Aeration Control by Real-Time Nitrification Control Utilizing Activated Sludge Model

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Abstract

In biological treatment processes for the water quality improvement in sewage treatment systems, a large amount of electric power is consumed for aeration. For this reason, the development of a new aeration control technology is pursued to realize both water quality improvement and energy saving.

We studied the technology for aeration control by "Real-Time Nitrification Control" by using an Activated Sludge Model (ASM) simulation in this study. We aim to establish a feedforward control technology of the aeration volume necessary for establishing the target value of water quality.

During experimental testing period at a full-scale sewage treatment plant in winter, the air-to-flow ratio was reduced by about 10% on a sunny day when compared with Dissolved Oxygen (DO) constant control. Even changes in inflow water quality and water temperature due to initial rainfall on a rainy day, the target value of water quality was secured in a stable condition. These results show that our technology is useful to realize water quality improvement and energy saving.

1 Preface

Activated sludge method that still plays a key role in sewage treatment today, has more than 100 years of history since its invention. This is a superb sewage treatment method by which decomposition of organic matters by aerobic respiration of microbes and nitrification of ammonia nitrogen (NH_4-N) are promoted by aeration of activated sludge in a reactor. This method, however, requires a large volume of air in order to maintain metabolism for microbes. Electric power for sufficient aeration volume takes about 23% of total power consumption in a sewage treatment facility(1).

At a sewage treatment plant, a large amount of electric power is consumed by blowers that supply a required amount of air to reactor tanks. This is because a specified amount of air is needed for the nitrification of NH_4-N and decomposition of organic matters. Power consumption can be reduced by decreasing the air blow volume, but too much reduction can result in the lowering of treated water quality. It is evident that there is a reciprocal trade-off relation between water quality improvement and reduction of power consumption. Striking the right balance of these factors is our biggest challenge. The development of technology to address this issue is needed(2). Specifically, it should be a new aeration control technology that, according to the sewage influent load, the required aeration volume is controlled as it manages both water treatment and air blow volume reduction.

Currently for aeration control, a Dissolved Oxygen (DO) constant control system is widely adopted, by which DO concentration is maintained at a constant level at the outlet of each reactor tank. This is, however, a kind of feedback control where the amount of air blow volume is controlled based on the DO value at the end of a reactor tank. As a result, it causes a reaction lag in response to the changing sewage influent load volume and there may be an energy loss due to excessive air supply even at a low load. There may, however, also be a deterioration of water quality due to a lack of air supply in the case of a high load. As a control approach to achieve an adequate air supply needed for biological treatment, there are the following two technologies:

(1) Technology to measure the inflow load
(2) Technology to calculate necessary aeration

volume and fluctuate such volume in a feedforward manner

In order to realize both water quality improvement and energy saving, a more advanced aeration control technology must be established. For nitrification-accelerated operation performed at sewage treatment plants, it becomes essential to grasp the NH_4-N concentration of influent to attain adequate nitrification, and to blow the air by defining the air blow volume needed for nitrification. Regarding the aforementioned (1) technology, continuous measurement of NH_4-N in reactor influent is required by means of sensors. The verification test, however, was not performed for the sustained stability of electrode type ammonium sensor ("ammonium sensor" hereafter) in inflow water. Regarding this (2) technology, it is necessary to estimate the amount of air volume favorable for nitrification by taking into consideration changes in downstream concentration based on influent NH_4-N. In the current study, some application examples in full-scale sewage treatment plant were reported regarding the control system that is operated based on the influent NH_4-N concentration. Such control systems utilize fuzzy control(3)(4) or treatment characteristic model (a model based on the relationship between actual amount of NH_4-N concentration treatment and the amount of air blow volume) by which correction control(5) is carried out. They are intended to estimate the required amount of air volume based on the past treatment conditions. There are, however, some risks that the control response is not enough in cases against sudden changes in influent water quality or changes in inflow water volume or water temperature. It is possible to estimate the required air volume based on the influent NH_4-N concentration, but there are very few reports stating that the said treatment characteristic model was applied to aeration control.

In this study, we verified the performance of our ammonium sensors and adopted an Activated Sludge Model (ASM) simulation proposed by the International Water Association (IWA) for our microbes reaction model. The ASM is a general name for a group of mathematical methods to model activated sludge systems.

We developed a technology under which we combine measurement of the influent NH_4-N load and simulation of treatment conditions by ASM simulation model, calculate the air flow rate to attain the target water quality, and control the air flow rate in a feedforward manner. Since this technology makes it possible to control the quantity of air blow volume required for nitrification in fast response to a change of the influent load, we decided to call it as the "real-time nitrification control." For performance evaluation, an ammonium sensor is installed in an existing sewage water treatment facility in order to measure the NH_4-N concentration of influent water. In addition, an arithmetic unit for nitrification control for ASM is installed and connected to an existing air blow process controller. In this arrangement, we examined and compared the results of control performance of real-time nitrification control, the effect of air blow volume reduction, and the effect of water quality improvement with those of existing DO constant control.

2 Real-Time Nitrification Control

2.1 Principle

The ASM is a general name for a group of mathematical methods to model the proliferative response of microorganisms in the activated sludge systems. This simulation model is currently recognized as a global standard of a processing model where the stripping reaction of microbes, organic matter, nitrogen and phosphorus in the activated sludge process is described(6). The ASM simulation can be used to estimate the quality of treated water, the required amount of oxygen, and the excess sludge volume generated. The ASM, however, is a complicated model and this factor is a disadvantage such that a very long time is needed for computation if a general-purpose desktop Personal Computer (PC) or laptop is used for analysis. For this reason, the application of the ASM for aeration control technology is rare though it is widely utilized for reactor design and analysis of operating conditions(7)-(13). In addition, practical applications are limited to cases when a part of the ASM simulation model is utilized(14)(15). Thanks to recent improvement of desktop PC or laptop performance, however, computation of the ASM simulation model can be accomplished in a short time by using a commercially available desktop PC or laptop.

In this research, we used a general-purpose PC or laptop and we utilized the results of ASM simulation model computation to interface with an existing DO constant control in real-time mode. In this way, we worked on the development of our aeration control technology. If successful, this technology could be easily introduced to facilities for a low cost and without requiring substantial modification of the existing facilities.

