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Optimizing and Controlling of Dissolved Oxygen in Advanced HA-A/A-MCO Sludge Reduction Process

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In order to explore the method of improving phosphorous and nitrogen removal in sludge reduction technologies, an advanced process combining excess sludge reduction and phosphorous and nitrogen removal is developed, for short, HA-A/A-MCO process (hydrolysis-acidogenosis-anaerobic/anoxic-multistep continuous oxic tank), which realizes phosphorous removal through hydrolysis acidification of raw sewage and phosphorus-release sludge improving phosphorus-release level and through eliminating anaerobic phosphorous accumulating sewage. Through controlling lower dissolved oxygen concentration (0.5-1.5 mg/L) and adopting orthogonal test, we research preferable dissolved oxygen controlling concentration of each oxic tank (No. 1 oxic tank, No. 2 oxic tank and No. 3 oxic tank). Results show that preferable dissolved oxygen controlling concentration of No. 1 oxic tank, No. 2 oxic tank and No. 3 oxic tank is 0.8, 1.0 and 1.0 mg/L, respectively. Under the condition of optimal operating mode, the removal rate of COD, total notrogen and total phosphorus in HA-A/A-MCO system is up to 97.8, 78.9 and 99.3 %, respectively. Moreover, in the condition of lower dissolved oxygen concentration, HA-A/A-MCO process can obtain excellent effect of pollutant removal and sludge reduction simultaneously, which resolves the contradict that sludge reduction leads to oxygen demand increasing of wastewater treatment system so as to increase energy consumption of aeration.

Key Words: Sludge reduction, Phosphorous and nitrogen removal, Lower dissolved oxygen, Optimizing and controlling.

INTRODUCTION

In order to explore the method of improving phosphorous and nitrogen removal in sludge reduction technologies[1,2], an advanced process combining excess sludge reduction and phosphorous and nitrogen removal is developed, for short, HA-A/A-MCO process (hydrolysis-acidogenosis-anaerobic/anoxic -multistep continuous oxic tank), which realizes phosphorous removal through hydrolysis acidification of raw sewage and phosphorus-release sludge improving phosphorus-release level and through eliminating anaerobic phosphorous accumulating sewage.

According to the literature[3,4], dissolved oxygen concentration of aeration phase is one of the key technological parameters affecting simultaneous phosphorous and nitrogen removal. Besides, economic factor is also one of the issues needing to take into account. So far, all kinds of sludge reduction technologies which are developed at home and abroad have a common intractable problem, which is that oxygen demand is increased while sludge reduction is realized. This will cause increasing of aeration consumption and operating cost. Therefore, the study investigates the influence of dissolved oxygen concentration on removal effect about HA-A/A-MCO process, which is combining excess sludge reduction and phosphorous and nitrogen removal.

EXPERIMENTAL

HA-A/A-MCO is an advanced sludge reduction process which is developed by our research group, whose flow path is shown in Fig. 1. It includes hydrolysis-acidification (HA) tank, anaerobic tank, anoxic tank, multistep continuous oxic tank, secondary sedimentation tank, side stream sedimentation tank and chemical phosphorous removal tank. The virtual volume of hydrolysis-acidification tank, anoxic tank and anaerobic tank is 50, 30 and 30 L respectively.

Corresponding hydraulic retention time (HRT) is 2.5 h, 1.5 h, 1.5 h respectively. Besides, multistep continuous oxic tank is divided into three areas: the first area is bacterial culture section, whose virtual volume and hydraulic retention time is 15 L, 0.5-0.75 h respectively; the second area is Protozoa culture section, whose virtual volume and hydraulic retention

TABLE-2
ANALYSIS TABLE OF ORTHOGONAL TEST RESULTS

Level/ Factor	DO content in No.1 oxic tank (mg/L)	DO content in No.2 oxic tank (mg/L)	DO content in No.3 oxic tank (mg/L)	Test result Removal rate η(%)			
	A	B	C	COD	TN	TP	$\eta_T = \eta_{COD} + \eta_{TN} + \eta_{TP}$
1	1(0.5)	1(0.8)	3(1.5)	93.1	68.1	91.2	252.4
2	2(0.8)	1(0.8)	1(0.8)	94.3	71.3	93.1	258.7
3	3(1.0)	1(0.8)	2(1.0)	93.4	71.1	91.8	256.3
4	1(0.5)	2(1.0)	2(1.0)	95.7	76.9	95.4	268
5	2(0.8)	2(1.0)	3(1.5)	96.1	72	95.7	263.8
6	3(1.0)	2(1.0)	1(0.8)	95.1	73.2	94.2	262.5
7	1(0.5)	3(1.5)	1(0.8)	95.8	69.4	92.1	257.3
8	2(0.8)	3(1.5)	2(1.0)	96.5	67.1	98.9	262.5
9	3(1.0)	3(1.5)	3(1.5)	97.1	58.9	96.4	252.4
K1	777.7	767.4	778.5	Remark: (1) K1, K2, K3 stands for the sum of total removal rate which each level generates results (ηT); (2) Range is D-value of the maximum value and minimum value among K1, K2 and K3			
K2	785	794.3	786.8				
K3	771.2	772.2	768.6				
Range	13.8	26.9	18.2				

