Influence of Temperature and Dissolved Oxygen on Nitrogen and Phosphorus Removal of Integrated Bioreactor

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Abstract: *An integrated biological membrane sewage treatment device has been designed based on the mechanism of microorganism nitrogen and phosphorus removal and the influence of temperature and dissolved oxygen on nitrogen and phosphorus removal of integrated bioreactor with adoption of this sewage treatment device. The research results shows that the optimal temperature range of microorganism nitrogen and phosphorus removal is 20-30 °C, and the effluent COD removal rate within this range maintains at over 90%;* NH_4^+*-N removal rate is between 95% and 97%. TN removal rate is approximately 81%. In practical production, the internal temperature environment of the sewage reactor should be maintained at above 15 °C, to decrease the inhibition of low-temperature environment on growth and reaction speed of nitrobacteria. In various concentrations of DO in the reactor, there is little change in the effluent COD concentration and effluent COD concentration is influenced by temperature. With the increasing of DO concentration, both effluent TN and TP concentrations present changing features of initially decreasing then increasing. The analysis of the influence of comprehensive dissolved oxygen on microorganism nitrogen and phosphorus removal reveals that when the concentration of DO maintains within the range of 1.0-1.5 mg/L, the sewage purification system can attain a higher nitrogen and phosphorus removal effect.*

Keywords: *Simultaneous nitrification and denitrification, Temperature, Dissolved oxygen, Nitrogen and phosphorus removal.*

Introduction

With the continuous expansion of city sizes and rapid growth of urban populations, an increasing number of sewage treatment plants being put into operation. Sewage treatment plants usually adopt a physical method, chemical method or biological method for sewage treatment. Biotechnology for purifying sewage is based on has low cost and is environmentally friendly, and has been extensively applied to each sewage treatment plants. Biological treatment technology is developed to be environmentally suitable for microbial growth to improve the degradation rate of microorganisms for organisms in sewage and to realize a sustainable method for water resources.

There are relatively mature sewage biological treatment technologies, which mainly include the activated sludge process [6, 8, 15, 16], the A/O and A^2/O process [10, 18], the oxidation ditch method [9, 19], SBR [1, 2, 17] and BAF [4] processes, etc. The biological nitrification and denitrification of traditional sewage treatment methods is done in reactors with various dissolved oxygen concentrations and then a series connection is made between reactors and mixed with liquor and sludge as the return operation. The process has common shortcomings of large building area and high management and operation cost. Therefore, optimizing the sewage treatment process and realizing nitrification and denitrification in an integrated reactor is of great significance in shortening the biological denitrification process, decreasing reaction time and simplifying the management process, which can also arouse simultaneous nitrification and denitrification studies of numerous scholars [3, 11, 13, 14]. In recent years, the sewage treatment device has been developing toward an integrated biological reactor with a small building area and low cost [7, 12] and is making obvious improvements in the efficiency of sewage treatment.

In practical production, as biological sewage treatment is affected by various factors, such as temperature, pH value, dissolved oxygen concentration and sludge structure [5, 20], it is very difficult to prevent further oxidation of NO_2^--N and realize biological simultaneous nitrification and denitrification completely. Therefore, the influence of different impact units on sewage treatment efficiency must be studied, as well as the effects of nitrogen and phosphorus removal. This paper has designed an integrated biological membrane sewage treatment device based on previous research results and studied the influence of temperature and dissolved oxygen on integrated bioreactor nitrogen and phosphorus removal with adoption of this sewage treatment device. The research results can provide helpful theoretical guidance for urban sewage treatment.

Materials and methods

Experiment device and process

The designed schematic of the experiment device is shown in Fig. 1. The reaction tank and sedimentation tank in the experimental device is composed of organic glass, and the effective volumes of the anoxic and aerobic zones in reaction tank are 4.8 L and 6 L respectively. These two are separated by clapboard where the aerator is located, and the total volume of the reaction device is 10.8 L. The upper layer of the aerobic zone is sponge carrier with biofilm activity, which can provide Ca, Fe, Mg, Si and other growth elements to microorganisms within the reaction area.

