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Applying real-time control to enhance the performance of nitrogen removal in CAST system

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Abstract: A bench-scale reactor(72 L) red with domestic sewage, was operated more than 3 months with three operation modes: traditional mode, modified mode and real-time control mode, so as to evaluate effects of the operation mode on the system performance and to develop a feasible control strategy. Results obtained from fixed-time control study indicate that the variations of the pH and oxidation-reduction potential(ORP) profiles can represent dynamic characteristics of system and the cycle sequences can be controlled and optimized by the control points on the pH and ORP profiles. A control strategy was, therefore, developed and applied to real-time control mode. Compared with traditional mode, the total nitrogen(TN) removal can be increased by approximately 16% in modified mode and a mean TN removal of 92% was achieved in real-time control mode. Moreover, approximately 12.5% aeration energy was saved in real-time control mode. The result of this study shows that the performance of nitrogen removal was enhanced in modified operation mode. Moreover, the real-time control made it possible to optimize process operation and save aeration energy.

Keywords: cyclic activated sludge technology; biological nitrogen removal; real-time control; oxidation-reduction potential(ORP)

Introduction

Over recent years two different groups of intermittent activated sludge processes have gained increasing importance in wastewater treatment. One group of processes has been made popular through Irvine and Wilderer (Irvine, 1979; Wilderer, 1992) and is known by the acronym of sequencing batch reactor (SBR). SBR methodology is very commonly used for scientific studies, lab-scale testing, and full-scale applications over the world. The second group is called cyclic activated sludge technology (CAST) which represents a certain technical development of a process philosophy (Goronszy, 1979; 1991; 1995). This process family is applied in large scale treatment throughout Germany, England, North America and Australia. This technology has been introduced into China and applied in some wastewater treatment plants last year.

The CAST system is a combination of a biological selector and variable volume process in which alternating anaerobic/anoxic and aerobic conditions necessary to meet the requirements for nitrogen and phosphorus removal are created (Goronszy, 1996; Demoulin, 1997; 2001). In a cycle, fill-aeration, settle, decant and idle sequences are involved. It is known that simultaneous nitrification and denitrification (SND) can take placed in CAST system. Unfortunately, in practice, the nitrogen removal is not in a satisfying level in this system under traditional operation mode because the susceptible microenvironment is difficult to create properly which favors nitrogen removal via SND.

Moreover, stricter regulations on wastewater effluent, space limitations on the treatment site, and energy consumption issues have heightened the importance of modifying biological wastewater processes using process control. Because the aeration time and influent fluctuation affect CAST system performance, traditional operation of the system with a predetermined fixed aeration time often fails to operate optimally. Consequently, real-time control strategies are essential for CAST system to enhance nutrient removal and save energy. Unfortunately, relatively few works have been performed regarding process control and optimization, specifically for the CAST process.

In the present study, a CAST system is operated with various operation modes at a constant influent filling time. The primary objective is to investigate the effect of operation mode on total nitrogen(TN) removal in the system so as to develop a new operation mode with an enhanced performance of nitrogen removal. The second objective is then to provide a real-time control strategy and to evaluate its performance, specifically with respect to nitrogen removal efficiency.

1 Materials and methods

1.1 Experimental equipment

A lab-scale CAST reactor with a useful volume of 72 L was used(Fig.1). It was divided into two parts: the main aeration zone and the biological selector which volume is 1/10 of the whole volume. 24 L domestic wastewater was introduced to the reactor in each cycle and the return flow was 20% of influent flow. The temperature in reactor was kept at 23 ± 2℃. The sludge retention time(SRT) was about 20 d and a concentration of mixed liquor suspended solids (MLSS) was maintained at approximately 4500 mg/L in main reaction zone at top water level. A computer was used for data acquisition and control. Oxidation-reduction potential (ORP) and pH probe were equipped in the system.

The domestic wastewater was collected from a septic tank in the campus in the Beijing University of Technology and the qualities of the wastewater are shown in Table 1.

