Advanced Treatment Process for Secondary Effluent of Municipal Wastewater Based on A/O Biological Filtration Technology

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Abstract: Through the removal effects of the anoxic/oxic (A/O) biological filtration technology on organic matters, nitrogen and phosphorus, the advanced treatment for secondary effluent of municipal wastewater was analytically characterized by means of filter material selection and natural biofilm start-up. The results show that the composite slag has the best adsorbing effects on ammonia nitrogen and phosphorus, reaching 57% and 32.2%, respectively; as the natural biofilm start-up is smoothly implemented, the removal rate of ammonia nitrogen reaches over 60% in the first phase and over 96% in the second phase. This study provides a reference for the advanced treatment for secondary effluent of municipal wastewater.

1. Introduction
The advanced treatment and recycling of wastewater play a positive role in reducing the water pollution degree, realizing resource conservation, etc. [1]. In terms of wastewater treatment, municipal wastewater is characterized by minor pollution and easy recycling, but the recycling difficulty still exists in the treatment process for wastewater of this kind, so it is very essential to investigate the related advanced treatment process technologies for secondary effluent of municipal wastewater. Condensation heat transfer enhancement, efficient adsorption, biological filtration, chemical oxidation and film separation are methods commonly used in the advanced treatment of municipal wastewater. Various indexes including ammonia nitrogen and some organic matters are prone to seasonal influences in the wastewater treatment of this type, and consequently, their contents may be partially high or even exceed the related standards.

In the further enhanced treatment for secondary effluent of municipal wastewater, the priority should be given to the control of organic matters, effluent turbidity and nutritive salt in wastewater, and the biological filtration technology is an effective control approach [2]. The main treatment unit used in this paper is anoxic/oxic (A/O) filter.

2. Method

2.1 Selection of test water
The test water selected in the stable operation phase was the effluent collected from Huangdao District Lingshanwei Sewage Treatment Plant of Qingdao Galaxy Water of Beijing Lucency Environmental Protection Technology Co., Ltd. The wastewater passing the north courtyard of the company could join in the wastewater from the south courtyard after being filtered and passing the lift pumps. The test water converged the wastewater from multiple places such as company plant, office building and canteen, so it was comprehensive.
In the biofilm culturing phase, the secondary effluent was prepared through manual simulation, where the compositions and quality situation of the simulated water are shown in Table 1.

| Compositions                        | Water quality              |
|-------------------------------------|-----------------------------|
| Glucose, starch, peptone, (NH₄)₂SO₄, KH₂PO₄, MgSO₄, FeSO₄ and soil leaching liquor | Chemical oxygen demand (COD) | Total nitrogen | Turbidity | Total phosphorus | Ammonia nitrogen |
| 61.0±0.5(mg/L)                      | 25.0±0.4                    | 3.05±0.2(NTU) | 2.8±0.2(mg/L) | 11.0±0.2       |

The wastewater in the sewage treatment station was transferred to the regulating reservoir after filtering, and was then biochemically treated in the A/O filter [3] until flowing into the millpond.

### 2.2 Analytical method of filter material indexes

The advanced treatment method for secondary effluent of municipal wastewater was the biological filtration technology, where filter material was a very important constituent, the adsorbing function of which played a significant role in the advanced purification treatment of secondary effluent. Ceramsite (C), composite slag (CS), zeolite (Z) and lava (L) were mainly selected by combining the practical situation, and their purification effects on the wastewater and application reasonability were compared. The calculation formulas for the related properties of the filter materials are as follows:

$$\rho = \frac{m}{V(2) - V(1)}$$  \hspace{1cm} (1)

The method of specific gravity was used in the test to determine the density $\rho$ of filter material. In the above equation, $m$ corresponds to the mass of filter material; $V(2)$ is the liquid level of pycnometer after the filter material is loaded; $V(1)$ is the initial liquid level in the pycnometer, which is 100 mL here.

$$p = \frac{V(3)}{V(4)} \times 100\%$$ \hspace{1cm} (2)

The porosity $p$ of the filter material is determined by adding clear water in the reactor. In the above equation, $V(4)$ is the determined volume of filter material and $V(3)$ is the volume of clear water discharged out of the reactor.

$$w = \frac{m(2) - m(1)}{m(1)} \times 100\%$$ \hspace{1cm} (3)

where $w$ is the water absorption of filter material; $m(1)$ is the initial mass of filter material after being dried in the drying oven, and $m(2)$ is the mass of saturated filter material that has absorbed distilled water.

$$b = \frac{m(2)}{m} \times 100\%$$ \hspace{1cm} (4)

$$wr = \frac{m(4)}{m} \times 100\%$$ \hspace{1cm} (5)

In the above two equations, $b$ represents the breakage rate of filter material; $wr$ is the wear rate of filter material; $m(4)$ is the mass of filter material below the sample sieve, $m(3)$ is the mass of filter material on the sample sieve, and $m$ is the mass of filter material.

