[**Sewerage Systems**]

Water Treatment Control by Using Sensing and Information Control Technologies (ICT)

Morio Miyahara,
Masayuki Nakata,
Kazuhiro Toyooka

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Abstract

Real-time Nitrification and Denitrification Control (RNDC) is a technology that combines Real-time Nitrification Control (RNC) and a chamber-specific aeration control system and adds a denitrification function to improve water quality and optimize air flow. The control consists, at first, of the RNDC controller. This continuously measures the inflow water quality of the reaction tank to grasp the inflow nitrogen load, and calculates the required aeration volume for each chamber in the reaction tank. This aeration is required for nitrification and denitrification using an activated sludge model. It also consists of an individual valve opening calculation device and an electric aeration volume control valve to supply the required aeration volume to the air flow.

After about two months of field performance verification test, the removal rate of ammonium nitrogen, nitrite nitrogen, and nitrate nitrogen in the reaction tank improved from 55.7% to 64.7% with respect to constant Dissolved Oxygen (DO) control with the existing valve. At the same time, the air to flow ratio was reduced by approximately 11.6%.

1 Preface

The activated sludge process has a history of more than 100 years since its invention, and treatment methods based on its principles still play a key role in sewage treatment today. In the activated sludge process, a mass of microorganisms called “activated sludge” is mixed with inflowing sewage in a reaction tank and is aerated (supplied with oxygen) to decompose organic matter and oxidize ammonia to treat sewage.

This processing method, however, requires the operation of a blower for aeration (air blast) in reaction tank, which consumes a large amount of electric power. For example, the water reclamation center in Tokyo is working to reduce the aeration amount because the amount of electricity required to operate the blower accounts for 40%(1) of the amount of electricity required for water treatment. An excessive reduction in the aeration amount, however, causes the quality of the treated water to deteriorate, so it is necessary to strike a good balance between reducing the power consumption of the blower and improving the water quality.

In an effort to reduce aeration volume, Real-time Nitrification Control (RNC) technology(2) was developed. The RNC technology determines the required aeration volume from the inflow water quality and performs appropriate aeration volume with the required aeration volume for each automated aeration control valve installed in the reaction tank. We have been developing technologies such as a chamber-specific aeration control system(3) that can reduce power consumption by stably supplying air. The RNC, in particular, is a new water treatment control system that uses Information and Communication Technology (ICT) to calculate the aeration amount using an activated sludge model(4). It does this based on a sensing technology using sensors such as an ammonia meter and information obtained from the sensor.

One of the efforts to improve water quality is the pseudo-Anaerobic-Oxic-Anoxic-Oxic (AOAO) method(5)(6). With this method, it is possible to promote the removal of nitrogen without increasing the air flow rate while making use of the structure of the existing reaction tank. As shown in **Fig. 1**, the feature of this method is that by partially throttling the manual riser valves (aeration volume control valves) installed in each section of the aerobic tank, denitrification occurs in a part of the aerobic tank. Its purpose is to form a progressive low Dissolved Oxygen (DO) region (hereinafter referred to as anoxic region). Manual riser valves, however, are operated at the most, only a few times a year. Consequently, the anoxic region cannot always be formed in an optimal position to promote denitrification in response to daily or hourly inflow load fluctuations. As such, the challenge is that the maximum effect cannot be obtained.

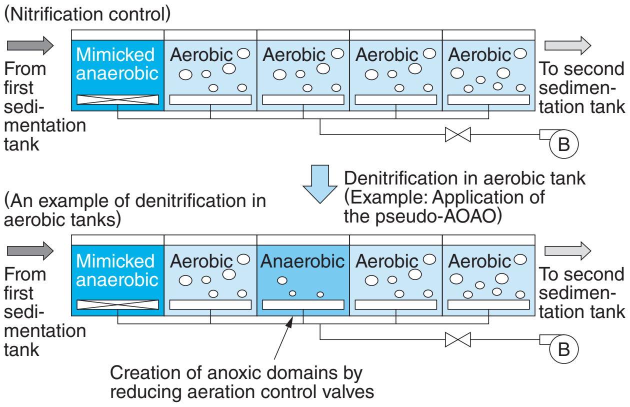

Fig. 1 Image of Pseudo-AOAO Method by Regulating the Manual Aeration Control Valve

For the nitrification control (mimicked AO method) in the upper illustration, the aeration control valve in the first tank is reduced to create an anaerobic condition and all tanks of the second and thereafter, are made aerobic. For an example of denitrification in aerobic tanks (pseudo-AOAO method) shown in the lower illustration, aeration control valves are reduced in the first and middle tanks (third in illustration) to make the tanks anaerobic to reinforce denitrification.

This paper introduces Real-time Nitrification and Denitrification Control (RNDC) technology for the purpose of both improving water quality and reducing power consumption. The RNDC added a denitrification function to the RNC by forming an anoxic region and combined it with a chamber-specific aeration control system. This technology is a result(7) of the "Joint research on real-time nitrification and denitrification control" with the Bureau of Sewerage, Tokyo Metropolitan Government.

2 Configuration of RNDC Technology

Fig. 2 shows the system configuration of RNDC. The RNDC uses the following input data coming from: the flow meter and NH_4-N meter installed at two locations: in the reaction tank and in