Table 1 The qualities of raw domestic wastewater

Parameter	Range	Mean
pH	7—8	7.5
COD, mg/L	200—600	400
NH_4^+-N, mg/L	30—50	40
TN, mg/L	40—60	50
TP, mg/L	7—12	9

1.2 Activated sludge

The activated sludge in the system was seeded from a wastewater treatment plant in Beijing, China, which has the

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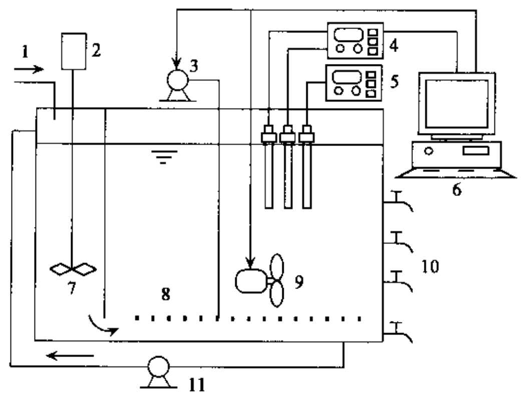

Fig.1 Schematic diagram of the CAST system
1. feed pipe; 2. stirrer; 3. air pump; 4. pH, ORP meter; 5. temperature controller; 6. computer; 7. biological selector; 8. main reaction zone; 9. submerged agitator; 10. drainage valves; 11. recycle pump

function of nutrient removal and operated under stable state. For the start-up the reactor was operated for 60 d until mean NH_4^+-N removal of more than 90% was achieved with mean COD removal of more than 75%.

1.3 Experimental procedure

The reactor was operated with three modes, traditional mode, modified mode and real-time control mode in phase 1, phase 2 and phase 3 respectively. The same aeration rate was kept in three modes. The sequences time assignment of a cycle in main reaction zone for different modes is shown in Fig.2. In this study, the lengths of the filling, settling and decant were fixed at 240 min, 60 min and 60 min respectively. The stirring in selector and recycle of mixed liquor were continuous throughout each cycle. In modified mode, the mixing in the main reaction zone was provided by a submerged agitator. The pH and ORP profiles were monitored and evaluated in all phases. In phase 3, the system was operated based on the real-time control strategies developed from phase 2. Conventional parameters such as COD, TN, NH_4^+-N, NO_3^--N and NO_2^--N were routinely analyzed.

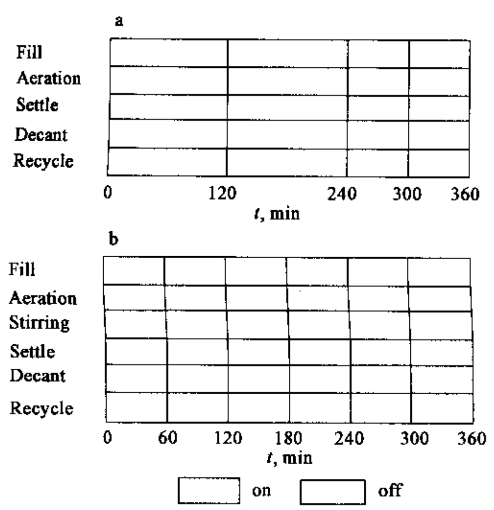

Fig.2 Time assignments in a cycle
a. traditional operation mode; b. modified operation mode

1.4 Analytical method

Continuous monitoring of pH and ORP were carried out by a WTW Multi340i meter with a pH probe and an ORP electrode. COD_{Cr}, TN, NH_4^+-N, NO_3^--N and NO_2^--N were analyzed according to standard methods(APHA, 1995).