For the execution of simulation, the ASM simulation model calls for organic matter fraction (screening or sorting) in influent water. The organic matter fraction is an index to classify matters used in the ASM simulation model, such as organic matters in influent water. This approach, however, is somewhat difficult to realize by using the currently available water quality measuring instruments. In actual sewage treatment plants, we have a track record of operational experience focusing mainly on NH_4-N nitrification. As such, in this research, we focused on aeration volume control needed for the NH_4-N nitrification in influent water to develop a practical control technology. We then promoted continuous measurements of NH_4-N concentration in influent water and worked on the control technology (real-time nitrification control) combined with ASM simulation. **Fig. 1** shows a configuration diagram of the real-time nitrification control system. The major constituent members are an ammonium sensor and a real-time nitrification controller (a laptop is used for computation) newly installed in an influent area of the reactor tank. For the ASM simulation model used with the real-time nitrification controller, the ASM2d unit(6)(16) is adopted because it is frequently used as an analytical tool in actual fields. For the simulation system, SIMWATER(17), a sewage treatment process simulator we developed, is used.

2.2 Control Flow

Fig. 2 shows a control flow of real-time nitrification control (determination procedure of treated water quality estimation and DO setup value decision). When the ASM simulation model is used in combination with existing DO constant control, there is an issue that the DO setup value to satisfy the target treated water quality cannot be determined directly because the ASM simulation model is a complicated reactor model. Accordingly, the DO setup value to meet the target treated water quality in response to the influent NH_4-N load is determined by the steps shown below.

(1) The major conditions of influent NH_4-N concentration, influent water volume, water temperature in reactor tank, and MLSS concentration are defined.

(2) Based on these conditions, the DO values at the end of reactor tanks are set up in multiple cases. Using the ASM simulation model, the aeration volume, by which the DO value at the end of each reactor tank can be obtained, is determined by repeated calculation of ASM simulation.

(3) Based on the result of ASM simulation for the aeration volume whose simulation determines the setup DO value, the NH_4-N concentration at the end of a reactor tank is estimated at the preset aeration

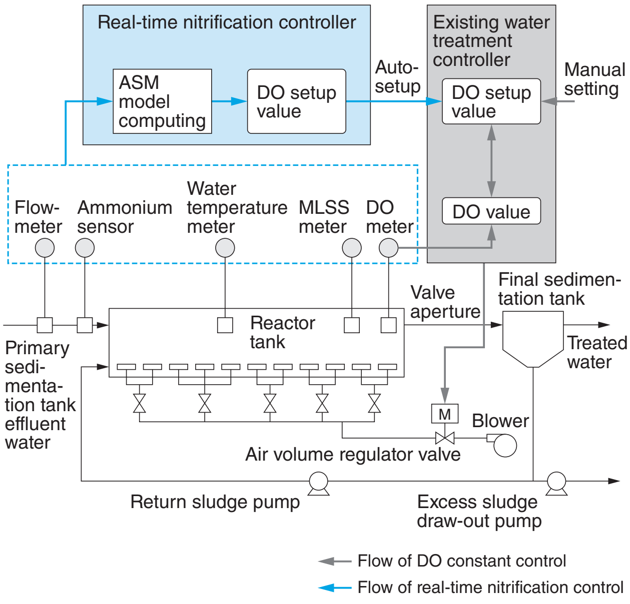


Fig. 1 Configuration Diagram of the Real-Time Nitrification Control System

A diagram of nitrification control flow using the ASM simulation model is shown.

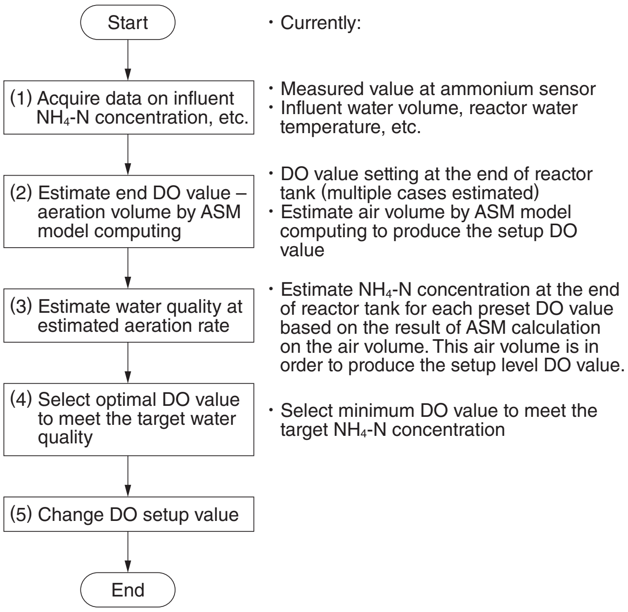


Fig. 2 Control Flow of Real-Time Nitrification Control (Determination Procedure of Treated Water Quality Estimation and DO Setup Value Decision)

A work flow chart of DO control setup value operation is shown.

volume.

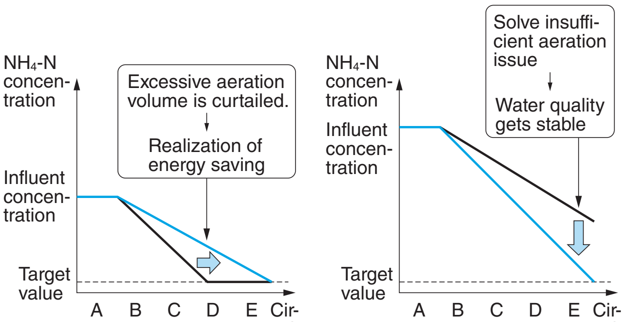
(4) The estimated NH_4-N concentration value for each DO value is compared with the separately defined target water quality at the end of a reactor tank. We then determine the lowest DO value yet meeting the target water quality.

(5) The obtained DO value is used as an updated DO setup value to overwrite the existing DO constant control value.

After that, aeration control is carried out based on the updated DO setup value and the water treatment conditions are automatically set up for optimal nitrification according to the fluctuation of the influent NH_4-N load. In this way, we realized the water treatment conditioning in a feedforward manner.

Fig. 3 shows a treatment concept for real-time nitrification control. In DO constant control, the control target value is generally set up on a safer side (with some design margin) considering the fluctuation of water volume and water quality and such setup value is determined based on our past experiences. For this reason, at a low load when the NH_4-N concentration is low or influent wastewater volume is less, nitrification reaction of NH_4-N is complete even in the middle of a reactor and excess aeration may occur as a result. In the case of our control, however, the lowering of the influent load in influent water is sensed and the DO setup value is lowered. The blower power consumption is reduced while securing quality treated water.

When the influent NH_4-N concentration is high or the influent water volume is increased due to rainfall, the influent load is increased in a short time. In DO constant control, there may arise a control lag in response to the fluctuation of influent water quality or water volume, and when there is a case where it cannot secure the enough aeration volume for maintaining the water quality. In our control method case, an increase in influent load in the influent water is sensed and the DO setup value is raised. In doing so, we can secure the treated water quality in response to the increased influent load value.