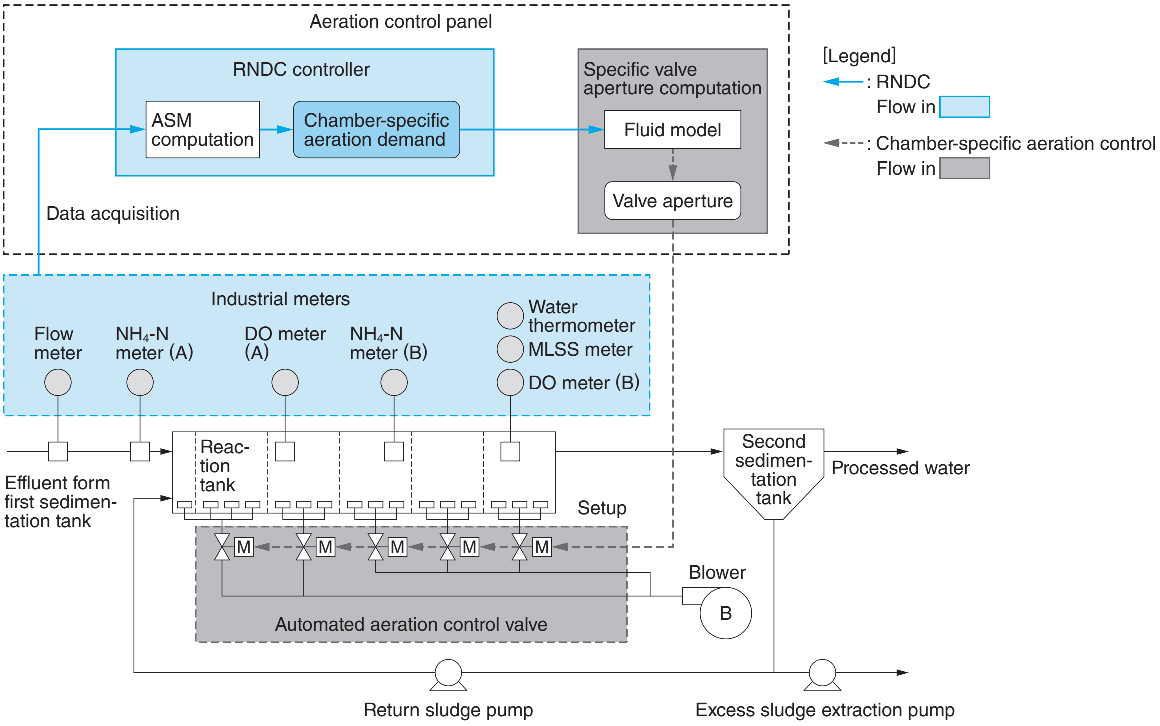

Fig. 2 System Configuration of RNDC

The box of black dotted line shows the aeration control panel. The box with the blue line or blue dotted line shows the RNDC configuration. The blue arrow mark shows a flow of control. The box with the grey line or grey dotted line shows a configuration of chamber-specific aeration control and the arrow mark of grey dotted line shows a flow of control. The overall flow of aeration control is as follows:
First place, the measured values are picked up from industrial meters. Using the acquired values, chamber-specific aeration demand is then calculated with the use of the RNDC controller. Lastly, the chamber-specific valve aperture computer is used to generate outputs of aeration demand in the form of valve apertures, and the aeration demand is adjusted with automated aeration control valves.

the inflow channel for the reaction tank (the water channel just before entering the reaction tank inlet). It also uses the data from the water temperature meter, the Mixed Liquor Suspended Solids (MLSS) meter (to measure the concentration of suspended solid materials in activated-sludge treatment process) and DO meter in the reaction tank. Then, The system then loads such data to the Activated Sludge Model 2d (ASM2d)(4) simulator which consists of the RNDC controller that determines the aeration volume for each chamber, and the individual valve opening for blowing air to each chamber according to the air blow volume and electric air flow control valve. The NH_4-N meter [located at (B) in **Fig. 2**] was used to adjust the ASM parameter (microbial reaction speed rate constant).

2.1 RNDC Controller

Fig. 3 shows the applications to compose the RNDC controller. The RNDC controller consists of two applications: the RNC controller and SIMWATER(8) - the ASM2d simulator. The RNC controller manages and controls the data such as plant data and SIMWATER calculation data, while SIMWATER mainly handles ASM calculation (predicting water quality and calculating required aeration volume for each chamber).

The air flow volume calculation process using both software is as follows.

(1) The RNC controller captures data such as inflow water volume and water quality.

(2) Using a list of chambers for nitrification or denitrification and the aeration volume of each chamber (hereinafter referred to as “the aeration volume table”), the RNC controller comprehensively calculates all combinations on the aeration volume table using SIMWATER.

(3) The RNC controller selects the aeration volume that achieves the target NH_4-N concentration at the outlet of the reaction tank, secures a larger oxygen-free region from the calculation results, and outputs it to the chamber-specific aeration control system. Meanwhile, since the RNDC is a feedforward control system, no NH_4-N meter is installed at the outlet of the reaction tank (details are described in **Section 3**).

2.2 Chamber-Specific Aeration Control System

The chamber-specific aeration control system consists of an individual valve opening calculator and an electric aeration volume control valve. Based on the airflow determined by RNDC, the valve opening is determined from an approximate expression created using one-dimensional fluid analysis, and thereafter controlled by Proportional-Integral-Differential

