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# Study on Hydrolysis-Acidification-A$^2$O Sludge Reduction Process for Operation Performance

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An advanced process combining sludge reduction and phosphorous and nitrogen removal is developed, for short hydrolysis-acidogenosis-anaerobic/anoxic-multistep continuous oxic tank [HA-A/A-MCO] process, whose biological treatment unit is hydrolysis-acidification, multistep continuous oxic tank and continuous flow A$^2$/O process coupled with side stream phosphorous removal by draining out anaerobic phosphorous accumulating sewage. Test results of the process treating campus wastewater show that under the condition of SRT = 60d, the influent COD = 316 to 407 mg/L, $NH_3$-N = 30 to 40 mg/L, TN = 35 to 53 mg/L, TP = 6 to 9 mg/L, the effluent COD, $NH_3$-N, TN and TP are equal to or less than 18 mg/L, 2.1 mg/L, 10.3 mg/L, 0.44 mg/L, respectively. VFA from hydrolysis-acidification process can improve phosphorous and nitrogen removal effectively, which can induce phosphorous content from anaerobic release reaching 57 mg/L and can make the amount of sidestream phosphorous removal sewage flowing into chemical phosphorous removal tank be just 13 % of influent flow. Nitrogen removal is realized by simultaneous nitrification and denitrification (SND) and only denitrification, which account for 50 % and 26 % of the total nitrogen removal respectively. Moreover, biofacies separation is realized in HA-A/A-MCO process and lower sludge yield which is 0.1 gMLSS/gCOD can be achieved by utilizing biological predation.

**Key Words: Phosphorous and nitrogen removal, Sludge reduction, Hydrolysis-acidification, Biofacies separation, Sludge yield.**

## INTRODUCTION

In order to explore the method of improving phosphorous and nitrogen removal in sludge reduction technologies[1-4], 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. The researching results show that this process has better performance of simultaneous 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, sidestream sedimentation tank and chemical phosphorous removal tank. And, the virtual volume of hydrolysis-acidification tank, anoxic tank and anaerobic tank is 50, 30 and 30 L respectively.

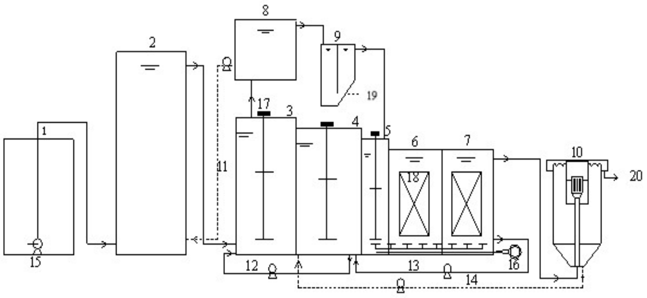

Fig. 1. Flow sketch map of HA-A/A-MCO process; 1. Influent tank; 2. Hydrolysis acidification tank; 3. Anaerobic tank; 4. Anoxic tank; 5, 6, 7. No.1 Oxic tank, No. 2 Oxic tank and No. 3 Oxic tank of multistep continuous oxic tank, respectively; 8. Sidestream sedimentation tank; 9. Chemical phosphorous 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

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 time is 30 L, 1.5 h respectively; 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, sidestream 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.

When HA-A/A-MCO process operates steadily, influent flow is 20 L/h. DO of each section of multistep continuous oxic tank is 0.5-1.5 mg/L, 0.5-1.5 mg/L 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 of the system is 60 d, mixed liquor suspended solids (MLSS) is 5100-5800 mg/L and sludge load is 0.18-0.21 kg COD/kg MLSS.d

**Experimental water quality:** Experimental waste water 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, DO concentration is measured with an YSI oxygen meter, VFA is measured by distillation-titration method and other parameters were analyzed as reported methods[5].

## RESULTS AND DISCUSSION

**Change of COD:** Fig. 2 reflects the information of COD removal effect in each tank when the system operates stably. When the influent COD = 316-407 mg/L (whose average value is 352 mg/L, its average concentration can be up to 660 mg/L by hydrolytic acidification. And soon afterwards, the effluent COD concentration from anaerobic tank, which undergoes anaerobic phosphorus release is 264 mg/L, the effluent COD concentration from anoxic tank which undergoes nitrogen removal by denitrification is 145 mg/L. The effluent COD concentration from No.1 oxic tank, No.2 oxic tank and No. 3 oxic tank of multistep continuous oxic tank is 134 mg/L, 88 mg/L, 13 mg/L, respectively. The average removal rate of COD is 96 % and the effluent COD concentration comes to the primary standard of the sewage discharge standard (GB18918-2002).