(a) At a low load (b) At a high load

Fig. 3 Treatment Concept for Real-Time Nitrification Control

At a low load, treatment may be completed in the middle area of a reactor tank. In such a case, the amount of aeration volume may be excessive. As the result, the aeration volume is reduced so that treatment is completed at the end of the reactor tank. If treatment cannot be completed during a high load period, the air blow volume is increased.

3 Development of Simulation Model for Real-Time Nitrification Control

3.1 Testing Facility and Testing Period

The verification test for real-time nitrification control using a full-scale sewage treatment plant was carried out at the Basin 3-1, Toyo System I (basin used for the test and target basin are the same) of the Tobu First Sewerage Office at the Sunamachi Water Reclamation Center. This Center adopts the confluent sewer system where sewage and rainwater are collected in one sewer pipe. For Basin 3-1, anaerobic-oxic activated sludge process is adopted (Pseudo-anaerobic tank: Circuit "a.k.a. 'Section' of the premises" A※1, Aerobic tank: Circuits "a.k.a. 'Sections' of the premises" B～E※1) (Circuits A～E are herein referred to as "each Circuit"). The reactor capacity is $8443m^3$ and the Hydraulic Retention Time (HRT) is approximately 8 hours. The next verification test period was fixed on August 12, 2013 to March 20, 2015. **Table 1** shows the verification processes of the respective testing items in this research.

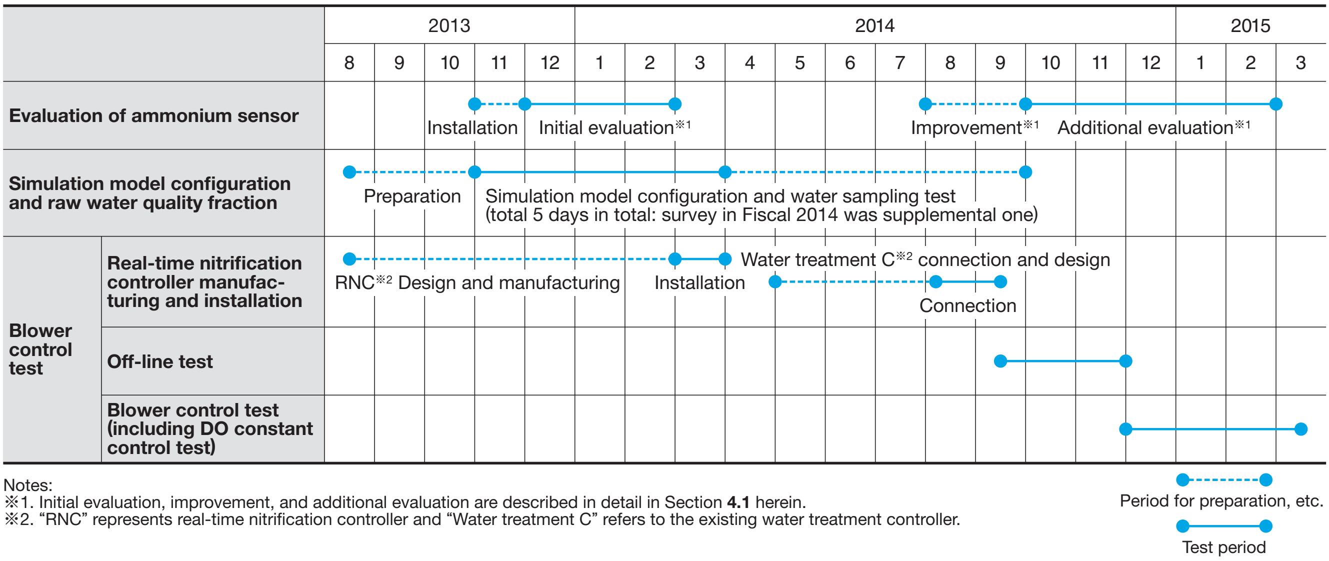
3.2 Adjustment and Evaluation of ASM Simulation Model

At the preliminary stage before the execution of real-time nitrification control in a full-scale sewage treatment plant, we conducted the grasping of treatment conditions in the testing basin, development of a reactor simulation model, and the reproduction and evaluation of treatment by ASM simulation.

In order to acquire data of water quality and treatment conditions to be used for ASM simulation, we made water quality investigation on reactor influent water at the target basin, water at the end of Circuits A,B,C and E, overflow water from final sedimentation basin, and return sludge. Water sampling was carried out on the selected total 5 days during the period from November, 2013 to September, 2014.

Table 1 Verification Processes of Respective Testing Items in this Research

This research tests were conducted from August 12, 2013 to March 20, 2015.



Notes:
※1. Initial evaluation, improvement, and additional evaluation are described in detail in Section **4.1** herein.
※2. "RNC" represents real-time nitrification controller and "Water treatment C" refers to the existing water treatment controller.

Table 2 Influent Fraction Data for Reactor Influent Water (November 12 to 13)

For the ASM, it is necessary to make organic matter demarcation in influent water (screening "sorting" organic matters contained in influent water into types of materials used in the ASM simulation model) to execute the simulation.

Name	Symbol	Value (mg/L)
Soluble abiotic biodegradable organic matters	S_I	25
Dissolved oxygen	S_{O2}	0.1
Nitrogen gas	S_{N2}	0
Fermentation product	S_A	10
Fermentable easily decomposed organic matters	S_F	4
Nitrate nitrogen	S_{NO3}	0
Soluble inorganic phosphor	S_{PO4}	3
Ammoniacal nitrogen	S_{NH4}	15.5
Alkalinity	S_{ALK}	200
Solid organisms non-biodegradable organic matter	X_I	10
Slow-biodegradable organic matter	X_S	83.7
Total amount of non-polyphosphate heterotrophic microbes	X_H	0
Total amount of autotroph	X_{ATU}	0
Total amount of polyphosphate heterotrophic microbes	X_{PAO}	0
Polyphosphoric acid	X_{PP}	0
Intracellular stored substance of phosphorus accumulating microbes	X_{PHA}	0
Suspended solids	X_{TSS}	82.275
Metal hydroxide	X_{MeOH}	0
Metal phosphide	X_{MeP}	0

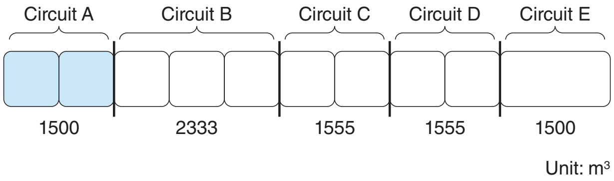


Fig. 4 Reactor Split Models and Volumes

In the full-scale sewage treatment plant, the reactor is split into Circuit A to Circuit E and each Circuit is split into one to 3 tanks.

