Korean J. Chem. Eng., **22**(5), 666-670 (2005)

Control and Nitrogen Load Estimation of Aerobic Stage in Full-Scale Sequencing Batch Reactor to Treat Strong Nitrogen Swine Wastewater

Kyung-Min Poo, Jeong-Hoon Im*, Joo-Hyung Ko, Ye-Jin Kim*, Hae-Jin Woo* and Chang-Won Kim*,†

Water Environment & Remediation Center, Korea Institute of Science and Technology,
39-1, Hawolkok-dong, Seongbuk-gu, Seoul 136-791, Korea
*Dept. of Environmental Engineering, Pusan National University,
San 30, Jangjun-dong, Keumjung-gu, Busan 609-735, Korea
(*Received 18 March 2005 • accepted 10 June 2005*)

Abstract−Three different control methods based on oxidation reduction potential (ORP) and dissolved oxygen (DO) for determining aeration time were evaluated for swine wastewater treatment at full-scale SBR. For determining the *Ending Point of Ammonia Oxidation (EPAO)*, the plateau in ORP profile, the derivative of DO, and absolute DO were tested. Below 0.5 kg NH_4^+-N/m^3·day of influent loading rate, three control methods produced good results; however, above this loading rate, only absolute DO method was feasible. The volumetric ammonia nitrogen load at the sub-cycle (Kg NH_4^+-N/m^3/sub-cycle) had an effect on the period of aeration. To put it more concretely, the higher loading rate required a longer ammonia nitrogen oxidation period. To estimate nitrogen load, the length of low DO period, which was defined as the required time to reach 3 mg DO/*l* from the start of aeration, was the most proper parameter.

Key words: Control, ORP, DO, SBR, Nitrification, Load Estimation

INTRODUCTION

A sequencing batch reactor (SBR) was considered as an appropriate treatment process to treat swine wastewater containing strong organics, nitrogen and phosphorus concentrations; for instance, the range of TCOD, SCOD, NH_4^+-N and PO_4^{3-}-P in the swine wastewater from Korea are 23,000-72,000 mg/*l*, 15,000-60,000 mg/*l*, 3,500-6,000 mg/*l* and 40-160 mg/*l*, respectively. The strong influent loading and toxic event were effectively handled by regulating fill ratios and aeration period of SBR. Therefore, the control of feed volume and on-off aeration in SBR was essential for treating the swine wastewater. Many applications of SBR control have been performed based on ORP and DO measurement [Plisson et al., 1996; Andreottola et al., 2001]. However, most researches were done for a low range of contaminants such as domestic wastewater at pilot plants or bench-scale plants. The feed volume and the aeration cycle for treating swine wastewater could be optimized effectively through fine tuning, and these local controls could possibly be managed by a remote control system. It was known that a remote central management system was could be an economical way to handle many plants at one place. Especially, small swine wastewater treatment plants are scattered around large rural areas, so expert managers cannot visit each swine plant everyday.

Over the past few decades a considerable number of studies have been made on a sequencing batch reactor (SBR) operation and control. SBR is known to be simple to operate, affordable for dynamic loading rate and less space requirement [Andreottola et al., 2001]. It has become very popular for treating strong wastewater such as swine wastewater in Korea [Poo et al., 2004]. The control of sequential on-off aeration is very important in the SBR. A great deal of effort has been made on control applications based on ORP (Oxidation Reduction potential), DO and pH measurement [Plisson et al., 1996; Andreottola et al., 2001]. What seems to be lacking, however, is fine-tuning for real applications because the researcher has dealt with ideal conditions like proper load and C/N ratio.

Basic measuring instruments such as ORP, pH and DO are used as monitoring tools in water and wastewater treatment system. They have been recently focused for control parameters due to stable and reliable data and giving a great deal of information to operators, depending on the point of view. Through two decades, ORP has been used as a control parameter for biological nitrification/denitrification [Zipper et al., 1998]. pH indicates the strength of acid or alkali in the water. Added to this, Al-Ghusain et al. [1995] mentioned pH measurements could be helping a single ORP usage for better nitrification/denitrification control. DO data infers the supply and consumption of oxygen in the reactor, and it has been used as a parameter to detect organic oxidation or nitrification [Poo et al., 2004].