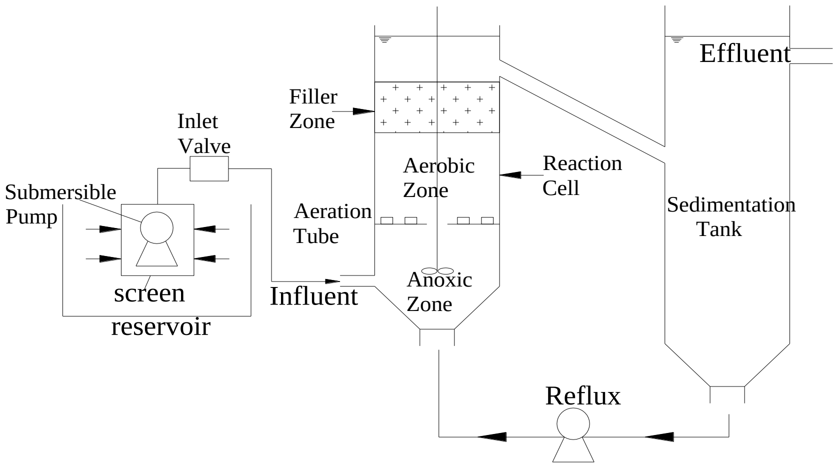

Fig. 1 Schematic of experiment device

The sewage used in the experiment flows from a storage tank to the reaction tank and then flows through the anaerobic and aerobic zones one by one. The water in the reaction zone flows from the upper part of the reactor to the sedimentation tank. The nitrification liquid and sludge are gradually separated from the water in the reaction area, and it backflows to the anaerobic zone within the reactor, and then the backflow water is slowly stirred with a blender, and the sewage treatment cycle is repeated two or more times until the concentrations of COD, NH_4^+-N, TN, TP and others become lower than the national standards.

Experiment water quality

Experiment influent is the selected sewage in the city center of one city; the water quality change of sewage within one day is shown in Table 1. The unit is mg/L, the main chemical components in the sewage are NH_4Cl, KH_2PO_4, $CaCl_2$ and various organic carbon sources, etc.

Table 1. Water quality of test wastewater (mg/L)

Composition	**COD**	NH_4^+-N	**TN**	**TP**	**pH**
Range	183.5-326.2	14.2-31.9	19.3-42.6	2.13-5.96	6.7-7.5
Mean	261.1	20.94	31.1	3.88	7.1

The following indicators have been adopted to test the effluent quality of the designed sewage treatment device. Five times of sampling have been selected for a single parameter and standard potassium dichromate method has been adopted to test the COD concentration; ammonia nitrogen adopts Nessler's Reagent method; nitrates and nitrites are tested with ion chromatography; TN and TP are tested with potassium sulfate oxidation and stannous chloride.

Results and discussion

Influence of temperature on sewage treatment

Temperature has a greater influence on the microorganism degrading organism in sewage. The reaction velocity of microorganism at various temperatures can be expressed as:

$$V_B/V_T = \gamma^{T-B}. \tag{1}$$

B and *T* are the mist suitable temperature and temperature at *T* value requested in microorganism reaction; *VB* and *VT* are the most suitable temperature and the reaction velocity of microorganism when temperature is at *T* respectively; γ is the temperature coefficient. The enzyme catalyzed reaction rate of microorganism can be expressed as

$$\delta = \beta \exp(-E_A/\omega T), \tag{2}$$

where δ is enzyme catalyzed reaction rate constant; β is related parameter; ω is gas constant; *T* is absolute temperature; *EA* is the activation energy of this reaction. It can be known from Eq. (1) and Eq. (2) that when the temperature is too high or too low, the activity and growth rate of microorganism obviously decrease, causing a decrease in the overall activity of microbial population in the sewage. Excessive low temperatures will also cause decreased activity of the microbial enzymes and affect the sewage purification effect.

