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Effect of sludge reduction in oxic-settling-anaerobic (OSA) systems with different anaerobic hydraulic retention times (HRTs)

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ABSTRACT

The performance of an oxic-settling-anaerobic (OSA) system in terms of sludge reduction was investigated for various anaerobic hydraulic retention times (HRTs) (7 d, 5 d, 3 d, 1 d, 12 h, and 6 h) for a sequencing batch reactor (SBR)-OSA system. Compared to the traditional SBR system, the rates of sludge reduction in the 7d, 5d-1, 5d-2, 3d, and 1d OSA systems were observed to be 66.6, 57.7, 52.5, 50.0, and 48.5%, respectively. In terms of the apparent yield and actual yield of sludge, the OSA systems with longer HRTs exhibited lower sludge yields and better sludge reduction performance. The systems with an HRT > 1 d achieved a considerable increase in sludge reduction, whereas those with an HRT < 1 d did not. The anaerobic HRT was observed to be an important factor in determining the sludge reduction of OSA systems.

Keywords: Anaerobic; Hydraulic retention time (HRT); Oxic-settling-anaerobic (OSA) system; Sludge reduction; Sewage treatment

1. Introduction

An oxic-settling-anaerobic (OSA) system, which is composed of a traditional activated sludge system and a special anaerobic reactor, achieves a 40–60% better performance in terms of sludge reduction compared to a traditional activated sludge system alone [1]. Many studies have investigated several aspects of OSA systems [2–5]; however, to date, the mechanisms underlying the reduction in sludge remain unclear, and many different opinions regarding potential mechanisms have been expressed [6]. Regardless of the mechanism, the anaerobic reactor plays a critical role in achieving a greater level of sludge reduction with an OSA system. The hydraulic retention time (HRT) is one of the most important operational parameters for maintaining steady operation, high performance in sludge reduction and microbial activity [7]. The effect of the HRT on OSA system performance has not yet been sufficiently examined [8,9]. Therefore, further investigations on the effect of the HRT are of practical value. The HRT not only affects

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Table 1
Water quality of artificial sewage

Index	Average Conc. (mg/L)	Index	Average Conc. (mg/L)
Chemical oxygen demand (COD)	260.0	Fe^{3+}	10.0
Total nitrogen (TN)	80.0	Al^{3+}	10.0
NH_4^+	25.0	Mg^{2+}	20.0
Total phosphorus (TP)	5.0	Ca^{2+}	20.0
Suspended solids (SS)	80.0	pH	6.5–7.5

sludge reduction performance, but also determines the volume of an anaerobic reactor. This study is relevant to the application of OSA systems and reveals the mechanism of sludge reduction.

2. Materials and methods

2.1. Experimental systems

In this study, the effect of the anaerobic HRT on sludge reduction in an OSA system was examined by operating 7d, 5d, 3d, 1d, 12 h, or 6 h sequencing batch reactor (SBR)-OSA systems. A traditional SBR system was used as a reference. The SBR-OSA systems were composed of a traditional SBR system and an anaerobic reactor. Except for the HRT, which was varied, the other operational parameters of the six SBR-OSA systems were held constant, and the HRT and the dissolved oxygen of the aerobic reactor were 2 d and 3–6 mg/L, respectively. The aerobic reactor and the anaerobic reactor were linked, and sludge was regularly exchanged at a rate of 10%. The influent of the systems was artificial sewage, whose water quality characteristics are presented in Table 1.

The systems operated continuously for 24 h and the operation cycle was 6 h long, including influent, absolute-rest precipitation, effluent and sludge exchange stages. Each system was automated and controlled by peristaltic pumps and time switches, and operated using the same time sequence and artificial sewage. The systems were operated at 4 cycles/d, with a react time of 5 h, a settle time of 40 min, an effluent discharge time of 5 min, and sludge interchanged time of 4 min. Four systems were operated simultaneously, and the study was conducted in two stages. In stage I, the four SBR-OSA systems were operated for 174 d with either a 5-d, 1-d, 12-h, or 6-h HRT, respectively. In stage II, which lasted 88 d, three SBR-OSA systems were operated with either a 3-d, 5-d (in operation for a total of 302 d), or 7-d HRT, respectively, and one system was operated as a traditional SBR system (named SBR-blank). The sludge was discharged regularly to maintain a comparatively stable mix liquor suspended solids (MLSS) after all of the systems were operated. The amount of sludge discharge depended on the water quality of the effluent, the MLSS of the system, and other physical and chemical indicators. The SBR-OSA system design is depicted in Fig. 1.

