Frontiers in Environmental Research
ISSN: 2960-026X
DOI: https://doi.org/10.61784/fer3017

NEW DEVELOPMENT OF BIOLOGICAL NITROGEN AND PHOSPHORUS REMOVAL PROCESSES FOR MUNICIPAL WASTEWATER

ZouTing Sun
Bohai college, Agricultural University Of Hebei, Cangzhou 061000, Heibei, China.
Corresponding Email: sunzouting@126.com

Abstracts: In recent years, with the acceleration of urbanization,surface water eutrophication caused by excessive nitrogen and phosphorus content in sewage has become increasingly serious,and highly efficient nitrogen and phosphorus removal technology has become a key demand for urban wastewater treatment. In this paper, we systematically sorted out the traditional and emerging technologies of biological nitrogen and phosphorus removal, and compared and analyzed their advantages and disadvantages. Firstly, the basic principles of biological nitrogen removal and phosphorus removal are introduced respectively, and the A_2/O process with nitrification-denitrification as the core is elaborated in detail. Secondly, for the emerging technologies, low energy consumption processes such as BCFs, SHARON-ANAMMOX combined process and Dephanox process were introduced. Finally, the advantages and disadvantages of traditional and novel processes are compared by observing the activity of microflora and other indicators. The results show that the traditional technology is mature and stable but less economical, while the new technology has significant potential for energy saving and consumption reduction, but needs to further solve the stability problem of engineering application. The multi-dimensional comparison framework and process optimization path proposed in this paper can provide theoretical references for the technological upgrading and process selection of urban wastewater treatment plants, and has positive significance in promoting the technological innovation and sustainable development of water environment treatment.
Keywords: Municipal wastewater; Biological nitrogen and phosphorus removal; New technology; New process

1 INTRODUCTION

With the acceleration of global urbanization, the discharge of urban wastewater has increased dramatically, in which the excess of nutrient salts such as nitrogen and phosphorus has become the main cause of eutrophication of surface water[1]. According to the statistics of the United Nations Environment Program (UNEP), about 40% of lakes and rivers around the world have been degraded due to eutrophication over the past decade, and the nitrogen and phosphorus loads in the tail water of municipal wastewater treatment plants have contributed as much as 30%-50%. Traditional biological nitrogen and phosphorus removal technologies (e.g. A_2/O process) achieve nitrogen and phosphorus removal through nitrification-denitrification and metabolism of phosphorus-aggregating bacteria,but their high carbon consumption, operational energy consumption, and process stability problems make it difficult to meet the demand for sustainable development under the “dual-carbon”goal[2]. In this context, it is urgent to develop new biological nitrogen and phosphorus removal technologies with high efficiency and low consumption.

In recent years, various improvement strategies have been proposed by the academic community to address the limitations of traditional technologies. For example, van Loosdrecht's team alleviated the sludge age contradiction between nitrifying bacteria and phosphorus aggregating bacteria by optimizing the sludge reflux ratio of the A_2/O process. Meanwhile, new autotrophic denitrification technologies represented by anaerobic ammonia oxidation(ANAMMOX)and short-range nitrification denitrification (SHARON) have attracted much attention due to the characteristics of no organic carbon source and low energy consumption[3]. Denitrification phosphorus removal technology achieves synchronous nitrogen and phosphorus removal through a"one carbon dual-use"mechanism, which has been proven to reduce carbon source demand by more than 30%.

This article systematically reviews and compares the advantages and bottlenecks of traditional and new technologies, aiming to provide theoretical support for the upgrading of urban sewage treatment plant processes, promote the transformation of biological nitrogen and phosphorus removal technology towards high efficiency and low-carbon direction, and assist in the sustainable development of water environment governance.

2 TRADITIONAL BIOLOGICAL DENITRIFICATION TECHNIQUES

2.1 Principles of Traditional Biological Nitrogen Removal

2.1.1 The principle of nitrogen removal

The biological denitrification process can be divided into three steps.

The first step is ammonification, which refers to the process of converting organic nitrogen compounds in water into ammonia nitrogen under the action of ammonifying bacteria. The process of ammonification is very fast, and no special measures need to be taken.

The second step is nitrification, which refers to the process under aerobic conditions where ammonia in water is first oxidized to nitrite by nitrite bacteria, and then further oxidized to nitrate by nitrate bacteria. During the reaction process, a long sludge age is required to ensure the activity and presence of nitrite and nitrate bacteria.