time is 30 L, 1.5 h respectively and the third area is metazoa culture section, whose virtual volume and hydraulic retention time is 40 L, 2 h respectively. Multistep continuous oxic tank is provided with oxygen by microporous aeration tube at the bottom of the tank. The second area and third area are filled with combined biological filler and the filling ratios are both 40 %. In addition, side stream sedimentation tank is used to offer anaerobic phosphorus release supernatant to chemical phosphorus removal tank, whose hydraulic retention time is 1 h. Secondary sedimentation tank adopts radial-flow one, whose hydraulic retention time is 1 h.

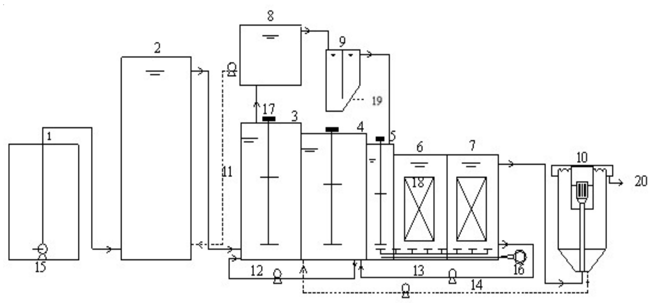

Fig. 1. Flow sketch map of HA-A/A-MCO process; 1. Influent tank; 2. Hydrolysis acidification tank; 3. Anaerobic tank; 4. Anoxic tank; 5, 6, 7. No.1 Oxic tank, No.2 Oxic tank and No.3 Oxic tank of multistep continuous oxic tank, respectively; 8. Sidestream sedimentation tank; 9. Chemical phosphorous removal tank; 10. Secondary sedimentation tank; 11. Phosphorus-release sludge return; 12. Denitration liquor return; 13. Nitration liquor return; 14. Excess sludge return;15.Flow control pump; 16. Air compressor; 17. Stirrer; 18. Filler; 19. High phosphorus sludge; 20. Effluent

When HA-A/A-MCO process operates steadily, influent flow is 20 L/h. Dissolved oxygen of each section of multistep continuous oxic tank is 0.5-1.5l, 0.5-1.5 and 1.0-1.5 mg/L. Return ratio of excess sludge, nitration liquor, denitration liquor and anaerobic phosphorus release sludge is 40, 150, 100 % and 2 % respectively. Sludge retention time (SRT) of the system is 60 d, mixed liquor suspended solids (MLSS) is 5100-5800mg/l and sludge load is 0.18-0.21kgCOD/kgMLSS.d.

Experimental water quality: Experimental wastewater is campus sewage of Chongqing university by adding amylum, glucose, milk powder, NH_4Cl, KH_2PO_4. Characteristics of the influent are as follows: ρ(COD) = 316-407 mg/L; ρ(NH_3-N) = 30-40 mg/L; total nitrogen concentration ρ(TN) = 35-53 mg/L; ρ(TP) = 8-12 mg/L; pH = 7-8; temperature is 16-24 ºC.

Detection method: COD is analyzed by HACH-COD instrument, dissolved oxygen concentration is measured with an YSI oxygen meter, VFA is measured by distillation-titration method and other parameters were analyzed[5].

RESULTS AND DISCUSSION

Arrange of orthogonal test: Through adopting $L_9(3^4)$ orthogonal array, using the orthogonal test of three factors and three levels (*i.e.* dissolved oxygen concentration of No.1 oxic tank is 0.5, 0.8 and 1.0 mg/L respectively, dissolved oxygen concentration of No.2 oxic tank is 0.8, 1.0 and 1.5 mg/L respectively, No.3 oxic tank is 0.8, 1.0 and 1.5 mg/L respectively.) we arrange the optimizing experiment of HA-A/A-MCO system according to Table-1. We mainly study the sewage treatment effect of the system in the condition of different combination of dissolved oxygen concentration. It includes performance of COD removal and simultaneous phosphorous and nitrogen removal.

TABLE-1
ARRANGEMENT OF ORTHOGONAL TEST

Level/ Factor	DO content in No.1 oxic tank (mg/L)	DO content in No.2 oxic tank (mg/L)	DO content in No.3 oxic tank (mg/L)
	A	**B**	**C**
1	1(0.5)	1(0.8)	3(1.5)
2	2(0.8)	1(0.8)	1(0.8)
3	3(1.0)	1(0.8)	2(1.0)
4	1(0.5)	2(1.0)	2(1.0)
5	2(0.8)	2(1.0)	3(1.5)
6	3(1.0)	2(1.0)	1(0.8)
7	1(0.5)	3(1.5)	1(0.8)
8	2(0.8)	3(1.5)	2(1.0)
9	3(1.0)	3(1.5)	3(1.5)

Result of orthogonal test: Result of orthogonal test is shown in Tables 2 and 3. Trial results of removal rate in the two tables are average value in the condition of stable operation for half a month.