In this research, the local control techniques such as determination of aeration period and the diagnosis of influent loading rate based on ORP and DO profile were presented and managed through the remote management system that can be managed by the fuzzy inferred system and artificial neural network (ANN)

MATERIALS AND METHODS

A full-scale SBR was installed at the Kimhae swine wastewater treatment plant located about 25 km away from Pusan National University where the remote management system was running. The raw swine wastewater was collected from the storage tank of scrapper-type barns. The influent characteristics are shown in Table 1. As the C/N ratio of raw wastewater was less than 3, the external carbon source should be required to complete denitrification. The

†To whom correspondence should be addressed.
E-mail: cwkim@pusan.ac.kr

Table 1. Characteristics of raw swine wastewater collected from scrapper-type barns

(Unit : mg/*l*)

SCOD	BOD_5	TSS	NH_4^+-N	T-P	Alkalinity	pH
11,000±2,000	8,000±1,500	1,500±100	3,800±400	20±5	13,000±2,000	8.7±0.2

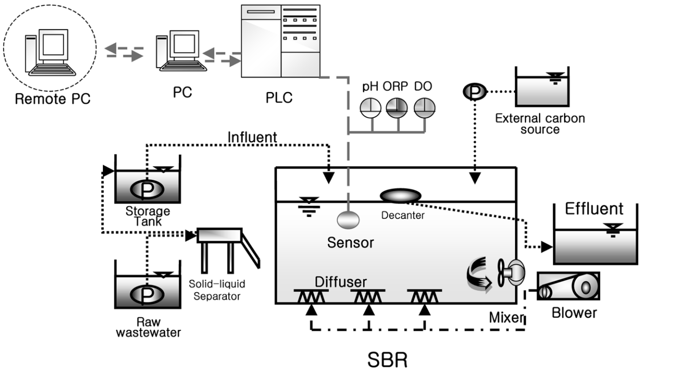

Fig. 1. Schematic diagram of the pilot scale SBR plant.

pilot SBR, schematically represented in Fig. 1, was rectangular shape with working volume of 20 m^3. A ring blower supplied 3.64 m^3 air/min through 30 units of disk type diffusers at the bottom of reactor. In anoxic stage, the impeller type mixer was used for proper mixing. ORP (U.S. filter, Strantrol 880, U.S.A.), DO (Knick, stratos 2401OXY, Germany) and pH (ECO IT21, EcoSys 2001 pH) sensors were installed in the reactor for on-line monitoring and control.

One whole-cycle of SBR consisted of five sub-cycles. One sub-cycle has one short anoxic period and one short aerobic period. The raw wastewater was fed intermittently to avoid ammonia toxicity [Poo et al., 2004] and the anoxic phase was operated by fixed time for 1 hr while the aerobic phase was controlled based on ORP or DO profile. The influent wastewater was fed at the beginning of each anoxic period except the final anoxic period. At the final anoxic period, methanol as external carbon source was fed to remove accumulated NOx-N. On-line DO and ORP data were saved every minute and displayed.

RESULTS AND DISCUSSION

1. Indication of the Ending Point of Ammonia Oxidation (EPAO) by ORP

Fig. 2 shows the profiles of ORP and effluent quality of NH_4^+-N and NO_3^--N with various loading rate from 0.14 to 0.43 kg NH_4^+-N/m^3/day. The horizontal axis in the figures represents real time when data was acquired. Under relatively low loading rate, the ORP bending point, which has been widely used for EPAO detection [Plisson et al., 1996; Paul et al., 1998; Andreottola et al., 2001], did not appear. However regardless of loading rate, the nitrification was completed when ORP profile reached a plateau as marked on the figures. Therefore, the starting point of the ORP plateau could be considered a more valuable control point. Effluent ammonia concentrations were maintained below 5 mg/*l*, all the time using EPAO control for 60 days even if the influent concentrations were fluctuating from 3,000 to 4,000 NH_4^+-N mg/*l* where the initial concentrations in the reactor were in the range of 30 to 100 mg/*l* depending on the loading rates.

