Effect of the combination of wetland and sewage treatment technology on the treatment of domestic sewage in Zhejiang province

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Abstract. Sample from 25 A^2O + horizontal flow constructed wetland (HFCWs) and 49 A^2O + vertical flow constructed wetland (VFCWs) in Suzhou, Huzhou, and tested inflow and outflow (COD, NH3-N, TN, TP and SS), to evaluate the stability of the effluent and the rate of compliance. The effects of the two combined processes on the treatment of rural domestic sewage and their design and operation were compared and studied. The results show that the stable effluent compliance rate of A^2O + VFCWs is higher than that of A^2O + HFCWs. The effluent quality stability of A^2O + VFCWs is better in winter, but worse in summer. The removal effect of the A^2O unit in the two combined processes is not ideal, which may be related to the low carbon to nitrogen ratio of the influent and less sludge. Based on the above results, it is recommended that the county-level city proceed with upgrading and reconstruction in terms of structure and operation.

1. Introduction
The constructed wetland has a good effect on removing nitrogen and phosphorus pollutants from sewage, and has the advantages of low investment cost, convenient maintenance and management, and no secondary pollution[1]. At present, the application of constructed wetland in rural domestic sewage is based on the design of subsurface flow.

This study takes the rural domestic sewage treatment facilities in Suzhou, Huzhou, city as the research object[2]. The 25 combined process facilities (A^2O + VFCWs) of A^2O and VFCWs and the 49 combined process facilities (A^2O + HFCWs) of A^2O and HFCWs in 19 townships were inspected on the spot. Use statistical methods to compare the two kinds of combination process of rural domestic sewage water stability and stability of the success rate, A^2O unit is analyzed and constructed wetland unit the individual contribution rate on contaminant removal. The design and operation of two combined processes are analyzed in order to provide reference for the performance improvement of the combined processes in the future.

2. Materials and methods

2.1. Research object overview
In 11 towns and villages of Suzhou, Huzhou, 79 combined process facilities of A^2O and constructed wetlands were randomly selected to conduct field investigation and water quality testing (table 1). Two types of wetland design depth of 1.2 m, are at the bottom of the anti-seepage film anti-seepage treatment, for the ground reference plane, HFCWs and VFCWs outlet height is 0.2 m and 0.9 m, HFCWs and
VFCWs design hydraulic load of about 0.93 m$^3$ respectively, and 0.36 (m, 2 d) - 1 m$^3$, (m, 2 d) - 1, under the condition of same processing scale HFCWs area is smaller than VFCWs, short hydraulic retention time. The packing type of HFCWs is light shale ceramicsite, and the packing type of VFCWs is sand and gravel particles with a diameter of 1~3 cm.

### Table 1. Water quality in the two combined processes in winter and summer. mg ∙ L$^{-1}$

| Season Section | Process Type     | Water quality along the way | NH$_3$ -N | TN  | TP  | COD | SS   |
|----------------|------------------|----------------------------|-----------|-----|-----|-----|------|
| Winter Season  | $\text{A}_2\text{O} + \text{HFCWs}$ (N=16) | $\text{A}_2\text{O}$ water | 27.9±13.9 | 38.2±18.9 | 2.5±1.1 | 40.2±29.2 | 15.2±14.9 |
|                |                  | $\text{A}_2\text{O}$ effluent | 13.5±11.9 | 25.9±12.5 | 2.2±1.2 | 30.5±26.2 | 16.5±23.1 |
|                |                  | Wetland effluent | 6.8±7.5 | 20.3±9.4 | 2.5±0.7 | 16.5±8.9 | 9.5±18.9 |
|                | $\text{A}_2\text{O} + \text{VFCWs}$ (N=8) | $\text{A}_2\text{O}$ water | 36.2±27.1 | 46.8±28.6 | 3.5±2.7 | 45.5±43.9 | 106.8±188.9 |
|                |                  | $\text{A}_2\text{O}$ effluent | 31.6±27.2 | 40.2±24.3 | 3.3±2.8 | 43.8±42.3 | 15.8±23.6 |
|                |                  | Wetland effluent | 4.1±3.4 | 33.5±21.8 | 1.7±0.8 | 12.5±2.7 | 12.9±16.7 |
| Summer Season  | $\text{A}_2\text{O} + \text{HFCWs}$ (N=29) | $\text{A}_2\text{O}$ water | 45.6±18.2 | 53.6±17.9 | 5.8±1.5 | 145.7±65.6 | 95.6±45.5 |
|                |                  | $\text{A}_2\text{O}$ effluent | 25.3±19.8 | 42.6±20.9 | 4.3±1.7 | 65.1255 | 33.5±15.8 |
|                |                  | Wetland effluent | 23.8±18.7 | 35.9±19.5 | 3.7±1.7 | 53.6±29.6 | 27.1±19.2 |
|                | $\text{A}_2\text{O} + \text{VFCWs}$ (N=15) | $\text{A}_2\text{O}$ water | 37.9±27.5 | 46.5±28.4 | 4.8±2.7 | 102.9±83.9 | 68.5±61.5 |
|                |                  | $\text{A}_2\text{O}$ effluent | 31.9±26.9 | 40.2±35.9 | 4.5±2.8 | 99.3±133.1 | 49.5±43.8 |
|                |                  | Wetland effluent | 11.5±16.9 | 36.5±21.8 | 3.8±2.2 | 27.9±24.6 | 17.9±17.7 |