2 Results and discussion

2.1 Effect of operation mode on TN removal

Data on daily average COD, TN and NH_4^+-N concentrations of the influent and effluent for entire study period are presented in Fig. 3. Overall, the system maintained low effluent COD concentrations (less than 50 mg/L) and a mean COD removal of more than 85% was achieved in three phases, which indicate the operation mode has no marked effect on COD removal in the system. Similarly, good nitrification efficiency (more than 90%) was achieved in three phases. At the same aeration rate and aeration time, in phase 1 and phase 2, changes in operation mode did not affect the nitrification performance significantly. However, the effluent TN in phase 1 was obviously higher than that in phase 2. The mean TN removal efficiency in phase 1 and phase 2 was 72% and 88% respectively which indicated that addition of stirring sequence was favorable for nitrogen removal and the nitrogen removal was enhanced consequently.

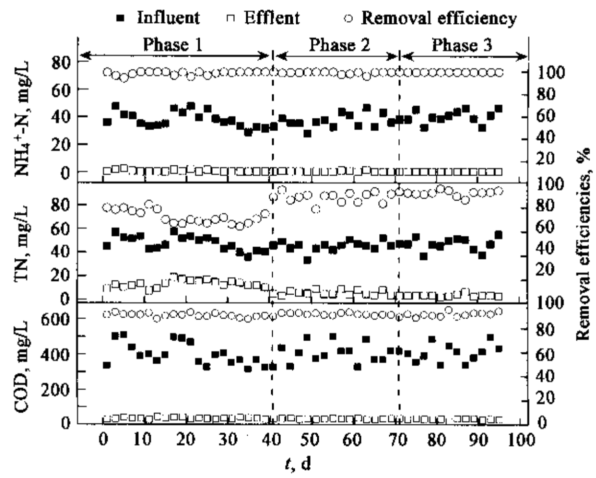

Fig.3 Performance of the CAST system

Since the nitrification efficiencies were kept at a higher level, the lower denitrification efficiency was the main reason for the lower nitrogen removal in phase 1. In traditional operation mode, denitrification mainly existed in the selector and sludge layer in the air off sequences of a cycle. However, the recycle flow was only 20% of influent flow, so the nitrate or nitrite amount denitrified in the selector is very limited. In fill/air off sequence, sludge and wastewater are separated so that denitrifying organisms can not utilize the nitrate or nitrite completely in wastewater although anoxic condition is available. Furthermore, in the settle and decant sequences, the organic carbon needed for denitrification has been consumed in aerobic sequence so that denitrification was inhibited. On the other hand, stirring sequences were introduced into modified mode in phase 2. As a result, the denitrification performance was enhanced and the TN removal efficiency was improved significantly.

2.2 Real-time control strategies based on pH and ORP profiles

Fig. 4 and Fig. 5 show the dynamics of ammonia, nitrate, nitrite and TN concentration and profiles of pH and ORP during filling sequence in phase 1 and phase 2.

Clearly, TN concentration at the end of filling sequence in phase 2 is lower than that in phase 1. But the process was not operated in an optimized mode in phase 2 because fixed aeration time and stirring time were not in an optimal level. As Fig.5 shows, nitrate and nitrite were almost exhausted (less than 0.5 mg/L) at 140 min in system whereas the stirring sequence was ended at 180 min. Moreover, ammonia concentration was already below 0.5 mg/L at 230 min, but the aeration stopped at 240 min. So, parts of energy were wasted in this cycle and the real-time control is necessary to be applied in the system.

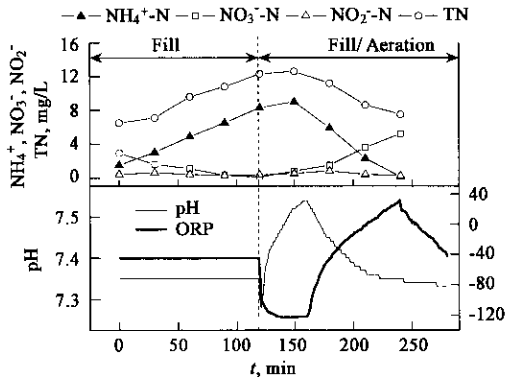

Fig.4 Dynamics of NH_4^+-N, NO_3^--N, NO_2^--N and TN concentration and profiles of pH, ORP in filling sequence under traditional operation mode