Fig. 3 shows the limitation of ORP based control for high loading rate. When the loading became very high, about more than 0.5 kg NH_4^+-N/m^3/day, which was equivalent with 0.18 kg NH_4^+-N/m^3 in terms of sub-cycle, the ORP was depicted abnormally. This phenomenon might be caused by the high suspended solids concentration of 13,000 mg/*l* accompanied with high NH_4^+-N loading. In this

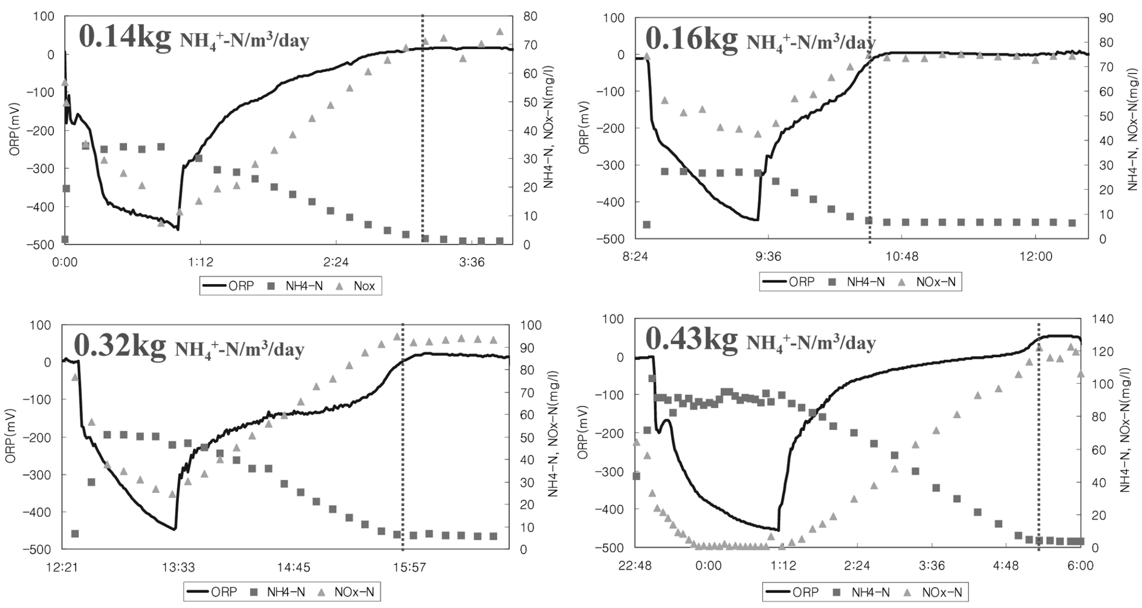

Fig. 2. ORP and nitrogen profiles under various loading rates during one sub-cycle.

