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Development of Sequencing Batch Reactor Performance For Nitrogen Wastewater Treatment

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Abstract

The performance of a typical sequencing batch reactor (SBR) for removing various nitrogen loadings was investigated in this study. The typical cycle of SBR consisted of filling of 5 min, aerating of 3 h, non-aerating of 4 h, settling of 1 h and decanting of 5 min (HRT was approximately 24 h). The results showed that the nitrogen removal efficiency was gradually increasing from ~ 36% at the low NH_4-N of 10 mg/L to ~ 50% at the higher NH_4-N of 20 mg/L and reached to the maximal efficiency of 82% at the highest concentration of 40 mg/L. This is due to the increasing NH_4-N and nitrogen removal rates which were 6.0 and 5.5 mg/L·h at the best reactor performance. Moreover, the high specific nitrogen removal rate of 20.5 mg N/g MLVSS was found and the most effective carbon consumption of 2.4 mg C/mg N was obtained during the experiment.

Keywords: Ammonium concentration; Nitrogen wastewater; SBR cycle; Simultaneous nitrification and denitrification

Introduction

Since nitrogen has become a key factor for water pollution from eutrophication and oxygen depletion, the stringent environmental regulations are carried out to decrease the nitrogen discharge. For example, the effluent nitrogen standards of 35 mg/L for household wastewater and that of 100 mg/L for industrial wastewater were reported in Thailand [1]. In general, the high nitrogen of 40-70 mg/L was found in the household and sewage wastewater, which mainly contain ammonium-nitrogen (NH_4-N) [2,3]. Some industries such as dairy and tannery also generate the high nitrogen wastewater in the range of 50-500 mg NH_4-N/L [4,5]. Moreover, the effluent from treatment system is one of significant sources for nitrogen wastewater discharge; the landfill leachate contained 250-600 mg NH_4-N/L [6] and the anaerobic digestion effluent contained 710 mg NH_4-N/L [7]. According to the World Health Organization (2004), the consumption of high nitrate-nitrogen (NO_3-N), the oxidized form of nitrogen, causes for blue baby syndrome in infants, and the NH_4-N contamination leads to unpleasant taste and smell of water. To maintain the good quality of water resource, the treatment technology is required to reduce the nitrogen contamination to be the acceptable level.

The common technology for nitrogen removal is biological nitrification and denitrification. The contaminated NH_4-N is oxidized to NO_2-N and continued to NO_3-N under high oxygen condition (named nitrification process), then the NO_3-N is reduced to N_2 releasing to the atmosphere under no oxygen condition (named denitrification process). The microorganisms involved in nitrification process have been reported; *Nitrosomonas sp.* and *Nitrosococcus sp.* for converting NH_4-N to NO_2-N [8,9], and *Nitrobacter sp.* and *Nitrospira sp.* for converting NO_2-N to NO_3-N [10,11]. In the meanwhile, several microorganisms were suggested to involve in denitrification process including *Ochrobactrum anthropi*, *Pseudonomas stutzeri*, *Alcaligenes faecalis*, and *Pseudomonas stutzer* [12-14]. Recently, various wastewater treatment systems including sequencing batch reactor (SBR), moving-bed biofilm reactor and intermittently aerated membrane bioreactor [15-17] were proposed for achieving simultaneous nitrification and denitrification. Among of the above mentions, the SBR is a widely used system in plants, due to its cost-effectiveness and ease operation. The conceptual of SBR operation includes four steps of filling, reacting, settling, decanting and idling. However, the periods of each step and its condition (i.e., DO and pH) were various in previous studies. For example, Guo et al. operated the SBR containing a cycle of filling (instantaneous), reacting of 7.5 h, settling of 0.5 h, decanting (instantaneous) and idling of 4 h [18]. The hydraulic retention time (HRT) and DO value were 10 h and 0.5-1.0 mg/L respectively. The operating cycle was modified to enhance the nitrification and denitrification processes by including aerobic and anaerobic in the reacting period [19]. During the reacting period, there was air supply for 8 min and no air supply for 15 min, and so on, until completing the 6 h. The aim of this study was to evaluate the performance of SBR under a typical cycle for nitrogen wastewater treatment, and clarify the nitrogen removal mechanisms.