2.2. Statistical analysis of data

The standard deviation coefficient method was used for the stability analysis of effluent water quality, and the calculation method was shown in the following formula.

$$ V_o = \frac{\sum (X_i - \bar{X})^2}{N} $$

In the above formula, $\bar{X}$ is the average value of each water quality index, $X_i$ is the monitoring value of each water quality index, N is the number of samples.

The deviation coefficient method and the model developed by NIKU[3] were used to calculate the yield of water. The calculation method of deviation coefficient is shown in the following formula.

$$ \beta = \frac{\sum (X_i - \bar{X})^3}{N} \left[ \frac{\sum (X_i - \bar{X})^2}{N} \right]^{-3} $$

In the model calculation method developed by NIKU et al., the stable compliance rate refers to the percentage of the number of samples whose effluent concentration conforms to the discharge standard concentration in a certain number of samples. The calculation method is shown in the following formula.
In the above formula, \( m_x = \phi X_S \)

In the above formula, \( m_x \) is the average effluent concentration and \( \phi \) is the stable reaching coefficient, which refers to the coefficient that reaches the designed effluent standard. The stable compliance coefficient can be calculated by the following formula.

\[
\phi = \sqrt{\vartheta^2 + 1} \cdot e^{-\frac{Z_{1-\alpha}}{\sqrt{\ln(\vartheta^2 + 1)}}}
\]

In the above formula, \( \vartheta \) is the coefficient of variation and the ratio of the standard deviation to the average effluent concentration. \( \alpha \) is the probability of not meeting the emission standard, and \( 1 - \alpha \) is the probability of meeting the emission standard.

3. Results and analysis

3.1. Analysis of effluent stability and compliance rate of two combined process facilities

3.1.1. Water stability.

The effluent standard deviation coefficients of the two combined processes in winter and summer are shown in Figure 1. Studies[4-6] have shown that the standard deviation coefficient \( V_\sigma \leq 0.5 \) is the normal fluctuation range, \( 0.5 < V_\sigma \leq 1.0 \) is the acceptable fluctuation range, and \( V_\sigma > 1.0 \) is considered as abnormal fluctuation.

In winter, the standard deviation coefficients of A2O + VFCWs effluent are NH3-N (0.72), TN (0.61), TP (0.44) and COD (0.43). The A2O + HFCWs effluent standard deviation coefficients are NH3-N (1.09), TN (0.45), TP (0.42) and COD (0.56).

Compared with A2O + HFCWs, the water stability of A2O + VFCWs is significantly better, especially for NH3-N and COD, the standard deviation coefficients of concentration are 0.32 and 0.12, respectively.

In summer, A2O + VFCWs effluent standard deviation coefficients are NH3-N (1.45), TN (0.57), TP (0.63) and COD (0.83), while A2O + HFCWs effluent standard deviation coefficients are NH3-N (0.81), TN (0.55), TP (0.37) and COD (0.56). The standard deviation coefficients of the indicators of A2O + HFCWs effluent are not much different in summer and winter, and even slightly improved than in winter; while the standard deviation coefficients of the indicators of A2O + VFCWs effluent are generally greatly increased in summer, indicating the stability of water quality Sex becomes worse.

