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Study on Nitrogen and Phosphorus Removal in the Filler-Reinforced Bardenpho Process

Zhang Lin [*], Li Huidong [*], Song Zhihui [**], Liu Junliang [**], Bi Yinlai [***]

[*] Department of Municipal Engineering , College of Civil Engineering, Inner Mongolia University of Technology of Zhang Lin and Li Huidong
No.49, Ai Min Street, Hohhot City, China
[**] Department of Municipal and Environmental Engineering, Urban and Rural Construction Institute, The Agriculture University of Heibei of Song Zhihui and Liu Junliang
No.289, LingYusi Street, Baoding City, China
[***] Department of civil engineering, Urban and Rural Construction Institute, North China Electric Power University of Bi Yinlai
Yonghua Street, Baoding City, China

Abstract

The volumetric flow rate of the second-phase project of the sewage treatment plant in a certain northern city is designed to be $8\times10^4 m^3/d$ with the value of average influent BOD_5 being 110mg/L and that of average influent TN being 45mg/L, which indicates that the carbon source is far from insufficient. Bardenpho is adopted as the major process of the sewage treatment plant, and efficient suspension filler is added to the first aerobic pool. The Bardenpho process with synchronous nitrogen and phosphorus removal function is characterized by long denitrification sludge age and full use of the carbon source in the zooglea microorganism. The addition of efficient suspension filler into the aerobic pool can increase the amount of micro-organisms and strengthen the nitrification. The combination of the two can ensure a good effect of nitrogen and phosphorus removal without additional carbon source when the carbon source from the influent is insufficient.

Key words

Bardenpho, internal carbon source, suspension filler for nitrogen and phosphorus removal

1. Introduction

The volumetric flow rate of the second-phase project of the sewage treatment plant in a certain northern city is designed to be 8×104m^3/d, and the amount of the actual daily treated water is 6×104m^3/d. The original major biochemical process is the conventional activated sludge process with a pre-anaerobic section, i.e. the A/O process for phosphorus removal. Afterwards it is upgraded and transformed into A^2/O+A/O process with the biological function of synchronous nitrogen and phosphorus removal, which is the Bardenpho process with synchronous nitrogen and phosphorus removal function [1-3].

To improve the nitrification capacity of the Bardenpho process, the high-efficiency biological carrier fluidized filler is added to the first aerobic pool, featuring large specific surface area, light material and good ability of biofilm culturing. Before adding the filler, the concentration of suspended solids in the biochemical pool is MLSS=4000mg/L, and the amount of sludge attached to the biofilm is 8000mg/L. With the filler added, the average MLSS in the first aerobic pool becomes 6400mg/L. The quality of the influent and effluent water after upgrading is shown in Table 1.

Table 1. The designed quality of the influent and effluent water Unit mg/L

Item	COD	BOD_5	SS	NH_3-N	TN	TP	pH
Designed quality of the influent water	350	200	170	35	45	5.5	6-9
Measured quality of the effluent water	250	110	160	35	45	5.2	6-9
Designed quality of the effluent water	≤50	≤10	≤10	≤5(8)	≤15	≤0.5	6-9

2. The operation situation and the methods of water quality testing

2.1 Biochemical pool transformation

When the original phosphorus removal A/O process is transformed into A^2/O+A/O, it is necessary to adjust the operation mode of different sections. The specific adjustments are as follows: (1) Transform part of each aerobic pool into an anaerobic pool; each anaerobic pool is increased with a volume of 489m^3; and the corresponding 3.0KW diving mixer needs to be added. (2) The area of 3040m^3 in the forepart of each aerobic pool needs to be transformed into an anoxic pool, and each anoxic pool should be added with two corresponding 4.0KW diving mixers. (3) To meet the requirements of denitrification, there should be two extra nitrification solution reflux pumps at the end of the first aerobic pool, and the parameters of the single pump are:

Q=1666m^3/d, H=1.2m, N=10KW. (4) The original aging, damaged aeration pipeline should be replaced; all the original aeration pipeline system should be updated with the gas supply of each replaced aerator being 3.0m^3/h; and 6300 additional aerators are needed. (5) The aerobic pools need to be added with high-efficiency biological carrier fluidized filler, and the amount for a single pool should be 29.7% of the volume of the first aerobic pool. (6) The part from the end of the second anoxic pool to the outlet of the biochemical pool should be transformed into an aeration pool with the capacity being about 956m^3. (7) After the transformation of the original aeration pool, the treatment scale of the A^2/O+A/O biological reaction pool is reduced to 4.2×104m^3/d; therefore, an additional A^2/O+A/O biological reaction pool is added, the treatment scale of which is 3.8×104m^3/d. After the transformation, the pool volume distribution of each section of the biochemical pool is as shown in Table 2.