Materials and Methods

Wastewater preparation

The synthetic wastewater was used for evaluating the SBR performance. The composition was following (per liter); NH_4Cl 0.04-0.15 g, KH_2PO_3 0.02 g, $MgSO_4$ 0.03 g, $CaCl_2$ 0.36 g, $FeSO_4$ 0.003 g and trace element 0.5 mL [20]. The NH_4-N was step-wise increased from 10 to 40 mg/L, while the low NO_2-N and NO_3-N of less than 1 mg/L was found in the influent. The fresh influent was prepared and immediately replaced with the 80% of water level in the reactor.

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Reactor set-up and operation

The lab-scale 15-L SBR was set-up by adding 2 L of dense sludge taking from an aerobic wastewater treatment plant of Wangthong Hospital (Phitsanulok, Thailand) and 10 L of synthetic wastewater. Two spargers for air supply were set-up at the base of the reactor, and a stirrer was controlled at 200 rpm for circulating the water and sludge.

The typical operation was modified from the previous results by the authors [21]. The reactor was operated under 3 cycles of aerating of 3 h, non-aerating of 4 h and settling of 1 h. filling and decanting were approximately 5 min at the first and last cycles (Figure 1). In the aeration, air was supplied at the flow rate of 0.5 L/min and the DO was around 5-6 mg/L. The DO was immediately dropped to 0.5 mg/L in the non-aeration, then approximately 50 mL of acetate solution was added in the first non-aeration to maintain the C/N ratio of 2 [21].

Analytical methods

The synthetic wastewater (influent) and treated water (effluent) were sampled for NH_4-N, NO_2-N and NO_3-N analysis in accordance with the standard method (APHA 1998). The nitrogen removal efficiency was calculated, as present in Equation 1. The chemical oxygen demand (COD) in the effluent was determined using COD analyzer (AL200 COD Vario, Aqualytic). The mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were measured after filtration and drying at 105°C (APHA 1998). Moreover, the pH and DO were frequently measured using pH meter (Eutech Instruments) and DO meter (CyberScan DO 110 Model).

To measure the NH_4-N removal rates, the water samples were taken every 0.5 h from the reactor operating under continuously air supply, and the reduction of NH_4-N referred to the NH_4-N removal rate. Similarly, the reduction of total nitrogen including NH_4-N, NO_2-N and NO_3-N in the reactor operating under no air supply and excess acetate was used to refer to the nitrogen removal rate.

$$\text{Efficiency} = \left(1 - \frac{[NH_4-N]_{\text{effluent}} + [NO_3-N]_{\text{effluent}} + [NO_2-N]_{\text{effluent}}}{[NH_4-N]_{\text{influent}}}\right) \times 100 \quad (1)$$

Results and Discussion

The influent NH_4-N fed to the reactor was started at 10 mg/L for being acclimatization. As shown in Figure 2, the nitrogen removal efficiency was relatively low of <10% in the beginning, and the efficiency was continuously increasing up to ~ 36% in a week. The NH_4-N was approximately 6.8 mg/L was found in the effluent, while no NO_2-N and NO_3-N was observed (Table 1). This present the low existence of microorganisms responsible for nitrogen removal in the initial sludge. The nitrogen removal efficiency was increasing to ~ 50%, ~ 64% and ~ 82%, when the influent NH_4-N was continuously increased to 20, 30 and 40 mg/L respectively. This revealed that the number of responsible microorganisms was increased by influent NH_4-N concentrations. The significant evidence to confirm the increasing responsible microorganisms in the reactor was that the specific nitrogen removal rate continued to increase during operation, as summarized in Table 1. The value was gradually increased from 4.04 mg N/g MLVSS·h at NH_4-N of 10 mg/L and reached to 4.2 mg N/g MLVSS·h at NH_4-N of 40 mg/ L. The majority of nitrogen in the effluent was NH_4-N (approximately 6-12 mg/L), while low values of NO_2-N and NO_3-N (of <2 mg/L) were remained. It can be note that the process of nitrification was the rate-limiting step in this reactor, although the excess oxygen of 5-6 mg/L was maintained.