At each water sampling day, water was sampled manually at 13:00, 17:00, and 21:00, and automatically at 21:00, 1:00, and 5:00 by using the automatic sampling machine. For reactor influent water in particular, organic matter fraction (screening or sorting) of reactor influent water ("influent fraction" hereafter) was carried out by the WERF method(18) in order to define composition details. **Table 2** shows the influent fraction data for reactor influent water (November 12 to 13).

At the next stage, reactor models were produced to make up a reactor model according to the tank structure of the test basin. Practically, the reactor was split into Circuit A to Circuit E like the actual full-scale sewage treatment plant, and then each Circuit was split into Tank 1 to Tank 3 ("each split tank") in consideration of volume ratio ("reactor split models"). **Fig. 4** shows the reactor split models and volumes.

Based on these established water quality models and reactor models, we made adjustment and evaluation of ASM simulation models through the calculation of real-time nitrification in off-line mode. Within the scope of the acquired water quality data, we set up the ASM parameters based on the result of water sampling test performed on sunny days from November 12 to 13, 2013. Regarding the flow of adjustments, ASM simulation was conducted based on the result of influent water fraction, the result was compared with the treatment conditions obtained from water sampling, and the ASM parameters (aeration volume distribution among the respective split tanks of tank array models and ASM-based initial concentration in each split tank) were evaluated. Based on the aperture of the riser valve, the air blow volume distribution among the respective split tanks was determined through adjustments based on the result of comparison. The initial concentration values in each split tank (all 19 items shown in **Table 2**) was determined through comparison between measured values of water quality at the end of each Circuit and the simulation result.

Fig. 5 shows the comparison of simulation values – measured values (NH_4-N concentration in influent water and each Circuit). This time's control target is NH_4-N and the result of ASM simulation for NH_4-N shows similar values with measured values obtained from each Circuit. The simulated values show it accurately responded with the chronological changes. Meanwhile, calculation values of NO_3-N concentration by ASM simulation were somewhat lower than the measured values. As a result, we adjusted the activated sludge parameter. Concretely, the typical value of 0.20 was modified to 0.05g-O_2/m^3, for $K_{O2,H}$ that is a parameter relating to denitrification (action or process to dissipate nitrogen compound into the atmosphere in a form of molecular nitrogen). $K_{O2,H}$ is a saturation/inhibition constant concerned with the DO concentration (SO_2) in heterotroph, showing how much degree of denitrification reaction by heterotroph is inhibited by the effect of DO concentration. When this value is high, denitrification continues even at a high DO concentration. If this value is small, denitrification can continue only if the DO concentration is low. For parameters and reaction speed coefficients deviating from descriptions above, a typical example defined by ASM2d was used.

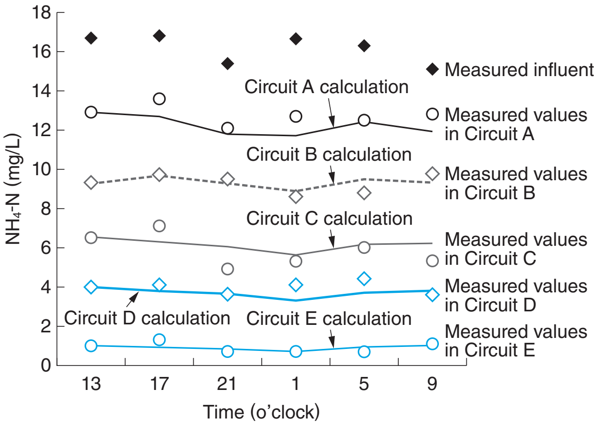


Fig. 5 Comparison of Simulation Values – Measured Values (NH_4-N Concentration in Influent Water and Each Circuit)

The simulation results match well with the measured NH_4-N concentration values in each Circuit and with chronological changes.

4 Verification Test

4.1 Evaluation of Ammonium Sensor

Real-time nitrification control was carried out while the influent NH_4-N value was continuously measured in a reactor tank. At the time of verification of this control in a full-scale wastewater treatment plant, accuracy of the ammonium sensor was evaluated. The specified measuring range of the used ammonium sensor (ion electrode type NH_4Dsc by HACH Company, Inc.) was 0.2～1000mg/L. In consideration of influent NH_4-N concentration at Basin 3-1, however, the measuring range was set at 0.2～50.0mg/L. The ammonium sensor was provided with an air nozzle by which air blow was intermittently applied to the sensor to remove contamination from the electrode surface.

Fig. 6 shows a trend graph of measured values at the ammonium sensor and values from manual analysis (initial evaluation period). Using an electrode type ammonium sensor at the influent section of the empirical reactor tank, evaluation of the ammonium sensor was carried out during the period from December, 2013 to February, 2014. During this evaluation period, influent water into the reactor tank was sampled on the spot where the ammonium sensor was installed for the purpose of comparison of accuracy. Solid-liquid separation of the sampled influent specimen was performed on site by a disk filter with a pore diameter of 0.45μm (DISMIC filter made by Advantec Toyo Kaisha, Ltd.) hydrophilic synthetic polymeric film of Polytetra-Fluoroethylene (PTFE), and the filtrate was saved in a vial bottle. By using Ion Chromatography (IC), we analyzed the filtrate-its NH_4-N concentration and nitrate nitrogen (NO_3-N) concentration. The result shows that the sensor values almost coincide with

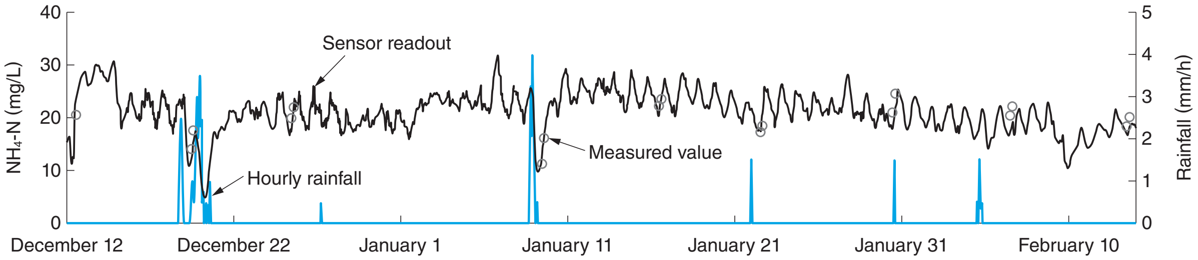


Fig. 6 Trend Graph of Measured Values at the Ammonium Sensor and Values from Manual Analysis (Initial Evaluation Period)

The sensor values match well with values obtained from manual analysis. Against an increase and/or a decrease in NH$_4$-N concentration caused by rainfall, it shows a positive following performance.