To study the influence of temperature on microorganism sewage treatment technology, removal tests of microorganisms for different organisms in sewage have been conducted respectively under three different temperatures of low temperature (10 ± 5) °C, middle temperature (25 ± 5) °C and high temperature (35 ± 5) °C by combining the temperature change situations of four seasons per year. To make the experiment results more accurate, the final sampling interval is confirmed as one day and the sampling time is 100 days. Eq. (3) has been adopted to evaluate the removal effect of microorganisms on organism in sewage.

$$\varepsilon_r = \frac{C_i - C_e}{C_i} \times 100\%, \tag{3}$$

where ε_r is organism removal rate; C_i and C_e are influent and effluent concentrations in the reaction tank.

(1) Influence of temperature on COD removal effect

The influent COD concentration range under three temperature periods is 235-310 mg/L. After microorganism treatment, the situation of effluent COD concentration with the changing of time is shown in Fig. 2.

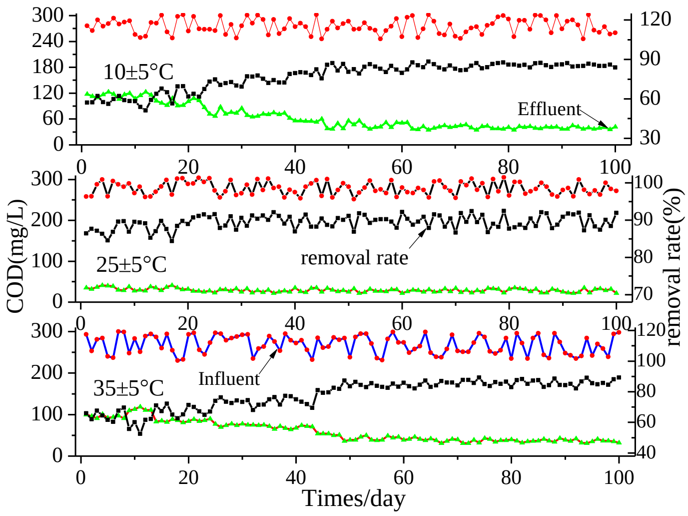

Fig. 2 Changes in concentration of COD with various temperatures

It can be seen from the figure that when the temperature in the reaction tank is controlled at the low temperature stage, because the activity of the microorganisms is decreased caused by the low temperature, its own metabolic capacity is weakened. The effluent COD concentration 15 d before the experiment is as high as 105-120 mg/L and the corresponding COD removal rate is only 55%-65%. When the time exceeds 15 d, the microorganisms in the reaction tank gradually become accustomed to the low temperature environment and the decomposition ability gradually strengthens. When the effluent COD concentration gradually decreases and the time exceeds 30 d, the effluent COD concentration decreases below 70 mg/L, and the COD removal rate exceeds 73%. The final effluent COD concentration stabilizes between 35-45 mg/L and the COD removal rate is between 85% and 89%. However, when the temperature in the reaction tank is controlled at a high temperature stage, effluent COD concentration and COD removal rate presents similar features as the low temperature stage, which is that at the preliminary stage of reaction, the microorganisms present lower decomposition velocity and the effluent COD concentration and COD removal rates are 100-115 mg/L, 52%-67% respectively. With the increasing of time and strengthening of decomposition efficiency, the final effluent COD concentration is stabilized at 30-40 mg/L and 85%-90%. However in the middle temperature stage, the enzyme activity of microorganisms at 20-30 °C is the highest and COD decomposition rate in the sewage is the highest. At the preliminary stage, effluent COD concentration and COD removal rate is

32-42 mg/L, 85%-88%. At the middle stage and post stage of observation, the effluent COD concentrations are lower than 30 mg/L, and the removal rate is maintained at over 90% basically and attains a better effect in COD removal in sewage.

