Intelligent Control System Based on Artificial Neural Network
Applied research in autotrophic nitrogen removal process

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Abstract. In view of the difficulty in controlling the stable operation of autotrophic nitrogen removal system, this study plans to design a DO intelligent control system based on artificial neural network control, which can intelligently and accurately control dissolved oxygen in liquid phase according to the water inflow and operation state of the system. Firstly, the autotrophic nitrogen removal system was constructed step by step, and the influence of dissolved oxygen with different concentrations was explored by using the characteristics of system microbes sensitive to dissolved oxygen. Then, the dissolved oxygen intelligent control system based on artificial neural network was developed. Finally, the operation mode of autotrophic nitrogen removal process optimized by the dissolved oxygen intelligent control system based on artificial neural network was explored and the key parameters of system operation were put forward. The single-stage autotrophic nitrogen removal system equipped with DO precise control system was tested by artificial simulated wastewater. Under various load conditions, the total nitrogen removal rate of the system was more than 86%, and the system was efficient and stable.

1. Introduction
At present, the protection of water resources in China is gradually increasing, the emission standards of nitrogen and phosphorus pollutants in urban sewage treatment plants are becoming stricter, the problem of insufficient carbon sources for dephosphorization and denitrification of urban sewage has become increasingly prominent.

The basic principle of the autotrophic denitrification system is to reasonably control the external environment so that nitrosating bacteria and anammox bacteria coexist in the reactor to achieve the purpose of synergistic denitrification. Compared with the traditional nitrification and denitrification process, the autotrophic denitrification technology has the advantages of 100% reduction in carbon source demand, 60% reduction in oxygen demand, 90% reduction in sludge production and 85% reduction in water plant operation cost. Carbon-free autotrophic denitrification technology will become the key to solving the bottleneck of urban sewage carbon source. At the same time, with the development trend of low carbon, low energy consumption and energy self-sufficiency in sewage treatment plants, the carbon shift turns the carbon source used in the traditional biological phosphorus and nitrogen removal, which is used for the energy extraction of the sewage plant itself to realize the energy self-sufficiency of the sewage plant. Therefore, autotrophic nitrogen removal technology will become the preferred technology of nitrogen removal in the future, and has broad application prospects.

However, the autotrophic nitrogen removal system still has the problem of difficult operation and control.
Intelligent control is the advanced stage of the development of automatic control, which has the ability of self-learning, self-adaptation and self-organization. It can solve the problem of complex control system which is difficult to solve by classical control. The introduction of intelligent control into sewage denitrification treatment can not only reduce the impact of system interference on operation, but also improve treatment efficiency and reduce operating costs. The research and application of intelligent control for wastewater treatment in China is still in its infancy and development stage. Therefore, it is of great practical significance to strengthen the research on intelligent control technology of sewage treatment.

Aiming at the shortcomings of difficult operation and control of the autotrophic nitrogen removal system, this project plans to design a DO intelligent control system based on artificial neural network control, which can intelligently and accurately control liquid dissolved oxygen according to the system's water intake and operating status. The principle of the intelligent control system, on the one hand, is based on the RBF neural network to achieve feedforward control, that is, to quickly determine the frequency output value of the inverter according to the system water intake, and adjust the DO setting value of the reactor. On the other hand, the self-adaptive PID closed loop based on BP neural network realizes precise feedback control, that is, the precise adjustment of DO is within the required range. The proposal of the DO control system plays an important role in inhibiting the growth of nitrifying bacteria in the autotrophic denitrification system and ensuring the operational stability of the reactor, and proposes a new idea for the automatic control of the sewage treatment system.

2. Materials and Methods

2.1. Design of DO Intelligent Control System Based on Artificial Neural Network

2.1.1. System structure design
The single-stage autotrophic denitrification system has a wide variety of microorganisms and a complex microenvironment. The activity of the system's functional bacteria is closely related to the dissolved oxygen concentration. DO is the key factor to realize the efficient operation of the single-stage autotrophic nitrogen removal process. DO control has nonlinear and large hysteresis characteristics, and traditional control methods are difficult to achieve stable control. And there are reports that the oxygen demand of the single-stage autotrophic nitrogen removal process is not static, it should be adjusted according to the ammonia nitrogen concentration and COD concentration of the system influent. To this end, the study constructed a feedforward and feedback compound control system.