Table 2. List of pool volume distribution of biochemical pool Unit: m^3

Design contents	**Total Effective Volume of a single pool**	**Anaerobic pool**	**Anoxic pool**	**Aerobic pool**	**Anoxic pool**	**Aerobic pool**
Original design parameters	12766	1061	0	11705	0	0
The first level A design parameters	12756	1550	3040	4957	2254	956

According to the order of the water flow, the transformed biochemical pool contains anaerobic pool, anoxic pool, aeration pool (the first aerobic pool), the rear anoxic pool and the second aerobic pool. The main operating parameters of each section are as follows:

Anaerobic pool: HRT=1.84h, θc=2.8d;

The first anoxic pool: HRT=3.2h, θc=4.8d;

Aeration pool (the first aerobic pool): HRT=7.5h, θc=11.2d;

The rear anoxic pool: HRT=2.4h, θc=3.6d;

The second anoxic pool: HRT=0.8h, MLSS= 600mg/L.

2.2 Methods of water quality testing

During the operation of the Bardenpho process, the main detection indexes are COD, NH3-N, TN, TP, pH and DO. To ensure the accuracy of the test data, all water quality indicators are tested with the methods identified in Water and Wastewater Monitoring and Analysis Method (Fourth Edition). Specific detection analysis methods are shown in Table 3.

Table 3. Methods of water quality detection analysis

Analysis items	Measuring methods	Instruments and equipment
COD	Potassium dichromate colorimetric method	Reflux and titration devices
NH_3-N	Nessler reagent colorimetric method	Spectrophotometer /HACHDR5000
TN	Alkaline potassium persulfate digestion colorimetric method	Spectrophotometer /HACHDR5000
TP	Molybdenum-antimony anti-spectrophotometric method	Spectrophotometer /HACHDR5000
pH	Direct measurement	Rex PHS-3Cportable pH meter