2.2. Monitoring index and measurement methods

The MLSS, mix liquid volatile suspended solids (MLVSS), and COD were measured according to standard methods [10]. The observed yield was determined for a given period of operation as the increase in MLSS/COD removal, using all of the data for the period of operation for which the yield was calculated. During the experiments, each parameter was measured three times.

Some abbreviations are herein defined to briefly describe the research. "SBR-OSA" refers to an OSA system that is based on a traditional SBR system. "SBR-Blank" refers to the traditional SBR system, used as a reference blank. The "7d system" refers to the SBR-OSA system with an HRT of 7 d. "d20" refers to the 20th day. This study required close to one year to complete and was conducted at room temperature. In addition, temperature is an important factor affecting sludge reduction performance and differs significantly between summer and winter. As previously

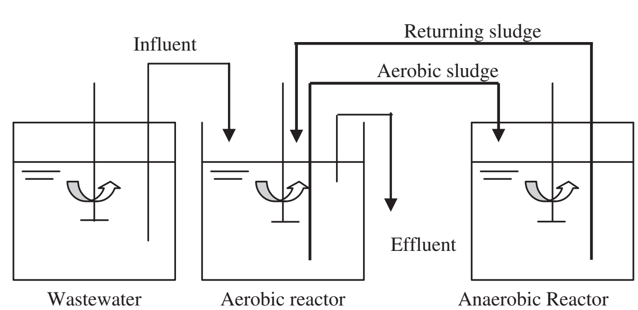

Fig. 1. Schematic view of experimental devices and processes for SBR-OSA.

mentioned, the 5d system was operated for the entire length of the study. Therefore, the abbreviations 5d-1 system and 5d-2 system refer to the operation of the 5d system in stage I and in stage II, respectively.

The observed sludge yield rate (Yobs) is an important measure of the sludge reduction of an SBR (-OSA) system. The absolute quantity of sludge reduction can be determined by comparing the Yobs of an SBR-OSA system with that of the traditional SBR system. To calculate Yobs, the absolute quantity of sludge increase over the study period is divided by the absolute cumulative quantity of COD removal to obtain the amount of sludge growth per unit mass of COD (mg-MLSS/mg-COD) (including the COD removal rate and related growth of MLSS, the cumulative loss of sludge during the study period, and the amount of excess sludge in the system). Thus, the Yobs value is calculated using Formula 1:

$$Y_{\mathrm{obs}} = \frac{(\mathrm{MLSS}_2 - \mathrm{MLSS}_1) \times V + W_1 + W_{\mathrm{s}}}{(\mathrm{COD}_1 - \mathrm{COD}_2) \times Q_{\mathrm{d}} \times T_{\mathrm{i}}} \quad (1)$$

$MLSS_2$ and $MLSS_1$ are the mean MLSS at the end and beginning of the study period (mg/L), respectively; V is the usable volume of the aerobic reactor (10 L); W_1 is the amount of excess sludge in the system (mg); W_s is the cumulative loss of sludge during the study period (mg); COD_1 and COD_2 are the mean COD of the influent and effluent (mg/L), respectively; Q_d is the amount of influent over four operation cycles per day (5 L/d); T_i is the total time during which the system is stable (68 d for the two stages).

3. Results and discussion

3.1. Comparison of the MLSS in the aerobic reactors of the systems

A long-term monitoring program of the MLSS in the aerobic reactors of all of the systems was implemented. For this program, system performance in terms of sludge reduction was evaluated by comparing the growth of the MLSS in the aerobic reactors among the systems with various HRTs. The MLSS variation curves for the aerobic reactors of the systems with various HRTs are presented in Figs. 2–4.

In stage I, the SBR systems of the 5d, 1d, 12 h and 6 h systems were first started simultaneously. All of the systems operated stably on d0. On d59, the anaerobic reactors were connected to these systems to complete the SBR-OSA systems. Thus, the system performance from d0 to d59 reflects the background SBR-only performance of these SBR-OSA systems

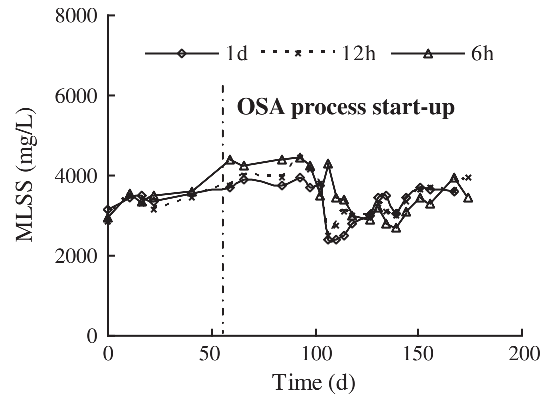

Fig. 2. MLSS variation curves for the aerobic reactors of the 6 h, 12 h, and 1d systems.