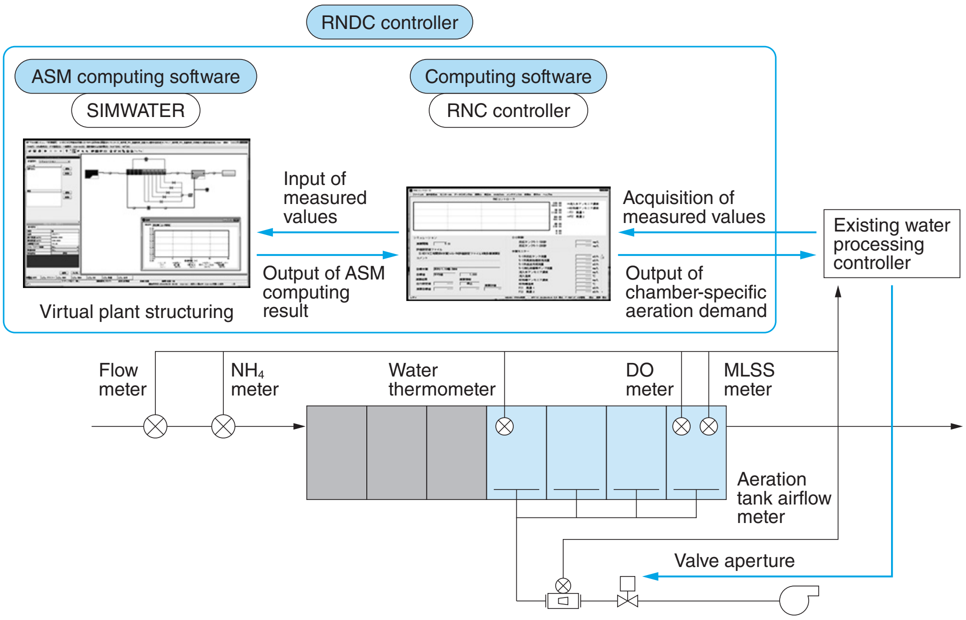

Fig. 3 Applications to Compose RNDC Controller

The RNDC Controller is composed of two applications. For the ASM computing software, SIMWATER, the predicted water quality defined by ASM calculation and the chamber-specific aeration demand are computed by using a previously established virtual plant. At the RNC controller of the control software, measured data are gathered from sensors and such instruments, SIMWATER input data are updated, operational instructions are sent out, and the data output of chamber-specific aeration demand computed by SIMWATER is sent to the water processing controller. The devices can also be used for mimicking control simulation in off-line mode.

(PID). Control that combines valve opening prediction and PID can reach the indicated value in a shorter time than PID control alone. In addition, since multiple valves are controlled simultaneously, it is possible to control the air blow operation even in a small step.

3 Method of RNDC Aeration Rate Decision and Simplification of Parameter Adjustment

Development of the RNDC requires (1) a method of determining the chamber-specific aeration amount (aeration volume table) required to incorporate the denitrification function into the RNC, and (2) simplification of ASM parameter setting and MLSS adjustment for actual operation. In **3.1**, we report the method of determining the aeration volume for each chamber necessary to incorporate the denitrification function, and in **3.2**, we report on the method of adjusting the ASM2d parameter and solids concentration.

3.1 Examination of Airflow Pattern in Each Chamber

In the nitrification control RNC developed by our company, the DO concentration range and step width (1.0 to 5.0 mg/L, 0.5 mg/L step) for simulation are determined in advance, and the NH_4-N concentration at the end of the reaction tank is determined under these DO conditions. By selecting the minimum DO value that satisfies the target value⑵, we could control the aeration volume.

In the RNDC, however, to promote denitrification, it is necessary to determine (1) the chamber (section) that forms the anoxic region and (2) the air flow rate for each electric aeration control valve chamber (section). Using actual measurement data and SIMWATER, we investigated the chambers that form the anoxic region and the aeration volume adjustment range for each chamber and the step size of the control.

3.1.1 Facility Overview and Simulation Model

The performance verification of the actual system was conducted in the 5-1 system reaction tank (hereinafter referred to as the experimental facility) at Minami-tama Water Reclamation Center under the Regional Service Office, Tokyo Metropolitan Government. **Fig. 4** shows the divisions inside the reaction tank and allocation of automated aeration control valves, and **Table 1** shows the outline of the facility.

A simulation was performed prior to the demonstration experiment. The tank row model was divided into 10 sections based on the structure of the actual facility, and the air flow rate of valve 1 was distributed between the B-2 and B-3 sections according to their respective volume ratios. Next, a

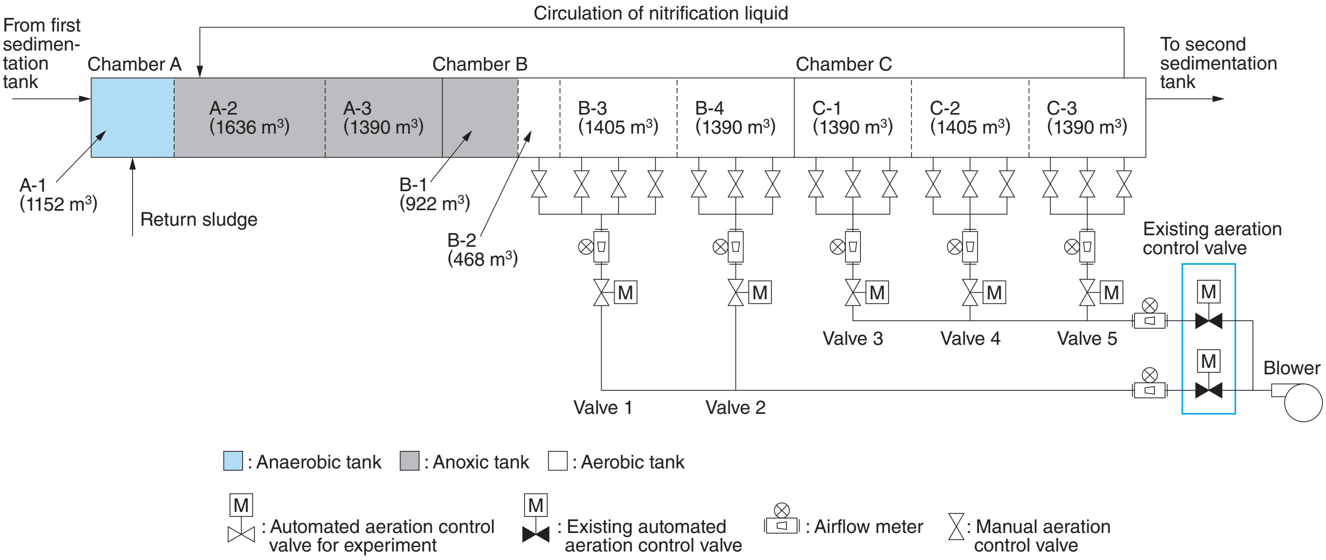

Fig. 4 **Divisions Inside Reaction Tank and Allocation of Automated Aeration Control Valves**

A schematic diagram is shown, assuming that three meandering channels are arranged into a straight line. For operation, Chamber A-1 is an anaerobic tank, Chamber A-2 to B-1 is an anoxic tank, and Chamber B-2 to C-3 is an aerobic tank. Return sludge is returned from the second sedimentation tank to Chamber A-1 and nitrification liquid is circulated from Chamber C-3 to Chamber A-2. Two automated aeration control valves for experiment are installed in between Chamber B-2 and Chamber B-4, and three units in between Chamber C-1 and Chamber C-3. Regarding existing aeration control valves, two units are installed at the former and latter stages, respectively. During control, they are fully open.

simulation was performed using the average values of the 24-hour test shown in **Table 2** as input values, and the overall oxygen transfer capacity coefficient (K_La) was estimated, and the solid concentration was adjusted. In addition, the ASM parameters were adjusted with the values of each sample used to calculate the average values shown in **Table 2**.

