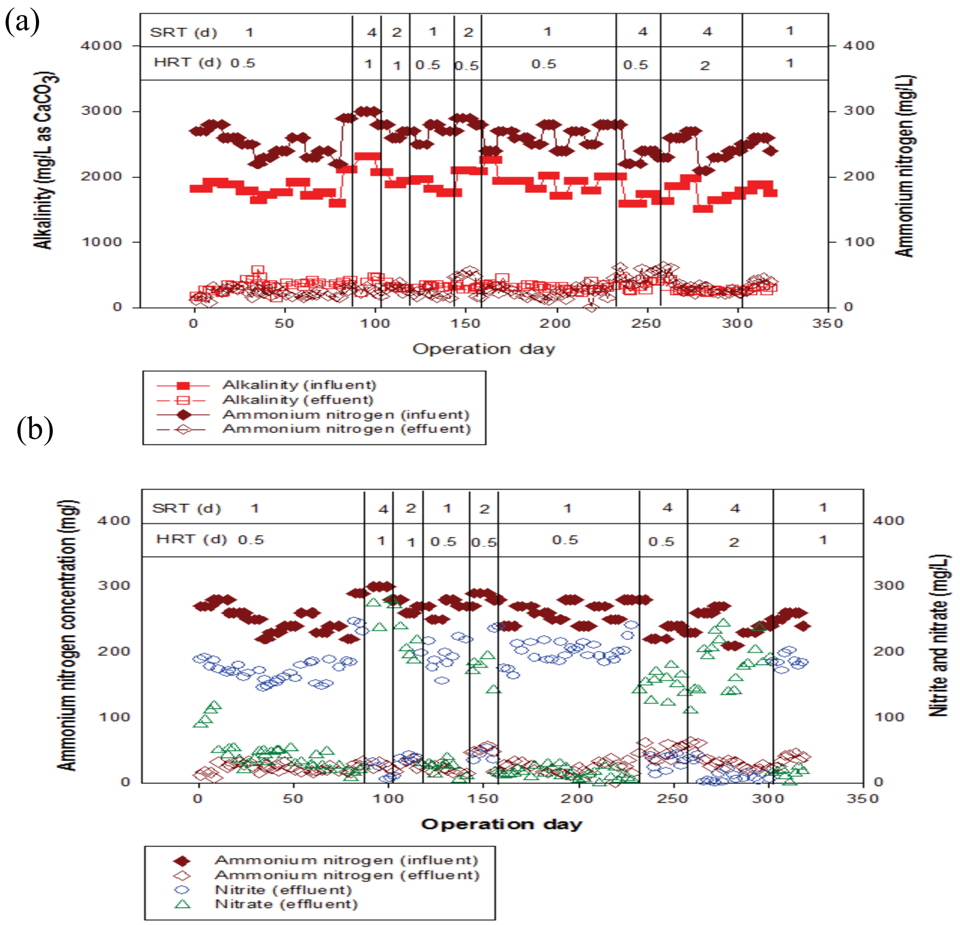


Fig. 2. Laboratory-scale nitritation sequencing batch reactor operation results: (a) alkalinity and ammonium nitrogen concentrations with respect to operation days and (b) inorganic nitrogen compound concentration with respect to operation days.

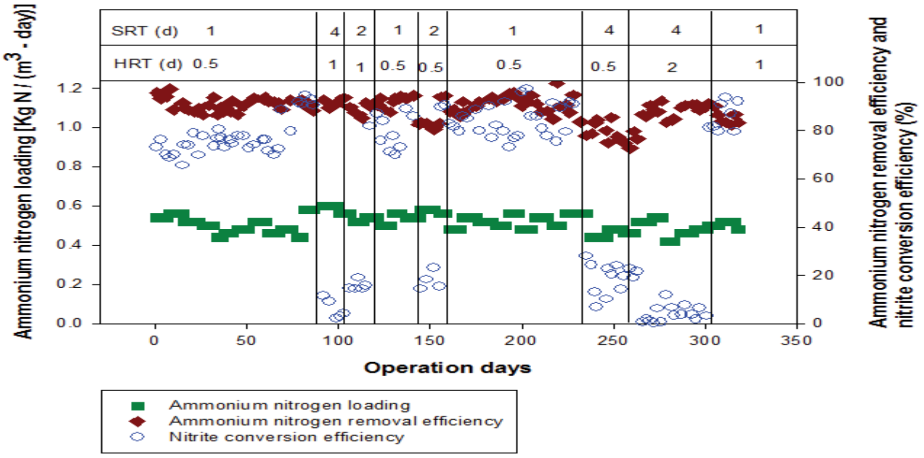


Fig. 3. Ammonium nitrogen loading and efficiency.