**Variation of $NH_3$-N in the system:** Fig. 3 shows the condition of $NH_3$-N variation along the flow. When the influent $NH_3$-N = 30-40 mg/L (whose average value is 34 mg/L), 2 % of anaerobic phosphorus release sludge through hydrolytic acidification makes the effluent $NH_3$-N concentration from hydrolytic tank increase to 42 mg/L, the increment is 8 mg/L.

On the basis of $NH_3$-N increment from hydrolytic tank, with a viewpoint of dynamic equilibrium, hydrolysis conversion rate of anaerobic phosphorus release sludge calculated theoretically by formula (1):

$$Q_i \times C_i + 2\ \%\ Q_i \times MLSS_{an} \times f \times m \times q = (100 + 2)\ \%\ Q_i \times C_e \quad (1)$$

where, $Q_i$-influent flow of hydrolytic tank, L/h; $C_i$-influent $NH_3$-N concentration of hydrolytic tank, mg/L; $C_e$-effluent $NH_3$-N concentration of hydrolytic tank, mg/L; $MLSS_{an}$-phosphorus release sludge concentration of sidestream sedimentation tank, calculated in 9000 mg/L; f-VSS/SS, about 0.75; q-hydrolysis conversion rate of anaerobic phosphorus release sludge, %; m-0.15, when sludge organic matter is in $C_5H_7NO_2$ terms[3,6], 1 g VSS by hydrolysis conversion can produce 0.15 g $NH_3$-N.

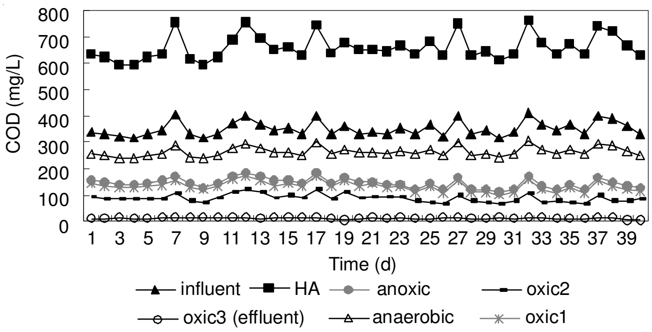

Fig. 2. Removal effect of COD of each tank

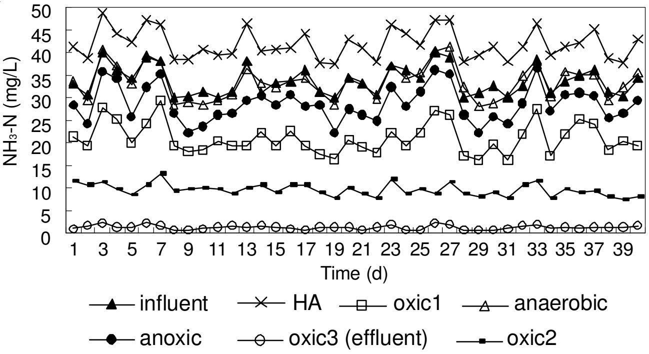

Fig. 3. Variation of $NH_3$-N of the system

According to calculation, the average hydrolysis conversion rate of anaerobic phosphorus release sludge is 44 %.

Soon afterwards, effluent $NH_3$-N concentration of anaerobic tank through return flow dilution is 33 mg/L. Owing to return of aerobic nitrification liquid, anoxic tank can also result in dilution and part nitrification of $NH_3$-N and effluent $NH_3$-N concentration is 29 mg/L. The effluent $NH_3$-N concentration from No. 1 oxic tank, No. 2 oxic tank and No.3 oxic tank of multistep continuous oxic tank is 21 mg/L, 10 mg/L, 1.3 mg/L, respectively. The average removal rate is 96 % and the effluent $NH_3$-N concentration can come to the primary standard of the sewage discharge standard (GB18918-2002).

**Phosphorus removal effect in the system:** During stable operation of the system, total phosphorus concentration in influent, effluent and the effluent of each reaction tank is measured once a day for the purpose of monitoring phosphorus removal effect of the system. The results are shown in Fig. 4.