On this basis, the properties of the selected filter material can be analyzed.
2.3 Biofilm start-up method
The water purification function of the biofilm method is realized by taking full advantages of the metabolic activities of various microorganisms in the biofilm [4], so the deeper and more comprehensive water purification is based on the formation of stable biofilm at the surface layer of filler. Under this circumstance, the biofilm start-up of reactor exerts a positive effect on the establishment and operation of the polarized biofilm treatment system. The reactor was started up in this study through natural biofilm culturing.

The whole biofilm start-up process was divided into two phases: single-column start-up and A/O operation. In the first phase, the columns A and O were connected into the pond via the peristaltic column, and the inflow quantity should be controlled at 1 L pe hour and hydraulic retention time (HRT) within 4 h. The successful completion of single-column start-up was marked by the steady removal state of COD and ammonia nitrogen, etc. In the second phase, the filters at the two poles should be connected in series to form the A/O biological filtration technology, at the time, the content of dissolved oxygen in the aerobic zone should be within 3.5 ±mg/L while that in the anaerobic zone did not exceed 0.25 mg/L, and the reflux ratio was 100% in this phase. That the removal of COD, ammonia nitrogen and phosphorus reached a steady state marked the smooth start-up. In the end, the removal effects on the pollutants in the two phases were analyzed.

2.4 Analytical method of adsorptive properties of filter materials
In order to analyze the adsorbing properties of the selected different filter materials, NH₄Cl and filter materials with different concentrations were added into the 250 mL conical flask, followed by oscillation at constant temperature, and the supernatant was taken to determine the residual content of ammonia nitrogen. After the oscillation for 24 h, the NH₄Cl concentration fell within 0.5-80 mg/L, and the mass of filter material was 5 g. The adsorption capacity $Q_c$ of filter material is expressed as below:

$$Q_c = \frac{V (c_0 - c_e)}{1000D}$$  

where $V$ is the volume of liquid phase; $c_0$ is the initial liquid-phase concentration; $c_e$ is equilibrium concentration; $D$ is adsorbent dose.

The adsorption rate of ammonia nitrogen was determined ditto by preparing the NH₄Cl concentration with ammonia nitrogen concentration of 5 mg/L. The volume of the NH₄Cl solution was 100 mL, the mass of filter material was 5 g, and the sampling interval was 10 min.

The content of phosphorous adsorbed by filter material and the concentration of residual phosphorus were determined ditto. The filter materials selected in this study were still limited at the level of organic matter adsorption, so the emphasis was laid on the investigation and analysis of ammonia nitrogen and phosphorus adsorption.

3. Results and Discussion

3.1 Adsorption properties of filter materials for ammonia nitrogen
The adsorption properties of different filter materials for ammonia nitrogen are shown in Figure 1.
It could be observed that the different filter materials showed great differences in the ammonia nitrogen adsorption. The increasing ammonia nitrogen concentration was in direct proportion to adsorption quantity, the content adsorbed by ceramsite was largely stable after the ammonia nitrogen concentration reached 21 mg/L, that by lava tended to be stable after 42 mg/L, and the contents adsorbed by other two filter materials basically reached a steady state after 60 mg/L. Ceramsite showed the poorest performance, with the corresponding content adsorbed only reaching 0.025 mg/g, and the adsorption properties of zeolite and composite slag were satisfying, with the corresponding content adsorbed reaching as high as 0.28 mg/g.

The removal efficiencies of different filter materials for ammonia nitrogen are displayed in Figure 2.

As shown in the above figure, the adsorbing effects of the filter materials on ammonia nitrogen presented one-to-one corresponding relations with the contents adsorbed, where zeolite and composite slag achieved favorable removal effects, and the maximum removal rate of ammonia nitrogen by composite slag could reach 57%; the removal effect of ceramsite was not that ideal, and the maximum removal rate was only 8% or so.

Based on the above results, zeolite was of excellent ion exchange performance and favorable adsorption properties for polar molecules, the pore canal of this filter material adsorbed many ions from the NH₄Cl solution during the filtration process through the coarse bar screen, thus reducing the overall ammonia nitrogen concentration in the wastewater. Comparatively speaking, the adsorption of ammonia nitrogen by composite slag was realized mainly through the electrostatic attraction, which was similar to the action exerted by zeolite, so the two filter materials reached high removal efficiencies for ammonia nitrogen.

3.2 Phosphorous absorption properties of filter materials
The phosphorous absorption properties of the selected filter materials are shown in Figure 3.
From the above figure, ceramsite almost did not adsorb phosphorus, nor did lava. The phosphorus adsorption capacity of zeolite could hardly much poorer than composite slag. On the whole, the composite slag showed the best phosphorus adsorption properties. After the phosphorous concentration reached 50 mg/L, the adsorption region of composite slag for phosphorous was stable, and the maximum content adsorbed could reach 27.2 mg/g.