about 80% with various combinations of HRTs and SRTs. In this result, stable states of ARE were obtained during overall operation days. However, NCE varied according to SRT. During the long SRT (2 and 4 d), the NCE was decreased at about 20%. In this period, enough time was provided for nitrification because of the long SRT. Thus, the selective ammonia-oxidizing bacteria (AOB) cultivation did not occur in the SBR. However, short SRT (1 d)

Table 3
Summary of ARR, NCR, ARE, NCE and MLSS during overall operation days

HRT (d)	SRT (d)	Value	ARR (kg N/m³ d)	NCR (kg N/m³ d)	ARE (%)	NCE (%)	MLSS (mg/L)
0.5	1	Max	0.544	0.494	97.3	94.6	9,520
		Min	0.380	0.200	73.0	70.1	7,040
		Median	0.448	0.342	82.6	76.2	8,750
		STD	0.04	0.05	7.0	7.3	740
0.5	2	Max	0.484	0.170	83.4	38.1	8,550
		Min	0.446	0.070	80.3	18.3	7,450
		Median	0.466	0.088	82.8	23.1	8,200
		STD	0.009	0.02	1.2	3.4	411
0.5	4	Max	0.468	0.176	85.4	24.3	8,360
		Min	0.334	0.026	72.3	6.9	6,050
		Median	0.366	0.079	78.2	19.5	7,270
		STD	0.03	0.02	3.7	5.3	697
1	1	Max	0.228	0.203	91.1	93.5	9,680
		Min	0.200	0.172	82.3	79.6	7,040
		Median	0.218	0.185	85.1	84.3	8,530
		STD	0.008	0.01	2.5	5.6	915
1	2	Max	0.250	0.043	91.5	19.1	8,640
		Min	0.220	0.032	85.0	13.8	6,450
		Median	0.230	0.037	87.3	14.5	7,530
		STD	0.01	0.005	2.4	1.8	783
1	4	Max	0.278	0.232	93.6	11.5	7,920
		Min	0.256	0.006	88.3	2.2	5,940
		Median	0.265	0.018	91.8	6.8	7,020
		STD	0.007	0.01	1.5	3.7	673
2	4	Max	0.125	0.011	92.2	12.0	9,890
		Min	0.088	0.0005	83.3	0.5	7,360
		Median	0.109	0.004	88.5	3.4	8,440
		STD	0.01	0.04	2.7	0.04	949

ARE: ammonium nitrogen removal efficiency; NCE: nitrite conversion efficiency; ARR: ammonium nitrogen removal rate; NCR: nitrite conversion rate; MLSS: Mixed liquor suspended solid.

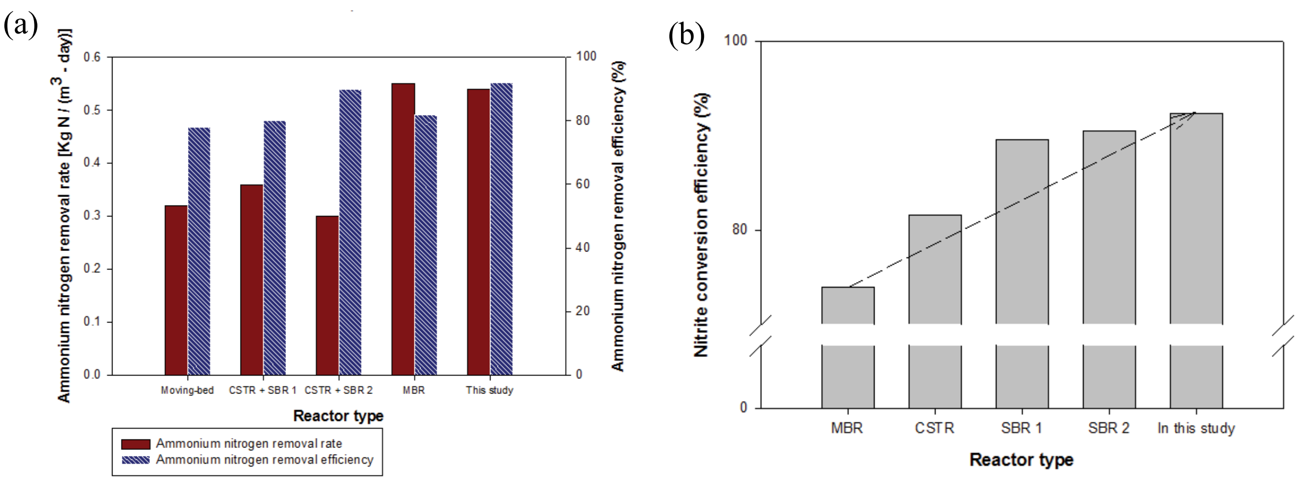


Fig. 4. Comparison of (a) ammonium nitrogen removal rate, ammonium nitrogen removal efficiency and (b) nitrite conversion efficiency with advanced research.