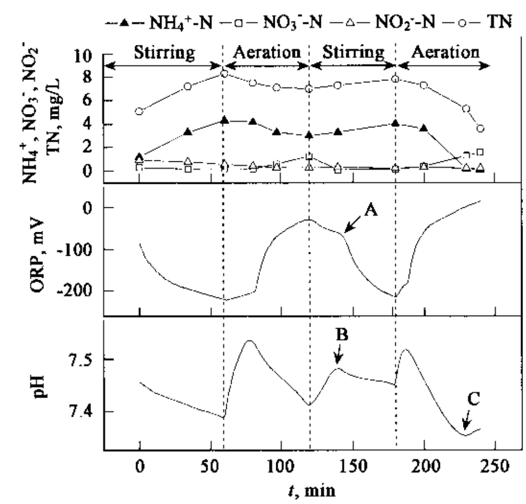

Fig.5 Dynamics of NH_4^+-N, NO_3^--N, NO_2^--N and TN concentration and profiles of pH, ORP in filling sequence under modified operation mode

ORP and pH have been demonstrated to be practical for process control for activated sludge processes (Chen, 2002; Kishida, 2003). Specifically, several investigators have identified the "nitrate knee" in the ORP profile, which indicates the end of denitrification (Koch, 1985), "ammonia valley" and "nitrate apex" (Al-Ghusain, 1994; 1995) in the pH profile, which signify the end of nitrification and denitrification respectively. In Fig.5, both ORP and pH were found to vary with the aerobic-anoxic sequences as a result of sequential nitrification and denitrification in system. The ORP dropped significantly because of anoxic denitrification. Also, the pH drops caused by nitrification and increases caused by denitrification were clearly identified.

Three significant points on the pH and ORP profiles are easily discerned as suggested in the literature. The nitrate knee (point A) on the ORP curve and nitrate apex (point B) on the pH curve indicated the end of denitrification and the ammonia valley (point C) corresponded to the end of nitrification. The absolute values of the pH data corresponding to the ammonia valley, nitrate apex and ORP values of the nitrate knee can not be used as the control points because of their variability. Rather, the derivatives of these values should be used. Fig.6 shows the derivatives of the pH profiles and two features (point E and point F) are found on the dpH/dt profile. At point E, dpH/dt changes from a positive value to negative value; at point F, the change of dpH/dt reversed which determined the end of denitrification and nitrification, respectively. On the ORP profile, at the end of denitrification, $d^2ORP/dt^2 = 0$ and this pinpoint (point D) can then be used to determine the end of denitrification (Fig.7).

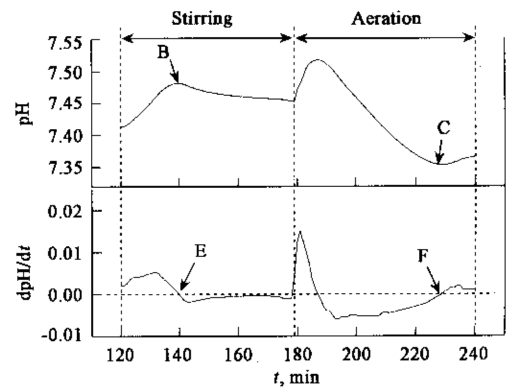

Fig.6 Moving averages of pH and dpH/dt

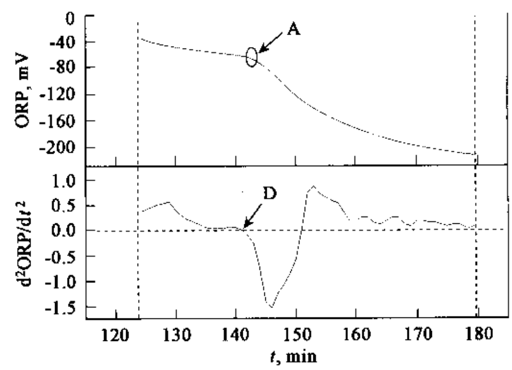

Fig.7 Moving averages of ORP and d^2ORP/dt^2

The control strategy presented in Fig. 8 requires the calculation of a moving average of pH-ORP data for noise control. In this study, the data points were averaged every 5 min. In addition, at the beginning of a cycle, 10 min anoxic mixing sequence was introduced to remove the residual nitrate and nitrite from last cycle.