Table 3 Period-Based Errors, Correlation Coefficients, and Determination Coefficients in Ammonium Sensor Evaluation

During initial evaluation period, the mean error was 1.9mg/L and the mean error rate was 9.9%, thus approximately meeting the requirements for the standard. In case of the deteriorated accuracy period, the mean error was 2.7mg/L and the mean error rate was 17%, thus deviating from the standard. After adjustment of the air blast nozzle during additional evaluation, however, the mean error was improved to 0.8mg/L and the mean error rate to 4.0%, sufficiently meeting the standard. The determination coefficient was 0.880 and this figure suggests it matches with the measured values.

	Range of actual measurement (mg/L)	Mean error (absolute value) (mg/L)	Mean error rate (absolute value) (%)	Correlation coefficient R	Determination coefficient R^2
Evaluation standard		(≦2.5)	(≦10)		
Initial evaluation period (3 months: December, 2013 to February, 2014)	11.2〜24.7	1.9	9.9	0.825	0.680
Time of accuracy lowered (for one month: March, 2014)	11.3〜20.1	2.7	17.0	0.428	0.184
Additional evaluation period (5 months: October, 2014 to February, 2015)	13.6〜22.3	0.8	4.0	0.938	0.880

the values obtained from manual analysis (analysis of materials by specific methods). It also shows a good following capability against an increase or decrease in NH$_4$-N concentration due to rainfall. Around the end of 3 months of verification testing, however, it began showing the phenomenon of a gap between sensor values and measured values. This was due to the adhesion problem by contaminants on the electrode surface. Consequently, we tried to adjust the positioning of the air blast nozzle for intermittent air blow cleaning and the air blowing direction. After that, we made an additional verification test.

Table 3 shows period-based errors, correlation coefficients, and determination coefficients in an ammonium sensor evaluation. Since there is no statutory standard on an evaluation of ammonium sensor performance(19), we tentatively adopted the performance criteria on automatic nitrogen and phosphor measuring instruments for total volume control, and confirmed whether errors in measured values by IC and those by ammonium sensor remained within the range of ±5% full-scale or the relative error kept within 10%. **Fig. 7** shows a comparison between measured values by ammonium sensor and those by manual analysis identified during the initial evaluation period (before the occurrence of a gap between the simulation values and the measured values) and the additional evaluation

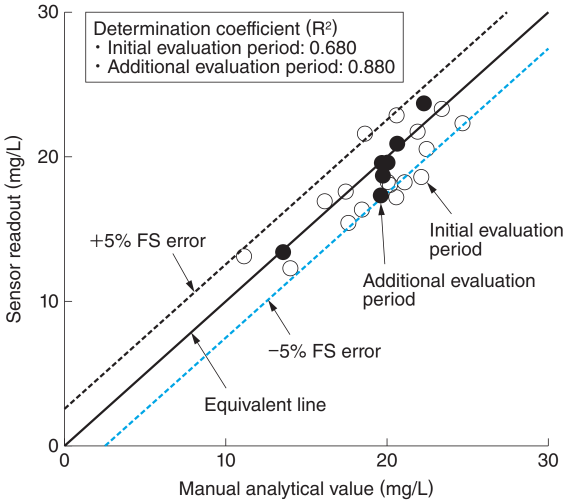


Fig. 7 Comparison between Measured Values by Ammonium Sensor and those by Manual Analysis

Correlation with manual measurements is shown in conjunction with sensor measurement and ion chromatography approach. White circles show the initial evaluation period and black circles show the additional evaluation period (after adjustment of air blast nozzle). Each measured value was kept within the range of ±5% value (±2.5mg/L) of full scale (50mg/L).

period (after adjustment of the air blast nozzle). In the initial evaluation period, errors were 1.9mg/L on average, mean relative error was 9.9%, and respective measured values were almost kept within the range of ±5% value (±2.5mg/L) of full scale (50mg/L). These values suggest that they meet the standard requirements. When accuracy was low, the mean error remained around 2.7mg/L and the mean relative error was 17%. This implies that the standard accuracy level requirements are not met. After the adjustment of air blast nozzle, however, both error and relative error values were remarkably lowered and the mean error stayed around 0.8mg/L and the mean relative error at 4.0%, suggesting that the standard accuracy level requirements are fully met. The determination coefficient at that time was 0.880 and there was a fortunate coincidence with the measured values. According to the result, we evaluated the fact that continuous measurement by using an ammonium sensor is possible for the influent water into the initial sedimentation tank.

4.2 Verification of Real-Time Nitrification Control

4.2.1 Preliminary Adjustments of the ASM Simulation System in Full-Scale Sewage Treatment Plant

Using an ASM simulation model and an ammonium sensor, we made a verification test on aeration control by using a real-time nitrification control approach in full-scale sewage treatment plant.

In order to adjust the ASM simulation model to fit with the present treatment conditions at the full-scale sewage treatment plant, we adjusted the reactor tank's inner material balance in the ASM simulation model shortly before the start of the verification test. To be specific, we made ASM simulation based on (1) the measured values (NH_4-N concentration, influent water volume, and return sludge volume) recorded on the previous day of control verification test; and further based on (2) ASM setting ratio and values: air flow distribution for each split tank and initial concentration values. At that time, we adjusted the excess sludge extraction volume related to ASM simulation and $K_{NH4\text{-}A}$ (saturation/inhibition constants concerned with the NH_4-N concentration "S_{NH4}" of nitrifying bacteria) that is an ASM parameter so that the MLSS concentration and the NH_4-N concentration at the end of a reactor tank can match the mean values on the previous day or the measured values. The initial concentration values at each split tank whose material balance was adjusted as discussed above were utilized for control verification test. In doing so, we could reflect the effect of MLSS concentration during the control verification test into real-time nitrification control.

For the calculation to determine the DO setup values during control, we used the initial concentration in each split tank after the adjustment of material balance as discussed above and the measured values at influent meters (NH_4-N concentration, influent water volume, return sludge volume, and water temperature). In performing the ASM simulation, we set up a total of 9 conditions at the intervals of 0.5mg/L within the range of 1.0 to 5.0mg/L for the DO concentration at the end of the reactor tank. Under these conditions, the air blow volume needed to attain a DO concentration at the end of a reactor tank is determined and the NH_4-N concentration at the end of a reactor tank (Circuit E) was calculated based on the determined air blow volume. In this manner, the minimum DO value to attain the target water quality of below 1.0mg/L was adopted as the DO setup value for actual aeration control. According to the laptop we used this time (CPU: Intel Core i5 2.6GHz), it took about 3 minutes and 30 seconds to calculate a total of 9 conditions.

The verification test for aeration control was carried out at two stages: (1) confirmation of operation of real-time nitrification controller for these control processes and off-line verification for ASM model simulation adjustments and (2) blower control test (on-line verification test) for aeration control performed at an actual reactor tank.

