Research on the general technical specification for biological filter for nitrogen

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Abstract: Biological filter for nitrogen removal is a new technology of wastewater treatment, which combines biological denitrification and physical filtration. In this paper, the operation status of biological filter for nitrogen removal at home and abroad, the necessity of developing the general technical specification of biological filter for nitrogen removal, and the general technical requirements of biological filter for nitrogen removal are described. Through the application of the research results of the general technical specifications of nitrogen removal biofilters, it is expected to promote the operational efficiency of China's nitrogen removal biofilters and achieve significant economic, social and environmental benefits.

1. Current situation of the operation of biological filters for nitrogen removal at home and abroad

At present, total nitrogen (TN) has become an important factor affecting the sustainable development of ecological environment of water. The control of TN from living, industrial and agricultural sources has become a major demand in the future economic development and ecological environment protection. Biological filter for nitrogen removal is a new technology for biological oxidation of wastewater or organic wastewater by aerobic microorganisms. This technology is widely used in the upgrading and treatment of TN in municipal sewage, industrial wastewater (such as printing and dyeing, pharmaceutical, papermaking, petrochemical, food processing and hospital wastewater), agricultural wastewater (such as livestock breeding) and other wastewater. It plays an important role in deep reduction of TN in centralized or decentralized sewage treatment facilities. It is the mainstream technology of efficient and economic removal of TN in the world, and a hot technology consistent with the development direction of energy conservation, consumption reduction and resource recycling.

The development and application of technology of biological filter for nitrogen removal began in the early 20th century in developed countries such as Europe and the United States. It has basically formed series of standardized and brand technology and products by the end of the 1980s. Since the birth of the first biological filter for denitrification in the world in 1969, the process has developed for
nearly 50 years. The main function of biological filter for denitrification is transforming the nitrate nitrogen in wastewater into nitrogen, so as to achieve the purpose of denitrification. With requirements for ammonia nitrogen removal, biological filter for denitrification should be combined with biological filter for denitrification to achieve removal of TN. Relatively speaking, the domestic technology of biological filter for nitrogen removal started late. However, in the past decade, through independent research and development or technology introduction, digestion, absorption and re-innovation, the domestic technology and equipment of biological filter for nitrogen removal has also made significant progress. With the promulgation and implementation of Discharge Standard of Pollutants for Municipal Sewage Treatment Plant (GB18918-2002) and the improvement of national and local requirements for discharge of sewage treatment plant under the new circumstances, the biological filter for nitrogen removal has been rapidly promoted and mainly applied to upgrading, reconstruction and deep treatment of sewage treatment plant for the purpose of removal of TN.

2. Necessity of research on general technical specifications of biological filter for nitrogen removal

The research on general technical specifications of biological filter for nitrogen removal is not only to support the implementation of relevant major environmental protection policies and plans, but also to continuously improve the technical standard system in the existing field of sewage (wastewater) treatment in China, so as to lead the high-quality development of the industry. From the period of the 12th Five Year Plan to the period of the 13th Five Year Plan, the state attached great importance to the sewage (wastewater) treatment work, and issued a series of major environmental protection industry policies, plans and guidance documents related to the sewage (wastewater) treatment. The research on the general technical specifications of biological filter for denitrification will play an important guiding role in improving the efficiency, safety and economy of the operation of biological filter for denitrification; promote the steady development of the wastewater denitrification industry in China; improve the overall level of control of TN, wastewater recycling, and system energy saving and consumption reduction in water environment treatment; and support the implementation of relevant national water pollution prevention and control policies and plans.