Variance Analysis: We can estimate remarkable factor function by variance analysis. On the basis of orthogonal test analytical result shown in Table-3, the variance analysis results of orthogonal test is shown in Table-4.

TABLE-3
ANALYSIS TABLE OF ORTHOGONAL TEST RESULTS

		K1	K2	K3	Range
η_{COD}	DO in No.1 oxic tank	284.6	286.4	285.6	1.8
	DO in No.2 oxic tank	280.8	286.9	289.4	8.6
	DO in No.3 oxic tank	284.7	285.6	287.4	2.7
η_{TN}	DO in No.1 oxic tank	214.4	210.4	205.2	9.2
	DO in No.2 oxic tank	210.5	222.1	195.4	26.7
	DO in No.3 oxic tank	213.9	215.1	198	17.1
η_{TP}	DO in No.1 oxic tank	279.7	285.7	282.4	6

TABLE-4
SQUARE DIFFERENCE ANALYSIS

Variance source	Square sum (Q)	Degree of freedom (f)	Average variance (S2)	F_i
Factor A	120.9	2	60.45	20.7
Factor B	286.74	2	143.37	49.1
Factor C	220.16	2	110.08	37.7
Error e	5.84	2	2.92	/

Remark: $Q=\sum_{i=1}^{n}(x_i-\bar{x})^2$, $S^2=\frac{Q}{f}$, $F_i=\frac{S_i^2}{S_e^2}>F_\alpha(f_i,f_e)$, $F\alpha(f_i,f_e)$ is as the judging standard of examining remarkable factor, $F_{0.05}(2, 2)=19$. Trial error $\sigma_e=\sqrt{S_e^2}=\sqrt{2.92}=1.71$, $d_e=\sigma_e/\bar{x}\times100=1.98\%<5\%$, it indicates results of orthogonal test excellent.

Analysis of orthogonal test result: Larger removal rate of COD, total nitrogen and total phosphorus indicates better performance. So that when Fi value is larger than $F_{critical}[F_{0.05}(2,2)=19]$, it is indicated that function of that factor is remarkable. As far as removal rate of COD, total nitrogen and total phosphorus is concerned, according to variance analysis results shown in Table-4, influences of three factors (A, B, C) on total removal rate of COD, total nitrogen and total phosphorus in the HA-A/A-MCO system all present quite remarkable. And combining with the results of orthogonal test shown in Table-3, we can find that the influence of dissolved oxygen content in No.2 oxic tank is the most remarkable, secondly, dissolved oxygen content in No.3 oxic tank is more remarkable, influence extent of dissolved oxygen content in No.1 oxic tank on total removal rate of contaminant is much lower. That is, when dissolved oxygen content in No.1 oxic tank is between 0.5 mg/L and 1.0 mg/L, bacterium can propagate well. When dissolved oxygen content retains in the scope [level 1(0.5 mg/L), level 2(0.8 mg/L), level 3(1.0 mg/L)], bacterial growth can not be impacted. Bacterium are leading microbe population and are also the major agents of organic matters removal, therefore, dissolved oxygen content in No. 1 oxic tank retaining in that scope affects scarcely to the performance of contaminant removal in the HA-A/A-MCO system.

Analysis of optimal operating mode: Selecting standard of optimal level is that larger Ki value of η_T indicates that its level is much more excellent. Therefore, according to Ki values in Table-3, the optimal level of HA-A/A-MCO system is A2(0.8 mg/L), B2(1.0 mg/L), C2(1.0 mg/L). That is, optimal dissolved oxygen content in each oxic tank is 0.8 mg/L, 1.0 mg/L, 1.0 mg/L, respectively. In the condition of optimal operating mode, removal rate of COD, total nitrogen and total phosphorus in HA-A/A-MCO system is 97.8, 78.9 and 99.3 %, respectively. That is, in the condition of lower dissolved oxygen concentration, the system can acquire simultaneously excellent effect of phosphorous and nitrogen removal.

Conclusion

Through controlling lower dissolved oxygen (DO) concentration (0.5-1.5 mg/L) and adopting orthogonal test, we research preferable dissolved oxygen controlling concentration of each oxic tank (No.1 oxic tank, No.2 oxic tank and No.3 oxic tank). The researching results show that preferable dissolved oxygen controlling concentration of No.1 oxic tank, No. 2 oxic tank and No. 3 oxic tank is 0.8, 1.0 and 1.0 mg/L, respectively. Under the condition of optimal operating mode, the removal rate of COD, total nitrogen and total phosphorus in HA-A/A-MCO system is up to 97.8, 78.9 and 99.3 %, respectively. Moreover, in the condition of lower dissolved oxygen concentration, HA-A/A-MCO process can obtain excellent effect of pollutant removal and sludge reduction simultaneously, which resolves the contradict that sludge reduction leads to oxygen demand increasing of wastewater treatment system so as to increase energy consumption of aeration.

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