Table 1 **Outline of Facility**

The facility outline of the 5-1 system of the Minami-tama Water Reclamation Center is shown. The removal method is a separate flow system, and treatment is performed by the anaerobic-anoxic-aerobic method by controlling the air flow with constant DO control in three meandering channels.

Item	Contents
Processing system	Anaerobic/anoxic/aerobic method
Reaction tank capacity	12,548 m^3
Max. processing capability	21,810 m^3/day
Hydrological retention time	13.8 h (at Max. processing capacity)
Water channel structure	Meandering type (3 channels)
Existing control system and setup values	DO constant control (DO setup value: 1.2 mg/L at Channel B end; 2.0 mg/L at Channel C end)
Discharge system in processing section	Separate type

Table 2 **Acquired Data from Aeration Constant Control (November 1, 2018 at the Minami-Tama Water Recycling Center)**

Operational values, water-quality analytical values, and sensor values acquired in fair weather days are respectively shown. Numerical values are mean values and figures in brackets show the range of variation for each item.

Item	Mean value (Variation range of each item)
Operational values	
Influent rate	732 (649〜839) m^3/h
Nitrification liquid circulation rate	479 (476〜482) m^3/h
Return sludge rate	270 (249〜312) m^3/h
Hydrological retention time	17.1 h
Total aeration rate※1	4402 (4321〜4483) Nm^3/h
Water-quality analytical values	
NH_4-N at reaction tank inlet	25.4 (20.0〜40.7) mg/L
NH_4-N at reaction tank outlet	0 (0〜0.1) mg/L
NO_3-N at reaction tank outlet	11.0 (8.9〜12.6) mg/L
Sensor values	
MLSS	1757 (1706〜1817) mg/L
Water temperature	25.8 (25.5〜26.0) ℃

Note. ※1: Total aeration rate of automated aeration control valves 1〜5

3.1.2 Examining Method of Determining Airflow Volume that Forms Anoxic Region

Several studies on denitrification in aerobic tanks were reported(5)(6). These investigations report that nitrification was promoted by making the front chamber of the aerobic tank under aerobic conditions, and by partially throttling the manual riser valves installed in the middle and rear chambers to suppress the air flow rate and form an anoxic region. By doing so, it operates and manages to promote denitrification. Based on this management method, the concept of the aeration volume in the RNDC and the control method of the automated aeration control valve were examined.

Each chamber connected to valve 1, valve 4, and valve 5 was always in an aerobic region. The purpose of valve 1 was to secure an air flow rate for progressing nitrification, while the purpose of valves 4 and 5 was to end nitrification.

Each chamber connected to valves 2 and 3 is set in the anoxic region to promote denitrification when the inflow load is low, and is set in the aerobic region when the load is high. **Fig. 5** shows the aeration patterns by aeration volume combination candidates under study by simulation. Considering the calculation time, we narrowed down the aeration pattern to three for control. First, (a) was selected as

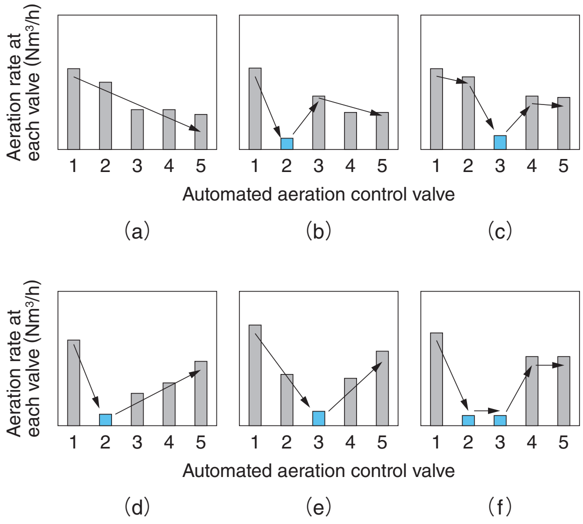

Fig. 5 **Aeration Patterns by Aeration Volume Combination Candidates under Study by Simulation**

The aeration patterns are divided into the tapered type of (a) to (c) and the valley type of (d) to (f). Type (a) is an aeration pattern of nitrification only, but the aeration patterns of (b) to (e) is based on the minimal aeration in the position of Valve 2 or Valve 3 (black bar section) forming a pattern of anoxic tanks. Type (f) is an aeration pattern that forms anoxic tanks in two positions at Valve 2 and Valve 3.

Table 3 Typical NH_4-N Influent Load (g-N/m^3/h) Verified by Simulation

We implemented a simulation to know which aeration pattern corresponds to (a), (d), or (f) selected in Fig. 5 while we were examining the variation range of inflow conditions about inflow water rate and NH_4-N concentration (NH_4-N inflow load). (Refer to Fig. 5 for aeration patterns.)

		Influent rate (m^3/h)		
		700	**800**	**900**
NH_4-N concentration (mg/L)	**40**	28	32	36
	30	21	24	27
	20	14	16	18

Table 4 Inflow Load Conditions and Applied Aeration Patterns

As a result of the simulation with SIMWATER, we clarified that the aeration pattern of (a) functions when the NH_4-N inflow load is high, that of (d) functions when the load is medium, and that of (f) functions when the load is low, respectively.