4.2.2 Aeration Control Experiment ① – Off-Line Verification

For off-line verification test, operation check for the real-time nitrification controller and ASM simulation model adjustments were carried out. The verification test was focused mainly on water quality calculation by ASM simulation model, software operation check relating to real-time nitrification controller setting and control, simulation model adjustments, and confirmation to identify whether the DO setup values from the real-time nitrification controller were kept within the adequate range for water treatment. The DO setup values were updated every hour for this verification test.

At the time of the verification test, the calculation results of the NH_4-N concentration appeared on the real-time nitrification controller found that these values were somewhat higher than the measured values. As a result, we changed the $KNH_4.A$ parameter of the activated sludge model: from typical value of 1.0 to $0.4gN/m^3$. After, the result of NH_4-N concentration calculation began to match well with the measured values. The value of $KNH_4.A$ is an ASM parameter relating to the proliferation of nitrifying bacteria and NH_4-N is concerned with the progress of nitrification under the condition of low concentration. By this parameter adjustment, the real-time nitrification controller was adjusted so that it can follow up with changes in influent loads on a sunny or rainy day and show an appropriate DO setup value under a normal range.

4.2.3 Aeration Control Experiment ② – On-Line Verification

Table 4 shows an aeration control experimental test period by real-time nitrification control. In consideration of stability of microbes in reactor tanks and safety of related equipment (mainly blowers and wind adjuster valves), the upper and lower limit values were set up for the DO values. In the updating of the DO values in this experiment, the update time was fixed at 30 minutes because we could confirm the following up for the changes of the DO values in the reactor tanks under testing can be done within approximately 10 minutes.

For the aeration control test, the control stability was confirmed twice through 6 hours of control testing (executed in December). After, the effect of blower power reduction and that of water quality improvement were verified through 28 to 76 hours of continuous control testing.

(1) Aeration control stability by real-time nitrification control

According to the result of about 6 hours of daytime testing, (Table 4) of blower control stability, there was no occurrence of problems like the interruption of communication and control disorders during real-time nitrification control test. The introduced and connected control facilities and software were in normal operation. We also confirmed that feed-forward control was possible in response to changes in the influent load by using the DO change control in the reactor under the real-time nitrification control. In addition, at the time of continuous verification testing for 28 to 76 hours, we confirmed the measured DO concentration fairly followed up with the changes of the DO setup values and there was stable aeration control.

Table 4 **Aeration Control Experimental Test Period by Real-Time Nitrification Control**

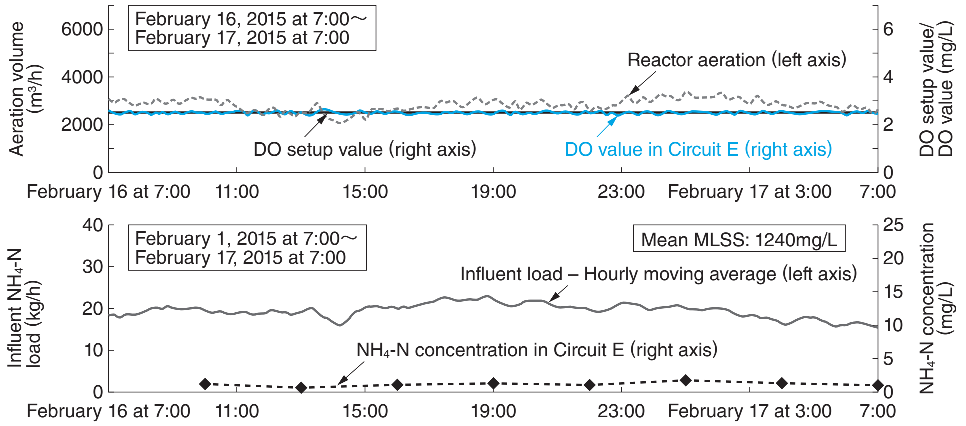
The aeration control experimental test period by real-time nitrification control is shown.

Experimental test period	Time (h)
December 4, 2014 at 9:30 to 15:30	6
December 11, 2014 at 9:30 to 16:30	7
January 21, 2015 at 9:30 to January 22 at 13:00	27.5
February 4, 2015 at 9:30 to February 5 at 13:30	28
February 17, 2015 at 9:30 to February at 19 8:30	47
February 24, 2015 at 9:30 to February at 26 13:30	52
March 9, 2015 at 9:30 to March 12 at 13:30	76

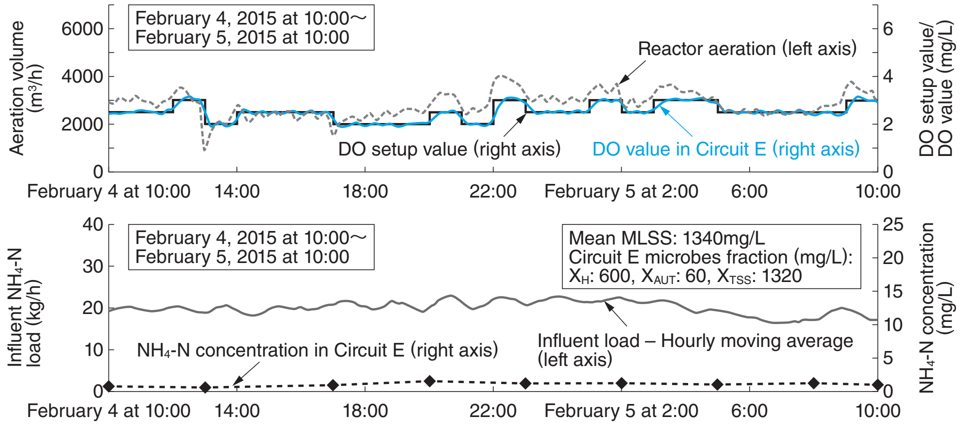
Fig. 8 shows the comparison results among: DO constant control on a sunny day, operation by real-time nitrification control, and treated water quality. This is an example of control results during the evaluation period. It shows the trend graphs obtained during the DO constant control test (February 16 at 7:00 to February 17 at 7:00) and the real-time nitrification control test (February 4 at 10:00 to February 5 at 10:00). This diagram also shows the mean MLSS concentration obtained during the evaluation test and a typical example of microbes fraction (X_H, X_{AUT}, X_{TSS}) in Circuit E used for ASM simulation. The DO setup value was kept constant at 2.5mg/L under DO constant control (Fig. 8 (a)) while the DO setup value under real-time nitrification control changed in the range of 2.0～3.0mg/L according to load fluctuation in influent water (Fig. 8 (b)). These facts show positive following capability by the measured DO concentration against the changes in the setup value. In about 10 minutes, the DO concentration became almost the same level of the setup value. In the case of real-time nitrification control, the result of reactor effluent water quality measurement indicates that stable treated water quality was maintained like the case of DO constant control against the same level of influent NH_4-N load (approx. 20kg/h).