3. The water quality analysis of the whole Bardenpho process

3.1 Conventional index analysis of activated sludge

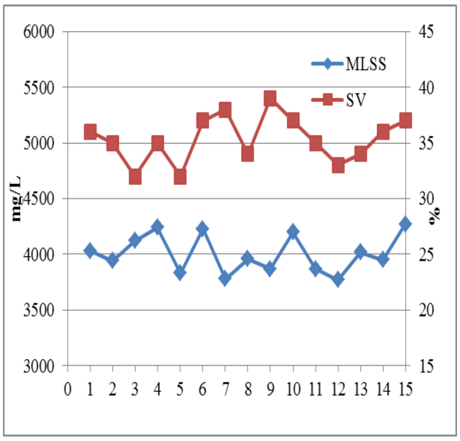

Fig.1. Sludge concentration and sludge settling ratio

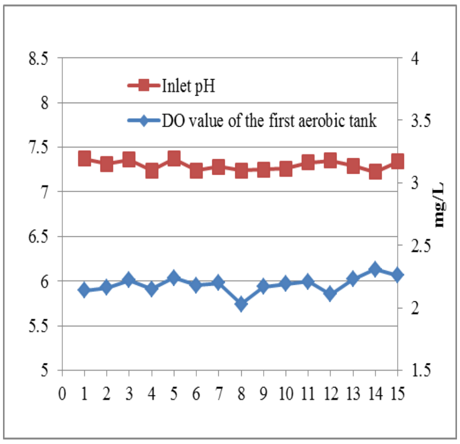

Fig.2. pH and DO

The conventional test indexes of activated sludge include: sludge settling ratio in 30min SV%, activated sludge concentration MLSS, dissolved oxygen in aeration pool DO, pH and other indicators. When the commissioning is completed, the main biochemical process enters into the normal operation phase. As can be seen from Fig.1, the sludge concentration of the suspended activated sludge in the first aerobic pool is within the range of 3770mg/L~4270mg/L. The concentration of the biofilm attached to the efficient suspended filler is not regarded as a daily test item, and the sludge concentration of the suspended activated sludge is taken as the attribute value of sludge concentration in the aeration pool. During the monitoring period, the average concentration of suspended activated sludge of4000mg/L has achieved the design requirements. Sludge settling ratio SV% is the important indicator determining whether the mixture of the reaction biochemical pool can effectively carry out mud-water separation. It can be seen from Fig.1 that the activated sludge settling ratio is between 32% and 39%, averaging 35.3%. The sludge settling ratio is in the normal range [4], and the activated sludge in the biochemical pool is equipped with good settling performance. As the raw water is from the urban domestic sewage with very small proportion of industrial waste water, the influent pH value is very stable. It can be seen from Fig.2 that the influent pH is within the range of 7.22~7.36, showing the typical acid and alkali characteristics of domestic sewage and satisfying the influent pH requirements of urban sewage treatment plant. After the replacement of aeration pipe and aerator, the aeration effect in the aeration pool is effectively improved with the dissolved oxygen DO in the aeration pool reaching 2.03mg/L~2.31mg/L; and the dissolved oxygen in the aeration pool is in a stable state, which meets the requirements for dissolved oxygen in the aerobic condition of activated sludge.

3.2 Index analysis of influent water

To accurately study the effect of denitrification and dephosphorization in the main biochemical system of Bardenpho process, the sampling point of influent index is determined at the outlet of the primary settling pool, and the influent water concentration of each water quality index is shown in Fig.3 and Fig.4.

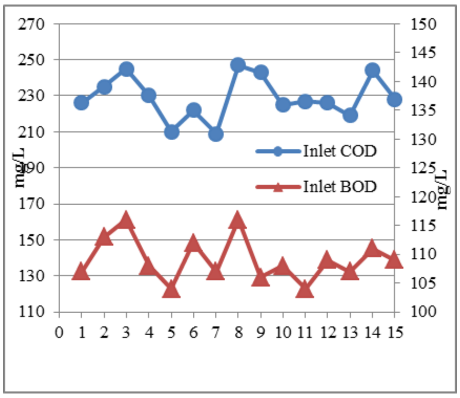

Fig.3. BOD and COD value of the influent water

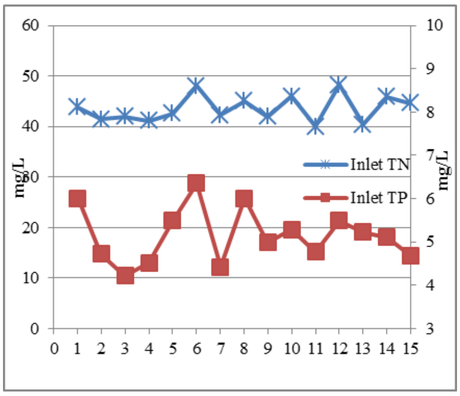

Fig.4. TN and TP value of the influent water

When the raw water flows through the sedimentation pool, the suspended matters with the specific gravity greater than 1 are removed. It is shown in Fig.3 that the COD value of the effluent water in the primary settling pool is within the range of 209mg/L ~ 247mg/L. It is lower to some extent compared with the COD value of the influent water from fine screen with a reduction of 60mg/L~90mg/L. The reason may be that some of the suspended inert organic matters are separated from the processing system along with the matters with the specific gravity greater than 1 through the sedimentation pool. BOD^5 indicates the amount of organic matter during the oxidative decomposition under the action of microbial synthesis. Biological enzymes are indispensable in the microbial metabolic activities, so the organic matters represented by BOD^5 are mainly soluble or organic matters difficult to settle. Fig.3 shows that BOD^5 value changes within 104mg/L~116mg/L after the raw water flows through the primary settling pool, which is slightly decreased or almost the same compared with the BOD^5 value of influent water from the fine screen.