(2) Influence of temperature on NH_4^+-N removal

The influent NH_4^+-N concentration range under three temperature periods is 15-29 mg/L and the changing situation of effluent NH_4^+-N concentration with passing of time is shown in Fig. 3. Similar to the change in COD concentration at different temperatures, when remaining at low temperature and high temperature stages, because the growth velocity and biological enzyme activity of microorganism at these two environments are inhibited, the NH_4^+-N concentration of system effluent at preliminary stage is higher, at around 10 mg/L and 9 mg/L and the removal rate is only 60% and 55%. After the reaction lasts for a period of time, microorganism adapts to the low temperature and high temperature environment. At the same time, because the biological membrane module has an interception effect on sludge within the system, which makes the sludge in the reaction tank constantly remain at higher concentration and ensures the growth enrichment of nitrobacteria. Moreover, the reflux liquid in the sedimentation tank has a dilution effect on influent in the reaction tank and gradually decreases the effluent NH_4^+-N gradually. The figure shows that at the middle and post periods of supervision, the effluent NH_4^+-N concentrations at low temperature and high temperature stages gradually decrease and finally are stabilized at about 6 mg/L and 2.5 mg/L and the removal rates are 81% and 88% respectively. However at the middle temperature stage, because the temperature is good for the growth of nitrobacteria, system effluent NH_4^+-N concentration is maintained between 0.6-1.1 mg/L, and the removal rate is between 95%-97% with good removal effect.

In the whole detection period, the NH_4^+-N removal rate at low temperature stage is at 74%; the NH_4^+-N removal rate at middle temperature stage is at 96%, while the NH_4^+-N removal rate at high temperature stage is at 80%. It can be seen that the NH_4^+-N removal in sewage at the middle temperature stage attains the optimal effect while the NH_4^+-N removal effect at the low temperature stage is the worst. Therefore, in practical production, the internal temperature environment in sewage reactor needs to be ensured above 15 °C and decreases the inhibition function of low temperature environment on the growth and reaction velocity of nitrobacteria.

(3) Influence of temperature on TN removal effect

Influent TN concentration under the condition of three temperature periods is 26-38 mg/L. The changing situation of effluent TN and removal rate with the passing of time is shown in Fig. 4. Because there is no large difference in influent TN concentration under three conditions, the average influent concentrations of low temperature, middle temperature and high temperature have been selected in the Fig. 4.

It can be seen from the figure that at low temperature and high temperature stage, the system effluent TN concentration at preliminary stage is larger, reaching 19-21 mg/L, which is due to the fact that the activity of nitrobacteria decreases under un-suitable condition, and the conversion rate from NH_4^+-N to NO_3^--N and NO_2^--N is relatively low. Meanwhile, because the biological enzyme activity is affected, denitrification in the reaction tank is relatively slow, causing the total TP amount in effluent is higher. Due to the reflux effect in mixed liquor as well as the adaption of microorganisms to temperature, the system effluent TN concentration gradually decreases. However, because the nitrogen metabolism and utilization rate is lower than the suitable temperature and effluent TN concentration slowly decreases. It can be seen from the figure that the effluent TN concentrations at low temperature and high temperature environment are stabilized at about 14 mg/L and 10 mg/L and the removal rates are stabilized at 55% and 68%. 20-30 °C is the suitable growth temperature of microorganism. Under this temperature, the system effluent TN concentration significantly decreases. Unless the TN concentration reaches the climax at 11 mg/L at 8-14 d, the effluent concentration at other time period is relatively low.