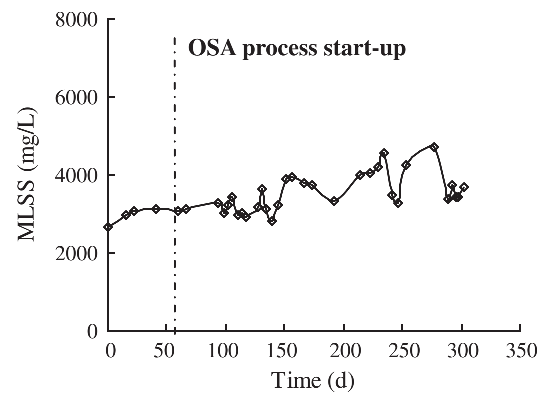

Fig. 3. MLSS variation curve for the aerobic reactor of the 5d system.

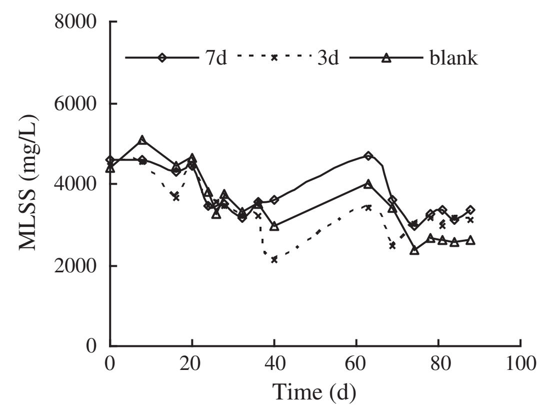

Fig. 4. MLSS variation curves for the aerobic reactors of the 7d, 3d, and reference systems.

(included in Figs. 2 and 3). The results presented in Figs. 2 and 3 reveal that the MLSS variation curves for the aerobic reactors were similar to each other before these systems were connected to the anaerobic reactors. Subsequently, the MLSS of each system increased steadily, and as the HRT was shortened, the MLSS increased dramatically. The small decreases in the MLSS of the 1d and 12 h systems on d106 were associated with high sludge discharges. After d106, the MLSS was allowed to increase again by decreasing the amount of sludge discharge; then, the sludge was incubated. In addition, the MLSS of the 12 h system increased faster than that of the 1d one. The MLSS of the 6 h system was greater than that of the other systems. To preserve the activity of the sludge in the 6 h system, the MLSS was maintained between 3,000 and 4,000 mg/L by discharging sludge regularly throughout the period of operation. As shown in Fig. 3, the MLSS of the 5d system increased slowly and remained between 3,000 and 4,000 mg/L without requiring the discharge of sludge in stage I.

In stage II, the operation of the 5d system was continued, whereas the 1d, 12 h, and 6 h systems were replaced by the 3d , 7d, and the SBR-Blank system. The SBR-Blank system was started on d0 of stage II and the variation in MLSS is shown in Fig. 4. As indicated in the figure, the MLSS of the 7d, 3d, and SBR-Blank systems first decreased and then increased before finally stabilizing. The MLSS of each of the three systems was initially greater than 4,000 mg/L; therefore, it was necessary to discharge sludge regularly at the beginning of this stage. These discharges decreased the MLSS of these systems to 3,000 mg/L. The reason that the MLSS of these systems then increased again is that no sludge was discharged from these systems during the Chinese New Year (d40–d63). After d63, the MLSS of these systems decreased to 3,000 mg/L in conjunction with the regular discharge of sludge. After achieving this level of MLSS, the three systems operated stably. Compared with the 3d and 7d systems, more sludge was discharged from the SBR-Blank system. The 5d system required the regular discharge of sludge after d192. The change in room temperature in winter and the discharge (or not) of sludge caused fluctuations in the MLSS of the 5d system. The MLSS increased more in stage II than in stage I, before finally remaining between 3,000 and 4,000 mg/L.

The results shown in Figs. 2–4 demonstrate that all of the SBR-OSA systems achieved increased sludge reduction and that the HRT was an important factor in determining the amounts of sludge reduction and the increases in the MLSS of the OSA systems.

3.2. Comparison of the Yobs

The Yobs and the rates of sludge reduction for the various SBR-OSA systems are presented in Table 2.

As the results presented in Table 2 demonstrate, the rates of sludge reduction in the 7d, 5d-1, 5d-2, 3d, 1d, 12 h, and 6 h OSA systems were observed to be 66.6, 57.7, 52.5, 50.0, 48.5, 27.3, and 11.6%, respectively.

