# 4-4 New approaches to the coexistence of water quality improvement and GHG reduction in wastewater treatment

**- Challenges of the Bureau of Sewerage, Tokyo Metropolitan Government toward the shift in operation management of activated sludge process in all Water Reclamation Centers in Tokyo. < Air volume control by ammonium concentration, restricted-aeration $A^2$/O process, monitoring of influent by electric conductivity> -**

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## ABSTRACT

Important issue of global warming attributed to elimination of several greenhouse gases like carbon dioxide has been frequently reported as a serious problem in recent years. Several countermeasures or trials aimed to its inhibition were introduced in world-wide scale. Effective measures of regulation for reduction of CO2 emission in industry field were started as a middle and long term goal in Japan. In Tokyo, one of a strategic plan “Earth Plan 2010” followed by “Earth Plan 2004” was set as a regional goal for prevention of global warming, therefore the reduction of electrical requirement for waste water treatment consisted of 33% amounts of emission from treatment plant had been constantly conducted. Here we report three effective results in respect to reduce energy consumption by three operation methods upgraded the activated sludge process.

First is the optimization of air volume supply at aeration by means of controlling dissolved oxygen according to $NH_4$-N concentration. We have more efficient operation of activated sludge process in aeration tank by utilize this method. Operation using the parameter configured in this experiment made 15% at maximum of air volume consumption cut off at monthly relative to the method using simply dissolved oxygen control.

Next is restricted $A^2$/O process with nitrified liquor recirculation on the basis of the conventional activated sludge process. Nitrogen removal ratio could be achieved 70% by means of this process, higher than conventional activated sludge process but equal level comparing to $A^2$/O process. In addition, its phosphorus removal ratio was also higher than conventional activated sludge process, meanwhile less than restricted $A^2$/O process. Electric power consumption supplied to the restricted $A^2$/O process was equal level comparing to conventional activated sludge process and 25% higher than $A^2$/O process. Therefore, introduction of restricted $A^2$/O process in substitution for standard $A^2$/O process will not only achieve initial and running cost savings, but also maintain much good final effluent water quality of waste water treatment plant.

Lastly, the control of air flow volume on the basis of monitoring characteristics of influent waste water had been discussed. Adoption of feed-forward control instead of feed-back control can be a key to appropriate air supply for treatment of waste water. This trial indicated possibility feed-forward control by monitoring electric conductivity of influent to attain saving electric energy consumption and improvement of effluent water quality.

**KEYWORDS** : Reducing greenhouse gas, Ammonia+DO control, Restricted-aeration $A^2$/O

process, Feed forward air volume control system, Electric conductivity

## INTRODUCTION

Sewage works discharges a great deal of greenhouse gas (GHG) in the process of wastewater and sludge treatment. Major sources GHG in sewage work are $CO_2$ from electricity consumption and $NO_2$ generated in the treatment. GHG emission of The Bureau of Sewerage, Tokyo Metropolitan Government (TMG) amounted to 856 thousand tonnes of $CO_2$ in fiscal 2009, and the breakdown is; electricity consumption 376 thousand tonnes of $CO_2$, NOx from sludge treatment 236 thousand tonnes of $CO_2$, NOx from water treatment 139 thousand tonnes of $CO_2$, and fuel, chemicals and other 105 thousand tones (Bureau of Sewerage, Tokyo Metropolitan Government, 2010a). In the situation that combating global warming is urgent, globally a great number of studies are carrying out in sewage fields. For example, studies about difference of GHG discharge amounts caused by variation of treatment methods (Keller *et al.* 2003)(Cakir *et al.* 2005), comparison of treatment method taking local characteristics into account (Wett *et al.* 2003), and emission reduction of $N_2O$ (Park *et al.* 2000). The Federal Environment Agency in Germany announced a research result that local wastewater treatment plant can reduce $CO_2$ emission by 40% from the 1990 level as a press release (Umbelt Bundes Amt 2010). The Bureau has created proactive set of measures for reducing GHG emissions, calling it "Earth Plan 2010 (Bureau of Sewerage, Tokyo Metropolitan Government, 2010a)", and has been implementing measures to reduce GHG by 25% or more from fiscal 2000. The steps are, for example, rising temperature of sludge incinerator to reduce generated $N_2O$, producing carbide fuel from sludge, generating solar electricity on a water reclamation center (wastewater treatment plant), and so on (Bureau of Sewerage, Tokyo Metropolitan Government, 2010a).

In Tokyo, several effective approaches to save energy were undertaken with enthusiasm in the process for treatment of waste water. In particular, a reduction in power required to run the blowers for aeration is very critical, because of height of all power consumption in sewage treatment process. One of a relatively simple control system, constant dissolved oxygen, had been installed around many waste water treatment plant to deal with the change of characteristics and flow rate during rain and storm conditions(Chevakidagarn *et al.* 2007)(Howarth *et al.* 2007)(Dabkowski *et al.* 2011)(Barbu *et al.* 2011). However, sufficient treatment by using constant dissolved oxygen system had not always been performed in waste water treatment plant adopted combined sewer system. Therefore, control of nitrification process by adjusting flow rate in aeration tank according to monitoring ammonia concentration level had been proposed as a new system instead of the system using dissolved oxygen data. Implementation of this new type of system made in obvious excess aeration supply cut off, because of monitoring the level of nitrification of ammonia. According to the result of simulation using activated sludge treatment model, it was indicated that nitrification control system could be reduced about 11% of air volume consumption during aeration (Furukawa *et al.* 2002). Yet, in case of change of environmental condition like rainfall or storm conditions, treatment of organic substances was insufficient relative to nitrification of ammonia. Additionally, low of oxygen concentration at the end of an aeration tank also induces phosphorus to increase by anaerobic elution. As a consequence of these situations, the new system using concentration of ammonia and dissolved oxygen had been introduced as a substitute for the simple nitrification control system. Monitoring ammonia concentration with dissolved oxygen may have great advantage. This report shows this in experimental results actually using waste water treatment plant in Tokyo.

The energy consumed under the process of nitrogen and phosphorus removal is mainly one of the significant factors in sewage treatment process. The amounts of energy consumed agitators at anaerobic and anoxic phase in nitrogen and phosphorus removal used $A^2/O$ had been gradually increased. Therefore, there was one case temporarily resting a part of agitator or intermittent operation as the countermeasure to reduce electric energy consumption in several treatment plants. Installation and technological development of new types of agitator being able to operate even by low-power has also been undertaken. On the other hand, pseudo anaerobic aerobic treatment method as restricted-aeration system at the first step of conventional activated sludge process can be also more than a little efficient approach. That is the operation for removal nitrogen and phosphorus using pseudo anaerobic phase formed by adjusting aeration condition according to the quality of influent waste water instead of agitators. This system does not requires immeasurable cost and can minimize new investment for reformation due to relatively scale-down work of construction, as a consequence, emission rate of $CO_2$ can be reduced by cutting off the power consumption for agitator. In addition, the minimum required air volume to make activated sludge agitate in aeration tank of restricted-aeration $A^2/O$ can be ensured by slight air volume corresponding to a few % levels all the air volume supplied in aeration tank.

It is represented that characteristics of influent waste water can be control of air flow rate as other interesting approach. Almost all WWTP in Tokyo had usually adopted feed-back control system monitoring of dissolved oxygen at the end of aeration tank. However, this type of system cannot prevent supplying excessive oxygen by reason of not focusing to oxygen used for nitrification of ammonia. Efficient accommodation had been required in Tokyo mainly adopted combined sewer system to deal with adequate waste water treatment in one third rainy days. Since one-third of the year is a rainy day in Tokyo, effective operation to improve effluent water quality had been required. Feed-forward control system had been introduced to the treatment of sewage or wastewater instead of traditional feed-back control system in Japan, because of equalization of treatment water (Toshiba Corp. 2001)(JFE Steel KK. 2009). As one case, control by electric conductivity, which does not use any reagents has lower running cost and is easy to maintenance. Therefore, the case of sewage treatment to adopt electric conductivity to evaluate activated sludge had also reported (Hitachi, Ltd. 2005). So, feed forward air volume control system by monitoring water pollution of primary effluent was examined to resolve this excessive supply of air volume.