		Influent rate (m^3/h)		
		700	**800**	**900**
NH_4-N concentration (mg/L)	**40**	(d)	(a)	(a)
	30	(f)	(d)	(a)
	20	(f)	(f)	(d)

the aeration pattern when the inflow load was high, and (f) was selected when the inflow load was low so that both circuits could be in the anoxic region. Based on the results of the above(5)(6), it is considered that more organic matter remains in the anoxic zone in (b) and (d) than in (c) and (e), which is advantageous for denitrification. The denitrification performance was compared by simulation for (b) and (d) where the automated aeration control valve was throttled. For comparison, the inflow NH_4-N load conditions were set as shown in Table 3 based on the results of the actual facility during fair weather. We simulated an intermediate load test under the NH_4-N concentration 30 mg/L, and the inflow water volume 800 m^3/h. The average values shown in Table 2 were used for the nitrifying liquid circulation rate, return sludge rate, MLSS, and water temperature. In addition, the air flow rate was adjusted so that the NH_4-N concentration at the outlet of the reaction tank was 1 mg/L. The denitrification performance was evaluated by the tri-state nitrogen removal rate. It was obtained by subtracting from 1 the value obtained by dividing the total concentration of NH_4-N, NO_3-N, and NO_2-N (hereafter referred to as "tri-state nitrogen") in the effluent of the reaction tank by the concentration of NH_4-N in the influent (the influent's NO_3-N concentration and NO_2-N concentration were assumed to be zero). By subtracting the value obtained by dividing by (assumed to be zero) from 1, this was obtained.

As a result, the tri-state nitrogen removal rate was 58.8% in (b), (d) was selected because it was 59.6%. In rainy weather it is difficult to secure an oxygen-free region due to changes in dissolved oxygen brought in and inflow water quality. As mentioned the above(2), we prioritized the stabilization of nitrification and excluded it from the study. Next, when simulations of (a), (d), and (f) were performed with all the NH_4-N load combinations shown in Table 3. The air flow pattern with the highest tri-state nitrogen removal rate is shown in Table 4 as the results.

3.1.3 Drafting Aeration Volume Table and Confirmation of Validity

Table 5 shows the aeration volume table. Based on the aeration volume pattern, the upper and lower limits of the aeration volume of the installed diffuser plates, and the aeration volume determined by the number of installed air diffusers (upper limit of 6000 Nm^3/h and lower limit of 3000 Nm^3/h for the entire aerobic tank), the combination of the aeration volume from each valve was examined.

The aeration volume step size was set to 100 Nm^3/h, taking into account the time required for calculation and the accuracy of the simulation of the treated water quality. As a result, we created a total of 33 sets of blowing volume tables: 14 sets for high load (a) (total aeration volume 4700 to 6000 Nm^3/h), 10 sets for medium load (d) (total aeration volume 3800 to 4700 Nm^3/h), and 9 sets for low load (f) (total aeration volume of 3000 to 3800 Nm^3/h).

The simulation was then performed using the RNC controller to imitate the control, and the validity of the air flow table was confirmed. Fig. 6 shows an example of RNDC by simulation. For the influent volume, nitrifying liquid circulation rate, return sludge rate, MLSS, and water temperature, the values of each sample obtained in the 24-hour test used to calculate the average values in Table 2 were used. For the NH_4-N concentration, the value of the NH_4-N meter (A) shown in Fig. 2 was used. The air flow rate was changed once an hour so that NH_4-N at the outlet of the reaction tank was 1 mg/L or less. As a result, it was confirmed that while the NH_4-N concentration and volume of water flowing into the reaction tank fluctuated, the total air flow

Table 5 **Aeration Volume Table (Partial)**

Based on the result of Table 4, an aeration volume table with the use of the RNDC was produced. The aeration pattern of (a) in a high aeration rate area, that of (d) in medium rate area, and that of (f) in low rate area, are combined and there are 33 patterns in total where the total aeration rate is expressed with increments of 100. "⋯" in the table that indicates omission. The blue box 🟦 indicates a valve that forms an anoxic region and promotes denitrification by setting the minimum air flow rate to 200 Nm³/h.

	Aeration pattern No.	Valve 1 (Nm³/h)	Valve 2 (Nm³/h)	Valve 3 (Nm³/h)	Valve 4 (Nm³/h)	Valve 5 (Nm³/h)	Total (Nm³/h)
(a)	1	1800	1300	1100	900	900	6000
	⋮						
	14	1500	1200	700	700	600	4700
(d)	15	1800	200	700	900	1100	4700
	⋮						
	24	1500	200	400	600	1100	3800
(f)	25	1500	200	200	900	1000	3800
	⋮						
	33	1200	200	200	600	800	3000