Regarding the first cycle operation, the NH_4-N concentration was dramatically decreased in the aerating period, while high NO_2-N was generated (data not shown). The generated NO_2-N was decreased immediately in the non-aerating period, and together with the reduction of total nitrogen and carbon concentrations. This phenomenon suggested that the nitrogen contaminant was removed by partial nitrification and denitrification. Due to the high DO of 5-6 mg/L in the aerating period, the lack of nitrite oxidizing microorganisms was the key reason for partial nitrification occurred in this reactor. However, the further study on microbial test is required to clarify the nitrogen removal mechanisms.

Since the acetate addition was controlled at the C/N ratio of 2, which was sufficient for simultaneous nitrification and denitrification [21], the ratio of carbon consumed and nitrogen removed (carbon consumption) was used as an indicator to define the reactor performance and microorganisms' activity. At the low NH_4-N of 10 mg/L, around 5.5 mg C was consumed to remove one gram of nitrogen. The carbon consumption was reduced to 4.0 and 3.1 mg C/mg N at the higher NH_4-N concentrations. The effective carbon consumption of

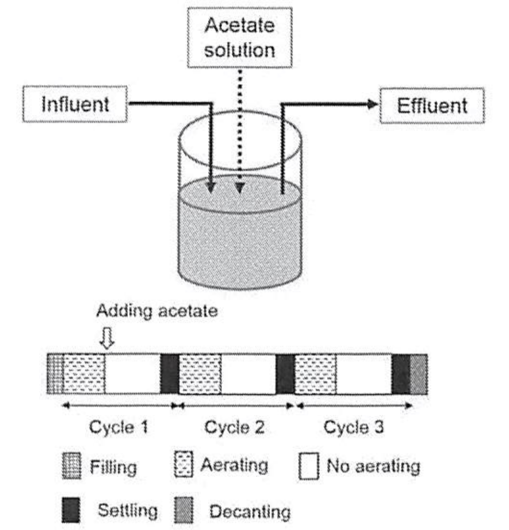

Figure 1: Schematic diagram of SBR operation in this study.

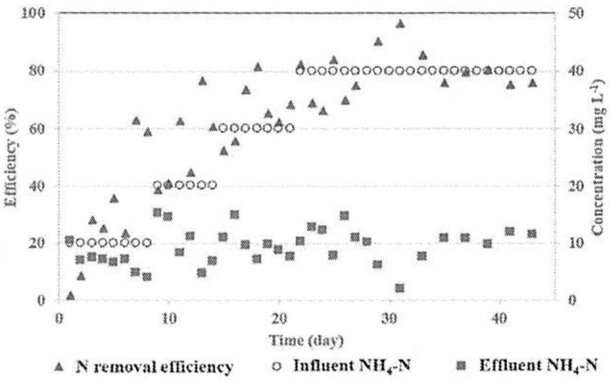

Figure 2: Change of nitrogen removal efficiency and effluent NH_4-N concentrations during increasing influent NH_4-N concentrations.

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Influent NH_4-N concentration mg/L)	C/N ratio	Average effluent concentration (mg/L)			Efficiency (%)	Specific N removal rate (mg N/g MLVSS h)	C consumption (mg C consumed/mg N removed)
		NH_4-N	NO_2-N	NO_3-N			
10	2.0	6.8 ± 6	0.0±0.1	0.0 ± 0.1	36 ± 26	4.04 ± 0.01	5.5 ± 0.1
20	2.0	11.1 ± 4	0.3±0.1	0.2 ± 0.1	50 ± 15	4.11 ± 0.01	4.0 ± 0.1
30	2.0	9.7 ± 3	0.4±0.2	1.4 ± 0.2	64 ± 6	4.17 ± 0.01	3.1 ± 0.1
40	2.0	8.5 ± 2	1.8±0.2	1.7 ± 0.2	82 ± 3	4.20 ± 0.01	2.4 ± 0.1

Table 1: Average concentrations of effluent NH_4-N, NO_2-N and NO_3-N at various influent NH_4-N concentrations.