## INVESTIGATION

### 【AMMONIA+DO SYSTEM】

**Schematic representation of Ammonia+DO control system**

Flow diagram and treating process by ammonia + dissolved Oxygen (Ammonia+DO) system are illustrated in Fig.1.

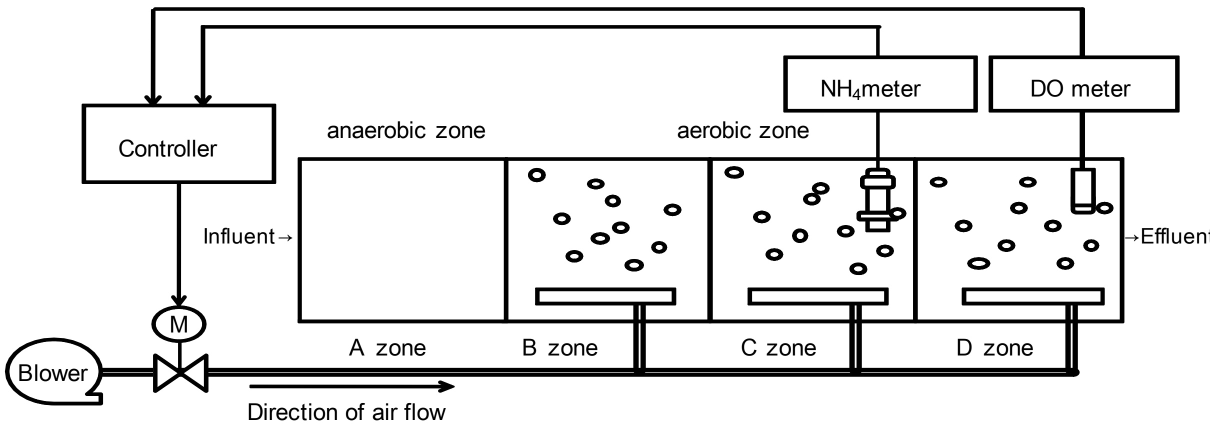


**Fig.1 Flow diagram and treatment process by Ammonia+DO system at aeration tank**

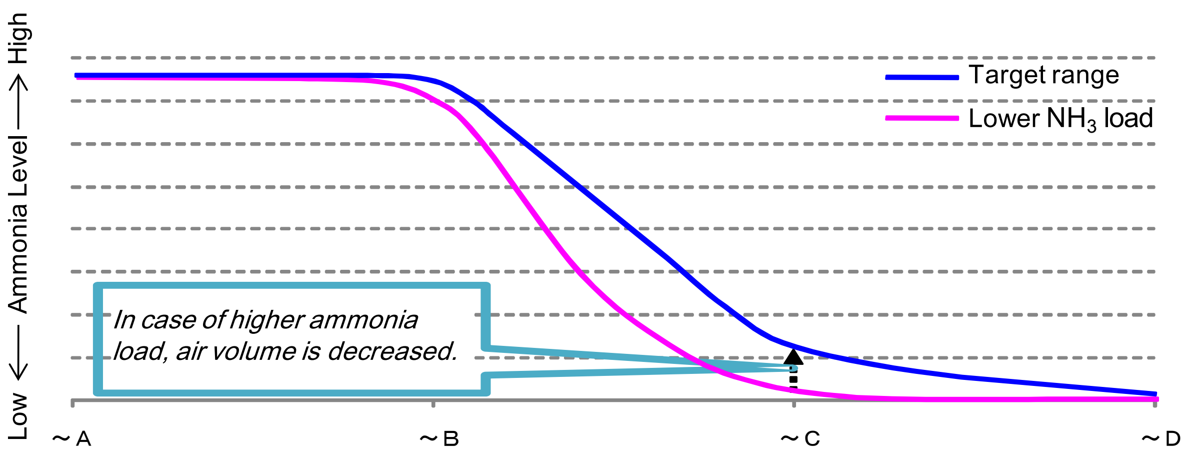


**Fig.2 Process of ammonia concentration at the phase of aeration tank**

This system allows a substantial lowing of air flow rate in aeration step by means of oxygen demand estimated from monitoring data of ammonia concentration level, and moreover control of dissolved oxygen at the end of aeration tank is complementary function to not decay quality of treatment water. Ammonia nitrification is made much more progress by addition of air flow rate in case of increasing ammonia concentration at C zone in consequence of declining effluent water quality or increase of water flow rate like during rainfall or storm conditions. On the other hand, ammonia nitrification can be restrained by running down aeration level, when ammonia concentration is lower level at C zone or also influent quantity is lower level so that air flow rate is reduced relatively to normal operation case. This system can achieve efficient operation to improve effluent water quality with saving energy, because of the control of ammonia nitrification with constant level of dissolved oxygen concentration at the end of D zone (Fig.2).

**Experimental site**

This experiment was undertaken at Kosuge Waste Water Treatment Plant (WWTP) in Tokyo. Treatment plant is located at south area of Katsushika ward in the eastern region of Tokyo and 160 thousand $m^3$ of sewer water, from 2,172ha width of area included Katsushika and a part of Adachi ward, are received per day in 2009 and planned treatment population is about 260 thousand people. Treatment plant consists of east and west treatment line separation, experimental site was east line treated about 70 thousand of waste water. The combined sewer system is adopted in all of this area, thus a large amount of storm sewage influent flows into the treatment plant. In addition, characteristics of influent waste water, as is obvious, can be easily changeable relatively to fine weather day. Schematic view of experimental treatment process is illustrated in Fig.3. The volume of A zone as anaerobic and from B to D zone as aerobic are 729m3 and 7,747, respectively.

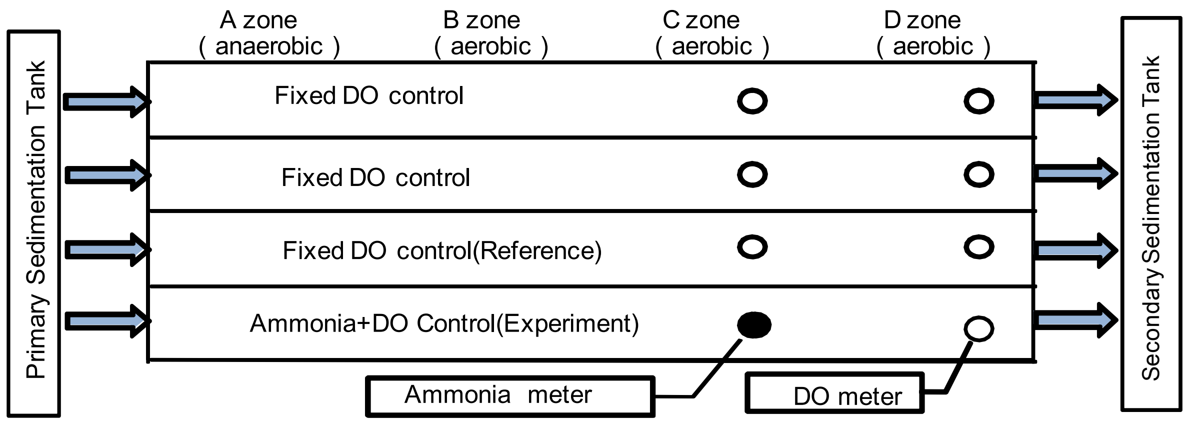


**Fig.3 Configuration of the east plant at the Kosuge Waste Water Treatment Plant**

**Parameter of the Ammonia+DO control system**

One aeration tank was used for Ammonia+DO control system, one of the other tanks was used for dissolved oxygen control system for comparison. Instrument used ionic electrode was installed for measuring $NH_4$-N concentration in Ammonia+DO control tank. This type of analyzer can be applied long-term continuous measurement due not to emit liquor waste and operation can be carried out on the basis of real-time on line data. These characteristics also show direct analysis by the detector under the waste water without using sampling pump and regents for analysis.

Parameters of Ammonia+DO control system are shown at Table.1. Monitoring of $NH_4$-N concentration was carried out at the end of C zone in the aeration tank. Parameter $NH_4$-N value was 2.0mg/L from January to April and 3.0mg/L after middle of May. Parameter dissolved oxygen value at the end of D zone was arranged to the range from 2.5-3.0mg/L to 1.5-2.2mg/L. Parameter dissolved oxygen value also for comparison at the end of C zone was 2.0-3.5mg/L. These parameter values were decided so as to be equal level in effluent water quality between experimental and comparing tank.