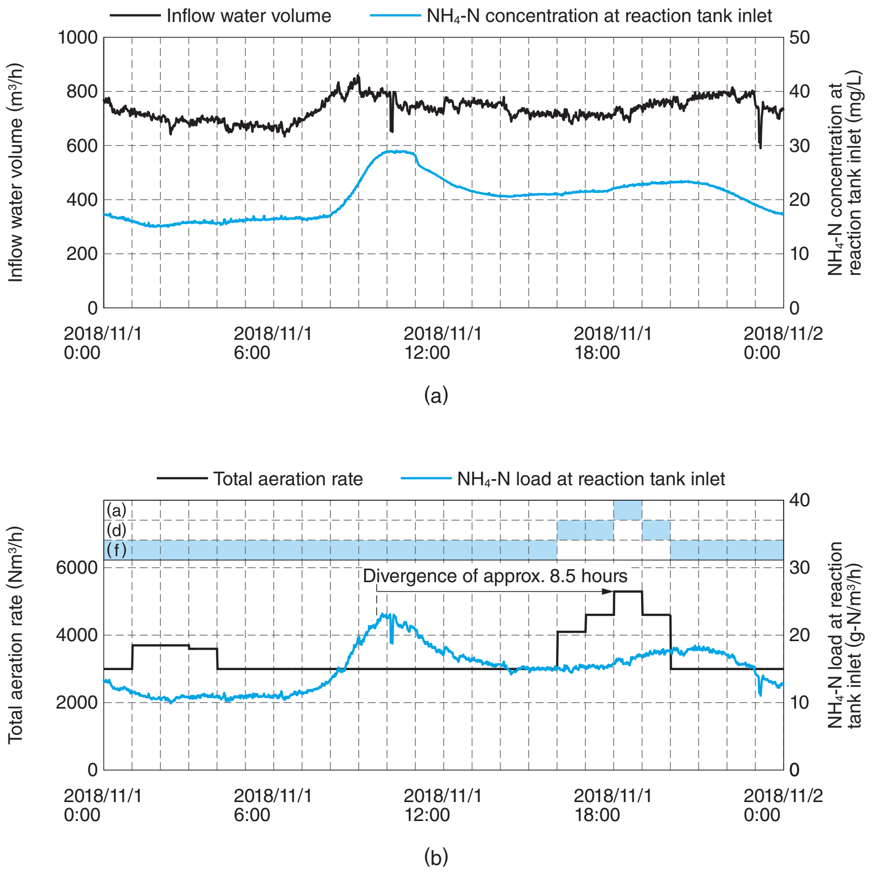

Fig. 6 **Example of RNDC by Simulation**

To confirm whether an adequate aeration table is established, simulation of control was carried out using the RNC controller. In the upper part of (b), the selected aeration pattern is shown colored in blue. In consideration of a divergence of 8.5 hours attributable to liquid flow-down time, the peak of inflow NH_4-N load seems to coincide with that of aeration rate. In addition, there is also a change in the aeration pattern along with an increase in the inflow NH_4-N load.

rate varied within the range of 3000 to 5300 Nm³/h and (a), (d), and (f) aeration patterns are selected according to load fluctuations. The difference between the peak of the inflow load and the peak of the total blast volume is about 8.5 hours. This is almost equal to the apparent retention time obtained by dividing the volume of the reaction tank by the sum of the volume of the inflow water, the circulating water volume of the nitrifying liquid, and the volume of the returned sludge.

Based on the above, it was confirmed that the required aeration volume for each circuit can be determined based on the inflow NH_4-N load using the aeration volume table in **Table 5**.

3.2 Simplification of Adjustment Function

The ASM2d has 21 reaction rate equations and 45 constants (parameters)(4). Adjustments, or calibrations, are necessary to accurately reproduce the conditions of the target facility in the simulation. For example, the reaction rate equation for growth of nitrifying bacteria under aerobic conditions is defined by the chemical formula (1) below. This formula consists of terms for maximum specific growth rate, dissolved oxygen, NH_4-N, phosphate-type phosphorus, alkalinity, and an amount of nitrifying bacteria.

$$\text{Growth rate of nitrification bacteria} = \mu_{AUT} \cdot \frac{S_{O_2}}{K_{O_2}+S_{O_2}} \cdot \frac{S_{NH_4}}{K_{NH_4}+S_{NH_4}} \cdot \frac{S_{PO_4}}{K_P+S_{PO_4}} \cdot \frac{S_{ALK}}{K_{ALK}+S_{ALK}} \cdot X_{AUT} \quad \cdots\cdots\cdots\cdots (1)$$

In a study conducted at Sunamachi Water Reclamation Center, Bureau of Sewerage, Tokyo Metropolitan Government during the development of RNC, nitrification control(2) could be realized by adjusting Value $K_{NH_4, A}$ (saturation constant of NH_4-N concentration for nitrification) and Value $K_{O_2, A}$ (saturation constant of dissolved oxygen concentration for nitrification).

In addition, a two-month continuous operation study revealed that the concentration of solids also needed to be adjusted periodically to achieve stable control over the long term. These adjustments require general knowledge of ASM and proficiency in handling simulators, which may hinder the introduction of this technology. We, therefore, decided to develop a function that automatically adjusts the parameters and solid concentration.

3.2.1 Adjustment of ASM Parameters

As mentioned above(2), the ASM parameters being adjusted are $K_{NH_4, A}$ and $K_{O_2, A}$. Since these parameters concern nitrification, an ammonium meter (B) was installed in the middle section of the reaction tank as shown in **Fig. 2** and its readout value was regarded as an index.

Fig. 7 shows the adjustment flow of ASM parameters. The adjustment was made only when the difference between the measured value of the ammonia meter (B) and the calculated value is outside the allowable range of the ASM parameter adjustment. The combinations of $K_{NH_4, A}$ and $K_{O_2, A}$ were thoroughly computed and we selected the combination that minimized the difference between the measured values and the calculated values. It should be noted that, when the measured values are extremely low due to rainfall, it is not possible to determine appropriate parameters, so no adjustments are made. As a result, the measured, and calculated, values are nearly matched.

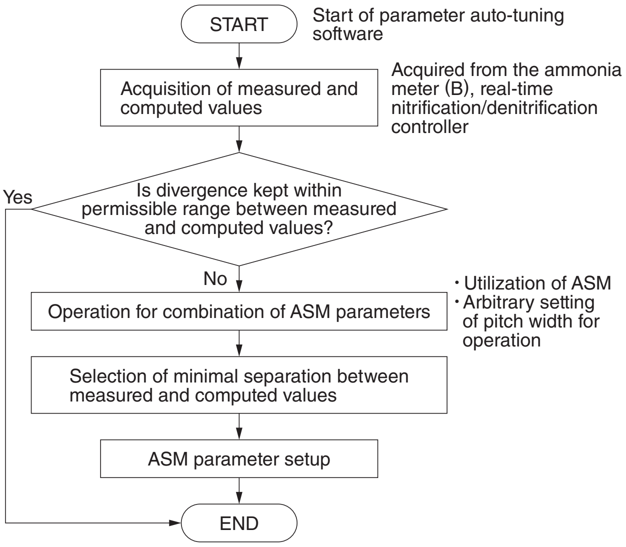

Fig. 7 Adjustment Flow of ASM Parameters

By an auto-tuning function of the ASM parameters provided in the RNC controller and based on the illustrated flowchart, automatic setting of the ASM parameters is possible, by which the measured values of the NH_4-N meter (B) in **Fig. 2** can be made to coincide with the computed values of NH_4-N in the same position of a virtual plant by the SIMWATER.

3.2.2 Adjustment of Solid Concentration

Since we considered that the adjustment of solids concentration is almost equal to that of MLSS concentration, we adopted a method to make the computed value coincide with the measured value from the MLSS meter installed in a practical reaction tank. **Fig. 8** shows the adjustment flow of solids. Specifically, the measured value of the MLSS meter and the calculated value are compared, and if the difference is outside the allowable range, the sludge withdrawal amount of the excess pump applying the Tank-in-series Model is changed and the MLSS calculated value is changed. Adjustments were made once a day to approximate the measured values. It was confirmed that the measured values and the calculated values were almost matched. Although this method may not reflect the actual concentration of nitrifying bacteria, it was confirmed that it does not interfere with control.