In summary, a longer HRT results in a lower Yobs, and thus better sludge reduction performance. Compared with the traditional SBR system, an OSA system exhibits a lower Yobs and better performance in terms of sludge reduction. Based on the literature, the rate of sludge reduction by an OSA system is between 40 and 60% [1]. In this study, the systems with an HRT > 1 d achieved a considerable increase in sludge reduction, whereas those with an HRT < 1 d did not. This result demonstrates that the HRT is an important factor in determining the amount of sludge reduction for OSA systems and that sludge reduction can be achieved with a short HRT (but longer than 1d), which can

Table 2
Observed sludge yield rates for SBR-OSA systems with various HRTs

Index	7d	5d-1	5d-2	3d	1d	12 h	6 h	Blank
COD_1 (mg/L)	160	160	160	160	160	160	160	160
COD_2 (mg/L)	22	23	15	21	21	20	18	19
$MLSS_1$ (mg/L)	4,570	3,420	4,020	4,430	2,380	2,490	4,280	4,410
$MLSS_2$ (mg/L)	3,340	3,760	3,670	3,090	3,610	3,580	3,930	2,613
V(L)	10	10	10	10	10	10	10	10
W_1 (mg)	19,905	6,493	15,198	25,217	49	6,806	25,426	42,500
W_s (mg)	607	436	565	573	410	420	430	595
Y_{obs} (KG-MLSS/KG-COD)	0.175	0.222	0.249	0.262	0.270	0.381	0.463	0.524
Rate of sludge reduction (%)	66.6	57.7	52.5	50.0	48.5	27.3	11.6	

greatly reduce the volume of an anaerobic reactor and is significant for applications of OSA systems.

4. Conclusions

(1) The rates of sludge reduction in the 7d, 5d-1, 5d-2, 3d, 1d, 12 h, and 6 h OSA systems were 66.6, 57.7, 52.5, 50.0, 48.5, 27.3, and 11.6%, respectively, in terms of the Yobs. A longer HRT results in a lower Yobs, and thus better sludge reduction performance. The length of the HRT was an important factor in determining the amount of sludge reduction in an OSA system.

(2) The systems with an HRT > 1 d achieved a considerable increase in sludge reduction, whereas those with an HRT < 1 d did not.

(3) Differences in room temperature can affect the growth rate of sludge. The stability of the temperature of these systems needs to be enhanced, whereas the other factors can remain the same.

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References

[1] Y.S. Wei, R.T. Van Houten, A.R. Borger, D.H. Eikelboom, Y.B. Fan, Minimization of excess sludge production for biological wastewater treatment, Water Res. 37 (2003) 4453–4467.

[2] P. Chudoba, A. Morel, B. Capdeville, The case of both energetic uncoupling and metabolic selection of microorganisms in the OSA activated sludge system, Environ. Technol. 13 (1992) 761–770.

[3] J.B. Copp, P.L. Dold, Comparing sludge production under aerobic and anoxic conditions, Water Sci. Technol. 38 (1998) 285–294.

[4] G.H. Chen, K.J. An, S. Saby, E. Brois, M. Djafer, Possible cause of excess sludge reduction in an oxic-settling-anaerobic activated sludge process (OSA process), Water Res. 37 (2003) 3855–3866.

[5] J.T. Novak, M.E. Sadler, S.N. Murthy, Mechanisms of floc destruction during anaerobic and aerobic digestion and the effect on conditioning and dewatering of biosolids, Water Res. 37 (2003) 3136–3144.

[6] J.F. Wang, Q.L. Zhao, W.B. Jin, J.K. Lin, Mechanism on minimization of excess sludge in oxic-settling-anaerobic (OSA) process, Front. Environ. Sci. Eng. China 2 (2008) 36–43.

[7] J.F. Wang, Q.L. Zhao, Z.G. Liu, J.K. Lin, Influence factors of excess sludge reduction of the oxic-settling-anaerobic technique, China Environ. Sci. 28 (2008) 427–432.

[8] J.T. Novak, D.H. Chon, B.A. Curtis, M. Doyle, Biological solids reduction using the cannibal process, Water Environ. Res. 79 (2007) 2380–2386.

[9] X.B. Zhong, F.X. Ye, Reduction of excess sludge production by aerobic- settling- anoxic, Environ. Eng. (China) 24 (2006) 26–28.

[10] American Public Health Association, American Water Works Association, Water Environment Federation, Standard Methods for the Examination of Water and Wastewater, nineteenth ed., American Public Health Association, Washington, DC, 1995.