**Table.1 Parameters of Ammonia+DO system**

| Method | Parameter | January | February | March | April | May |
|---|---|---|---|---|---|---|
| Ammonia+DO | DO (mg/L)[a] | 2.5-3.0 | 2.5-3.0(-20)<br>1.5-2.5(21-) | 1.5-2.5 | 1.5-2.2 | 1.5-2.2 |
| | $NH_4$-N (mgN/L) | 2.0 | | | | 2.0(-17)<br>3.0(18-) |
| Fixed DO | DO (mg/L)[b] | 2.0 | 2.0(-20)<br>2.5(21-) | 2.5(-13)<br>3.5(14-)<br>2.0/3.0[c](16-) | 2.0/3.0[c] | 2.0(-17)<br>2.5(18-) |

a:Dissolved Oxygen for Ammonia+DO control was analyzed at end of the D Zone of the aeration tank.
b:Dissolved Oxygen for Fixed DO control was analyzed at end of the C Zone to control of the aeration tank.
c:Dissolved oxygen value was 2.0mg/L from 8 A.M. to 4 P.M. and 3.0mg/L rest of the day.

**Methods for investigation**

Two reaction tanks were selected for the experiment on the basis of preliminary research. One was Ammonia+DO control system, the other was dissolved oxygen control system. The amounts of flow rate and influent waste water quality of these tanks are almost equal level. Comparing examination of the relative rate of air volume supply was undertaken not to affect the difference of influent water volume. $NH_4$-N, $NO_2$-N and $PO_4$-P concentrations at the end of D zone except $NH_4$-N concentrations at the end of C zone were analyzed to evaluate water quality experimental results according to the official method. Additionally, air volume at aeration tank, the amounts of flow rate of influent and dissolved oxygen concentration at the end of C, D zone were monitored per 1 hour, respectively.

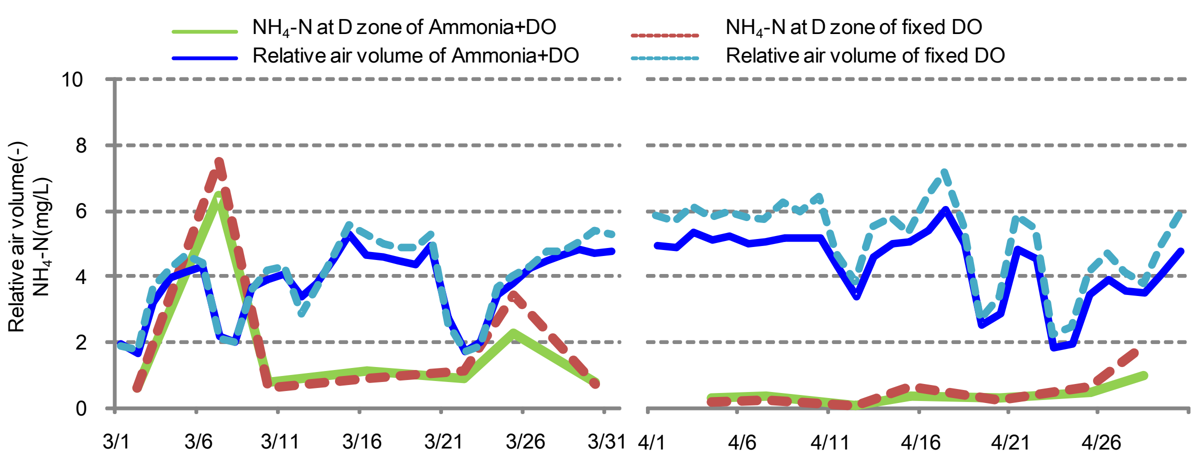


**Fig.4 Relationship of air volume supply for aeration and $NH_4$-N concentrations after**

**Results of waste water treatment**

Relation of relative rate supplied air volume to comparison tank and $NH_4$-N at the end of D zone is shown in Fig.4. Concentrations of $NH_4$-N were analyzed by samples collected on 10 A.M. $NH_4$-N concentrations were temporarily increased in experimental and comparison tank, because of snow on March 6th. By constant inflow of storm water from 21st to 23rd, $NH_4$-N concentrations were also temporarily increased in experimental and comparison tank. On the other time, the water quality in effluent at the end of D zone of experimental and comparison tank were similarly equal level. Continuous operation for optimization of parameters from January to February could be induced relative rate of air volume supply to the amounts of influent to decrease to comparison. Relative rate of air volume to the amounts of influent in experimental tank was 3.8 and comparison tank was 4.0 at monthly average, respectively. Thus 3.7% of relative rate of air volume to the amounts of influent was reduced by means of these operations.

Meanwhile, significant reduction of relative rate of air volume supply to the amounts of influent was not observed during the period influenced by storm sewage. Since April, as reduction of relative rate of air volume supply to the amounts of influent had been observed constantly and dominantly, it followed that average relative rate of air volume supply to the amounts of influent was 4.4 at experimental and 5.1 at comparison, respectively. Average reduction of relative rate of air volume supply to the amounts of influent reached 15%. The rates of reduction of experimental tank to comparison during investigation period are indicated in Table.2. As previously described, gradual decrease of reduction of relative rate of air volume supply to the amounts of influent had been observed after modification of parameter from January to February, therefore average reduction of relative rate of air volume supply to the amounts of influent reached up to almost 16%.

**Table.2 The amounts of air volume reduction by adopting Ammonia+DO control system compared to dissolved oxygen control system**

| Month | January | February | March | April | May |
|---|---|---|---|---|---|
| Reduction rate (%)[a] | +7.6 | +16.8 | -3.7 | -15.4 | -15.7 |

a:monthly average

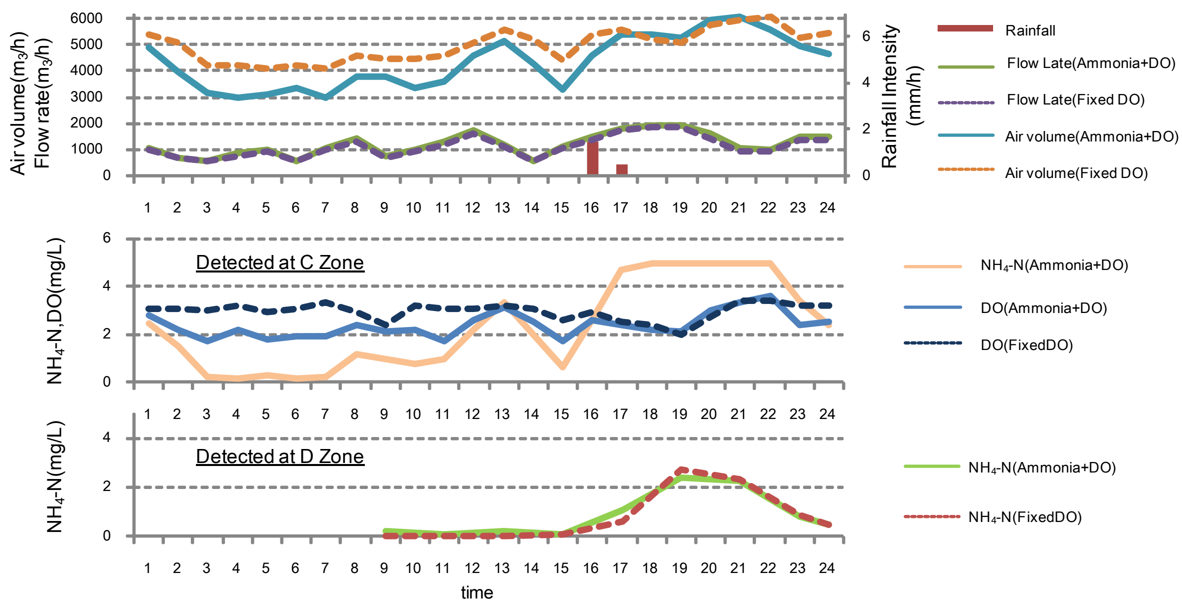


**Fig.5 One case of processing status of waste water at rainy day （May 17th, 2011）**

Drastic change in quality and quantity of waste water can be occurred in the rain against the fine day. Influence of such characteristics and quantity to the operation of Ammonia+DO control system was researched during experimental period. Rainfall of 2mm was observed in experiment undertaken at May 17th, flow rate of influent was increased twice as high compared to typical fine day condition. Processing status of waste water during experimental period is shown in Fig.5. Increase of flow rate of air volume in experimental and comparison tank, because of insufficient nitrification attributed to increasing of amounts of influent water. These results indicated reliable operation for treatment can be maintained within 1.5 at maximum relative to typical fine day level as an acceptable range. The Ammonia+DO control system is good for operation to improve effluent water quality with saving energy, as water quality of equal level relative to dissolved oxygen system can be maintained even the changeable condition of influent water quantity and flow rate of air volume supply during aeration can be saved in less changeable case of influent water quantity.