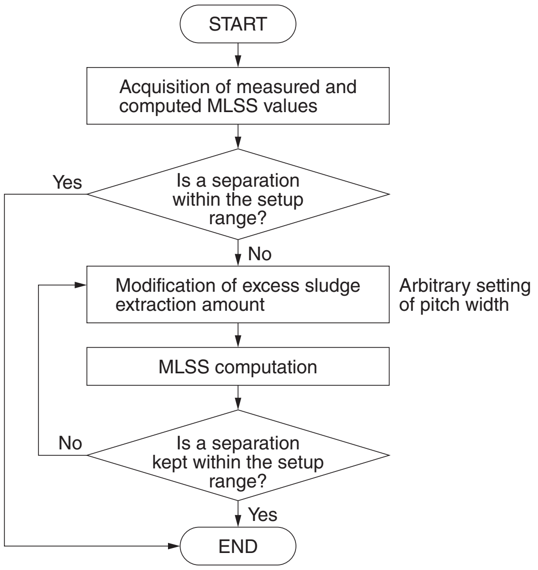

Fig. 8 **Adjustment Flow of Solids**

By virtue of the auto-tuning function of a suspended solids balancer (MLSS) installed in the RNC controller and based on the illustrated flowchart, the measured value of the MLSS meter can be automatically made to coincide with the computed MLSS value of the virtual plant by the SIMWATER.

4 RNDC Performance Verification

The RNDC was installed in the facility (**Table 1**) and performance verification test was performed from January 19, 2019 to February 17, 2019. Input data items and calculation conditions to the simulator were the same as in **3.1.3**. During the performance verification test, the existing automated aeration control valve was fully opened, and only the automated aeration control valve for the experiment was used. **Fig. 9** shows an example of RNDC aeration with automated aeration control valves. As shown in (a), the ASM calculation result (total aeration volume set value) changes according to the inflow load fluctuation of the NH_4-N concentration. In addition, as shown in (b), it was confirmed that the aeration volume of valves 2 and 3 was controlled to approximately 200 Nm³/h during the hours when the total aeration volume was low, as expected. Fluctuations in the aeration volume can be seen even when the aeration volume setting does not change. This is thought to be due to the influence of pressure fluctuations in the main blast pipe (blower discharge pressure) because the blast air system

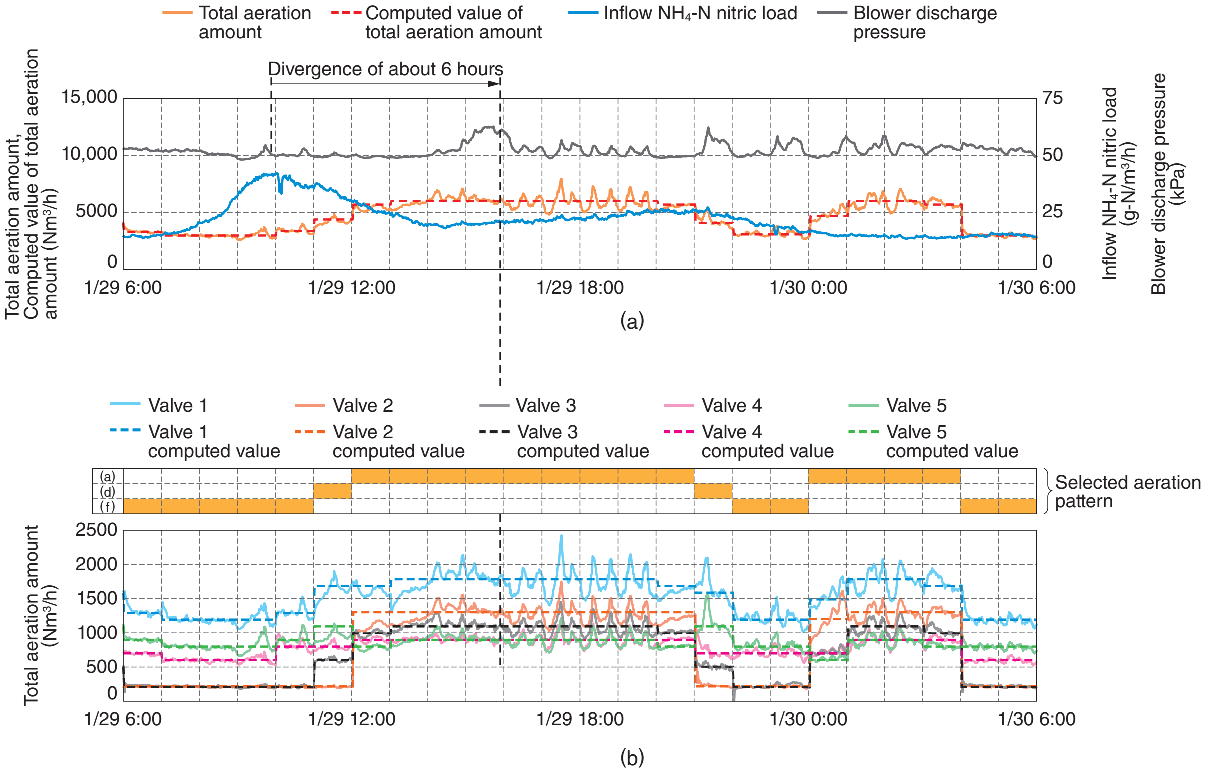

Fig. 9 **Example of RNDC Aeration with Automated Aeration Control Valves**

When RNDC control is performed on actual machines, the aeration amount indicated by solid lines roughly follows the computed aeration amount indicated by dotted lines. Regarding variations in the aeration amount, the peak of aeration amount appears about 6 hours after the peak of the inflow NH_4-N load. From 15:00 to 21:00, the blower discharge pressure seems to vary and the aeration amount at the respective valves also changes during this period.

was shared with blast air systems other than those used in the demonstration experiment.