2.3 Overall performance with real-time control

The control scheme presented above was applied to the CAST system in phase 3. The overall performance of the system with the control scheme is also shown in Fig.3. The COD and TN mean removal efficiencies are 90% and 92% in phase 3. The average effluent TN level was 3.6 mg/L and the mean aeration time was 105 min. Therefore, compared with the previous phases, a 12.5% of aeration energy is reduced in the system with online control. Moreover, in phase 3, the effluent TN concentration were relatively stable whereas it was fluctuant in phase 1 and phase 2 (Fig.3), which means that

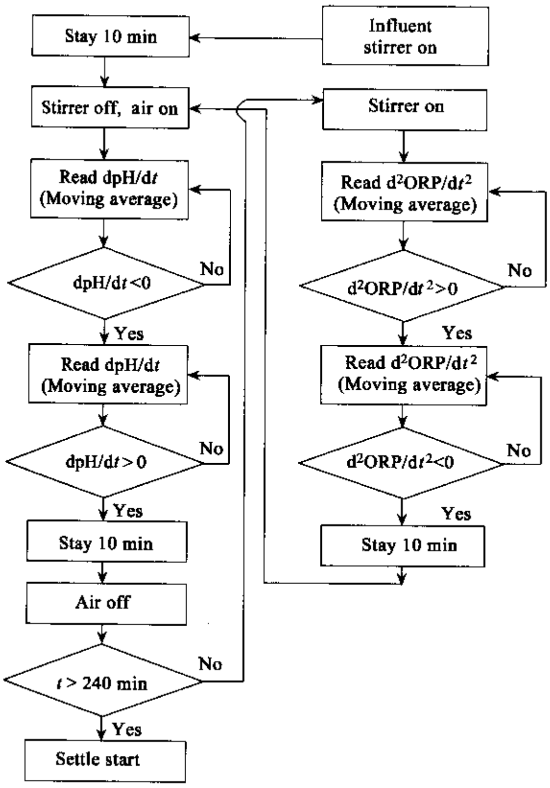

Fig.8 Control strategy with dpH/dt and d^{2}ORP/dt^2

the real-time control operation has a greater ability for system to accommodate the disturbance of influent loading.

Fig.9 shows a typical cycle of the dynamics of NH_4^+-N, NO_2^--N, NO_3^--N, TN concentration and the pH, ORP profiles in the CAST system operated by the control point uses of the ammonia valley and nitrate knee. The system turns air and stirrer on or off properly according to the strategy shown in Fig.8. The aeration and stirring were terminated within 10 min of detecting the ammonia valley and the nitrate knee, respectively. So, the process was operated under a relatively optimized condition with the real-time control strategies.

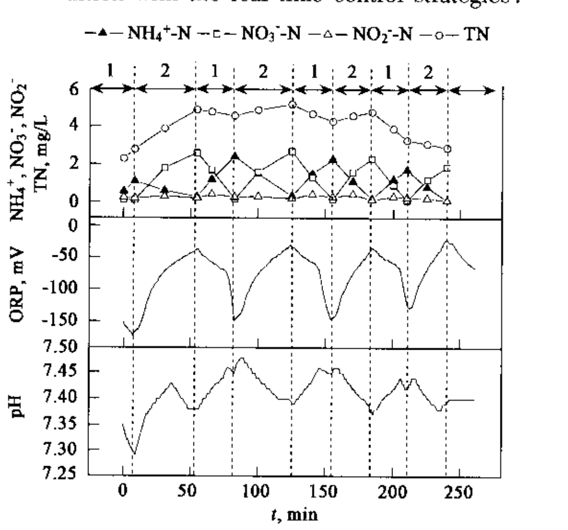

Fig.9 Dynamics of NH_4^+-N, NO_3^--N, NO_2^--N and TN concentration and profiles of pH, ORP in filling sequence under real-time mode