**Annual savings of energy**

As 10% of air volume supply could be reduced on the basis of the estimation by the operation in these results also taken into account for influence of rainfall frequency, this amounts of emission cut corresponds to 28tons of $CO_2$ in one year.

**Operation and maintenance**

Operation maintenance of ammonia meter was carried out per one month. Electrode of ammonia meter was exchanged to new ionic electrode three times per one year.

**Estimated operation cost**

$300,000 was used for installation of this system, moreover running cost required for maintenance and supplies expense is approximately $5,000.

**Requirements for installation**

Treatment plant receiving drastic change of quantity and quality of influent waste water has to be avoided to installation of Ammonia+DO control system, because of difficulty for saving energy by reduction of air flow rate. It should be appreciated that this system could be introduced in a treatment plant having complete nitrification due to its control by means of monitoring data of $NH_4$-N concentration. This system may not be adequate for high concentration of $NH_4$-N in effluent water not to nitrify sufficiently. As another requirement, it is significant that reduction of air flow rate is directly proportional to GHG reduction. Installation for a treatment plant introduced control system such as using inlet-vane or inverter control is suggested.

**Future plans**

○Because nitrification rate is easily changeable by water temperature variation, influence of operation strategy or parameters by difference of temperature and adequate condition of this system according to all season has to be optimized.

○Operation strategy during the time remaining influence to quality and quantity by storm water such as attenuation of $NH_4$-N concentration according to passage of time.

○Requirement toward installation to the other treatment plant having several characteristics has to be specified.

## 【RESTRICTED-AERATION $A^2$/O SYSTEM】

**Experimental site of restricted-aeration $A^2$/O system**

Schematic View of Kitatama nigou Waste Water Treatment Plant undertaken this experiment are illustrated in Fig.6.

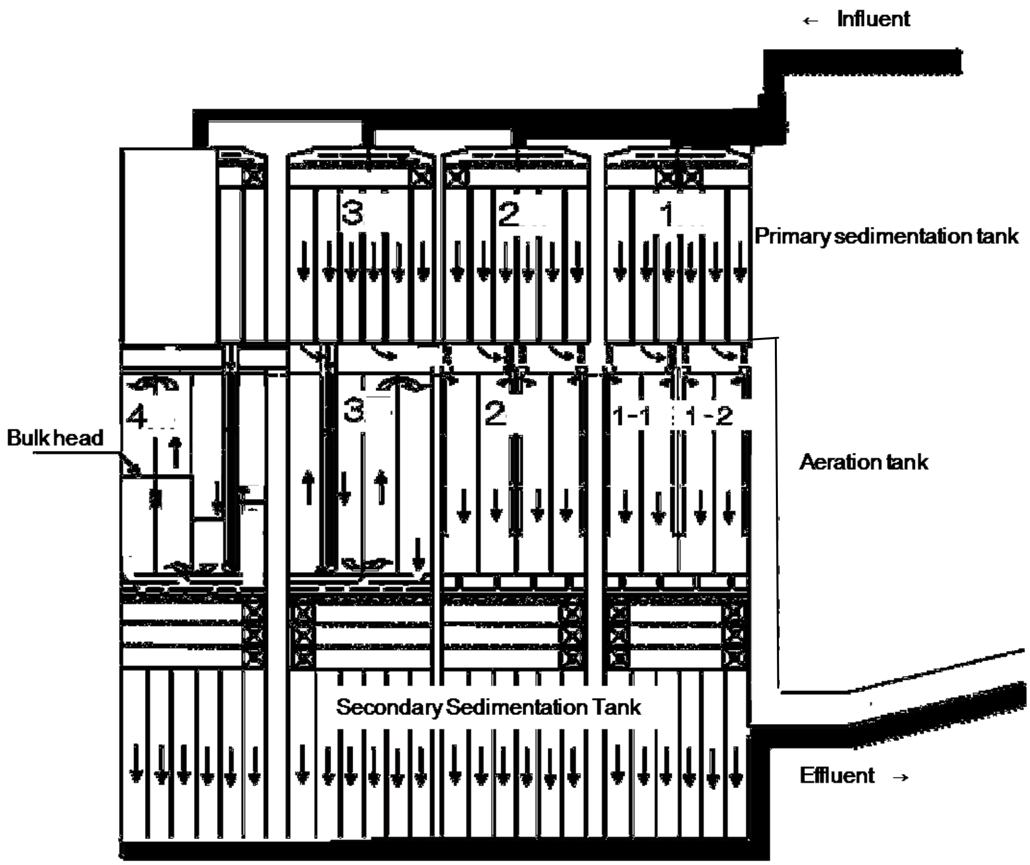


**Fig.6 Schematic view of Kitatama nigou Waste Water Treatment Plant**

Treatment plant is separated to three trains of conventional activated sludge plant and one train of $A^2$/O plant. In this experiment, one of three trains of conventional activated sludge plant was altered for use in restricted-$A^2$/O process. This treatment plant receives combined sewer waste water. Meanwhile, all influent waste water flowing into each aeration tank is the same.

The submersible pump provided for nitrified liquor recirculation to aeration tank used for restricted-$A^2$/O process was installed at the end of aeration tank, and returned nitrified liquor recirculation to the anoxic tank. Aeration tank used for conventional activated sludge and restricted-$A^2$/O process were equal size, however that of $A^2$/O was about two times bigger than the other one. All pumps used in return sludge or nitrified liquor recirculation were operated by constant flow rate.

**Experimental procedure of restricted-aeration $A^2$/O system**

Experimental period was from May 2009 to February 2010. Composite water samples of influent and each effluent, restricted-aeration process, conventional activated sludge process and $A^2$/O process, of 24 hours were collected on every Wednesday by automatic water sampler.

Activated sludge mixtures of B zone for except $A^2/O$ process were sampled for the measuring of nitrification rate and denitrification rate, and sampled at the end of anoxic phase in regard to $A^2/O$ process. Additionally, electric power consumption supplied to nitrified liquor recirculation pump, return sludge pump and agitator were compared by electric power meters. Operational situation during experimental time of each treatment processes are shown in Table.3 and water quality of influent water to aeration tank and effluent water of each treatment processes are shown in Table.4.