The control system structure is shown in Figure 1. Based on the feedforward control of the RBF neural network, the frequency output value of the inverter can be quickly determined according to the system inlet water. And adjust the DO set value of the reactor. If the water quality changes, the corresponding DO setting value also changes. BP neural network based self-adaptive PID closed-loop feedback control is used to accurately adjust do within the required range. The do control system has the advantages of flexible control and real-time performance, which plays an important role in restraining the growth of nob and ensuring the operation stability of the reactor.
In addition, the default temperature value of the system in this test is 30°C and the temperature variable is not added in the control system. However, the DO control system can be applied to water treatment systems under different temperature conditions. When the system needs to treat sewage under other temperature conditions, it only needs to use the actual temperature value as the input value of the RBF neural network and provide it to the feedforward control system for the calculation of the output frequency. At this time, the DO control system combines temperature, and the water conditions quickly calculate the DO set value, and the DO is maintained in a reasonable range.

2.1.2. Design of feedforward controller based on RBF neural network

Aiming at the changes of influent ammonia nitrogen and COD concentration, a 6-input single-output RBF neural network is constructed, and the structure is shown in Figure 2. The 6 input variables are the influent NH₄⁺–N concentration, the influent COD concentration and the effluent NH₄⁺–N, NO₃⁻–N, NO₂⁻–N, COD concentration that meets the emission standards, respectively n₁, n₂, n₃, n₄, n₅, n₆ said. The output variable is the frequency output value of the inverter, which is used to control the aerator adjustment system DO, represented by p.
2.1.3. Design of PID feedback controller based on BP neural network
The structure of the adaptive PID controller based on BP neural network is shown in Figure 3. The control structure has three layers. The input layer has a neuron, which is the deviation $e$ between the DO set value and the measured value; the hidden layer has three neurons, which are the proportional, integral and differential terms in PID control; output the layer has a neuron that performs weighted calculations on the hidden layer information to complete the sum output function of the network. The weighted value of the output layer is the weighted sum of the deviation term, the deviation integral term, and the deviation differential term. $K_P$, $K_I$ and $K_D$ represent the connection weight of the hidden layer and the output layer, so the hidden layer to the output layer is equivalent to a traditional PID controller.

![Figure 3 Structure diagram of BP neural network](image)

2.2. Construction of SNAP system based on DO precise control

2.2.1. Test device
The SBBR reactor device used in the experiment is shown in Figure 4. The test device is equipped with an online dissolved oxygen meter, a frequency converter and an industrial computer to form a single-stage autotrophic denitrification intelligent control system. The single-stage autotrophic nitrogen removal intelligent system based on DO precise control is equipped with an online ammonia nitrogen meter and a COD meter to realize a feedforward control system.
2.2.2. Test water quality
The test water used artificial simulated sewage, and the pH was controlled at 7.8±0.2. By adding an appropriate amount of NH₄HCO₃ to tap water to prepare influent water with different ammonia nitrogen concentrations. The remaining components of the simulated sewage include: glucose, appropriate amount; KH₂PO₄, 25mg/L; FeSO₄, 6.25mg/L; MgSO₄·7H₂O, 100mg/L; CaCl₂, 150mg/L; EDTA, 25mg/L. Taking into account the needs of microbial growth, trace elements are added to the distribution water. The specific composition is shown in Table 1.

| Name            | Content | Name            | Content |
|-----------------|---------|-----------------|---------|
| ZnSO₄·7H₂O      | 0.43g/L | CuSO₄·5H₂O      | 0.43g/L |
| CuCl₂·6H₂O      | 0.24g/L | Na₂MoO₄·2H₂O    | 0.22g/L |
| MnCl₂·7H₂O      | 0.99g/L | NiCl₂·6H₂O      | 0.19g/L |
| H₃BO₄           | 0.014g/L| Na₂WO₄·2H₂O     | 0.05g/L |

3. Results and discussion
The control effect of dissolved oxygen intelligent precise control system based on artificial neural network is tested when the influent ammonia nitrogen load changes in the range of 0.05~0.2kgm⁻³d⁻¹.

The MicroLogix1100, 1763-L16BWA is used as PLC controller in the test process. The controller is equipped with 10-point digital input, 2-channel 0~10V analog input and 6-point relay digital output. RSLogix500 is the PLC development software, Rslinx Classic Gateway is the configuration.
communication software, BOOTP-DHCP Server is the IP address allocation software, and RSview32 is the man-machine interface design software. The I/O address allocation of the controller and each module is shown in Table 2.