As can be seen from Fig.4, the TN value of effluent in the primary settling pool is in the range of 40.0mg/L~48.2mg/L, and the average TN value of the effluent is 43.5mg/L during the inspection. Thus, the TN of effluents in the biochemical pool is equivalent to the design value, and then it is measured that $BOD^5/TN=2.6$. According to the requirements of biological nitrogen and phosphorus removal in wastewater treatment, when $BOD_5/TN \geq 4.0$, there will be a relatively sufficient carbon source for denitrifying bacteria to conduct denitrification in the anaerobic condition. Therefore, the carbon source of the influent raw water of the sewage treatment plant is apparently insufficient [5]. Fig.4 shows that the TP value of effluent from the primary settling pool is in the range of 4.21mg/L~6.35mg/L, the average TP value of the effluent is 5.2mg/L, and that the TP of the biochemical pool is equivalent to the design value. $BOD_5/TP=21$, which is in line with the requirements of $BOD_5/TP \geq 17$ in the *Outdoor Drainage Design Code* GB 50014.

3.3 Index analysis of influent water

The NH_3-N, TN, TP, COD, BOD_5 value of effluents from the secondary settling pool are shown in Fig. 5 and Fig.6.

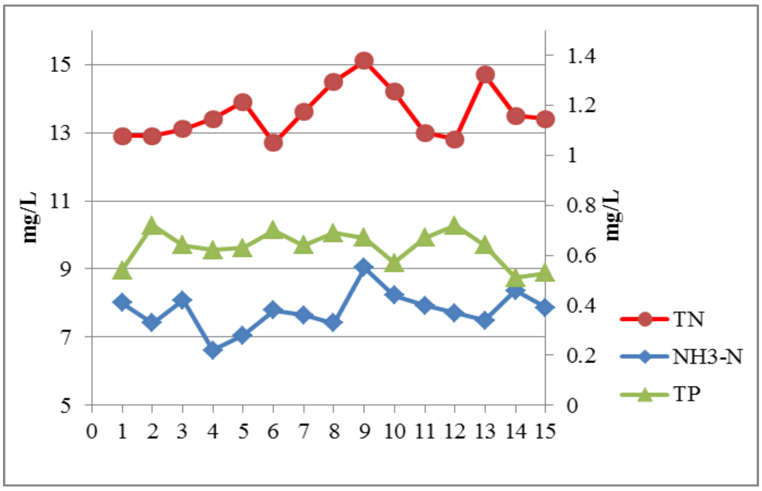

Fig.5. Anmonia nitrogen, TP and TN value of the effluent

NO_3-N transformed from NH_3-N by the nitrification of microorganisms is a necessary condition for denitrification in anoxic pool. As shown in Fig.5, the NH_3-N value of the effluent in the secondary sedimentation pool is between 0.22mg/L ~0.55mg/L, the effluent value of which is much smaller than the 5mg/L stipulated in the standard of A level of the first grade, indicating that the nitrification reaction in the aeration pool is relatively thorough. The reasons analyzed are as follows: the improved aeration system provides a stable amount of dissolved oxygen for the aeration pool; in the main biochemical process, the designed hydraulic retention time (HRT) of the first aerobic pool is 7.5h, but actually HRT> 7.5h because the influent water hasn't reached the designed amount of water inflow; and the efficient suspended filler added to the first aerobic pool increases the number of microbes in the aeration pool, thus ensuring adequate amount of nitrifying bacteria. To sum up, sufficient water retention time, good oxygenation capacity and ample microbial biomass can help ensure efficient removal of NH_3-N.

It can be seen from Fig. 5 that the effluent TN in the secondary sedimentation pool is in the range of 12.7mg/L~15.1mg/L, which basically meets the requirement of TN≤15 mg/L in the first-class A standard. The denitrifying bacteria in the anoxic pool reduce NO_3^--N into N_2 which overflows the entire biochemical system by taking the degradable or easily-degradable organic matters as electron donors and the NO_3^--N obtained from the nitrification stage as the electron acceptors, thus achieving the purpose of biological denitrification. Adequate organics are the sufficient condition for denitrification, but it is clear from the above-mentioned that the influent carbon source is seriously deficient, which is theoretically unable to guarantee the sufficient nitrogen removal. However, the Bardenpho process is characterized with long sludge age and rear section for enhancing denitrification; for the sludge age in the first anoxic pool, HRT=3.2h, θc=4.8d. Longer sludge age and longer denitrification hydraulic retention time contribute to ensuring that the denitrifying bacteria can make full use of the internal carbon source. The hydraulic retention time in the rear anoxic pool equals to 2.4h. The internal carbon sources include starch granules, glycogen and other metachromatic granules formed in the zooglea, which remedies the shortage of carbon source in raw water.