**Table.3 Operational situation during experimental time of each treatment processes**

| | | Restricted-aeration $A^2/O$ process | | | Standard-activated sludge process | | | $A^2/O$ process | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Ave. | Min | Max. | Ave. | Min | Max. | Ave. | Min | Max. |
| Flow rate ($m^3$/day) | | 12,623 | 5,153 | 18,856 | 13,004 | 7,465 | 18,912 | 23,271 | 14,524 | 28,415 |
| Return sludge (%) | | 26 | 16 | 57 | 23 | 15 | 39 | 25 | 0 | 38 |
| Nitrified liquor recirculation (%) | | 148 | 7 | 355 | – | – | – | 82 | 5 | 132 |
| Circulation rate (%) | | 174 | 23 | 412 | 23 | 15 | 39 | 107 | 36 | 164 |
| Aeration ratio | | 2.9 | 1.3 | 4.4 | 3.2 | 1.6 | 4.4 | 3.0 | 1.6 | 3.9 |
| MLSS (mg/L) | | 2,020 | 1,610 | 2,500 | 2,040 | 1,310 | 2,630 | 1,950 | 1,430 | 2,770 |
| SRT (day) | | 10.3 | 5.0 | 25.5 | 12.2 | 5.7 | 36.9 | 10.9 | 6.8 | 25.5 |
| ASRT (day) | | 5.1 | 2.5 | 12.7 | 9.1 | 4.3 | 27.7 | 6.1 | 3.8 | 14.4 |
| HRT (h) | Anaerobic | 2.3 | 1.5 | 5.6 | 2.2 | 1.5 | 3.9 | 0.9 | 0.7 | 1.4 |
| | Anoxic | 2.3 | 1.5 | 5.6 | – | – | – | 3.6 | 2.8 | 5.4 |
| | Aerobic | 4.6 | 3.1 | 11.3 | 6.7 | 4.6 | 11.7 | 5.7 | 4.5 | 8.7 |
| | Total | 9.2 | 6.2 | 22.5 | 8.9 | 6.1 | 15.5 | 9.6 | 7.9 | 15.4 |

*Cells were black out the tank to be operated by restricted-aeration

**Table.4 Water quality of influent and effluent of each treatment processes**

| | Influent water | | | Restricted-aeration A²/O process | | | Standard-activated sludge process | | | A²/O process | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ave. | Max. | Min. | Ave. | Max. | Min. | Ave. | Max. | Min. | Ave. | Max. | Min. |
| BOD(mg/L) | 116 | 176 | 50 | 5 | 11 | 1 | 2 | 4 | 1 | 4 | 7 | 1 |
| ATU-BOD(mg/L) | 89 | 114 | 39 | 1 | 4 | 0 | 1 | 1 | 0 | 2 | 3 | 1 |
| Dis.[a]-ATU-BOD(mg/L) | 35 | 51 | 13 | – | – | – | – | – | – | – | – | – |
| T-N(mg/L) | 23 | 27 | 10 | 6.9 | 9.2 | 3.6 | 9.1 | 11 | 6.4 | 7.2 | 9.1 | 5.4 |
| NH4-N(mg/L) | 16 | 20 | 7 | 1.4 | 4.7 | 0.0 | 0.6 | 4.9 | 0.0 | 0.4 | 1.5 | 0.0 |
| T-P(mg/L) | 3.6 | 5.2 | 1.6 | 1.1 | 4.3 | 0.3 | 1.2 | 2.6 | 0.1 | 0.6 | 1.8 | 0.2 |
| PO4-P(mg/L) | 2.2 | 3.5 | 0.9 | 0.7 | 1.8 | 0.1 | 1.1 | 2.7 | 0.1 | 0.4 | 1.8 | 0.1 |

a BOD samples were analyzed after filtration of 5C filter paper.

**The amounts of emission of excess sludge**

As emission rate of excess sludge significantly related to elimination performance of nitrogen and phosphorus, first of all, emission rate was considered in the evaluation of treatment. Emission rate was calculated from the concentration of suspended solid and dissolved

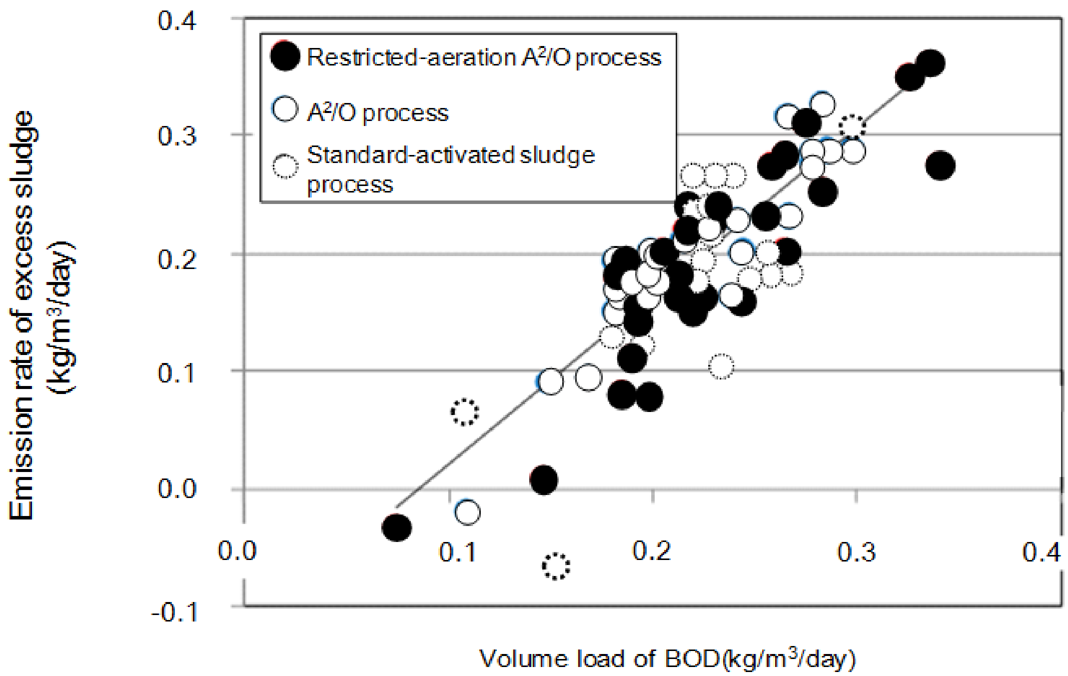


**Fig.7 Relationships volume load of BOD and emission rate of excess sludge**

biochemical oxygen demand (BOD). These experimental results indicated that emission rate of excess sludge depended on the load of BOD. The volume load of ATU-BOD was strongly correlated with emission rate of excess sludge in restricted-$A^2$/O process and also $A^2$/O process, thus emission rate of excess sludge could be estimated by BOD of influent waste water and amounts of treatment water. Furthermore, relationship emission rate of excess sludge per unit volume size of aeration tank converted to apply the conditions of other treatment plant and the volume load of ATU-BOD in the restricted-$A^2$/O process and also $A^2$/O process is illustrated in Fig.7. On the basis of this correlation, excess sludge is generated under 0.08kg/$m^3$/day of the volume load of ATU-BOD, however can approximately increase linearly over above value. In other words, increasing of emission rate of excess sludge can lead nitrogen and phosphorus elimination efficiency to improve.

### Phosphorus removal in restricted-aeration $A^2$/O system

Increasing of emission rate of excess sludge is significantly available for phosphorus removal. As emission rate of excess sludge well correlated the volume load of ATU-BOD, the relationships of the volume load of ATU-BOD and phosphorus removal was also considered. This correlation was represented in Fig.8. Analyzed data of the restricted-$A^2$/O process and $A^2$/O process had similar trend, therefore these results indicate that performance between both processes had little difference about phosphorus removal. We can also estimate phosphorus removal efficiency by means of correlating equation of Fig.8. This trend graph shown at Fig.8 is straight line not from origin, therefore there is limited level of the volume load of ATU-BOD to cause increased phosphorus concentration. On the other hand, stability of phosphorus removal extremely attributes to operation by specific level of the volume load of ATU-BOD.