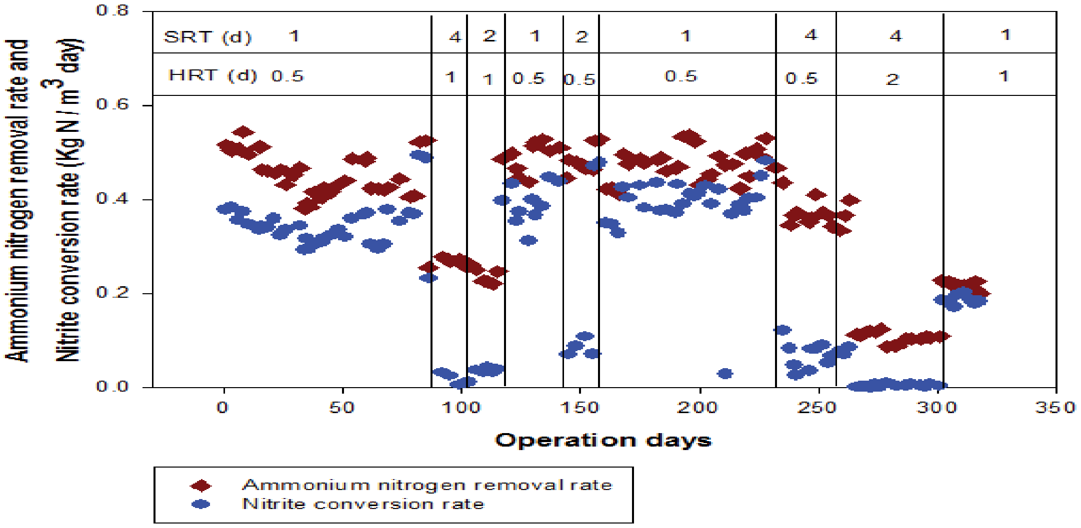


Fig. 5. Change of ammonium nitrogen removal rate and nitrite conversion rate.

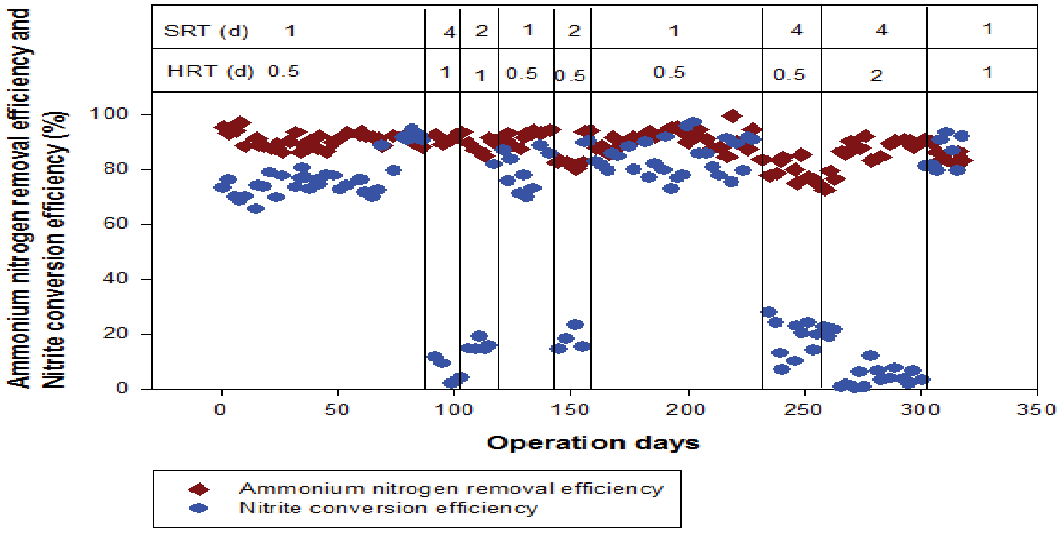


Fig. 6. Change of ammonium nitrogen removal efficiency and nitrite conversion efficiency.

showed nitrite accumulation in the effluent. Selective AOB cultivation was occurred through washout of nitrite oxidizing bacteria (NOB). Thus, it can be seen that nitrite was accumulated in the effluent by washout due to the difference of growth rate between AOB and NOB. In the short SRT (in the case of this study is 1 d), NCE was shown at approximately 80%. Box–Whisker plot is a tool of statistical data analysis by Tukey. It shows maximum (greatest value), upper quartile (25% of data greater than value), median (50% of data greater than value), lower quartile (25% of data less than value) and minimum (least value). Fig. 7 shows the schematic diagram of Box–Whisker plot [15]. Fig. 8 shows the Box and Whisker plots based on the SBR operation results. Through Fig. 8a, ARE was affected by HRT. ARE was increased when HRT was increased. Because 0.5 day of HRT was too short for the