(2) Effect of air blow volume reduction by real-time nitrification control

In order to verify the effect of air blow volume reduction by real-time nitrification control, we made a series of comparison test on the aeration volume in reactor tanks during the period from January 6 to March 12, 2014 on sunny days when the fluctuation of the water quality was minimal. Data were extracted under the conditions of ① the one-day data to be extracted from 10:00 to 10:00 on the next day, ② rainy days were excluded, and ③ the reactor effluent NH_4-N concentration was below 1.0mg/L (according to the daily routine test result at



(a) DO constant control



(b) Real-time nitrification control

Fig. 8 **Comparison Results among: DO Constant Control on a Sunny Day, Operation by Real-Time Nitrification Control, and Treated Water Quality**

For DO constant control, the DO value in Circuit E was kept constant “blue line in (a)” while for real-time nitrification control, the DO value in Circuit E changed to match the load change in influent water “blue line in (b).” In the case of real-time nitrification control, the follow-up performance of the measured DO concentration was high to match the changes in setting values “black line in (b).” Almost the same value as the setup value was attained in about 10 minutes. Against the same level of influent NH_4-N load (approx. 20kg/h), real-time nitrification control maintained almost the equivalent level of stabile treated water quality as DO constant control.

Table 5 **Reactor Air to Flow Ratio: DO Constant Control**

The extraction data of the reactor aeration volume under DO constant control are shown.

Date	Treated water NH_4-N (mg/L)	Aeration volume (m³/h)	Influent rate (m³/h)	NH_4-N load (kg/h)
January 7 to 8	0.0	3278	932	22.9
January 9 to 10	0.2	2199	576	16.2
January 13 to 14	0.3	2832	746	17.9
January 14 to 15	0.6	3044	750	18.4
January 19 to 20	0.3	3043	887	21.2
January 26 to 27	0.4	3013	1022	21.3
January 29 to 30	0.6	3252	1003	20.8
February 2 to 3	0.1	2628	814	17.4
February 3 to 4	0.3	2402	810	17.9
February 6 to 7	0.6	3033	1044	20.9
February 12 to 13	0.1	2907	803	19.4
February 13 to 14	0.0	3210	849	20.5
February 16 to 17	0.4	2728	781	18.9
February 27 to 28	0.0	2606	936	20.9
March 6 to 7	0.3	2971	1099	24.5
Average	0.3	2876	864	19.9

Table 6 **Reactor Air to Flow Ratio: Real-Time Nitrification Control**

The extraction data of the reactor aeration volume under real-time nitrification control are shown.

Date	Treated water NH_4-N (mg/L)	Aeration volume (m³/h)	Influent rate (m³/h)	NH_4-N load (kg/h)
January 21 to 22	0.0	2445	908	19.2
February 4 to 5	0.0	2821	894	20.1
February 17 to 18	0.0	2648	817	18.6
February 25 to 26	0.0	2965	907	21.1
March 11 to 12	0.0	2856	1046	24.2
Average	0.0	2747	915	20.6

Sunamachi Water Reclamation Center). **Table 5** shows the extraction data under DO constant control, **Table 6** shows the extraction data under real-time nitrification control, and **Table 7** shows the comparison results on reactor aeration volume.

Table 7 **Comparison Results on Reactor Aeration Volume**

During the evaluation period, the mean value of reactor aeration volume by real-time nitrification control resulted in a reduction of about 4.5% compared with DO constant control. When comparison of the aeration volume was made in consideration of influent water volume or influent NH_4-N load, the air flow rate to influent water volume showed a reduction of about 10% or that to influent NH_4-N load showed a reduction of about 7.5%. The real-time nitrification control provided the effect of aeration volume reduction.

Comparison item	Ratio to DO constant control (%)※1
Aeration volume	−4.5
Influent water volume Influent load	5.9 3.4
Air flow rate (Influent water volume) Air flow rate (Influent NH_4-N load)	−10.4 −7.5

Note: ※1. A negative value means a reduction.

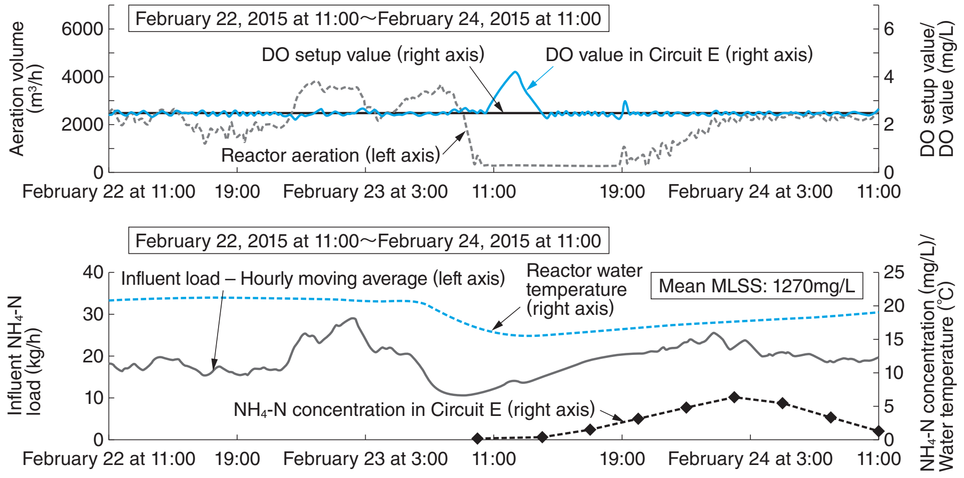
According to the mean value of reactor aeration during the test period, real-time nitrification control showed about 4.5% of reduction compared with DO constant control. Compared with the influent water volume and influent NH_4-N load during the test period, the influent water volume showed a 5.9% increase and the influent load showed a 3.4% increase under real-time nitrification control. When the aeration is compared considering the differences in the influent water volume and influent NH_4-N load, the air to flow ratio against influent water volume is about 10% reduction and the same against influent NH_4-N load is about 7.5% reduction.

Given these results, we considered that there is possibility of aeration reduction by real-time nitrification control, provided that both influent water volume and influent water quality are kept at the same level on a fine day. Meanwhile, this time's comparison was made on the data collected in winter season. Since the situation of nitrification can change with the water temperature rise in summer season, we intend to continue long-term verification testing including the summertime to verify the effect on air blow volume reduction.