Comparing the two combined processes, it is found that the standard deviation coefficients of various indicators of A2O + VFCWs effluent in summer are larger than that of A2O + HFCWs and the effluent stability.
3.1.2 Outlet stability compliance rate and deviation coefficient.

The stable compliance rate and deviation coefficient of the two combined processes are shown in Table 2.

Table 2. Stable compliance rates and deviation coefficient of effluent in the two combined processes in winter and summer.

| Season | Process Name | Stable compliance rate (%) | Deviation factor |
|--------|--------------|-----------------------------|------------------|
|        | NH₃-N | TP | COD | SS | NH₃-N | TP | COD | SS |
| Winter | A²O+VFCWs | 98.9 | 88.7 | 100 | 93.8 | -1.03 | -1.19 | -0.79 | -0.75 |
|        | A²O+HFCWs | 97.2 | 86.5 | 100 | 90.8 | -1.02 | -1.45 | -0.74 | -0.76 |
| Summer | A²O+VFCWs | 89.8 | 44.5 | 98.1 | 85.3 | -1.13 | 1.15 | -1.08 | -1.13 |
|        | A²O+HFCWs | 66.2 | 32.4 | 93.1 | 58.0 | 0.29 | 1.17 | -1.26 | 0.35 |

Analysis using the NIKUS model found that the effluent stability compliance rates of the two combined processes in winter are not much different. Among them, the stable compliance rates of NH₃-N and COD are close to 100%, and the stable compliance rates of TP and SS are above 90%. Due to the incomplete rain and sewage diversion in this area, rainwater enters through the pipe network during the rain, which dilutes the influent concentration. In addition, part of the rainwater enters the secondary treatment unit through the constructed wetland surface, reducing the effluent concentration. Under the combined effect of the two, the effluent concentration is reduced, which indirectly increases the facility's stable compliance rate in winter.

In summer, the stable compliance rates of NH₃-N, TP, COD, and SS of A²O + VFCWs effluent decreased slightly compared with winter, which were 87.9%, 43.3%, 97.9%, and 84.7%, which were 23.1% and 11.7% higher than 5.0% and 27.1% of A²O + HFCWs. Further analysis using the deviation coefficient method revealed that the effluent deviation coefficients of the two combined processes in winter are both less than 0, which indicates that the concentration of the effluent is less than the specified concentration discharge value, and the effluent stable compliance rate is higher. In summer, the TP deviation coefficients of NH₃-N, TP, SS and A²O + VFCWs effluent of A²O + HFCWs effluent are all greater than 0. The rate of stable compliance of some pollutants by the two combined processes is low.

Whether the NIKUS model method or the coefficient of deviation method is used, it is shown that the stable compliance rate of A²O + VFCWs is higher than A²O + HFCWs.

In winter, the stable compliance rate of the two combined processes is high, and there is not much difference. In summer, the TP stable compliance rate of the effluent of A²O + VFCWs becomes worse, while the A²O + HFCWs is the stable compliance rate of NH₃-N, TP and SS Both become worse.

The stability of the effluent decreased in summer. This conclusion is inconsistent with environmental engineering and scientific research on constructed wetlands. It was found through on-site investigations that there is a general incomplete rain and sewage diversion in rural areas in the region. There is a strong rainfall process in summer, and the instantaneous impact load is too large, resulting in Sludge loss, which affects the treatment effect of the facility.

3.2 Study on the pollutant removal effect of the whole process and each treatment unit

The contribution rate of A²O and constructed wetlands to the removal of various pollutants is shown in Figure 2 and Figure 3. The average removal rate of COD, NH₃-N, TN and TP by the combined process of A²O + VFCWs was found is (81.9 ± 18.5)%,(94.6 ± 8.5%), (49.1 ± 16.9)%,(51.2 ± 17.1)% in winner, which are (71.7 ± 13.6)%,(80.0 ± 16.9)%,(30.0 ± 17.6)%,(30.9 ± 18.7)% in summer. Units that play a major role in the removal of pollutants are VFCWs.
Figure 2. Proportion of pollutant removal in the combined process of A^2O+VFCWs.

