4-2-3 Development of Simultaneous Nitrification and Denitrification Process in Aerobic Tank of Suspended Growth Treatment Process using Ammonia and Nitrate Sensors

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ABSTRACT

Nitrogen removal of suspended growth treatment is generally carried out through separate processes, an aerobic process for nitrification and an anoxic process for denitrification. In recent years, it was found that nitrification and denitrification could proceed simultaneously in a single reactor, known as simultaneous nitrification and denitrification (SND). However, there is little application of SND to the conventional activated sludge process that is widely in use for municipal wastewater treatment. In this study, applicability of SND to the conventional activated sludge process, which has spiral flow aeration, was investigated in order to improve nitrogen removal and energy efficiency. SND with high nitrogen removal efficiency was achieved by controlling air flow rate using ammonia and nitrate sensors. Moreover, since this new system enables nitrification and denitrification in a single aerobic tank, a nitrified liquid circulation pump becomes unnecessary and anoxic tank volume can be reduced.

KEYWORDS: Simultaneous nitrification and denitrification, air flow rate control, NH_4-N sensor, NO_x-N sensor

INTRODUCTION

In improvement of effluent quality of wastewater treatment plants, which use suspended growth treatment, the introduction of advanced treatment system is essential for removal of nitrogen and phosphorus. The advanced treatment generally consists of separate processes, an aerobic process for nitrification and an anoxic process for denitrification. However, upgrading of the existing conventional activated sludge facility to an advanced treatment facility may result in reduction in the treatment capacity per reaction tank volume and increase in the power consumption. In recent years, it has been found that nitrification and denitrification take place simultaneously in one reaction tank. This phenomenon is called “simultaneous nitrification and denitrification (SND)” and this utilizes the nitrification and denitrification processes by creating the status of alternately high and low concentration of the dissolved oxygen (DO) in the reaction tank (Münch *et al.* 1996, Pochana and Keller 1999, Zeng *et al.* 2004). While this SND is able to reduce the air flow rate by making treatment processes efficient, SND, in practical use, is based on primarily batch sequential reactor or oxidation ditch process (Barnard *et al.* 2013), and there is little application of SND to the conventional activated sludge method which is widely used in municipal wastewater treatment plants (WWTPs).

Accordingly, focused on this SND, a new technology of stable treatment based on conventional activated sludge facility, which has an aerobic tank with one direction spiral flow by aeration, was examined in order to establish a new method with large treatment capacity and low power consumption as compared with the present advanced treatment. A control method using an ammonia nitrogen (NH_4-N) sensor and a nitrite and nitrate nitrogen (NOx-N) sensor was considered in order to achieve a stable nitrogen removal was also examined.

CONFIRMATION OF THE PRINCIPLES OF DENITRIFICATION IN AEROBIC TANK

Shibaura Water Reclamation Center is one of the largest WWTPs of combined sewer system in Tokyo. It locates in the center of Tokyo, and the large portion of the treatment area of the facility is a downtown business district. The experiments were conducted at one of the treatment systems in the facility. Specifications and operational parameters of the treatment system used in the experiment are shown in Table 1. The reaction tank is designed as a deep-tank with the effective water depth of 10.2 m and an anaerobic/oxic (A/O) process is applied to the reaction tank. Diffusers of the tank are at 4.0 m depth and a single sided spiral flow of water is made by the aeration.

Denitrification in the aerobic tank had been seen in the system and rarely seen in the other system which has shallow depth tanks. Also, denitrification progressed relatively on weekend when nitrogen loading was low and almost no progress of denitrification on weekdays when the nitrogen loading is high. The situation with relatively large denitrification is shown in Figure 1. In the first part of the aerobic tank, denitrification was observed and total nitrogen (T-N) decreased with decreasing NH_4-N.

To facilitate denitrification, DO in the reaction tank should be decreased and anoxic region should also be established. Figure 2 shows cross-sectional distribution of DO in the aerobic tank. DO at the bottom of the aerobic tank was lower than 0.5 mg/L and decreased to 0.1 mg/L below the diffuser plates, so that denitrification could occur at those area. From these observations, it was considered that nitrification and denitrification mechanism of the deep aerobic tank with spiral flow was consist of (i) nitrification above the diffusers, (ii) progress of denitrification below the diffusers,

Table 1. Specifications and operational parameters of the treatment system used in the experiment
(Annual performance results in 2015)

Specification of Reaction tank	Treatment method	A/O process
	Effective depth / diffusion depth (m)	10.2 /4.0
	Width/ Length (m) x No. of stream	9.1/91 x 2
	Volume (m^3)	16,800
Annual Average	Average HRT (hour)	9.3
	Return sludge ratio	0.59
	MLSS (mg/L)	1630

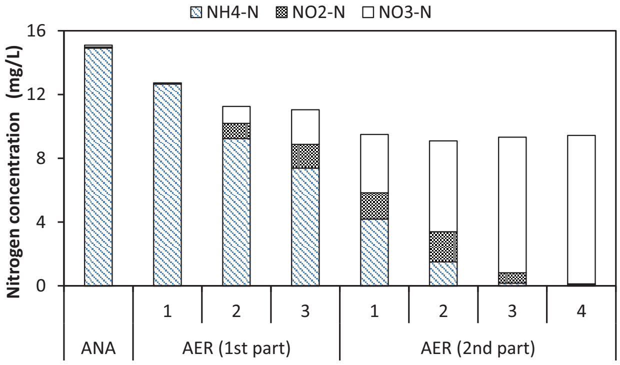

Figure 1. Example of denitrification in an aerobic tank of the system used in the experiment (ANA: anaerobic, AER: Aerobic)

and (iii) repetition of (i) and (ii) along the reaction tank.