On the other hand, although the domestic technology of biological filter for nitrogen removal has achieved some good application results in upgrading and treatment or deep reduction of TN in municipal sewage, industrial wastewater and agricultural wastewater, there is still a big gap in the technology, capacity and process level of the existing systems of biological filter for nitrogen removal in the market. Unified and advanced standards are urgently required to promote the establishment of a good market order, and lay a good foundation for systematical and scientific management of all kinds of sewage denitrification projects and even water environment treatment projects by competent departments of different industries. In terms of the development of technical standards, the current industry and group standards of biological filter for denitrification in China mainly include: HJ 2014-2012 Technical Specifications for Sewage Treatment Engineering Using the Biological Filter Method, T/CAQI 24-2016 Biological Enhanced Sewage and Wastewater Treatment: Technical Specifications for Engineering of Downflow Deep Bed Filter System for Denitrification, CECS 265-2009 Technical Specifications for Engineering of Biological Filter for Aeration, CECS 451-2016 Code for Design of Upflow Filter, etc. Among them, HJ 2014-2012 Technical Specifications for Sewage Treatment Engineering Using the Biological Filter Method specifies the technical requirements for process design, main process equipments, detection and control, construction acceptance, operation and maintenance and other aspects of sewage (wastewater) treatment engineering with biological filter process dominated by aerobic process. The standard is applicable to treatment engineering of municipal sewage treated with the biological filter method and industrial wastewater similar to municipal sewage, and can be used as the technical basis for environmental impact assessment, design, construction, environmental protection acceptance and operation management after completion. However, it is not applicable to the anaerobic biological filter treatment process of sewage (wastewater). The implementation of the above technical standard has promoted the
development of technology of biological filter for nitrogen removal to a certain extent, but it is still unable to effectively solve the problems of vicious competition in the market and difficult implementation of supervision and management. Therefore, it is urgent to establish unified general technical specifications of biological filter for nitrogen removal, in order to promote the standardized development of technology, improve the market competitiveness of advanced technology and guarantee the ecological civilization construction of China in the new era and the coordinated development of social economy and environmental protection. The development of the general technical specifications for biological filter for nitrogen removal is also a continuous improvement of the technical standard system in the field of sewage (wastewater) treatment in China.

3. General technical requirements of biological filter for nitrogen removal

3.1. System composition of biological filter for nitrogen removal

The research object of the general technical specifications of biological filter for nitrogen removal is the biological filter system used to remove TN content in sewage (wastewater). The system of biological filter for nitrogen removal is usually composed of biological filter unit, mixing unit (carbon source dosing unit or other electron donor dosing units), backwashing unit, power control unit, etc.

(1) Biological filter unit: It can be divided into biological filter for denitrification (mainly for removal of nitrate nitrogen) and biological filter for nitrification (mainly for removal of ammonia nitrogen) by function. It can be divided into upflow biological filter and downflow biological filter by flow direction. Among them:

——The upflow biological filter for denitrification is generally composed of a water distribution area, a water and gas distribution system, a supporting layer, a filter material layer, a backwashing drainage channel, a water outlet system and an automatic control system;

——The downflow biological filter for denitrification is generally composed of an intake canal, a backwashing drainage channel, a filter material layer, a supporting layer, a water and gas distribution system, a water outlet system and an automatic control system;

——The biological filter for nitrification is generally composed of a water distribution area, a water and gas distribution system, a supporting layer, a process aeration system, a filter material layer, a water outflow system and an automatic control system.

(2) Mixing unit: It includes carbon source dosing unit (heterotrophic denitrification) and electron donor dosing unit (autotrophic denitrification). The carbon source dosing unit includes a carbon source feeding pool and a mixing pool, and the electron donor dosing unit includes an electron donor adding pool and a mixing pool.

(3) Backwashing unit: It includes backwashing water pump, backwashing fan, valve and pipeline, etc. The backwashing water pump should be of energy-saving and efficient series, and there should be no leakage during operation. The backwashing water pump should be equipped with standby unit. The energy efficiency value, noise level requirements and other relevant requirements of backwashing fan should comply with the provisions of GB 19761-2009 Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Fan and JB/T8690-2014 Noise Limit of Fan. The backwashing blower should be equipped with standby unit.

(4) Power control unit: It includes filtering subsystem, backwashing subsystem and carbon source dosing subsystem. The downflow biological filter for nitrogen removal should also include nitrogen removal subsystem. The control unit should be realized by intelligent control mode.