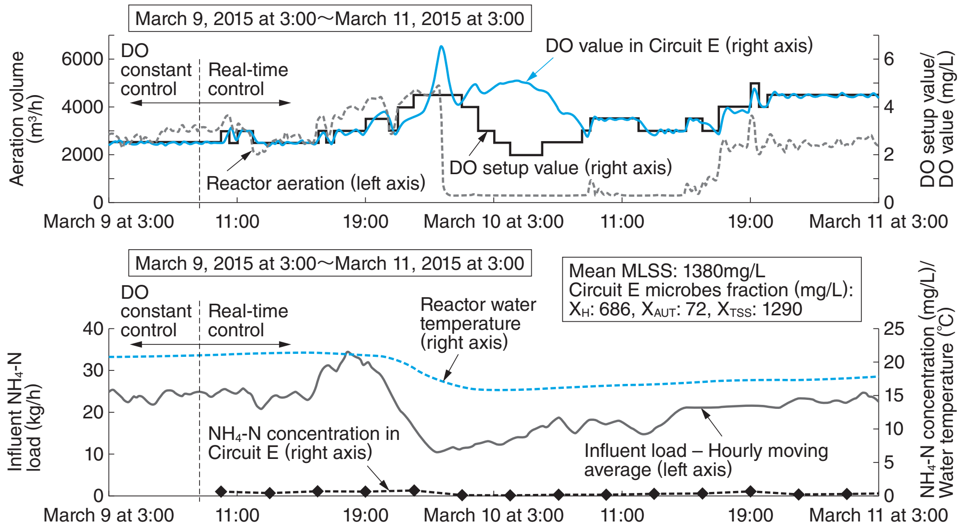
(3) Effect of water quality improvement by real-time nitrification control

In order to verify the effect of water quality improvement by real-time nitrification control, we made a series of comparison tests on the result of DO constant control on rainy days when the influent NH_4-N load changed greatly during the verification period (February 22 at 11:00 to 24 at 11:00), and on the result of real-time nitrification control (March 9 at 3:00 to 11 at 3:00). **Fig. 9** shows the comparison results among: DO constant control on a rainy day, operation by real-time nitrification control, and treated water quality. Diagrams in **Fig. 9** also show a typical example of mean MLSS concentration during the evaluation period and microbes fraction (X_H, X_{AUT}, X_{TSS}) in Circuit E used for ASM simulation. Except for a rise in the DO value (around 12:00 on February 23) due to dissolved oxygen brought by rainfall under DO constant control, it seemed the DO value mostly stayed around 2.5mg/L, the set value. In the case of real-time nitrification control, the DO value was raised (4.5mg/L at the maximum) to match an increase (March 9 at 19:00 and thereafter) in the influent NH_4-N load due to the effect of rainfall. After, the aeration volume became lowest due to DO brought by rainfall (March 10 at 0:00 and thereafter) and there was a deviation between DO setup value and DO value from each other. In the process of recovery from influence by rainfall (March 10 at 15:00 and thereafter), the DO value was controlled to rise (5.0mg/L at the maximum). The lowering of nitrification rate due to an increase in the influent NH_4-N load and the lowering of water temperature caused by rain water inflow can be considered the cause. To be specific, the NH_4-N concentration in reactor treated water under DO constant control (**Fig. 9** (a)) was raised as high as 5.3mg/L around 2am on February 24 due to nitrification rate reduction caused by a low water temperature in the reactor tank. While in the case of real-time nitrification control (**Fig. 9** (b)), the DO value was raised considering the reduction of the nitrification rate possibly caused by the lowering of water temperature in the reactor tank. As a result, the effluent NH_4-N concentration was maintained at 1.0mg/L or below. Also, at the time of real-time nitrification control, the DO setup value was changed in response to an increase in the influent NH_4-N load and the mean DO setup value became higher than 2.5mg/L in the verification period, which led to an increase in the aeration volume.

For a feedback control under DO constant control, the aeration volume is determined based on the DO value at the end of a reactor tank after finishing the treatment. In the case of real-time nitrification control, a feedforward change is made in the DO setup value to match the changes in the influent load. It was verified that the NH_4-N concentration of the treated water was kept constant as a result. In particular, in the case of an example for this time where the nitrification rate is lowered due to a low



(a) DO constant control



(b) Real-time nitrification control

Fig. 9 **Comparison Results among: DO Constant Control on a Rainy Day, Operation by Real-Time Nitrification Control, and Treated Water Quality**

In the case of DO constant control, the NH_4-N concentration in reactor effluent water (black dotted line in (a)) was raised up to 5.3mg/L on February 24 around 2:00. This phenomenon suggests that the nitrification rate was also lowered due to the lowering of water temperature in reactor tank "blue dotted line in (a)." In the case of real-time nitrification control in similar situation, there was no rise in the NH_4-N concentration in reactor effluent water "black dotted line in (b)" because the DO value was raised at that time. In fact, the value was maintained below 1.0mg/L. This suggests that degradation of the water quality was prevented by raising the DO setup value in consideration of possible lowering of nitrification rate due to the lowering of water temperature in the reactor tank (blue dotted line in (b)).

water temperature attributable to the rainfall influent in winter, we could obtain the test result that our real-time nitrification control can contribute to the prevention of deterioration of water quality stability in winter and we also reconfirmed the necessity to proceed with further research and study on this matter.

5 Postscript

This research was conducted to verify aeration control technology based on our real-time nitrification control in the full-scale sewage treatment plant. For this control, the influent water quality is continuously measured by means of an ammonium sensor to determine the influent load, the water treatment condition in the reactor tank is simulated by using the ASM2d, a standard ASM simulation model. In a feedforward manner, we decide the DO setup value needed to support the nitrification reaction inside the reactor tank and such DO setup value will intervene in the existing DO control. As a result of verification, we confirmed the long-time stability of the ammonium sensors. In addition, we came to know that this control can realize a 10% reduction of influent-based air flow rate on a sunny day and improvement of the treated water quality on a rainy day.

This control technology is applied by using general-purpose software and commercially available desktop PCs or laptops. Since the behavior of biological treatments was simulated by ASM simulation model before, it is easy to work on the simulation model change like reactor tank arrays and such simulation model could be highly applicable to other water treatment plants and water treatment methods.

Currently, the sewage treatment plant world is promoting facility renovation and it is developing new processing technologies for better quality level of discharge water. It takes time and money in making progress with such activities. Given above, the application of our control technology to the existing treatment facilities is effective to realize both water quality improvement and energy saving in the shortest possible time.

Going forward, we will conduct long-term field testing even including the summertime period and we will organize the merits of our control system and standardize the approach.

In doing so, we will release a product that can be used for the existing treatment facilities.

- The result of this research has been acquired through business outsourcing by the Bureau of Sewerage Tokyo Metropolitan Government.
- All product and company names mentioned in this paper are the trademarks and/or service marks of their respective owners.

(Note)

※1. At the said Water Reclamation Center, the facility used for the test - a block in the reactor tank is called a “circuit.” Accordingly, we have used a word “circuit” in accordance with the term used for the said facilities.

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