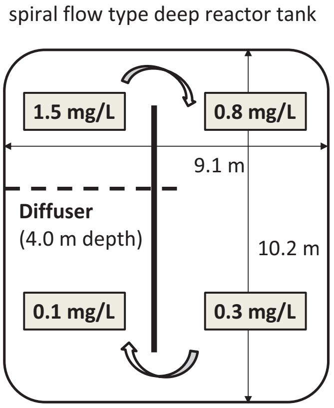

Figure 2. Cross-sectional distribution of DO in the aerobic tank

DEVELOPMENT OF AIR FLOW CONTROL SYSTEM

In order to keep SND stable in the deep aerobic tank with a single sided spiral flow, air flow rate control system was studied. It is necessary to form low DO (anoxic) regions continuously for denitrification in an aerobic tank. On the other hand, nitrification should always be completed in the reaction tank. In order to satisfy these different conditions, it was concluded that the reaction tank should be split into two parts, because denitrification tends to occur in the first part of the aerobic tank where organic matter concentrations are high, and denitrification unlikely occur in the second part due to low organic matter concentration. In addition, it was decided to control the air flow rate separately. The first part was defined as the zone where denitrification is facilitated by suppressing air flow rate and keeping the balance of nitrification and denitrification, and the second part was defined as the zone where nitrification is securely completed.

In the first part, nitrification progresses and NO_x-N increases in the upper area of the reaction tank, then denitrification of NO_x-N progresses in the lower area of the reaction tank. Therefore, if the air flow rate is excessive, NO_x-N will be gradually accumulated and its concentration will increase. On the other hand, if the air flow rate isn't enough, sufficient NO_x-N will not be detected. Thus, it was considered that the air flow rate control by NO_x-N concentration is the best method and it was decided to use a NO_x-N sensor (which measures the total concentration of NO_2-N and NO_3-N). In addition, the installation position of the NO_x-N sensor shall be the vicinity of the outlet of the first part and close to the water surface in order to obtain the amount of nitrification (Figure 3). The target value of the NO_x-N sensor shall be set in order to promote denitrification by suppressing excess nitrification. Therefore, the set value is lower than NO_x-N concentration at the time of DO control. The actual set value would vary depending on the load of ammonia in the in-flow. For setting, the following two points must be noted: (i) remained NH_4-N may be exceed the capacity of nitrification of the second part when nitrification is excessively suppressed at the first part, (ii) setting to zero makes it difficult to confirm the nitrification progress.

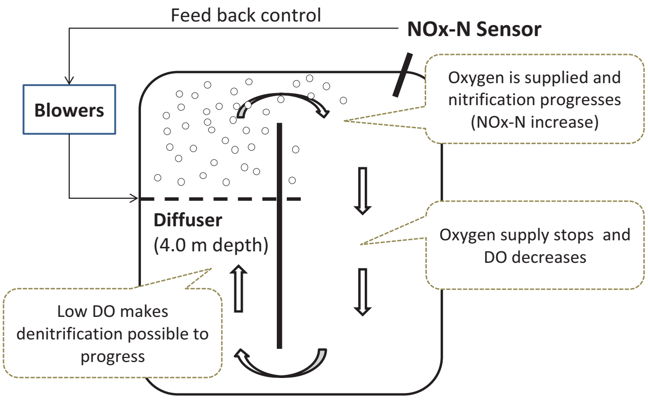

Figure 3. Process of nitrification and denitrification by the spiral flow in the first part of an aerobic tank

At the second part of the aerobic tank, air flow rate should be controlled as the minimum to ensure complete nitrification. Therefore, it was concluded that NH_4-N sensor should be used for a continuous measurement of nitrification progress in the second part. To complete nitrification and avoid excess air injection, minimum residual NH_4-N should be maintained at the end of the aerobic tank (approximately 0.5~1 mg/L of NH_4-N). In terms of measurement accuracy, it is desirable that NH_4-N sensor is placed in a position where NH_4-N concentration is approximately 2~3 mg/L and the set value in its installed position should be approximately 2~3 mg/L.