The removal efficiencies of different filter materials for phosphorous are presented in Figure 4.

Figure 3 Phosphorus Adsorption Capacities of Filter Materials

Figure 4 Phosphorous Removal Efficiencies of Filter Materials

It could be observed from the above figure that the removal efficiencies of different filter materials for phosphorous also presented one-to-one corresponding relations with the content adsorbed, where the maximum removal efficiency of composite slag for phosphorous could reach 32.2%.

Through a summary of the ammonia nitrogen and phosphorous adsorption capacities of the selected filter materials, both zeolite and composite slag showed the best removal effects on ammonia nitrogen and phosphorus in municipal wastewater. In addition, the cost should also be taken into consideration in the selection of filter materials. As a by-product generated in the smelting industry, composite slag has the lowest cost. Therefore, composite slag can be chosen as the filter material to start up the biofilter through a comprehensive analysis. The compositions and related physiochemical properties of composite slag are listed in the following Table 2.

Table 2 Compositions and Properties of Composite Slag

| Main compositions | Calcium oxide, aluminum oxide, ferric oxide, ferrous oxide, silicon dioxide, magnesium oxide and phosphorus pentoxide |
|-------------------|----------------------------------------------------------------------------------------------------------------|
| Physiochemical properties | Particle size | Water absorption | Density | Porosity |
|                    | 2.5±0.5(cm) | 24.88(%) | 1.03(g/cm³) | 32.19(%) |

3.3 Pollutant removal effects during biofilm start-up

During the first start-up phase, the removal effects on ammonia nitrogen and chemical COD of columns
A and O are displayed in Figure 5 (a)-(d).
Figure 5 Removal Effects on Ammonia Nitrogen and COD of Columns A and O in the First Phase: (a) COD of column A; (b) ammonia nitrogen of column A; (c) COD of column O; (d) ammonia nitrogen of column O (I-inflow, O-effluent)

It could be seen that the overall start-up effects of columns A and O presented consistent variation trend. To be specific, the removal efficiency of COD was under linear growth within the first 10 d, and fluctuated basically at 50%; the removal efficiency of ammonia nitrogen was largely kept over 60% just at 10 d, so the single-column start-up was smoothly realized in the first phase.

The removal effects on ammonia nitrogen, COD and total phosphorus in the second A/O operation phase are shown in Figure 6 (a)-(c).
It could be found that as the removal degree was high in column O, the overall removal rate of COD could reach about 60%; the removal effect on ammonia nitrogen was very good, with overall removal efficiency of over 96%; the overall removal efficiency of total phosphorus presented an increasing trend within the first days, but after then, the removal efficiency declined.

Based on the above results, the overall single-column start-up was fast in the first phase, which might be ascribed to overall high indoor temperature and water temperature, the microbial growth was then accelerated, the biofilm enjoyed rapid growth, and the biofilm culturing time was correspondingly shortened in the first phase. In the second phase, the ammonia nitrogen concentration could reach Level A treatment standard after the treatment. In the treatment of total phosphorous, however, the phosphorous demand reached a relatively stable state under the biological assimilation possibly because of approximate saturation in the later phase under the adsorption of composite slag itself, so the overall removal efficiency was partially low. To sum up, this reactor shows excellent performance in the removal of organic matters, nitrogen and phosphorus, etc., and thus the biofilm start-up process is smoothly realized.

4. Conclusion

The selection of filter materials and biofilm start-up were combined to finally propose two processes: A/O biofilm filtration and natural biofilm culturing. Through the comparison of their removal effects on organic matters and ammonia nitrogen, it was obtained that the composite slag had superior performance in the secondary treatment of wastewater, with outstanding adsorption properties and removal effects on ammonia nitrogen and phosphorus; natural biofilm start-up showed good advanced treatment effect on the secondary effluent in municipal wastewater. This provides a direction for the advanced treatment of secondary effluent from municipal wastewater.

References

[1] Fu J T, Wang L, Li X W et al. Application of CM Large Surface Area Block Piece-Type Ceramic Ultrafiltration Membrane in Advanced Treatment of Chemical Wastewater. Technology of Water Treatment, 2017, 43(04):86-88, 93.
[2] Fowdar H S, Hatt B E, Cresswell T, et al. Phosphorus Fate and Dynamics in Greywater Biofiltration Systems. Environmental Science & Technology, 2017, 51(4):2280-2287.
[3] Li S X, Zhu J P, Hu X Y. Phosphorous Release Effect of Different Kinds of Sludge under Anaerobic Condition. Journal of Southwest University of Science and Technology, 2019, 34(2):39-44.
[4] Sotto R D, Ho J, Lee W, et al. Discriminating activated sludge flocs from biofilm microbial communities in a novel pilot-scale reciprocation MBR using high-throughput 16S rRNA gene sequencing. Journal of Environmental Management, 2018, 217:268-277.