Table 2 I/O address allocation table

| Assign address | Variable                  |
|----------------|---------------------------|
| I:1.0          | DO value of dissolved     |
|                | Oxygen meter              |
| O:1.1          | Inverter frequency        |

The construction process of the low ammonia nitrogen wastewater SNAP system mainly includes three stages: the adaptation period, the nitrosating bacteria enrichment period, and the anammox bacteria enrichment period. The construction of the low ammonia nitrogen wastewater SNAP system based on the precise control of DO is mainly used in the system construction third stage (the enrichment period of anammox bacteria).

Table 3 DO concentration and blower frequency under different influent load

| Influent nitrogen load(kgm⁻³d⁻¹) | DO(mg/L) | Blower frequency(HZ) |
|-----------------------------------|----------|-----------------------|
| 0.05                              | 1.26     | 32.9                  |
| 0.06                              | 1.27     | 33.0                  |
| 0.08                              | 1.29     | 33.2                  |
| 0.1                               | 1.31     | 33.4                  |
| 0.12                              | 1.35     | 33.5                  |
| 0.14                              | 1.40     | 33.6                  |
| 0.16                              | 1.42     | 33.8                  |
| 0.18                              | 1.44     | 34.0                  |
| 0.2                               | 1.45     | 34.2                  |

Table 4 Effluent quality under different influent loads

| Influent nitrogen load (kgm⁻³d⁻¹) | Average nitrate nitrogen concentration in effluent (mg/L) | Average nitrous acid concentration in effluent (mg/L) | Average ammonia nitrogen concentration in effluent (mg/L) | Average total Nitrogen removal rate |
|-----------------------------------|----------------------------------------------------------|-----------------------------------------------------|----------------------------------------------------------|-----------------------------------|
| 0.05                              | 11.25                                                    | 1.60                                                | 0.60                                                     | 86.5%                             |
| 0.06                              | 10.40                                                    | 1.40                                                | 0.73                                                     | 87.4%                             |
| 0.08                              | 9.18                                                     | 1.68                                                | 0.80                                                     | 88.4%                             |
| 0.1                               | 7.64                                                     | 3.76                                                | 1.12                                                     | 87.4%                             |
| 0.12                              | 8.72                                                     | 1.90                                                | 0.60                                                     | 88.7%                             |
| 0.14                              | 9.67                                                     | 3.31                                                | 0.39                                                     | 86.6%                             |
| 0.16                              | 9.90                                                     | 3.06                                                | 0.30                                                     | 86.7%                             |
| 0.18                              | 9.77                                                     | 2.46                                                | 0.47                                                     | 87.3%                             |
| 0.2                               | 9.73                                                     | 2.23                                                | 0.54                                                     | 87.5%                             |

The liquid phase dissolved oxygen value in different depths of the SNAP reactor has a gradient change, closer to the gas junction interface, the greater the DO value. The experimental process, the online dissolved oxygen probe is always placed at the center of the reactor and 3 cm below the liquid. If you dissolve the position adjustment of the oxygen probe online, you must re-check the feedforward
control system. The inlet ammonia nitrogen load is in the range of 0.05~0.2kgm$^{-3}$d$^{-1}$, and when the effluent ammonia nitrogen, nitrate nitrogen, and nitrous nitrogen concentration reach the standard stably, and the RBF neural network feedforward control system calculates the obtained DO set value, and and the blower frequency under this DO value is shown in Table 3. It can be seen that the influent load is significantly correlated with the DO set value. The larger the load is, the larger the DO value is.

The total nitrogen removal rate of single stage autotrophic nitrogen removal system based on DO precise control is shown in table 4. Under various load conditions, the total nitrogen removal rate of the system is stable at more than 86%, and the system is efficient and stable.

4. Conclusion
A dissolved oxygen intelligent control system based on artificial neural network is constructed, which can realize the efficient construction and operation of a single-stage autotrophic nitrogen removal system. The DO control system is mainly composed of RBF neural network feedforward controller and BP neural network PID closed-loop feedback controller. The feedforward control can quickly determine the frequency output value of the inverter and the DO setting value of the system according to the water inlet situation, and the feedback control can realize the precise adjustment of the DO. Under various load conditions, the total nitrogen removal rate of the single-stage autotrophic nitrogen removal system equipped with Do precision control system is more than 86%, and the system operates efficiently and stably.

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