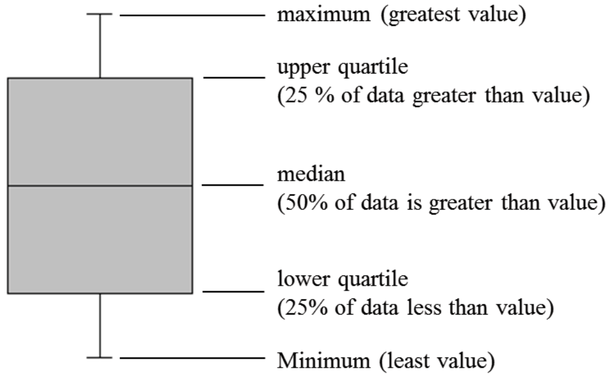


Fig. 7. Conceptual diagram of Box–Whisker plot.

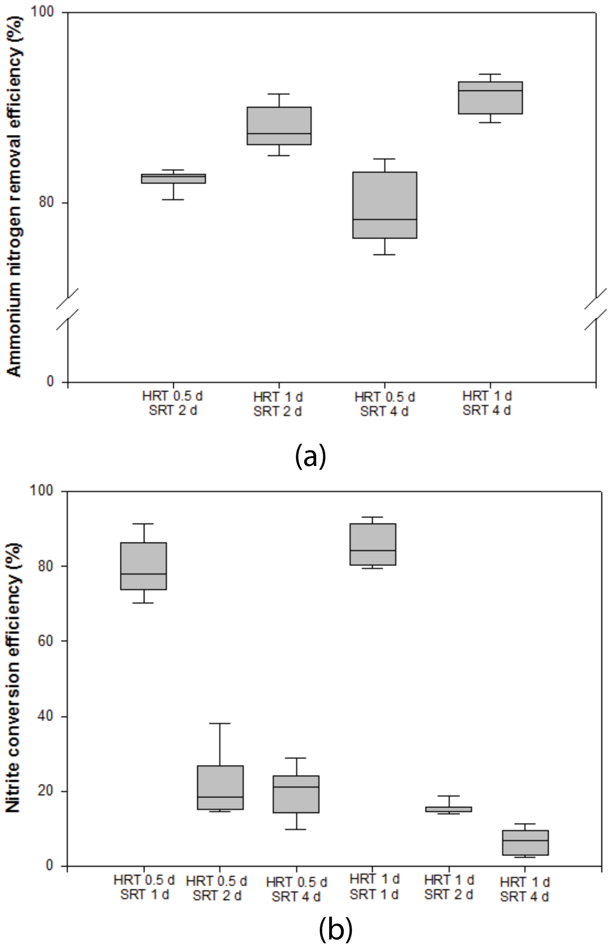


Fig. 8. Change of (a) ammonium nitrogen removal rate and (b) nitrite conversion rate according to the combination of HRT and SRT.

completion of ammonium nitrogen removal by AOB in the SBR. Fig. 8b shows that at the same HRT and different SRT, NCE was affected by SRT. An HRT of 2 d seemed to be too long for nitritation. ARR and NCR were changed by controlling HRT, but ARE and NCE changed a little due to varying conditions of SRT. However, ARR and NCR changed according to different conditions of HRT.

4. Conclusions

The following conclusions are derived using the operation results for a long-term laboratory-scale nitritation SBR. The overall ARE was maintained at approximately over 70%, but the NCE was changed according to operating conditions of SRT. In this study, stable nitritation occurred in SRT at 1 d, nitrite and nitrate in the effluent were controlled through the artificial control of retention time in the SBR process, because nitrite was accumulated in the effluent by difference in growth rates between AOB and NOB through NOB washout. The maximum ARR was 0.544 kg N/(m^3 d) and the maximum NCR was 0.49 kg N/(m^3 d) during the overall operation days. These values are similar or higher than those of the other nitritation processes. The SBR process is one of the effective methods for nitrogen removal using nitritation. Furthermore, the SBR process is advantageous because of its resistance to ammonium nitrogen shock loading. The application of nitritation still has several problems to recycle water treatment process in MWTP, such as the selective cultivation of AOB, the control of the operation conditions and the maintenance of a steady-state nitritation. The results showed that SBR process can have better applicability of nitritation in MWTP in the stage of the treatment process selection.

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