The results indicate that during the two-month runtime, when influent total phosphorus content is 8-12 mg/L, the effluent total phosphorus value of hydrolysis-acidification tank is 12-18 mg/L. Anaerobic phosphorus release content can be up to 50-63 mg/L, average value is 57 mg/L. According to running manner of HA-A/A-MCO process, part of anaerobic phosphorus release supernatant needs to be discharged into chemical phosphorus tank through sidestream sedimentation tank. This is the reason why total phosphorus content in anoxic tank (average value is 48 mg/L) is a little lower than that in anaerobic tank. The mixed liquor after anoxic process along with supernatant from chemical phosphorous removal tank flow into No.1 oxic tank, No.2 oxic tank and No.3 oxic tank of multistep continuous oxic tank in turn, where P can be absorbed adequately. Total phosphorus content absorbed in No.1 oxic tank is just 10 % of that in effluent of anoxic tank. This case may be caused by the controlled condition (including hydraulic retention time, DO and organic matter quantity *etc.*) of No. 1 oxic tank going against the propagation of phosphate accumulating organisms (PAOs). While, the total phosphorus content absorbed in No. 2 and No. 3 oxic tank is significantly increased. And the effluent total phosphorus content of No. 2 oxic tank and No. 3 oxic tank is 12.6-16 mg/L and 0.37-0.6 mg/L (average 0.44 mg/L), respectively, which can fully come to the primary standard of the sewage discharge standard (GB18918-2002). This also illuminates that PAOs can survive in protozoan and metazoan culture section, even there is no the phenomena that high-grade microbe phagocytosing PAOs affects the effect of phosphorus removal.

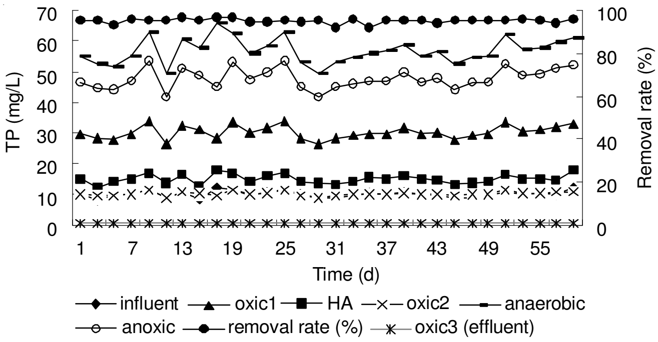

Fig. 4. Variation of total phosphorus content in the system

**Nitrogen removal effect in the system:** Figs. 5 and 6 reflect the nitrogen removal effect of the system and nitrogen removal pattern, respectively. The results in Figs. 5 and 6 indicate that when influent total nitrogen = 35-53 mg/L (average value is 47 mg/L), the concentration of total nitrogen has no obvious change after hydrolysis acidification, whose average value is 46.8 mg/L. Combining with the previous result that the concentration of $NH_3$-N increases after raw sewage going through hydrolysis acidification, it was considered by integrated analysis that total nitrogen having no increase after hydrolysis acidification is perhaps as a result of return sludge into anaerobic tank bringing to some denitrifying bacteria and removing nitrogen through denitrification in hydrolytic tank.

The average concentration of total nitrogen from anaerobic tank effluent is 42.2 mg/L after return liquid dilution and anoxic denitrification and the rate of nitrogen removal in anaerobic phase is about 13 %. The concentration of total nitrogen from anoxic tank effluent is 19-35 mg/L (average is 30.1 mg/L) and the rate of nitrogen removal in anoxic phase is about 34 %, which includes noxic denitrification and assimilation consuming nitrogen. When sludge yield (Ys) is calculated in 0.1 gSS/gCOD.d, about 4 mg/L total nitrogen is used for microbial synthesis (biological matter is in $C_5H_7NO_2$ terms) which occurs mainly in anoxic phase and aerobic phase, of which, assimilation consuming nitrogen is about 3 mg/L in anoxic phase and nitrogen removal through denitrification is 9.5 mg/L (covering 76 % of total nitrogen removal in this phase). So, denitrification is the main way for nitrogen removal in anoxic tank.