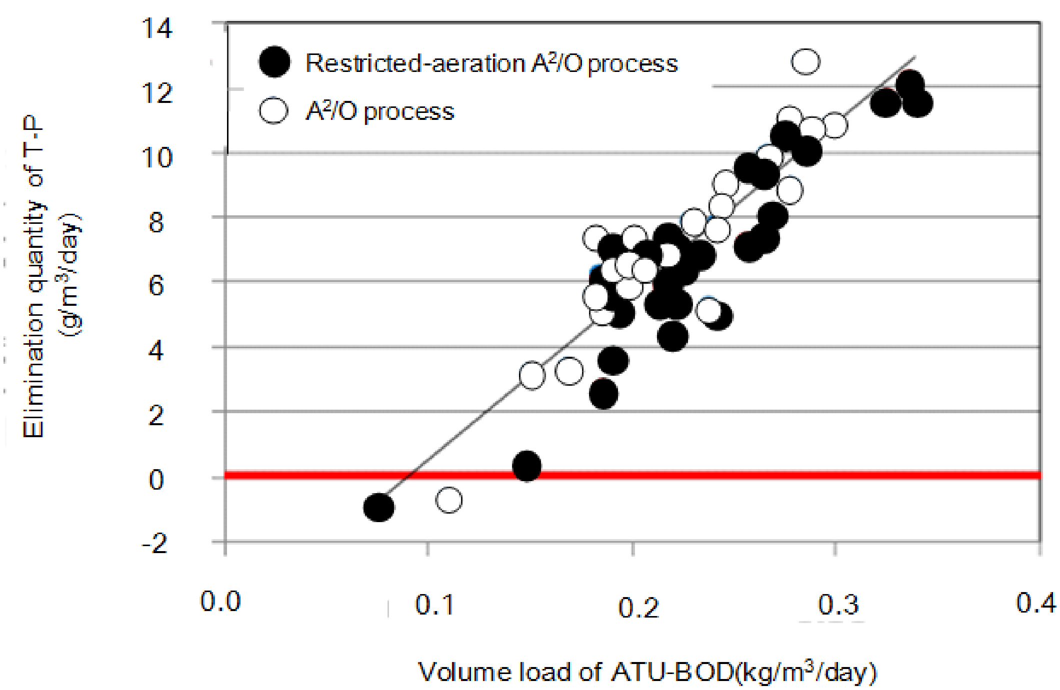


**Fig.8 Relationships of volume load of ATU-BOD and Elimination quantity of T-P**

**Nitrogen removal in restricted-aeration $A^2/O$ system**

Breakdown of nitrogen treatment downstream of reaction tank was considered in order to compare with nitrogen removal. Firstly, the amounts of phosphorus emitted as excess sludge were calculated from its breakdown, continuously solid volume of excess sludge was calculated by phosphorus concentration in sludge. Additionally, nitrogen emitted as excess sludge was estimated due to the value multiplied solid volume by nitrogen concentration contained in sludge. This approach for estimation is more appropriate in biological/constantaneously nitrogen and phosphorus removal. Breakdown of average nitrogen removal in experimental period were shown in Fig.9. Elimination rate of nitrogen by restricted-$A^2/O$ process was highest level at 74%. $A^2/O$ process had equal level and its slight difference depended on nitrified liquor recirculation rate (restricted-$A^2/O$ process:148%, $A^2/O$ process:82%). These observations represent that two treatment process, restricted-$A^2/O$ and $A^2/O$ process, have hardly definite difference.

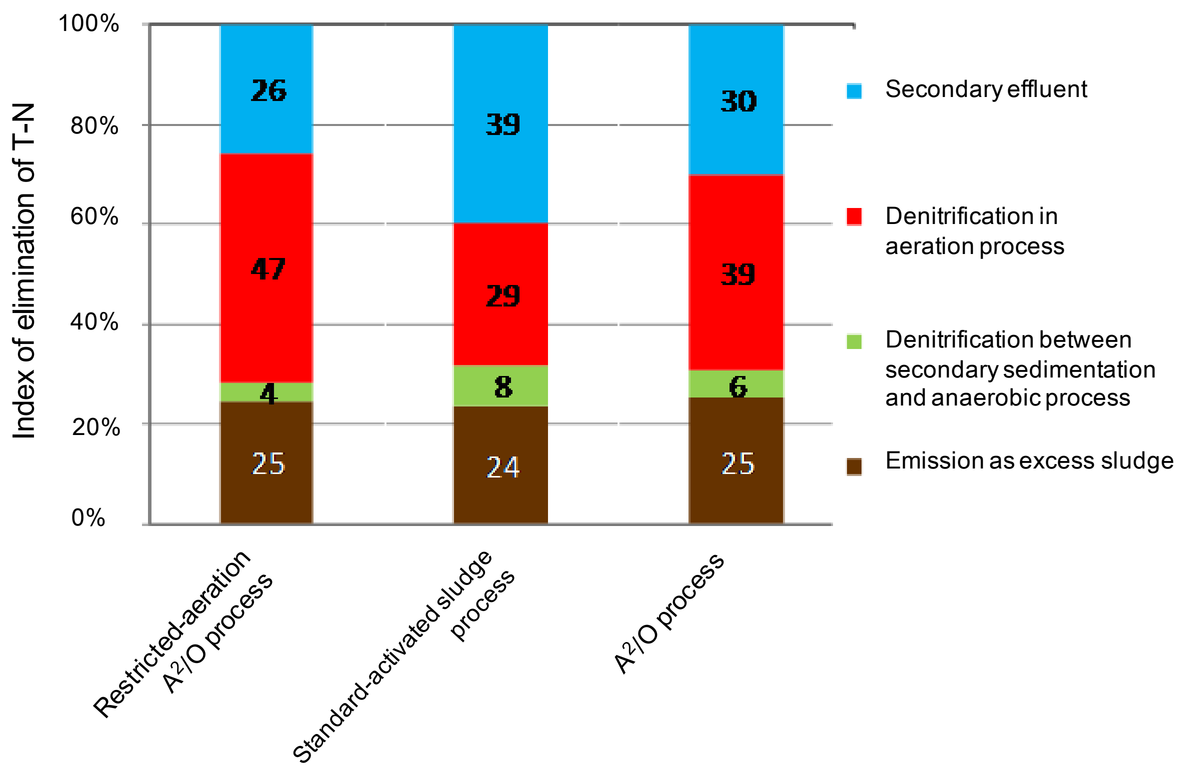


**Fig.9 Compositions of T-N emission by treatment process**

**Cost by implementation of restricted-aeration $A^2/O$ system**

Initial and running cost of restricted-$A^2/O$, $A^2/O$ and conventional activated sludge process (pseudo AO) were compared. Initial cost shows construction cost to alter a part of aeration tank. Experimental results are shown in Fig.10. Result of estimation indicated that initial cost of restricted-$A^2/O$ process is only slightly higher than that of conventional activated sludge process, but much lower than that of $A^2/O$ process. Running cost of restricted-$A^2/O$ process is equal level to conventional activated sludge process, but slightly lower than $A^2/O$ process. Experimental tank used for conventional activated sludge process was completely-mixed type easy to simultaneously progress nitrification and denitrification in aeration tank. Therefore, as oxygen demand decreases by elimination of BOD attributed to denitrification, additional exchanges from extrusion type to completely-mixed type aeration tank applied restricted-A$^2$/O are critically efficient for improvement of final effluent water quality and also reduction of treatment cost.

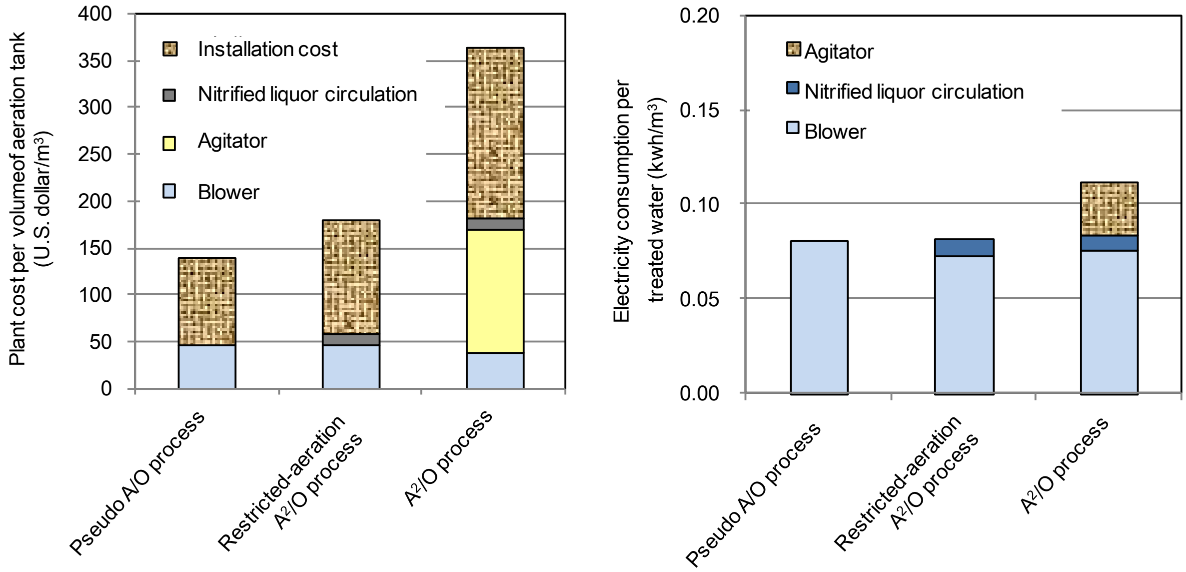


**Fig.10 Comparison of initial and running cost during process operation**

【Feed Forward Air Volume Control System for GHG Reduction in Wastewater Treatment】

**Experimental procedure**

Investigations using actual plant were conducted at Ochiai Water Reclamation Center (conventional activated sludge process). First, correlation between EC and other properties of water was examined to know whether fluctuation of water pollution can be monitored by measuring EC. Second, for using fluctuation of water pollution monitored by EC meter to control supplied air volume, relation between primary effluent EC and concentration of dissolved oxygen (DO) was examined. Third, behaviour of EC in reaction tank was investigated with small scale reaction tank. This investigation was conducted at Nakano Water Reclamation Center (A/O process).