The third step is denitrification, which refers to the process in which denitrifying bacteria reduce nitrite and nitrate to nitrogen under anaerobic conditions, and add a carbon source to the reaction system to provide energy, causing nitrogen to be released from the water. Denitrifying bacteria are facultative anaerobic bacteria that can only undergo denitrification under anaerobic or anaerobic conditions, so it is necessary to create an anaerobic or anaerobic environment for them[4]. The reaction equation is as follows:

(1) Ammonification reaction

$$\mathrm{RCHNH_2COOH + O_2 \rightarrow NH_3 + CO_2 \uparrow + RCOOH} \quad (1)$$

(2) Nitrification reaction

$$\mathrm{NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+} \quad (2)$$

$$\mathrm{NO_2^- + 0.5O_2 \rightarrow NO_3^-} \quad (3)$$

The overall reaction equation for nitrification is

$$\mathrm{NH_4^- + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+} \quad (4)$$

(3) Denitrificatin

$$\mathrm{NO_3^- + 2H(Electron\ donor\text{-}organic\ matter) \rightarrow NO_2^- + H_2O} \quad (5)$$

$$\mathrm{NO_2^- + 5H(Electron\ donor\text{-}organic\ matter) \rightarrow 0.5\,N_2 \uparrow + 2H_2O + OH^-} \quad (6)$$

2.1.2 The principle of phosphorus removal

It refers to the process of releasing phosphorus using polyphosphate accumulating bacteria under anaerobic conditions; Under aerobic conditions, a large amount of phosphorus is absorbed from the external environment until there is an excess of phosphorus in the reaction system. The quantity is too large to meet the physiological needs of polyphosphate accumulating bacteria for reaction,so phosphorus can only be stored in the form of aggregates within the bacterial body. At the same time,it acts to form sludge with high phosphorus content and discharges it out of the system. At this point, the phosphorus content in the sewage is greatly reduced, achieving the expected results of phosphorus removal from the sewage. The process of biological phosphorus removal can be divided into the following three steps:

（1）Phosphorus uptake by phosphorus-colonizing bacteria

In a certain space and under sufficient oxygen conditions, the phosphorus removal bacteria oxidize and decompose the BOD or accumulated acids in the water, releasing energy that is mostly used to ingest phosphorus from the wastewater.

（2）Phosphorus Release by Polyphosphorus Bacteria

In a certain space and under anaerobic conditions, the phosphate removing bacteria break down large quantities of polyphosphates in the body by oxidation, accompanied by the production of large quantities of ATP. It consumes ATP, takes in organic matter from external sewage, and stores it inside the cell-in the form of poly-B-hydroxybutyric acid, for example. At the same time the phosphoric acid produced is excreted from the body, reducing cell damage.

（3）Release of phosphorus-rich sludge

In a given space and under aerobic conditions, more phosphorus is taken in and stored than is released under otherwise identical conditions but with insufficient oxygen. The wastewater biological phosphorus removal process, in order to achieve the goal of efficient phosphorus removal, needs to utilize this characteristic of the phosphorus removing bacteria to discharge the excess remaining sludge out of the system.

The reaction equations involved in the process are as follows.

(1) Phosphorus uptake by Polyphosphorus bacteria

$$\begin{aligned}&\mathrm{C_2H_4O_2 + 0.16NH_4^+ + 1.2O_2 + 0.2PO_3^{4-}}\\&\mathrm{\rightarrow 0.16C_5H_7NO_2 + 0.2\left(HPO_3\right) + 0.44OH^- + 1.44H_2O}\end{aligned} \quad (7)$$

(2) Phosphorus release from polyphosphorus bacteria

$$\mathrm{C_2H_4O_2 + \left(HPO_3\right) + H_2O \rightarrow \left(C_2H_4O_2\right)_2 + PO_3^{4-} + 3H^+} \quad (8)$$

2.2 Traditional Biological Nitrogen and Phosphorus Removal Process

Traditional biological denitrification and phosphorus removal process, based on the principle of microbial denitrification and phosphorus removal, to achieve the requirements of the environmental conditions for the growth of microorganisms can be denitrified, phosphorus removal-environmental conditions for aerobic, anaerobic and anoxic sewage treatment. Adjustment and combination of processes applicable to different situations (different sludge contents, different amounts and methods of reflux of mixed liquids, different forms of wastewater intake)to form a variety of different biological denitrification and removal of phosphorus process combinations applicable to the actual

situation[5].
A_2/O process is based on theA/O process, anaerobic structures are added before the process. The formation of an anaerobic tank-anoxic tank-aerobic tank structure combination form, is by far the simplest and most realize the synchronization of nitrogen and phosphorus removal process.A_2/O process flow, as shown in Figure 1.
First, the sewage and return sludge are passed into the anaerobic tank. Return sludge carries a small amount of nitrate nitrogen, then part of the nitrogen can first be converted into N_2 by denitrification. At this time, the organic matter in the mixture is initially degraded, while the phosphorus release by the phosphorus bacteria for the subsequent reaction to provide a biochemical reaction ATP. Then, the sewage into the anoxic tank, denitrification bacteria to the nitrate nitrogen salts brought in by the return of the mixture, as well as the organic matter of the influent water to denitrify denitrogenation. Finally, the ammonia and nitrogen in the water in the aerobic pool, nitrification reaction to generate nitrate nitrogen. The phosphorus-concentrating bacteria absorb part of the phosphorus from the water, which is separated in the sedimentation tank and discharged from the system as phosphorus-rich sludge[6].