3.2. Process of biological filter for nitrogen removal

Since TN in sewage (wastewater) is mainly represented by nitrate nitrogen and NH₃-N, the technology of biological filter for denitrification involves the transformation of ammonia nitrogen and the removal of nitrate nitrogen. That is, the process includes process of biological filter for denitrification, and the combination process of biological filter for denitrification-biological filter for nitrification or biological filter for nitrification-biological filter for denitrification. The process of biological filter for
nitrogen removal should meet the design requirements for water inflow, complies with the discharge standard, comprehensively consider the characteristics and advantages of each process, and be determined after technical and economic comparison.

1) Process of biological filter for denitrification

The process route of biological filter for denitrification is shown in Fig. 1.

![Fig. 1 Process route of biological filter for denitrification](image)

In Fig. 1, after pretreatment the sewage (wastewater) enters the mixing unit first, and then enters the biological filter for denitrification after adding carbon source/electron donor (if required). The water outflow from the biological filter for denitrification enters the clean water basin. Part of the clean water in the clean water basin is used as the backwashing water, and the remaining clean water is discharged or recycled up to the standard. The biological filter for nitrogen removal is usually backwashed by water washing, air washing or air-water mixed washing on a regular basis to restore its performance. The backwashing water feeding uses water outflow of biological filter for denitrification, and the backwashing water drainage enters the backwashing drain basin, and then enters the pretreatment stage for circulation. If the water inflow carbon source is sufficient \((\text{BOD}_5/\text{TN} > 4)\), the sewage (wastewater) can be denitrified through its own carbon source. If the water inflow carbon source is insufficient, additional carbon source is required.

2) Process of biological filter for denitrification+biological filter for nitrification

Water inflow has a demand for ammonia nitrogen removal, and the carbon source of water inflow is sufficient. The process of biological filter for denitrification+biological filter for nitrification should be used. The process route is shown in Fig. 2.

![Fig. 2 Process route of biological filter for denitrification+biological filter for nitrification](image)

In Fig. 2, after pretreatment the sewage (wastewater) enters the mixing unit first, and then enters the biological filter for denitrification for denitrification and removal of nitrate nitrogen after adding carbon source/electron donor (if required). The water outflow of biological filter for denitrification enters into biological filter for nitrification for further transformation of ammonia nitrogen. The biological filter for nitrification uses aeration fan for aeration, and the nitrification liquid flows back to biological filter for denitrification. The water outflow of biological filter for nitrification enters the clean water basin. Part of the clean water in the clean water basin is used as the backwashing water,
and the remaining clean water is discharged or recycled up to the standard. The biological filter for denitrification and biological filter for nitrification are usually backwashed by water washing, air washing or air-water mixed washing on a regular basis to restore its performance. The backwashing water feeding uses water outflow of biological filter for nitrification, and the backwashing water drainage enters the backwashing drain basin, and then enters the pretreatment stage for circulation.

(3) **Process of biological filter for nitrification+biological filter for denitrification**

Water inflow has a demand for ammonia nitrogen removal. When the carbon source of water inflow is insufficient, the process of biological filter for nitrification+biological filter for denitrification should be used. The process route is shown in Fig. 3.

![Fig. 3 Process route of biological filter for nitrification+biological filter for denitrification](image)

In Fig. 3, after pretreatment the sewage (wastewater) enters the biological filter for nitrification first for transformation of ammonia nitrogen. Water outflow of the biological filter for nitrification enters the mixing unit, and enters the biological filter for denitrification for denitrification and removal of nitrate nitrogen after adding carbon source/electron donor (if required). The water outflow of biological filter for denitrification enters the clean water basin. Part of the clean water in the clean water basin is used as the backwashing water, and the remaining clean water is discharged or recycled up to the standard. The biological filter for nitrification and biological filter for denitrification are usually backwashed by water washing, air washing or gas-water mixed washing on a regular basis to restore its performance. The backwashing water comes from water outflow of biological filter for denitrification, and the backwashing water drainage enters the backwashing drain basin, and then enters the pretreatment stage for circulation.