As is shown in Fig.5, the effluent TP in the secondary sedimentation pool is within the range of 0.51mg/L~0.72mg/L, which is higher than the requirements of TP≤0.5mg/L stipulated in the standard A of the first class but satisfies TP≤1.0mg/L stipulated in the standard B of the first class. Polyphosphate bacteria fully release their phosphorus in the anaerobic pool and form synthetic PHB which is to be stored in the cell. In the aerobic pool, energy is generated by decomposing PHB, and part of it is used to absorb the phosphate in the water. This process is characterized by the fact that polyphosphate bacteria can absorb excess phosphorus and store it in the cells so as to achieve the purpose of removing TP in water. Because of the long sludge age and ideal effect of nitrogen removal, the NO_3^- concentration of the reflux sludge from the secondary sedimentation pool to the front end of the biochemical pool is relatively high. When the reflux sludge enters the anaerobic pool, it will compete for the VFA and other organic matters with polyphosphate bacteria, weakening their phosphorus release effect in the anaerobic pool and affecting the removal of phosphorus of phosphorus bacteria in the aeration pool.

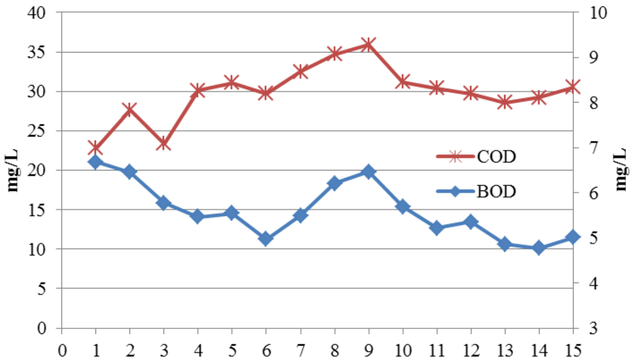

Fig.6. BOD_5 and COD value of the effluent

It can be seen from Fig.6 that COD value of the effluent from the secondary sedimentation tank is within 22.8mg/L~35.9mg/L and that the average value during the inspection period is 29.8mg/L, which has reached the requirements in the standard A of the first class. The BOD_5 value of the effluent from the secondary sedimentation tank is in the range of 5.01mg/L~6.68mg/L and that the average value during the inspection period is 5.60mg/L, having reached the requirements in the standard A of the first class. The purification of COD and BOD_5 in the sewage relies mainly on the adsorption of activated sludge and the degradation of microorganisms in the activated sludge. Good activated sludge has the characteristics of efficient adsorption and degradation of organic matter in water. As is indicated above, the activated sludge in the biochemical system is in a good state, which is ready for BOD_5 and COD to achieve the standard A of the first class.

4. Study on the effect of nitrogen and phosphorus removal in different working sections of the biochemical pool

The overall situation of the influent and effluent water in the Bardenpho process demonstrates that the treatment effect is favorable. To further study the operation characteristics of each section, the water quality are tested in different points of the biochemical pool (see Fig.7 and Fig.8).