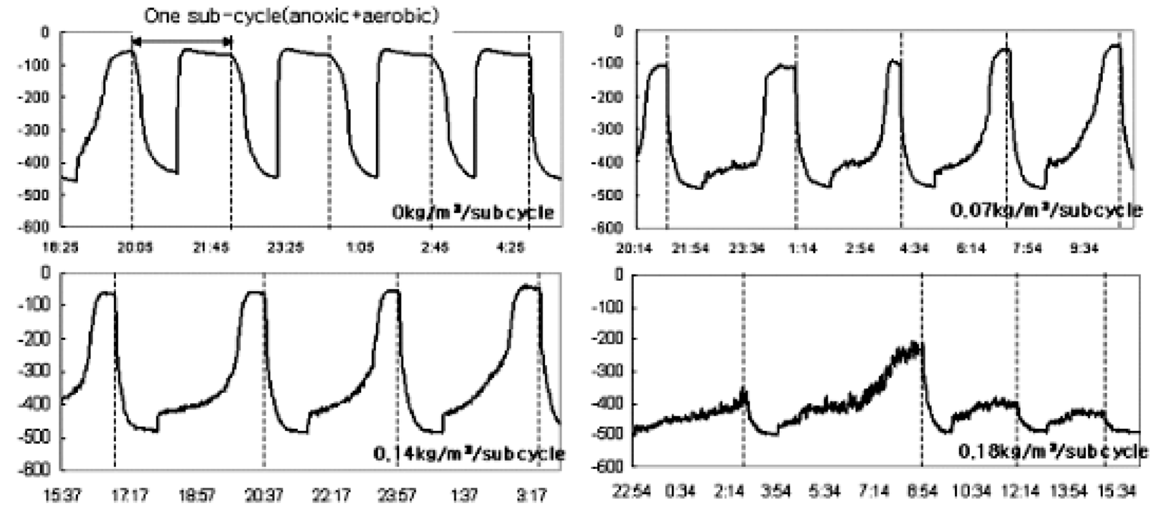

Fig. 3. Abnormal ORP profile at the high ammonia loading rate.

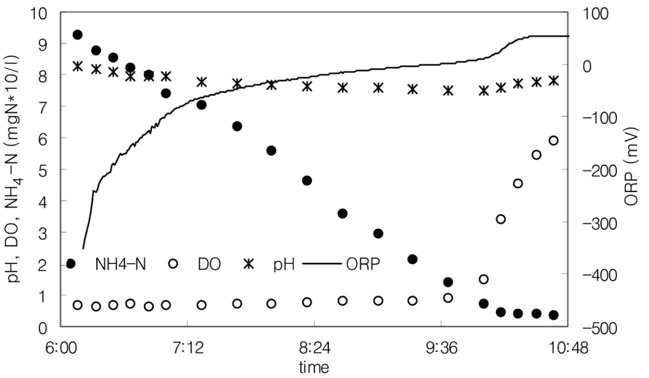

Fig. 4. Variation of pH, DO, ORP and ammonia during aerobic phase.

case the ORP profile cannot be used for control purposes and an alternative control method should be considered.

2. Alternative Control Method: DO Profiles Indicating EPAO

Fig. 4 shows pH, DO, ORP and NH_4^+-N during nitrification in the pilot SBR whose influent loading rate was 0.43 kg NH_4^+-N/m^3/day. The DO profile during nitrification was maintained below 1 mg/*l* for 220 minutes, indicating that most DO was consumed for the nitrification. The abrupt DO jumps from about 1 to 6 mg/*l* occurred at the ending point of ammonia oxidation (EPAO) because DO was no longer required for the nitrification. There were two possibilities for determining optimum EPAO. The one was the moment when the first order derivative of DO(ΔDO/Δt) maintained the highest value, and the other was the moment when the absolute DO was above a certain value indicating completion of nitrification.

Based on the first suggestion, the EPAO was determined as the point when the first order derivatives of DO(ΔDO/Δt) were detected over 0.1 consecutively three times as shown at the upper part in Fig. 5. In the case of a good condition of DO sensor, the DO profile was relatively clean and smooth so that the EPAO was determined easily. However, once the sensor condition became poor, the DO/Δt values were scattered around widely due to electrical noise and then it was extremely difficult to detect EPAO as shown at the lower part in Fig. 5. Therefore, the second suggestion needs to be considered.

Fig. 6 shows the absolute DO for aeration time control. Based on the second suggestion, at the ammonia loading rates of 0.16 and 0.32 kg NH_4^+-N/m^3/day the nitrification was completed at an absolute DO of around 2 mg/*l*. At higher loading rate of 0.43 kg/m^3/day the nitrification was completed at an absolute DO of around 2.6 mg/*l*. Therefore, the absolute DO of 3 mg/*l* was selected as the optimum EPAO.