3.3. **Technical requirements of biological filter for nitrogen removal**

3.3.1. **General requirements.** The general layout of biological filter for nitrogen removal should be selected according to topography, meteorology, geological conditions, operation, environmental safety and other factors, and should conform to the relevant provisions of GB 50014-2006 Code for Design of Outdoor Water Drainage. The form and direction of water inflow of biological filter for nitrogen removal should be designed and selected according to different water inflow quality and treatment requirements. The inhibition rate of luminescent bacteria in the water outflow of biological filter for nitrogen removal should be equal to or less than 30%. For the three levels of water outflow (TN≤15 mg/L, TN≤10 mg/L and TN≤5 mg/L), the corresponding TN volumetric loading rate, hydraulic retention time and filtration rate parameters are given in the general technical specifications of biological filter for nitrogen removal, as well as the specific design parameters under the three processes, such as filter material selection, carbon source dosing and determination of backwash parameters.

3.3.2. **Water inflow requirements.** The total solid content (SS) of the sewage entering the biological filter should be equal to or less than 60 mg/L. If the limit value is exceeded, the pollutants such as various large particle solids and grease fiber should be intercepted and blocked for pretreatment; the
treatment object of the biological filter for nitrogen removal should be biochemical sewage, so the ratio of five-day biochemical oxygen demand to chemical oxygen demand (BOD5/COD) should be greater than 0.3; and the pH value of water inflow of biological filter for nitrogen removal should be 6.5 ~ 9.5, and the water temperature should be 15 ℃ ~ 30 ℃. The dissolved oxygen content in the water inflow of biological filter for denitrification should be equal to or less than 2mg/L. TN of single-stage biological filter for denitrification should be equal to or less than 50 mg/L. In addition, there should be no substance that can inhibit and poison microorganisms in the sewage entering the biological filter for nitrogen removal. These substances should be strictly controlled when the biological treatment process is adopted.

3.3.3. Technical parameter requirements of each unit of the system.

a) Biological filter unit
   ——For upflow biological filter for denitrification, its hydraulic retention time should be 15 min ~ 20 min, average filtration rate should be 10 m/h ~ 15 m/h, and peak filtration rate and compulsory filtration rate should be 15 m/h ~ 18 m/h. In addition, the apparent density of the filter material should be equal to or greater than 1.4g/cm³, and the filling height of the filter material should be equal to or greater than 2.5m. The thickness of each layer of filter material supporting layer should be 100 mm ~ 150 mm, and the total thickness should be equal to or less than 300 mm.
   ——For downflow biological filter for denitrification, its hydraulic retention time should be 15 min ~ 30 min, average filtration rate should be 5 m/h ~ 8.5 m/h, and peak filtration rate and compulsory filtration rate should be 6 m/h ~ 12 m/h. In addition, the density of filter material should be equal to or greater than 2.5g/cm³. The filling height of filter material should be determined in combination with factors such as floor area, treatment load, fan selection and resistance of filter material layer. It should be equal to or greater than 1.8m. The supporting layer of filter material should adopt gravels with various grades, the density of gravels should be equal to or greater than 2.5g/cm³ (specific gravity), the impurity content of various non-gravels should be equal to or less than 1%, the solubility of hydrochloric acid should be equal to or less than 3%, the thickness of each layer should be 70 mm ~ 100 mm, and the total thickness should be 300 mm ~ 500 mm. Time control is used for nitrogen removal of the downflow biological filter for nitrogen removal, and the cycle of nitrogen removal should be 2 h ~ 8 h.
   ——For biological filter for nitrification, the filling height of its filter material should be 3.0 m ~ 4.0 m. The thickness of each layer of filter material supporting layer should be 100 mm ~ 150 mm, and the total thickness should be equal to or less than 300 mm. In addition, the aeration and backwash fan and pipes of the biological filter for nitrification should be set separately and distinguished according to provisions of the corresponding standards.

b) Mixing unit
   ——Carbon source dosing unit: When heterotrophic denitrification is carried out in biological filter for nitrogen removal and the carbon source of water inflow is insufficient (BOD5/TN≤4), carbon source should be added. The carbon source can be methanol, acetic acid, sodium acetate, etc. The adding amount of carbon source should be calculated according to the amount of nitrogen to be removed by the filter.
   ——Electron donor dosing unit: The biological filter for nitrogen removal should be equipped with an additional electron donor for autotrophic denitrification or combined heterotrophic and autotrophic denitrification. The electron donor of autotrophic denitrification or combined heterotrophic and autotrophic denitrification can be iron powder, elemental sulfur, sodium sulfide, sodium thiosulfate, etc. The adding amount should be calculated according to the amount of nitrogen to be removed by the filter.