**Correlation of electrical conductivity and water quality**

Samples showed below were collected several times, and their EC and other properties ware measured.
Investigation term: 24 March 2008 ~ 16 June
Samples: influent, primary effluent, secondary effluent, and sand filtered water
EC meter: TOA DKK CM-20S
Measured properties: EC, $COD_{Mn}$, ammonium nitrogen, nitrite nitrogen, and phosphate phosphorus

**Electrical conductivity and supplied air volume control**

In terms of constant air flow and DO controlled, EC of primary effluent and DO in the end of reaction tank were measured successively.
Investigation term: 25 July 2008 ~ 26 December
Air control methods: constant air flow during 25 July ~ 10 September
DO controlled during 24 November ~ 26 December
EC meter: TOADKK CM-21P
DO meter: MITSUBISHI TY3301
Interval of measuring: 10minutes

**Behaviour of EC in reaction tank**

Investigation was conducted as following: 10 litres of Primary effluent and 3.5 litre of reverse sludge were poured into a cylindrical reaction tank that has capacity of 15 litres. EC was measured every ten minutes. Other properties were measured at intervals of half or 1 hour.

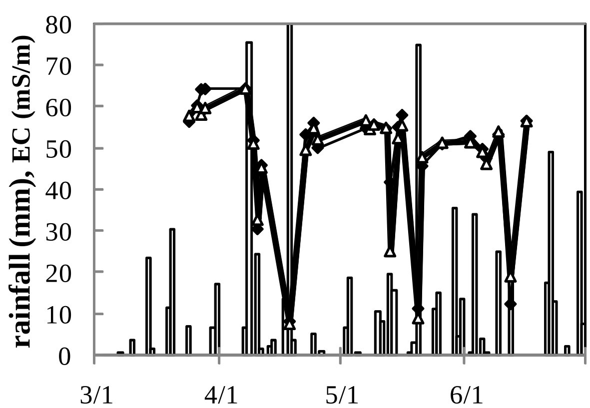

**Fig.11 EC of influent (◆ with fine line) and primary effluent (△ with bold line) from 24 March 2008 to 16 June, the white bar shows dairy rainfall total (white bar) from 1 March to 30 June.**

**RESULTS AND DISCUSSION**

**Correlation of electrical conductivity and water quality**

***Variation of Electrical Conductivity***

Fig.11 shows variation of EC and rainfall in investigation term. EC of influent and primary effluent were high level of 55mS/m or more when they were not affected by rain. In contrast, EC of sewage was decreased by dilution on rainy days. Meanwhile, EC was decreased by diluting with rain water in rainy days. If it was more rainfall, EC tended to be lower. EC values of secondary effluent and sand filtered water were 40~45mS/m on Fig.12 when they were not affected by rain. Those EC were tended to decrease in rainy days just like influent's and primary effluent's, but their range were smaller.

***Correlation with Other Water Quality***

Relations between EC and COD of influent and primary effluent were shown in Fig.13. The correlations are strong, and correlation coefficients were 0.93. From this result, EC can be used for alternative indicator of COD. Having steeper slope of linear approximate equation, EC of

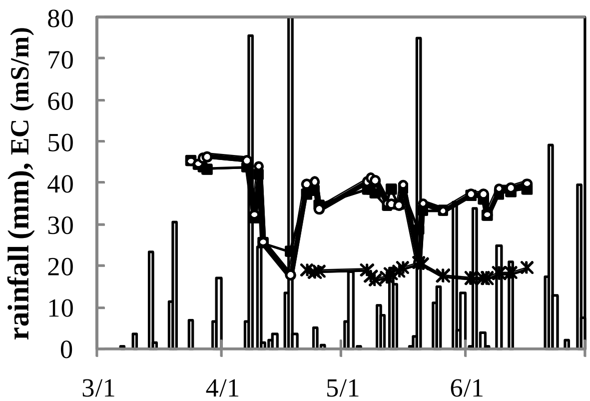


**Fig.12 EC of secondary effluent (■ with fine line), sand filtered water (○ with bold line) from 24 March 2008 to 16 June and tap water (∗ with middle width line) from 22 April to 16 June, the white bar shows dairy rainfall total from 1 March to 30 June.**

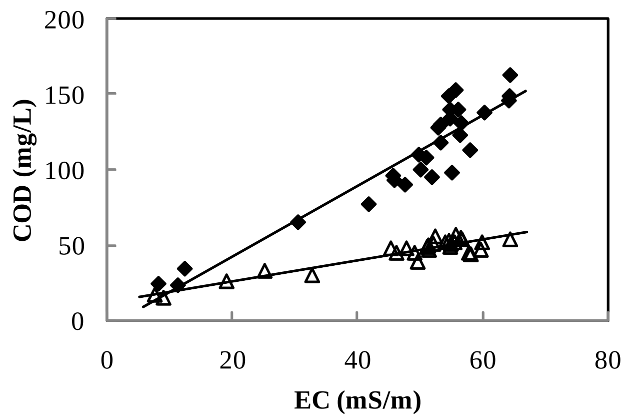


**Fig.13 Concentration dependence of EC for COD, in influent (◆) and primary effluent (△). The data were collected from 24 March to 16 June.**

influent can detect variation of COD in high sensitivity.

Because of it, effluent is suit for monitoring water quality with the intention of controlling reaction tank by feed forward method.

Table.5 shows correlation efficiencies of measured samples. Correlations between EC of primary effluent and ammonium nitrogen and phosphate phosphorus were high level of 0.9 or more as well as EC and COD. Fig.14 and 15 shows the correlations. In contrast, samples after reaction tank such as secondary effluent and sand filtered water have some low efficiencies. Because of these result, EC can be used for index of water quality if monitoring spot is selected properly.

**Table.5 Correlation coefficients between EC and COD, ammonium nitrogen, nitrite nitrogen, phosphate phosphorus, turbidity and chromaticity. The number of date is 28.**

| | influent | primary efflue | secondary effluent | sand filtered water |
|---|---|---|---|---|
| COD | 0.93 | 0.93 | 0.44 | 0.83 |
| $NH_4$-N | | 0.95 | | |
| $NO_3$-N | | | | 0.47 |
| $PO_4$-P | | 0.96 | | 0.64 |
| Turbidit | | | | -0.14 |
| Chromat | | | | 0.85 |

**Electrical Conductivity and Supplied Air Volume Control**

*Constant Air Blow term* An example of EC of primary effluent, DO in the end of reaction tank and air volume variation is shown in Fig.16. EC value decreased with rain in July 29 (the rainfall was 38.5mm) and after that the value increased. In that day, DO value definitely increased at almost the same time EC decreased. Increasing DO value means pollutant concentration decreased because of rain. EC meter can detect decreasing pollutant as well as DO meter. In not rainy days, the DO value increased (decreased) and supplied air flow decreased (increased) in response to the decrease (increase) of EC after the elapse of retention time. EC value has correlation with DO value whether it is rain or not. In fact, in this investigation term, EC value exceeded 57.5mS/m before DO value decreased below 2.0mg/L 9times in 10 and this phenomenon has repeatability.