Fig. 7 shows the result of real time control based on the second suggestion. The influent loading rate was increased at each sub-cycle from 0.09 to 0.18 kg NH_4^+-N/m^3/sub-cycle, and the fluctuation of the DO profile was dramatically increased. However, this fluctuation was not an obstacle to control the aeration time based on EPAO of 3 mg/*l* DO. It was concluded that the absolute DO method was easier and clearer for detecting EPAO than that based on ORP. Specially, the EPAO determined by absolute DO method can be valid for different DO sensors, while EPAO by the ΔO/Δt Also, a lower DO at the end of the aeration stage, such as 3 mg/*l*, enhanced denitrification at the following anoxic stage. The absolute value of DO can be changed depending on aeration rate per reactor volume.

To determine EPAO for proper control of aeration time for SBR operation, the applicability of three methods including ORP, ΔDO/Δt and absolute DO was compared and summarized in Table 2. The absolute DO method was the most practical way among the three parameters.

3. Estimating Influent NH_4^+-N Loading Rate Based on DO Profile

The DO profile was used for estimating the NH_4^+-N loading rate. At the beginning of the aerobic stage, the DO value was maintained relatively low for certain period of time, which could be correlated with the NH_4^+-N loading rate. Then all of a sudden the value increased rapidly due to completion of ammonia oxidation. The length of the low DO period obtained from Fig. 8 correlated very well with the influent NH_4^+-N loading rate, as shown in Fig. 9. With this information, the loading rate was inferred by using fuzzy inference system and appropriate feed volume to SBR could be determined. For the inference rules, the proper length of low DO period

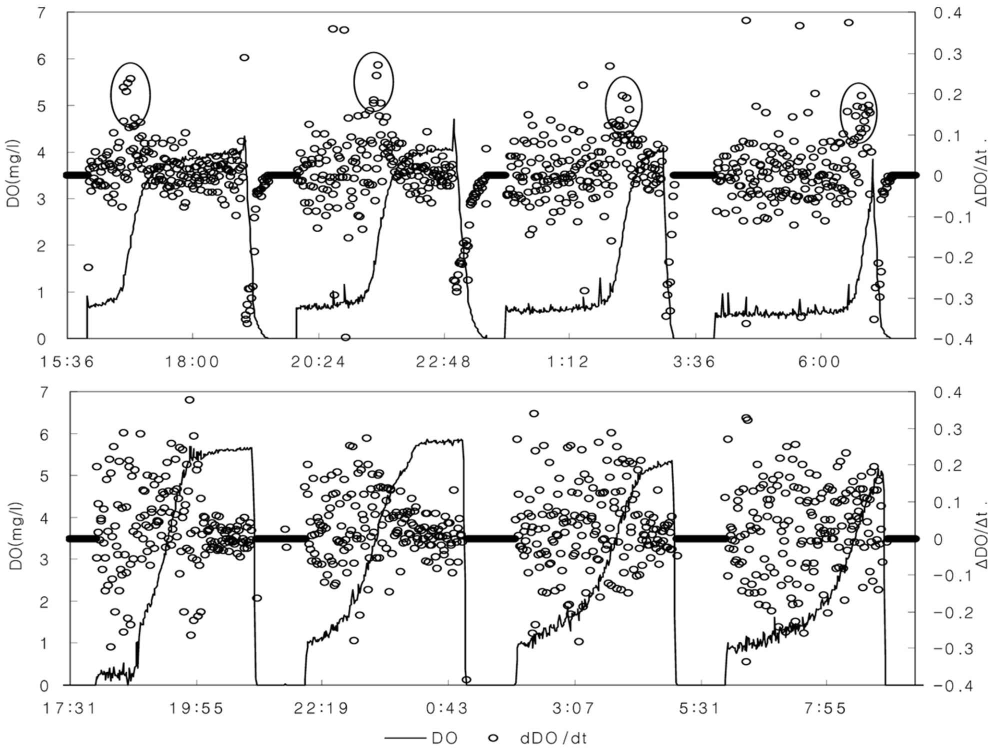

Fig. 5. Variation of DO and ΔDO/Δt under different loading rate (*Upper : good condition of DO sensor*, Lower : poor condition of DO sensor).