EXAMINATION AND VALIDATION IN AN ACTUAL FACILITY

Table 2. Treatment status during the examination period

	Weekday	Weekend
Treatment volume (m^3/day)	141,000	97,000
T-N of inflow (mg/L)	35	27
HRT (hour)	7.4	8.0
SRT (day)	7.2	8.0

Based on the results of the development studies, NO_x-N and NH_4-N sensors were installed to a deep reaction tank (Figure 4). Then, an actual air flow rate control was carried out in order to verify the performance of nitrogen removal in continuous operation from June to September 2013. In this facility, the differences between weekday and weekend in the loading of organic matter and nitrogen are considerably significant. Therefore, a wide range data in loading conditions were collected as much as possible by measuring the quality of the combined sample of each 24-hour from Wednesday to Thursday as high weekday loading, and from Sunday to Monday as low weekend loading. The treatment status during the examination is shown in Table 2. The set value of the NO_x-N sensor was 1.5 mg/L for both weekday and weekend. And the set values of NH_4-N sensor were 2 mg/L and 4~5 mg/L for weekend and weekday respectively.

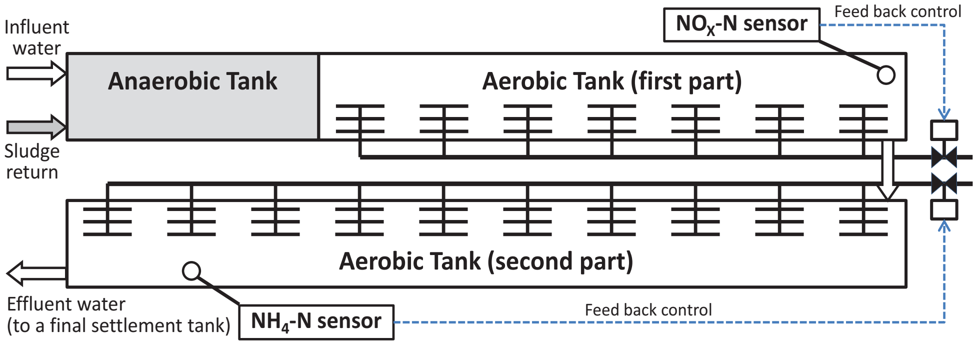

Figure 4. Division of the reaction tank and the air flow control system with NOx-N and NH_4-N sensors

Relationship between volumetric nitrogen loading and nitrogen removal rate is shown in Figure 5. The nitrogen removal decreased when the nitrogen loading became higher, excluding the data during rainfall. Nitrogen removal was lowered during rainfall due to hindrance of denitrification by increase of DO in the whole aerobic tank. On the other hand, it was considered that the nitrogen removal increased in condition of low nitrogen loading due to expansion of the denitrification zone, and the expansion was achieved by overall reduction of DO in the reaction tank, and it was enabled by the air flow rate control with the NO_x-N and NH_4-N sensors. In addition, in case of same nitrogen loading, nitrogen removal was higher than A^2/O process at the other facility (Figure 5). Consequently, it was suggested that this system can be operated at higher loading conditions compared to the A^2/O facility with the same nitrogen removal and has the possibility of the same nitrogen removal with more compact facility.

In an A^2/O process, power consumption per treated water volume generally becomes 30% higher than a conventional activated sludge process (Kasai *et al*. 2010) due to the addition of a mixer and nitrified liquor recirculation equipment. In this technique, power consumption can be successfully reduced by eliminating such equipment. Also, it is possible to reduce air flow rate by the reduction of organic matter during denitrification. In the experiment, the amount of air flow was reduced approximately 10% in the average compared with the DO controlled systems and about 25% improvement of nitrogen removal was achieved in case of low nitrogen loading in the weekend.

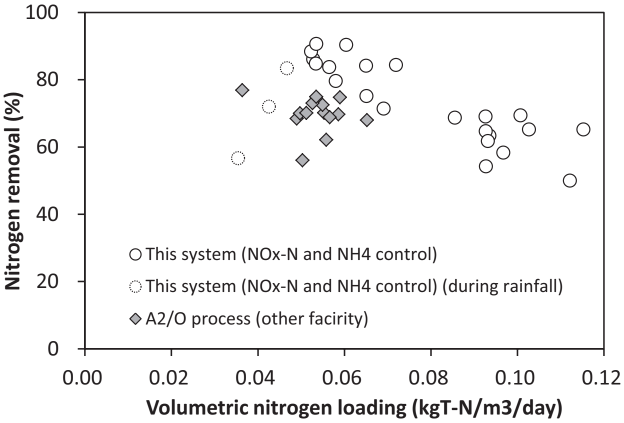

Figure 5 Relationship between volumetric nitrogen loading and nitrogen removal rate

SUMMARY AND CONCLUSION

Simultaneous nitrification and denitrification (SND) with high nitrogen removal efficiency was achieved by individual control by NO_x-N and NH_4-N sensors for the first and second parts of the deep aerobic tank of conventional activated sludge process. Higher nitrogen removal is obtained compared with A^2/O process under below the certain level of nitrogen loading. Moreover, since this new technology enables nitrification and denitrification in a single aerobic tank, a nitrified liquid circulation pump becomes unnecessary and anoxic tank volume can be reduced. Therefore, it is possible to reduce power consumption more than that of A^2/O process or conventional activated sludge treatment process of nitrification (DO controlled). In the future, it is planned to introduce this system to other three of the existing WWTPs and verification of performance will be carried out by long-term continuous operation in the different influent quality.

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