For the A^2O + HFCWs combined process, the average removal of COD, NH₃-N, TN and TP. The rate in winter is (59.5 ± 21.1)% , (79.5 ± 19.7)% , (42.1 ± 17.5)% , (24.9 ± 10.7)% , and the average removal rate in summer is (62.5 ± 18.1)% , (58.3 ± 30.7)% , (40.7 ± 20.1)% and (28.4 ± 15.5)% . The unit that plays a major role in pollutant removal is A^2O.

In the A^2O + VFCWs process, each pollutant is mainly removed by VFCWs, with a contribution rate of 51% to 95%. In the A^2O + HFCWs process, the main role for NH₃-N, TN and COD is A^2O, the contribution rate is 53% ~ 80%.

4. Conclusion

1) The water yield rate of A^2O+VFCWs is higher than that of A^2O+HFCWs in winter and summer. The water quality stability of A^2O+VFCWs was good in winter, but it fluctuated greatly in summer, and the stability was decreased.
2) In the combined process of A\textsuperscript{2}O+VFCWs, VFCWs plays a major role in pollutant removal. In the combined process of A\textsuperscript{2}O+HFCWs, it is A\textsuperscript{2}O that plays a major role in pollutant removal.

3) Due to the low carbon-to-nitrogen ratio of the inlet water and less sludge, the average removal rate of TN and TP by the A\textsuperscript{2}O unit in A\textsuperscript{2}O + VFCWs is (20.7 ± 16.3)% and (15.6 ± 10.2)% in winter, and in summer it is (20.4 ± 11.9)% and (12.6 ± 13.9)%. The average removal rate of A\textsuperscript{2}O units in A\textsuperscript{2}O + HFCWs to TN and TP is (33.2 ± 16.3)% and (25.0 ± 10.2)% in winter, and (31.3 ± 24.1)% and (21.9 ± 17.4)% in summer. This is because the effective volume of the A\textsuperscript{2}O unit of A\textsuperscript{2}O + VFCWs is relatively small, and the dissolved oxygen control is insufficient, resulting in its removal rate of each pollutant is significantly lower than the A\textsuperscript{2}O unit in the A\textsuperscript{2}O + HFCWs combined process facilities.

4) The A\textsuperscript{2}O + constructed wetland combination process in this area has a lot of room for improvement in the treatment of rural domestic sewage. You can start from increasing the volume of the reaction unit, optimizing the reactor structure, and optimizing the control of dissolved oxygen, reflux ratio, etc. to improve the pollutant removal effect of the A\textsuperscript{2}O unit and the constructed wetland unit, and give full play to the role and function of rural sewage treatment facilities.

References
[1] DRIZO A,FROST C A, GRACE J, et al. Physico-chemical screening of phosphate-removing substrates for use in constructed wetland systems[J]. Water Research, 1999, 33(17): 3595-3602.
[2] Gui Shuanglin,Wang Shunfa,Wu Yongming,et al.Study on the effect of biofiltration tower-constructed wetland technology on purification of rural domestic sewage [J].Journal of Environmental Engineering ,2011,5(10):2312-2314.
[3] Huang Jinlou, Chen Qin, Xu Lianhuang. Problems and Solutions of Artificial Wetlands in Application [J].] Environmental Science ,2013,34(1):401-408.
[4] Meng Hong, Li Chuansong, Zhou Jian, et al. Effect of C/N value on denitrification of sequence batch deep bed denitrification constructed wetland [J].China Water Supply and Drainage ,2016,32(13):1-5.
[5] YU G,PENG H,FU Y,et al .Enhanced nitrogen removal of low c/n wastewater in constructed wetlands with co-immobilizing solid carbon source and denitrifying bacteria[J]. Bioresource Technology,2019,280: 337-344.
[6] Wang Ningning, Zhao Yangguo, Sun Wenli, et al. Effects of dissolved oxygen content on removal of pollutants in constructed wetlands [J].] Journal of Ocean University of China (Natural Science Edition),2018,48(6): 24-30.