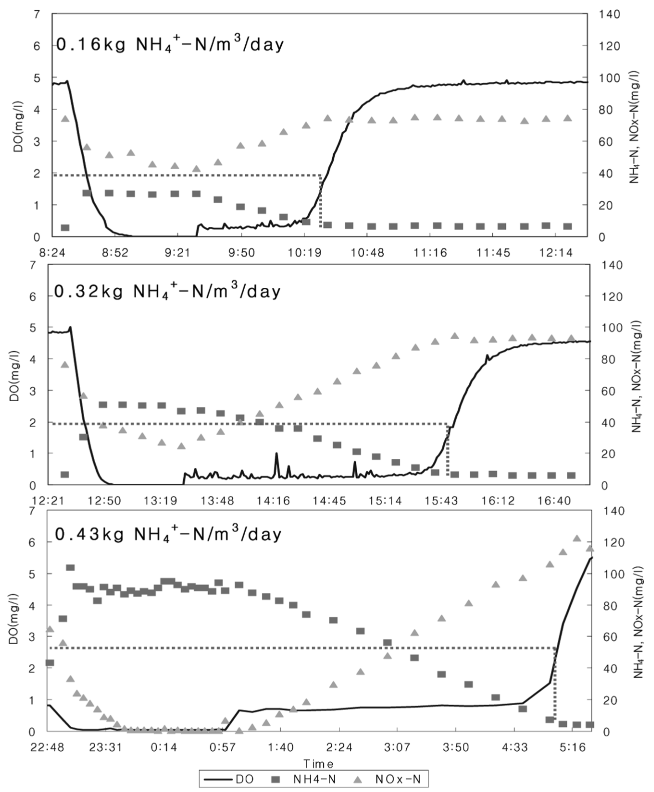

Fig. 6. The absolute DO for aeration time control.

was between 120-160 minutes in the tested pilot plant, which would be in the range of 0.15-0.2 kg NH_4^+-N/m^3/day. Below 100 minutes and above 180 minutes were considered as under-loaded and over-loaded conditions, respectively. For example, if the length of the low DO period was 100 minutes, the system judged that it was an under-loaded condition and then increased feed volume 10% more at the next sub-cycle. By repeating this inference, the proper feed volume that is loading rate could be automatically adjusted.

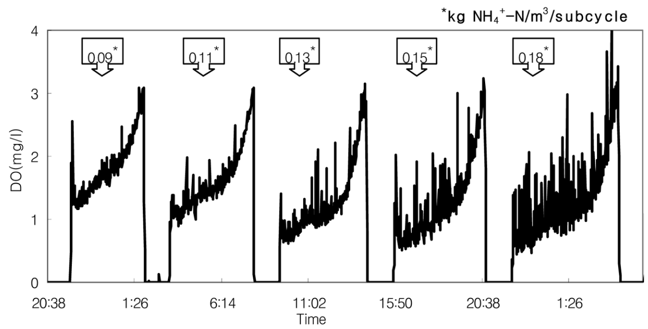

Fig. 7. On-line control based on DO when load was changed from 0.09 to 0.18 kg NH_4^+-N/m^3/sub-cycle.

Table 2. A summary of the control algorithms on aerobic stage

	ORP	ΔDO/Δt	Absolute DO
EPAO detection	Plateau	Higher value	3 mg/*l*
High load control	△	×	○
Reproducibility	○	×	○
Real application	△	×	○

○=good, △=medium, ×=poor

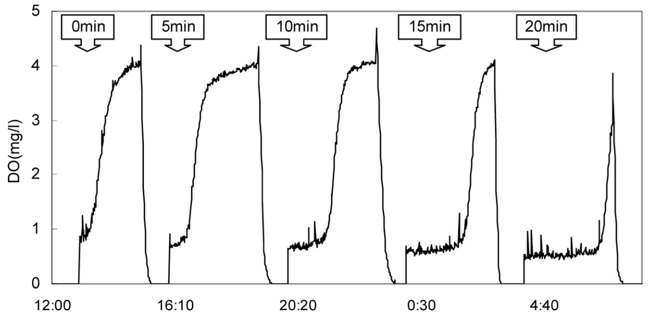

Fig. 8. Variation of length of low DO period related to influent NH_4^+-N loading rate.