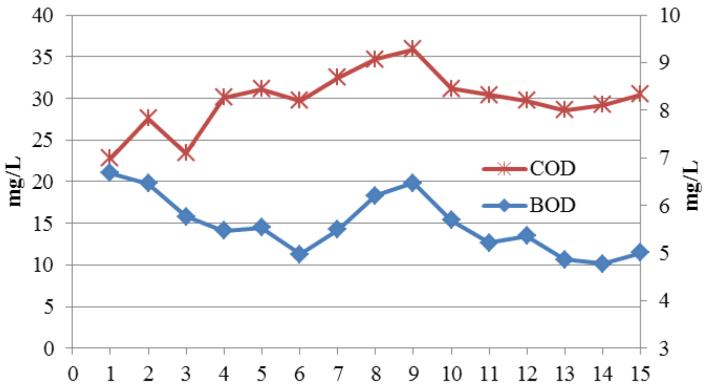

Fig.7. BOD_5 and COD value of the effluent

As can be seen from Fig. 7, the removal of TN by the Bardenpho process is mainly carried out in the first anoxic pool [6]. The TN at the end of the first anoxic pool is between 17.9mg/L~20.4mg/L, which basically reaches the standard B of the first class; and the average TN removal rate of the first anoxic pool is 55.4%. The TN value of the rear anoxic pool is within the range of 14.3mg/L~16.7mg/L with the average effluent being 15.4mg/L during the detection; the average TN removal rate in it is 9.3%, slightly higher than the standard A of the first class. The average TN of the total effluent is 13.58 mg/L, so the removal quantum of TN is about 1.72 mg/L for the secondary sedimentation pool and other treatment facilities and the average removal rate is about 4.2%. The removal of TN by subsequent treatment facilities is mainly completed in the secondary settling pool. Without oxygenation equipment, the retention time in the secondary sedimentation pool is relatively long (HRT=2.5h). When the dissolved oxygen in the mixture of the aeration pool is consumed by microorganisms to a certain level in the secondary sedimentation pool, the denitrification effect occurring can lead to the slight decline of TN of effluent from the secondary sedimentation pool [7-9].

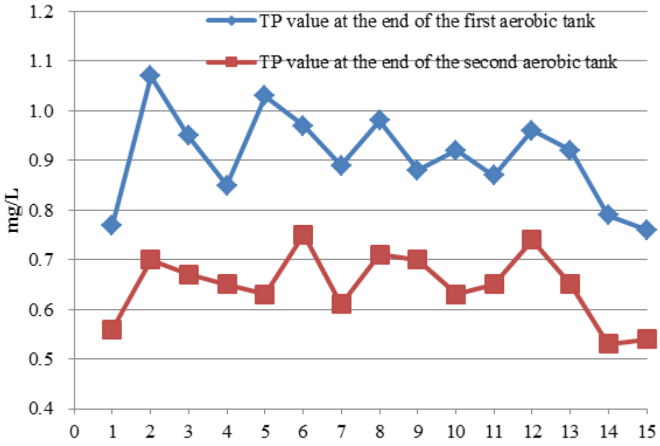

Fig.8. TP value at different points of the biochemical pool

As is shown in Fig. 8, the TP value at the end of the first aerobic pool is in the range of 0.76mg/L~1.07mg/L, averaging 0.91mg/L during the monitoring period, and the average removal rate is 82.2%. Through the aeration pool at the end, the TP value of effluent from the second aerobic pool is between 0.53mg/L~0.75mg/L, averaging 0.65mg/L during the monitoring period which is quite close to the average TP of the total effluent (0.63mg/L), and the average removal rate is 5.1%. Therefore, the removal of TP is mainly completed in the first phase of the biochemical pool, and the removal effect of TP by the follow-up treatment facilities is very trivial [10].

5. Conclusion and suggestions

(1) The filler-reinforced Bardenpho process increases the number of microorganisms in the aeration pool. Combined with good aeration and other operation conditions, it upgrades nitrification to a sufficient one, providing adequate conditions for denitrification.

(2) Bardenpho process, which is characterized by long sludge age, long hydraulic retention time and low sludge load, has strong adaptability to sewage with low C/N ratio. Therefore, it can help maximize the development of internal carbon source from the zooglea to save lots of external carbon sources and ensure the smooth progress of denitrification to render sewage treatment efficient and economical.

(3) Low sludge load, long sludge age and other factors result in a lesser satisfactory phosphorus removal effect of Bardenpho process. In view of the contradiction in synchronous biological nitrogen and phosphorus removal, it is recommended to adopt chemical-assisted phosphorus removal. Chemical phosphorus removal agent like PAC can be added at the outlet of the biochemical pool or other positions to guarantee that the total phosphorus amount in the effluent can satisfy the TP concentration control requirements of standard A of the first class [11-12].

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