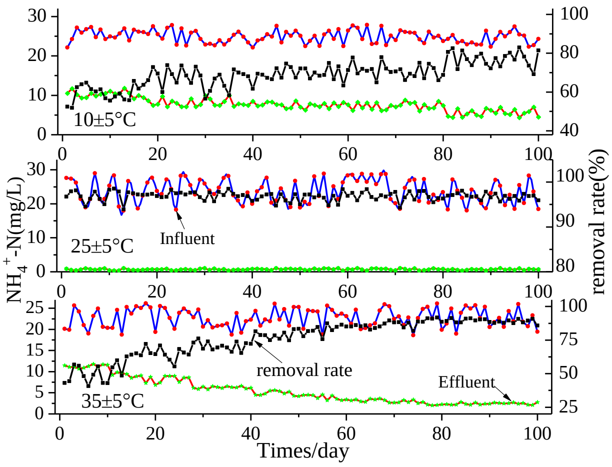

Fig. 3 Changes in concentration of NH_4^+-N with various temperatures

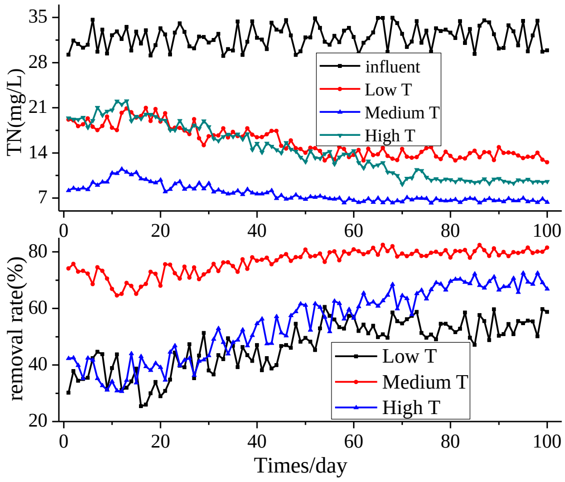

Fig. 4 Changes of concentration and removal rate of TN with various temperatures

The conversion rate from NH_4^+-N to NO_3^--N and NO_2^--N within the reaction tank has been greatly improved and later, the nitrogen ion in solution has been transferred to N_2 and then is removed through denitrification. At the same time, the isolation effect of designed biological membrane can effectively intercept sludge, which can make the sludge concentration within reaction tank maintain at a higher level and further strengthen the removal of TN. It can be seen from the figure that the final system effluent TN concentration is stabilized at 6.6 mg/L and the removal rate is close to 81%.

Within the test cycle, the TN removal effect at low temperature is the worst. Therefore, by combining the above analysis, the environmental temperature of the reactor must be ensured at above 15 °C and decrease the inhibition function of low temperature environment for the growth and reaction velocity of nitrobacteria. Because the concentration changing trend of TP under different temperature conditions is basically the same as TN, so it will not be repeated here.

(4) Influence of Dissolved Oxygen on Sewage Treatment

<u>(a) Influence of dissolved oxygen on the effect of nitrogen removal</u>

Maintain the inner temperature in reactor at 20-30 °C, and pH at 7.1-7.4, and ensure that the system effluent concentration is not interfered by other factors. The water quality of experimental sewage is as follows: COD influent concentration is 250-290 mg/L; NH_4^+-N concentration is 25-30 mg/L; influent TN concentration is 29-35 mg/L and sludge concentration is 2.2 g/L.

Through adjusting air intake, the DO in reactor is adjusted into seven concentrations at 0.2, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 mg/L. The reactor operates 30 d at the early stage and stabilizes the decomposition rate of microorganisms for organism in sewage. In the following, continuous monitoring is conducted of 10 d, and finally, the average value of concentration of each element is selected in each DO range to attain its effluent TN concentration and removal rate under different DO concentrations, as shown in Fig. 5.

It can be seen from Fig. 5 that under the condition of the reactor with various concentrations of DO, there is little change in effluent COD concentration. Within suitable temperature and pH environment, the COD effluent concentration changes within the range of 20-30 mg/L and the COD removal rate is at about 90%. DO has little influence on effluent COD concentration, aerobic granular sludge has good organism metabolism ability and the COD concentration is influenced by temperature.