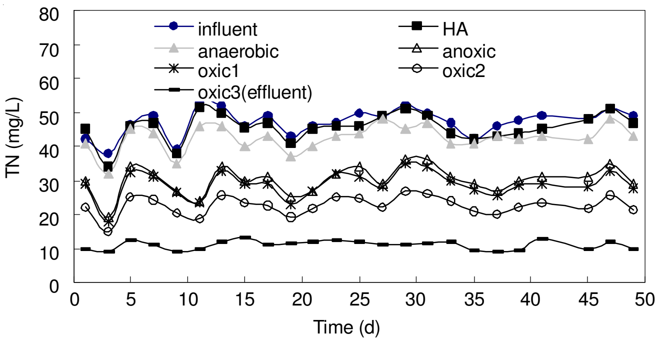

Fig. 5. Effect of nitrogen removal of the system

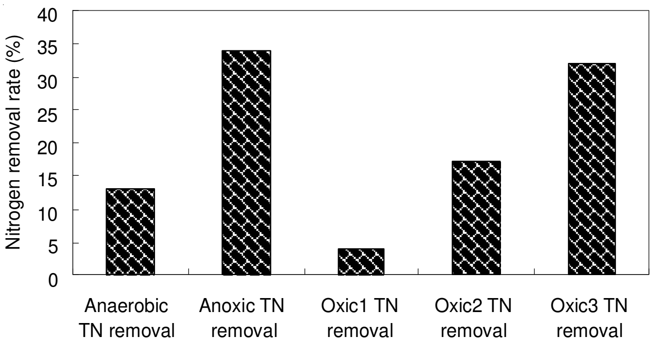

Fig. 6. Manner of biological nitrogen removal of HA-A/A-MCO system

The total nitrogen removal rate of aeration tank is 53 %. Among it, total nitrogen content from No.1 oxic tank effluent is 18-35.1 mg/L (average is 28.7 mg/L), nitrogen removal rate is 4 % and the nitrogen removal is mainly as a result of simultaneous nitrification and denitrification (SND) and liquid supernatant dilution from chemical phosphorus removal. Total nitrogen content from No. 2 oxic tank effluent is 14.9-26.6 mg/L (average is 22.5 mg/L), the ratio of nitrogen removal is 17 %. Total nitrogen content from No.3 oxic tank effluent is 9-13 mg/L (average is 10.9 mg/L), the ratio of nitrogen removal is high up to 32 %. The main reason for total nitrogen decreasing in No.2 oxic tank and No.3 oxic tank is that nitrification and denitrification and biological synthesis consuming nitrogen. Amount of assimilation consuming nitrogen is about 1 mg/L in aeration tank, however, amount of nitrogen removal through simultaneous nitrification and denitrification is 18 mg/L. Therefore, simultaneous nitrification and denitrification is the main way of biological nitrogen removal in aeration tank, which covers 50 % of total nitrogen removal in the system.

**Change of sludge yield in the system:** From the beginning of testing device starting, we test continuously for two months about the kinds and quantity of dominant microbes in No.1 oxic tank, No. 2 oxic tank and No. 3 oxic tank of multistep continuous oxic tank, moreover, determine the change of sludge yield in HA-A/A-MCO system, the result is shown in Fig. 7.

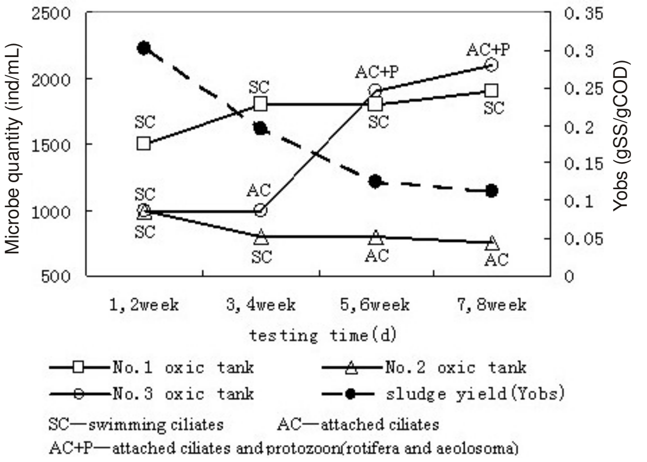

Fig. 7. Relation between preponderant microbe species of oxidation tank and sludge yield

Calculation of sludge yield refers to formula from (2) to (4).