4.1 Water Quality Improvement Effect

Using the followability of the NH$_4$-N concentration at the outlet of the reaction tank to the target value and the removal rate of tri-state nitrogen as indices, a comparison was made with the case of constant DO control (performed in the same reaction tank).

The tri-state nitrogen concentration was obtained by collecting the overflow water of the first sedimentation tank and the activated sludge at the outlet of the reaction tank every 4 hours and analyzed the filtered sample by ion chromatography. The tri-state nitrogen removal rate was determined by calculated using the daily average value of such tri-state nitrogen concentration. The amount of inflow water, the amount of circulating nitrifying liquid, and the amount of return sludge were the same as during constant DO control.

Table 6 shows the results of comparison between RNDC and DO constant control. The NH$_4$-N concentration at the reaction tank outlet, on average, was 0.7 mg/L, close to the target value at RNDC, while the target value was 1.0 mg/L. Under constant DO control (1.2 mg/L at the end of Chamber B and 2.0 mg/L at the end of Chamber C), the average was 0.2 mg/L, which was lower than the target. This is the result of the anaerobic-anoxic-aerobic treatment method used in the facility used for verification test, and the nitrification liquid is circulated in the second half of the chamber C, which is the result of efforts to achieve complete nitrification.

In addition, the tri-state nitrogen concentration at the reaction tank outlet was 2.2 mg/L lower on average with RNDC than with constant DO control, and the tri-state nitrogen removal rate improved from 55.7% to 64.7%. The phosphate phosphorus concentration measured by RDNC during the investigation period was 0.4 mg/L on average for RDNC and 0.8 mg/L for constant DO control, with no adverse effects were observed.

Table 6 Result of Comparison between RNDC and DO Constant Control (Period: 9 January to 17 February 2019)

The mean operating time of RNDC with actual machines and the daily mean value of water quality analysis during verification are shown. Below the level of dotted lines, tri-nitrogen removal rate being the evaluation index for control and the reduction rate of air-to-flow ratio per unit influent volume are shown. Numerals on the left indicate the RNDC, those in the center indicate the DO constant control, and those on the right fall on the difference between RNDC and DO constant control.

Item	RNDC※a	DO※b	Difference※c
Data acquisition days (fine day)	8	12	−4
Operation values (hourly average)			
Influent volume (m^3/h)	834	841	−7
Nitrification liquid circulation amount (m^3/h)	479	492	−13
Return sludge flow rate (m^3/h)	423	413	10
Total aeration amount (Nm^3/h)	4461	5063	−602
Water quality analytical value (daily average)			
Tri-nitrogen at reaction tank inlet (mg/L)	25.3	25.3	0.0
Tri-nitrogen at reaction tank outlet (mg/L)	9.0	11.2	−2.2
Ammonium nitrogen at reaction tank inlet (mg/L)	25.0	24.9	0.1
Ammonium nitrogen at reaction tank outlet (mg/L)	0.7	0.2	0.5
Measured value at MLSS meter (mg/L)	2792	2737	55
Water temperature at reaction tank (℃)	20.3	20.2	0.1
Tri-state nitrogen removal rate (%)	64.7	55.7	9.0
Nitrification liquid circulation rate (%)	57.5	58.8	−1.3
Air-to-flow ratio (—)	5.3	6.0	−0.7
Reduction rate of air-to-flow ratio per unit influent volume (%)	11.6	—	—

Note. ※a: Real-time nitrification denitrification control,
※b: DO constant control, ※c: Difference between a-b

4.2 Evaluation of Effect of Energy Saving

The energy-saving effect is determined by the blow volume reduction rate calculated from the air supply ratio (aeration volume/inflow water volume), and the correlation formula between the intake aeration volume of the fan and the power [$y = 0.0133x + 237$, $R^2 = 0.916$, y: fan power (kW), x: amount of air drawn into the fan (Nm^3/h)]. The energy-saving effect was determined based on two factors: the aeration reduction rate calculated from the air-to-flow ratio (aeration amount/inflow water amount) and the blower power reduction rate calculated from the blower intake aeration volume and the correlation formula for electric power [$y = 0.0133x + 237$, $R^2 = 0.916$, y: Blower power (kW), x: Blower suction aeration volume (Nm^3/h)].

As a result, as shown in **Table 6**, the RNDC air blow reduction rate for constant DO control was 11.6% (7.1 to 19.7%) on average. This effect is comparable with the reduction of blower power by 7.2% (4.4 to 12.2%) when the RNDC is introduced to all tanks at Minami-Tama Water Recycling Center. The air-to-flow ratio for constant DO control fluctuated between 5.6 and 7.1, while that for the RNDC was between 5.2 and 5.7, and the fluctuation was small.

5 Postscript

In this study, the following results were obtained.

(1) Development of RNDC

Using the ASM2d simulator, air flow control was performed to actively increase or decrease the number of chambers in the oxygen-free region according to the nitrogen inflow load fluctuation, and the effect of promoting denitrification was demonstrated.

(2) Simplification of adjustment functions

A function for adjusting the concentration of solids using ASM parameters and MLSS as indices has been added. By eliminating the need for manual adjustment of parameters, the introduction of RNDC prevents the burden of increased operation management, making it a more practical control technology.

(3) Evaluation of RNDC with actual equipment

Performance verification was performed using equipment (anaerobic-anoxic-aerobic method). The tri-state nitrogen removal rate in the reaction tank was improved from 55.7% to 64.7%, and the air-to-flow ratio was reduced by about 11.6%. Based on this result, it was considered that the total nitrogen removal rate also improved about the same extent. When RNDC was introduced to all ponds in Minamitama Water Reclamation Center, it was equivalent to a 7.2% reduction in fan power consumption.

As described above, it was confirmed that the RNDC, which combines the calculation of the required air flow rate using ASM and the chamber-specific air flow control technology, can achieve both air flow reduction and water quality improvement. We also believe that RNDC can be applied to various treatment methods by changing the Tank-in-series Model. From these points, RNDC is expected to make a major contribution to future sewerage projects.

In the future, we plan to improve the specifications to make them more practical by conducting demonstrations at combined treatment plants and reducing costs by reducing the number of electric aeration volume control valves installed.

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