1. anoxic sequence; 2. aerobic sequence

3 Conclusions

In the present work, a lab-scale CAST system was operated more than 3 months to evaluate the effects of the operation mode on the system performance and develop a feasible control strategy. A 16% increment of TN removal efficiency was obtained in modified operation mode compared with traditional mode. The ORP and pH profiles in phase 2 indicate that the anoxic sequence can be controlled by a control point (nitrate knee) on the ORP profile, which indicates the end of denitrification, and the aerobic sequence controlled by another point (ammonia valley) on the pH profile, which indicates the end of nitrification. Therefore, a control strategy was developed and applied to the system in phase 3. With the control strategy used, the system performance of nitrogen removal was enhanced further and a mean TN removal of 92% was achieved. Additionally, a 12.5% of mean aeration time was reduced in phase 3 compared with previous phases.

Results show that the performance of nitrogen removal was enhanced simply through modifying the operation mode. The application of pH and ORP profiles as real-time control parameters to control the process operation in the CAST system appeared promising, which shows potential to enhance the reality and stability of nitrogen removal. The present study is expected to modify and optimize the operation of CAST system to maintain a lower effluent nitrogen concentration and save significant aeration energy costs.

References:

Al-Ghusain I A, Hao O J, 1995. Use of pH as control parameter for aerobic/anoxic sludge digestion[J]. J Environ Eng, 121: 225—235.

Al-Ghusain I A, Huang J, Hao O J *et al.*, 1994. Using pH as a real time control parameter for wastewater treatment and sludge digestion process[J]. Wat Sci Tech, 30(4): 159—168.

APHA(American Public Health Association), 1995. Standard methods for the examination of water and wastewater[M]. 19th ed. Water environment federation. Washington DC, USA: American Public Health Association.

Chen K C, Chen C Y, Peng J W *et al.*, 2002. Real-time control of an immobilized-cell reactor for wastewater treatment using ORP[J]. Wat Res, 36: 230—238.

Demoulin G, Goronszy M C, Wutscher K *et al.*, 1997. Co-current nitrification/denitrification and biological P-removal in cyclic activated sludge plants by redox controlled cycle operation[J]. Wat Sci Tech, 35(1): 215—224.

Demoulin G, Rudiger A, Goronszy M C, 2001. Cyclic activated sludge technology—recent operating experience with a 90000 p.e. plant in Germany [J]. Wat Sci Tech, 43(3): 331—337.

Goronszy M C, 1979. Intermittent operation of the extended aeration process for small systems[J]. JWPCF, 51(2): 274—279.

Goronszy M C, Rigel D, 1991. Biological phosphorus removal in a fed-batch reactor without anoxic mixing sequences[J]. JWPCF, 63(3): 248—258.

Goronszy M C, Slater N, Konicki D, 1995. The cyclic activated sludge system for resort area wastewater treatment[J]. Wat Sci Tech, 32(9/10): 105—114.

Goronszy M C, Demoulin G, Newland M, 1996. Aerated denitrification in full-scale activated sludge facilities[J]. Wat Sci Tech, 34(1/2): 487—491.

Irvine R L, Busch A W, 1979. Sequencing batch biological reactors—an overview[J]. JWPCF, 51: 235—243.

Kishida N, Kim J H, Chen M *et al.*, 2003. Effectiveness of oxidation-reduction potential and pH as monitoring and control parameters for nitrogen removal in swine wastewater treatment by sequencing batch reactors [J]. J Biosci Bioeng, 96: 285—290.

Koch F A, Oldham W K, 1985. Oxidation-reduction potential—a tool for monitoring, control and optimization of biological nutrient removal system [J]. Wat Sci Tech, 17: 259—281.

Wilderer P A, 1992. Sequencing batch biofilm reactor technology[M]. In: Harnessing biotechnology for the 21st Century (Ladisch M. R., Rose A. ed.). Aereican Chemical Society. 475—479.

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