$$\Delta TSS = TSS_{n+i} - TSS_n + TSS_w = 10^{-3}[(\sum_1^7 V_j \times X_j + \sum_1^3 M_k \times N_k)_{n+i} - (\sum_1^7 V_j \times X_j + \sum_1^3 M_k \times N_k)_n + i \times Q_w \times X_r] \tag{2}$$

$$\Delta COD = \sum_n^{n+i}[(COD_o - COD_e) \times Q_o \times 10^{-6} \times 24] \tag{3}$$

$$Y = \Delta TSS / \Delta COD_r \tag{4}$$

where, Y-sludge yield for i days, kg $kg^{-1}$, in COD terms; $\Delta TSS$-the total quantity of sludge generated for i days, kg; $\Delta COD_r$-the total quantity of COD removal for i days, kg; $TSS_n$, $TSS_{n+I}$-the total sludge quantity for the No. n day and the No. n+i day respectively, kg; $TSS_w$-the total quantity of sludge disposed for i days, kg; $V_{1,...,7}$-effective volume of hydrolysis acidification tank, anaerobic tank, anoxic tank, No.1 oxic tank, No. 2 oxic tank and No.3 oxic tank and secondary sedimentation tank, respectively, L; $X_{1,...,7}$-sludge concentration of hydrolysis acidification tank, anaerobic tank, anoxic tank, No.1 oxic tank, No.2 oxic tank and No.3 oxic tank and secondary sedimentation tank, respectively, g $L^{-1}$; $M_{1,2,3}$-biomass liveweight of each filler in every region of aeration tank, kg/root; $N_{1,2,3}$-root number of filler in every region of aeration tank, root; $Q_w$-sludge flow disposed, L $d^{-1}$; $X_r$-concentration of return sludge from secondary sedimentation tank, $gL_{-1}$; $COD_o$, $COD_e$-the concentration of influent COD and effluent, mg $L^{-1}$; $Q_o$-the influent flow of the system, L $h^{-1}$.

During the 8 weeks from testing device starting to stable operation, swimming ciliates (such as paramecium, reniform ciliates) is the dominant species in No.1 oxic tank and the quantity presents the tendency of progressive increase. After two months, the quantity steadies basically, achieves the maximum value 1900 ind/mL; superior species in No.1 oxic tank evolves from initial swimming ciliates to attached ciliates(such as bunching ciliates, clock ciliates). After two months, the quantity achieves the maximum value 800 ind/mL; In the initial stage of esting device starting, swimming ciliates is the dominant species in No.3 oxic tank, until the third week and fourth week, the superiority of attached is quite obvious, until the fifth week and sixth week, a given mass of metazoa(such as rotifera and aeolosoma) begins to emerge. After two months, the quantity of protozoon and histozoa is up to 1400 ind/mL and 650 ind/mL respectively in No. 3 oxic tank. It is thus clear that grading grow of microfauna and prolonging food chain are realized preferably in multistep continuous oxic tank.

Combining with change of sludge yield showed in Fig. 7, it can be found that the quantity of high-grade microbes becomes more along with the phenomenon of biofacies separation being obvious. Meanwhile, sludge yield becomes smaller, falls to 0.1 gMLSS/gCOD from initial 0.3 gMLSS/gCOD, which just constitutes a quarter of sludge yield of traditional activated sludge process (about 0.4 gMLSS/gCOD[7,8]). It is thus clear that biofacies separation to prolong food chain of the system and using predation of microfauna can make HA-A/A-MCO process acquire favourable effect of sludge reduction.

## Conclusion

When the inflow COD, $NH_3$-N, total nitrogen, total phosphorus content of HA-A/A-MCO process is 316-407 mg/L, 30-40 mg/L, 35-53 mg/L, 8-12 mg/L, respectively, the effluent COD ≤ 18 mg/L, $NH_3$-N ≤ 2.1 mg/L, total nitrogen ≤ 10.3 mg/L, total phosphorus ≤ 0.44 mg/L. The effluent water quality can come to the primary standard of the sewage discharge standard (GB18918-2002) and HA-A/A-MCO process has favourable effect of contaminant removal. VFA from hydrolysis-acidification process can improve phosphorous and nitrogen removal effectively, which can induce phosphorous content from anaerobic release reaching 57mg/L and can make the amount of sidestream phosphorous removal sewage flowing into chemical phosphorous removal tank be just 13 % of influent flow. Nitrogen removal is realized by simultaneous nitrification and denitrification (SND) and denitrification, which account for 50 % and 26 % of the total nitrogen removal respectively. Moreover, biofacies separation is realized in HA-A/A-MCO process and lower sludge yield which is 0.1 g MLSS/gCOD can be achieved by utilizing biological predation.

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