When the DO concentration is at 0.2 and 0.5 mg/L, the effluent NH_4^+-N concentration is high, reaching 13 and 6.4 mg/L respectively, and the removal rates are only 49% and 74%. When the DO concentration gradually increases, there is an obvious decrease in effluent NH_4^+-N concentration. When DO $\geq$ 1.0 mg/L, NH_4^+-N concentration is decreased to below 2 mg/L, the removal rate is above 93%. Because nitrite bacteria is classic aerobic bacteria, with the increasing of DO concentration, NH_4^+-N is conversed to NO_3^--N and NO_2^--N and nitrification efficiency has been strengthened. Meanwhile, when DO < 0.5 mg/L, because the reaction tank can be regarded as an anoxic environment, excessive DO concentration significantly inhibits the activity of nitrite bacteria and nitration reaction is slow. Therefore, when DO concentration reaches above 1.0 mg/L, nitrogen removal from sewage can attain a better effect.

With the increasing of DO concentration (see Fig. 5), effluent TN concentration presents a changing feature of firstly decreasing and then increasing, and the concentration value decreases from the initial 16 mg/L to the minimum value of 6.5 mg/L. When DO concentration exceeds 1 mg/L, TN concentration increases to 15 mg/L gradually and the change range of removal rate is 53%-80%. When DO < 0.5 mg/L, the activity of nitrite bacteria is inhibited, which affects nitrification rate, affects the decomposition of NH_4^+-N and then makes the effluent concentration of TN larger. Meanwhile, when DO $\geq$ 2.0 mg/L, decomposition of NH_4^+-N is not affected, further denitrification effect needs anoxic environment, excessive DO concentration is due to the fact that the activity of anaerobic microorganism is inhibited which causes the further increase of TN concentration. When the DO concentration range is at 0.5-1.5 mg/L, the velocity of nitration is higher. At the same time, the DO concentration is suitable, which ensures that there is much un-dissolved oxygen in particle sledge, assuring that the anoxic environment of denitrification bacteria makes decomposition activity and maintains the final TN effluent concentration at a lower level. Within 0.5-1.5 mg/L (see Fig. 5), TN concentration decreases to 6.5-8 mg/L and the removal rate is at 75-80%.

Based on above comprehensive analysis, it can be confirmed that in a suitable temperature environment and when the concentration of DO is within 1.0-1.5 mg/L, the system effluent can have a better nitrogen removal effect.

<u>(b) Influence of dissolved oxygen on phosphorus removal effect</u>
Maintain the environmental temperature and pH value unchanged in the reactor and influent TP concentration at 2.5-3.4 mg/L. Effluent TP concentration and removal rate under different DO conditions are as shown in Fig. 6.