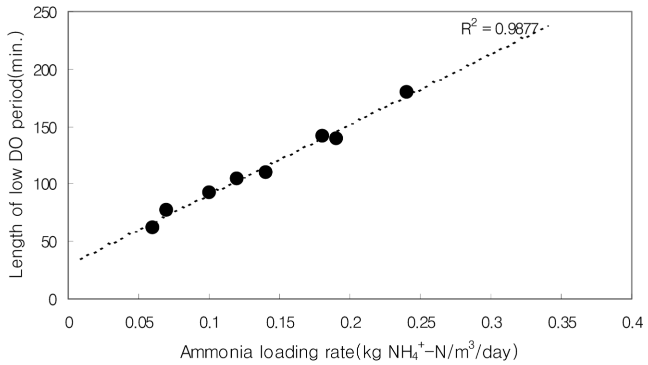

Fig. 9. Relation between influent loading rate and length of low DO period.

CONCLUSION

Aerobic stage control methods based on ORP or DO were developed. In the ORP profile, the plateau was the proper control point for the completion of ammonia oxidation. But the ORP profile fluctuated abnormally at high loading rate, about more than 0.5 kg NH_4^+-N/m^3/day (0.18 kg NH_4^+-N/m^3/sub-cycle), so control was not possible. The control based on $\Delta DO/\Delta t$ was severely affected by signal noises, and not proper for field-scale application. On the contrary, the control based on absolute DO was applicable even to high loading rate and it was not interrupted by the noises of the DO sensor. Influent loading rate was inferred with the low DO period and feed volume. A remote central management system based on artificial intelligence would be useful to operate small-scale SBR plants and for an unmanned wastewater treatment system.

ACKNOWLEDGMENTS

This study was supported financially by Korean Ministry of Agriculture and Forestry, Hanchang Water Tech Co. Ltd. and Environmental Vision21 Ltd. through the Institute for Environmental Technology and Industry (IETI), Pusan National University, Korea.

REFERENCES

Al-Ghusain, I. A. and Hao, O. J., "Use of pH as Control Parameter for Aerobic/Anaerobic Sludge Digestion," *J. Envir. Engrg.*, **121**(3), 225 (1995).

Andreottola, G., Foladori, P. and Ragazzi, M., "On-line Control of a SBR System for Nitrogen Removal from Industrial Wastewater," *Wat. Sci. Tech.*, **43**(3), 93 (2001).

Paul, E., Plisson, S. S., Mauret, M. and Cantet, J., "Process State Evaluation of Alternation Oxic-anoxic Activated Sludge using ORP, pH, and DO," *Wat. Sci. Tech.*, **38**(3), 299 (1998).

Plisson, S. S., Capdeville, B., Mauret, M., Deguin, A. and Baptiste, P., "Real-time Control of Nitrogen Removal using three ORP Bending Points: Signification, Control Strategy and Results," *Wat. Sci. Tech.*, **33**(1), 275 (1996).

Poo, K. M., Jun, B. H., Lee, S. H., Im, J. H., Woo, H. J. and Kim, C. W., "Treatment of Strong Nitrogen Swine Wastewater at Full-scale Sequencing Batch Reactor," *Wat. Sci. Tech.*, **49**(5-6), 315 (2004).

Yoo, C. K., Lee, J. M. and Lee, I. B., "Nonlinear Model-based Dissolved Oxygen Control in a Biological Wastewater Treatment Process," *Korean J. Chem. Eng.*, **21**, 14 (2004).

Zipper, T., Fleischmann, N. and Haberl, R., "Development of a New System for Control and Optimization of Small Wastewater Treatment Plants using Oxidation-Reduction Potential (ORP)," *Wat. Sci. Tech.*, **38**(3), 307 (1998).