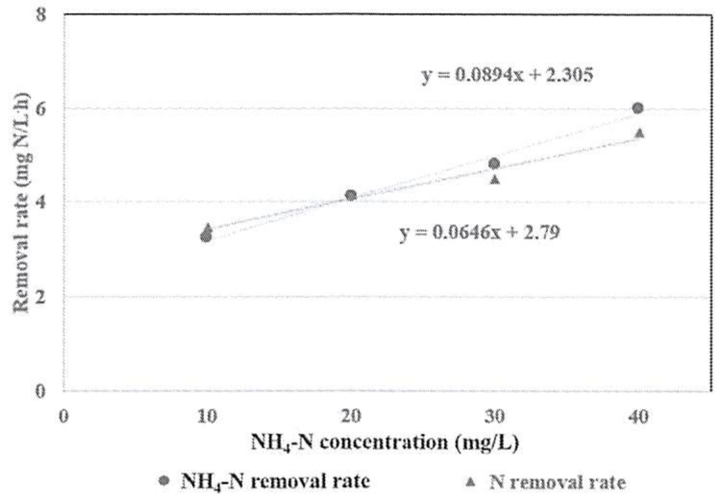

Figure 3: Change of NH_4-N and nitrogen removal rates during increasing influent NH_4-N concentrations.

SBR cycle	HRT (d)	Influent NH_4-N (mg/L)	Carbon	Efficiency (%)	Reference
Filling 5 min, Non-aerating 1.5 h, Aerating 4 h, Settling 5 min Decanting 0.2 h and Idling 0.2 h	0.3	35	Acetate (C/N=3)	61%	Wang et al. 2009
Aeration 0.5 h, Non-aerating 2.8 h, Settling 1 h, and Idling 0.5 h	3.6	35	Acetate (COD/N=20)	>90%	Li and Irvin 2007
Filling 5 min, Aaerating 3 h, Non-aerating 4 h, Settling 1 h and Decanting 5 min	1	40	Acetate (C/N=2)	82%	This study
Filling (instantaneous), Reacting 7.5 h, Settling 0.5 h, Decanting (instantaneous) and Idling 4 h	0.5	40	N/A (C/N=10)	85%	Guo et al. 2013
Fillling 1 h, Aerating 3 h, Settling 1 h, Decanting 10 min and Idling 0.8 h	0.3	50	N/A (COD/N=8)	98%	Chen et al. 2015
Filling, Aerating 1 h, Non-aerating 1 h, Settling 0.5 h, Decanting 0.8 h	7.5	50	Ethanol (C/N=3.5)	98%	Guo et al. 2007
Filling 2 min, Aeration 4.2 h, Non-aerating 1.5 h, Setting 0.8 h, Decanting 0.3 h	0.5	80	Metanol (COD/N=3)	>90%	Wu et al. 2007

Table 2: Performance of SBR for nitrogen wastewater treatment.

2.4 mg C/mg N was found at the highest NH_4-N of 40 mg/L, referring that the carbon was utilized efficiently for denitrification process and very low carbon was utilized by other competitive heterogeneous microorganisms.

In addition, the NH_4-N and nitrogen removal rates at various influent NH_4-N concentrations were present in Figure 3. At the low NH_4-N of 10 mg/L, the removal rates for NH_4-N was 3.2 mg/L·h and that for nitrogen was 3.5 mg/L·h. Both removal rates were continuously increasing up to 6.0 and 5.5 mg/L·h for NH_4-N and nitrogen at the highest NH_4-N of 40 mg/L. These revealed the enhancement of reactor performance by the typical SBR operation. However, the increasing NH_4-N removal rate was higher than the increasing nitrogen removal rate. This caused the remaining of NO_2-N and NO_3-N in the effluent at higher concentrations.

The performance of SBR operating in this study was compared to previous studies which operated under different SBR cycles. From Table 2, it can be seen that the good performance of SBR operating under the typical cycle of aerating of 3 h, non-aerating of 4 h and settling of 1 h was obtained at the low carbon addition. Although the long HRT of 24 h was operated in this study, the HRT can be reduced to approximately 16 h (two cycles of SBR) with the efficiency of ~ 80% (data not shown).

Conclusion

The SBR operating under three cycles of aerating of 3 h, non-aerating of 4 h and settling of 1 h can remove nitrogen from the wastewater effectively. The best performance of 82% was found at the highest NH_4-N of 40 mg/L. The average effluent NH_4-N, NO_2-N and NO_3-N were 8.5, 1.8 and 1.7 mg/L respectively. The increase in active microorganisms for nitrification and denitrification enhanced the removal rates of NH_4-N and nitrogen at the higher NH_4-N concentrations. In addition, the carbon consumption and specific nitrogen removal rate were also more effective rather than a low NH_4-N concentration.

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