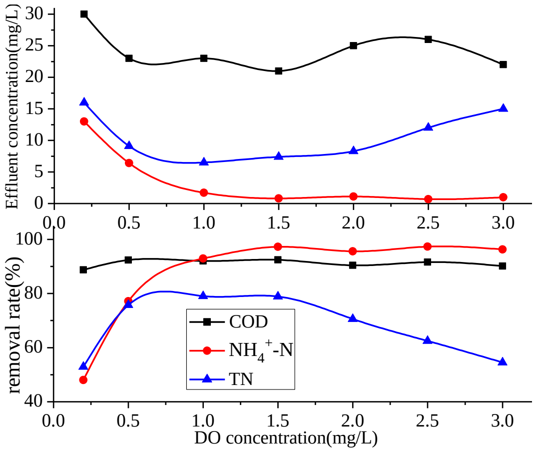

Fig. 5 Effluent concentration of three indexes under different DO concentration

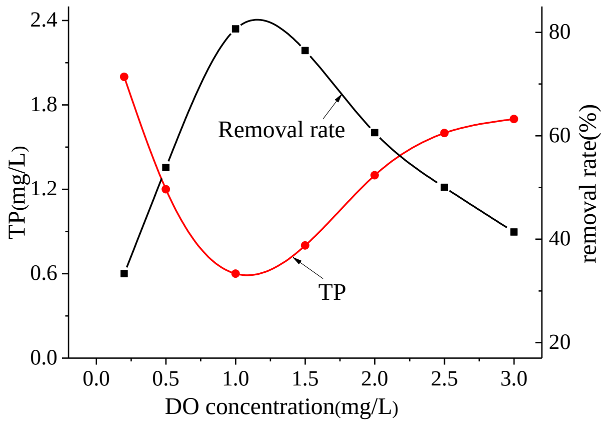

Fig. 6 Effluent concentration and removal rate of TP with various DO concentrations

Fig. 6 shows that when DO ≤ 0.5 mg/L, TP the removal effect is bad and the removal rate is only 33% and 54%. When the DO is relatively low, the activity of aerobic phosphorus accumulating bacteria is weak, which has no reaction or slow reaction to phosphate in solution. Under anoxic condition and in the reaction tank, sewage phosphorus removal depends on denitrification effect of nitrate. When 0.5 < DO ≤ 1.5 mg/L, effluent TP concentration gradually decreases, at about 0.6-1.0 mg/L, and the removal rate gradually increases to 70-80%. However, when DO concentration increases further, TP concentration starts to increase again. When the concentration reaches 3.0 mg/L, the removal rate is only 42%, which is due to the fact that when the concentration of DO in the reaction tank is extremely high, it inhibits the denitrification effect of microorganism and causes much of the nitrate nitrogen to remain in the solution. Because nitrate nitrogen destroys the denitrification effect of nitrate nitrogen in anaerobic condition of biological phosphorus removal, it affects the removal of phosphorus accumulating bacteria for phosphorus element. Because activated sludge can provide an anaerobic environment, therefore when DO = 1.5 mg/L, it can ensure the reflection of phosphorus accumulating bacteria and aerobic absorption of phosphorus reaching a balanced state.

The analysis of influence of DO on biological removal of nitrogen and phosphorus reveals that when DO concentration is maintained within the range of 1.0-1.5 mg/L, the sewage purification system can attain a higher nitrogen and phosphorus effect.

Conclusion

1) An integrated biological membrane sewage treatment device has been designed with features of small investment, less land occupation and easy operation, which has achieved a better effect in reducing reaction time and simplifies the management process and realized nitrogen and phosphorus removal process of simultaneous nitrification and denitrification.
2) When the temperature is too high or too low, the microbial metabolic capacity and biological enzyme activity have been inhibited and nitrogen and phosphorus removal velocity in sewage obviously decreases. Based on research in this paper, the optimal temperature range of microbial nitrogen and phosphorus removal is 20-30 °C, and the

effluent COD removal rate within this range remains at above 90%. The NH_4^+-N removal rate is between 95%-97%, and the TN removal rate is approximately 81%. The influence degree of various temperatures on microbial nitrogen and phosphorus removal effect is middle temperature (20-30 °C) > high temperature (30-40 °C) > low temperature (5-15 °C). In practical production, the internal environmental temperature in sewage reactor should be maintained at above 15 °C and decrease the inhibition function of low temperature environment for growth and reaction velocity of nitrobacteria.

3) When the reactor has DO various concentrations, there is little change in effluent COD concentration, and effluent COD concentration is influenced by temperature. With the increasing of DO concentration, both effluent TN and TP concentrations presents a changing feature of initially decreasing and then increasing. The analysis of influence of DO on microbial nitrogen and phosphorus removal reveals that when DO concentration maintains within the range of 1.0-1.5 mg/L, sewage purification system can attain higher nitrogen and phosphorus removal effect.

Acknowledgements

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