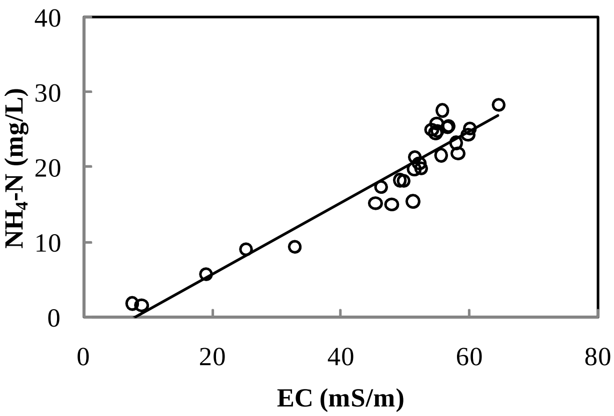


**Fig.14 Concentration dependence of EC for ammonium nitrogen in primary effluent (○). The data were collected from 24 March to 16 June.**

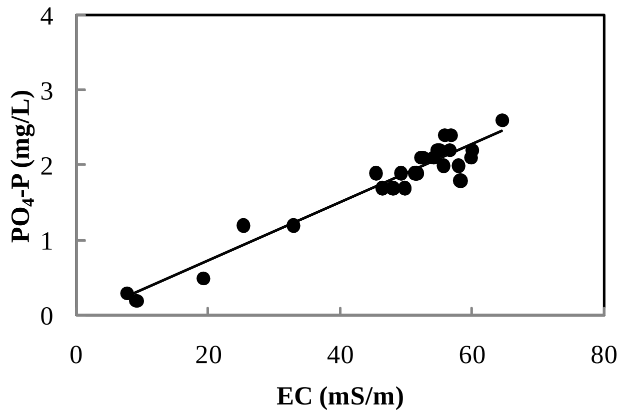


**Fig.15 Concentration dependence of EC for phosphate phosphorus in primary effluent (●). The data were collected from 24 March to 16 June.**

Although the survey was conducted for eleven consecutive days without cleaning the electrode, the measurement value was stable, which means it is easy to maintenance.

*DO controlled term* Variation of EC of primary effluent, DO in the end of reaction tank and supplied air volume is shown in Fig.17. It can be read by this graph that variation pattern of effluent quality indicated by EC value was similar to that of supplied air volume. From this result, it is thought that excess and deficiency of air volume and variation of DO can be suppressed and optimization of operation will be achieved by controlling air volume with feed forward method using the data of

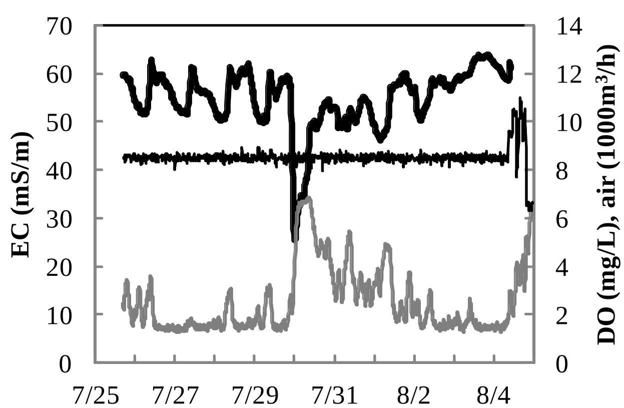


**Fig.16 EC of primary effluent (bold black line), supplied air volume (fine black line) and DO in the end of reaction tank (gray line) at constant air flow term from 25 Jury 2008 to 4 August.**

primary effluent EC variation.

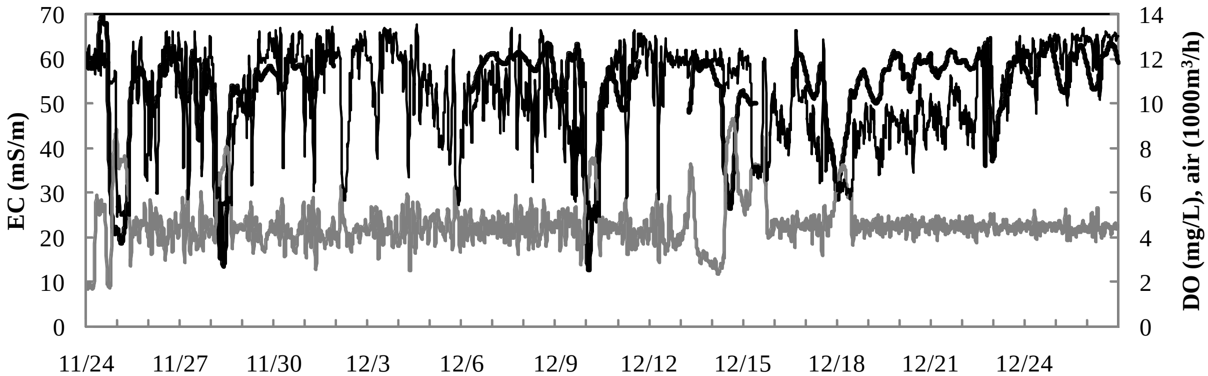


**Fig.17 EC of primary effluent (bold black line), supplied air volume (fine black line) and DO in the end of reaction tank (gray line) at DO controlled term from 24 November 2008 to 26 December.**

**Behavior of EC in reaction tank**

Fig.18 shows variation of EC and other properties. EC value of mixed liquor increased as phosphate phosphorus does while the reaction tank kept anoxic condition for 2 hours. After starting aeration, EC value decreased as phosphate phosphorus and ammonium nitrogen did. Between until concentration of phosphate phosphorus got closer to 0mg/L and after that, there was a little different in rate of EC decline.

It was observed that how EC value changes as treatment proceeds. EC value in the reaction tank changes mainly with concentrations of phosphate phosphorus and ammonium nitrogen was indicated.

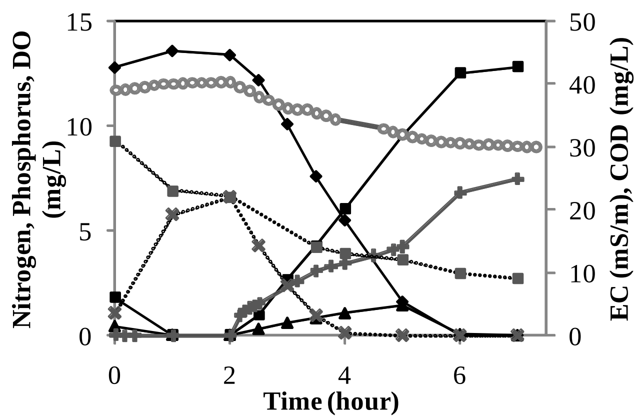


**Fig.18 Variation of EC (○), COD (gray■ with dotted line), ammonium nitrogen (◆), nitrate nitrogen (▲), nitrite nitrogen (black ■), phosphate phosphorus (×) and DO (+) in experimental reaction tank.**

**SUMMARY AND CONCLUSIONS**

The results in these experiments led to the following conclusion:

Long-term wastewater treatment operation by means of ammonium-nitrogen and also dissolved oxygen concentration was undertaken to keep reducing electric power consumption and improving effluent water quality. The results indicated that this system achieved more efficient operation from the aspect of wastewater treatment and electric power consumption compared to the traditional dissolved oxygen control system under the condition of relatively less changeable water quality and quantity. Though the condition of nitrification and/or installation type of aeration facilities according to each treatment plant had to be taken into account, it was confirmed that this system was adequate to introduce in order to reduce power consumption used for blower.

Operation of restricted-aeration $A^2/O$ system to simultaneously and efficiently remove nitrogen and phosphorus by means of forming pseudo anaerobic condition in substitution for the form of anaerobic phase by using agitator was researched. Results indicated that restricted-aeration $A^2/O$ system made final effluent water quality improve equal level compared to the $A^2/O$ system by much lower initial and running cost. Especially, it is relatively easy to construct new facilities to the existing plant.

Feed-forward control system by means of electric conductivity which had researched in sewage and wastewater treatment field system as efficient control instead of traditional dissolved oxygen control was investigated. Electric conductivity correlated several water qualities, and tended to follow variation during rain and storm water conditions. Because of endurance to long-term operations, installation of feed-forward control system for aeration to use electric conductivity by selection of appropriate monitoring point would attain streamlining and efficiency of operation for wastewater treatment.

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