c) Backwashing unit
   Air washing, water washing or gas-water combined backwashing should be adopted for the backwashing of biological filter for nitrogen removal. The backwashing should be carried out in order
of air washing, air-water combined washing and water washing. The water source for backwashing is the water outflow of biological filter for nitrogen removal, and the backwashing pool should meet the water demand of a single filter for one backwashing cycle. In order to ensure the backwashing effect, the air washing time of biological filter for nitrogen removal should be 2 min ~ 5 min; the air-water combined washing time should be 5 min ~ 8 min; and the water washing time should be 5 min ~ 15 min. The air washing intensity should be 14 L/(m²·s) ~ 30 L/(m²·s); and the water washing intensity should be 4 L/(m²·s) ~ 6 L/(m²·s). The backwashing effect of biological filter for nitrogen removal should be determined according to the factors such as water quality of water outflow and resistance of filter bed. The backwashing wastewater enters the pretreatment stage for treatment.

d) Power control unit (instrument unit)

In order to ensure the normal operation of the power control unit, the water inflow system of the biological filter for denitrification should be provided with a flowmeter, and a single filter should be provided with a level gauge or a differential pressure transmitter and the high and low limit alarm. The backwashing wastewater pool should be equipped with a level gauge. The backwashing water pipe and gas pipe should be equipped with a pressure monitoring device. Mechanical and electrical equipments involved in control and management should be equipped with detection devices for working and failure status.

3.3.4. **Automatic control and safety requirements.** The system of biological filter for nitrogen removal should be equipped with a complete automatic control and detection system, and its design should comply with the relevant provisions of GB/T 3797-2016 Electrical Control Equipments. The biological filter for nitrogen removal should adopt an automatic control (PLC) system with centralized monitoring management and decentralized control. The control system of biological filter for nitrogen removal should be equipped with alarm and operation monitoring devices, including the operation status and failure signal of backwashing water pump, blower and air compressor; the switch status and failure signal of operation control valve; and the frequency of frequency converter provided for backwashing water pump and blower. In addition, the air storage tank of air compressor should be equipped with a pressure monitoring device and high and low limit alarm; the control system of biological filter for nitrogen removal should have the safety control function under the emergency state of mechanical and electrical equipments, the control box on site should have an emergency stop button; and the electrical control should be equipped with a reliable grounding device and have obvious signs.

4. **Conclusion**

- Biological filter for denitrification is a treatment unit integrating biological treatment and filtration functions. It has multiple functions such as nitrogen removal, phosphorus removal and suspended solid removal. The combined process integrates biological oxidation, nitrogen removal and suspended solid retention, and eliminates the subsequent sedimentation tank. It is characterized by high volumetric loading rate, short hydraulic retention time, less infrastructure investment, good water outflow quality, low operation energy consumption, etc.

- Based on a large number of engineering application information, the general technical specifications of biological filter for nitrogen removal comprehensively study the composition, technological process and requirements of system of biological filter for nitrogen removal. The specifications are applicable to the biological filter system mainly aiming at removal of TN in the treatment of domestic sewage, industrial wastewater, surface water and underground water. It can provide a standardized technical basis for the design, application and technical evaluation of biological filter for nitrogen removal. The specifications are advanced, universal and operable. They play a guiding role in improvement of the overall level of TN control in wastewater in China and promotion of specialization, marketization and standardization of the technology of nitrogen removal of biological filter.
The research team of general technical specifications of biological filter for nitrogen removal has accumulated a lot of experience in research and development, design and application of process of biological filter for nitrogen removal; and has a number of patents and research and development achievements of biological filter. It has been successfully applied in the upgrading and reconstruction projects with quasi Class III and quasi Class IV discharge standard in micro-polluted source water pretreatment and sewage treatment plants for many times. It greatly improves the removal efficiency of removal of TN, and plays a key role in the up-to-standard discharge of sewage (wastewater).

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