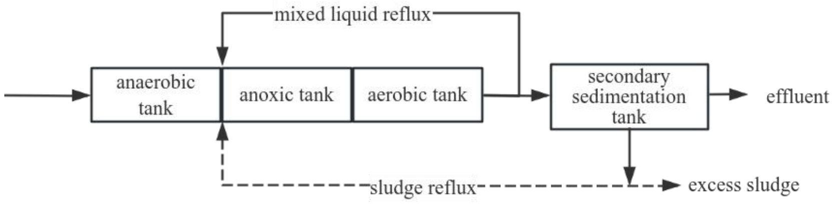

Figure 1 A_2/O Process Flow Chart

3 NEW TECHNOLOGY AND PROCESS OF BIOLOGICAL NITROGEN REMOVAL AND PHOSPHORUS REMOVAL

3.1New Technology for Nitrogen Removal and Phosphorus Removal

3.1.1Redenitrification and phosphorus removal
Comeau et al. discovered a new class of phosphorus-polymerizing bacteria that can remove both nitrogen and phosphorus from wastewater in the presence of insufficient oxygen. It is different from the traditional phosphorus removal process in the polyphosphorus bacteria, which was later named denitrifying polyphosphorus bacteria[7]. Macromolecular organic matter is hydrolyzed and acidified into small molecules of volatile fatty acids(VFA) by acidic anaerobes under anaerobic conditions, and denitrifying polyphosphate-oxidizing bacteria (DPAOs) take up the VFA from the environment into the body in an active transport mode, assimilating them into the endocarbon source storage PHA; while in the anoxic segment, DPAOs can use NO_3- or NO_2-as electron acceptors under anoxic conditions to oxidatively decompose PHA stored in the body during the anaerobic stage to generate energy from PHA stored in the body[8]. Part of this energy is used for the growth and reproduction of its own cells, and the other part is used to overdose on inorganic phosphates from the environment and stored in the body as polyphosphate. At the same time, the NO_3-N or NO_2-N in the system is reduced to N_2, realizing: two uses of one carbon. There are DEPHANOX process, A_2N-SBR process and BCFS process, which have high application value[9].

3.1.2Simultaneous nitrification and denitrification
Simultaneous nitrification denitrification is a new type of nitrification denitrification technology found in the treatment of sewage leaching process. The main application method of this technology is to utilize the same reactor to deal with both nitrification and denitrification processes. Combined with relevant evidence, the theory is feasibleand can reduce carbon demand and sludge production by 30%[10]. Developed to date, simultaneous nitrification denitrification has become a more efficient denitrification technology for wastewater treatment in major cities. There are many examples of successful applications of SND, such as SBR, biological rotor, CAST, oxidation ditch and other processes.

3.1.3Anaerobic ammonia oxidation
It is a biological process in which microorganisms use nitrite as an electron acceptor and biochemical reactions occur under anaerobic conditions to directly convert ammonia nitrogen to nitrogen [11]. This process was discovered by Mulder et al.of Delft Technology, the Netherlands, when treating effluent water. The traditional nitrification-denitrification process requires an external carbon source in order to carry out the reaction properly, while the new technology does not require an external carbon source during the reaction, but also consumes low energy, has less operating costs, and avoids the secondary pollution that may be caused by a variety of chemicals to the water and the environment. Studies have demonstrated that the best overall performance under fully anaerobic conditions is achieved when the temperature reaches about 30℃ and the pH is 8. In addition, Blum et al.showed that the environmental factors affecting anaerobic ammonia oxidizing bacteria (AnAOB) also include dissolved oxygen (DO), organic matter concentration, and C/N ratio. Therefore, efficient enrichment of AnAOB requires changing the process operating conditions according to the water quality to provide optimal growth conditions[12].

3.1.4Short-range nitration and denitrification
Partial-denitrification(PD) can ensure a stable supply of Anammox electron acceptors by controlling the end product in

conventional denitrification to NO_2-N and inhibiting its further reduction[13]. The main consideration of the short-range denitrification process is to achieve a stable conversion of nitrate to nitrite for sustained nitrite accumulation. It nitrifies the ammonia and nitrogen in the effluent through the action of microorganisms first to nitrate, and then denitrifies the nitrate to nitrogen emission. Compared with the traditional nitrification-denitrification process, the short-range nitrification-denitrification technology has a higher nitrogen treatment efficiency and can complete the nitrogen conversion in a smaller reactor, which saves the footprint of the treatment facility, improves the nitrogen removal efficiency, and better meets the requirements of nitrogen emission indexes[14]. Currently, based on the basic principle of short-range nitrification denitrification for nitrogen removal, there are Sharon-Anammox combined process and Sharon process, etc.

3.2New process of Nitrogen Removal and Phosphorus Removal

3.2.1Dephanox technology

Dephanox process, which is the basis of denitrification denitrification and phosphorus removal process, the theory and application of the process to further resolve the contradiction between nitrogen and phosphorus, the process is shown in Figure 2. In Dephanox process, the sludge rich in DPAOs directly enters the anoxic tank without passing through the aerobic tank, so it does not consume PHA in the aerobic stage, but almost all of it is used as the internal carbon source material to realize the excess phosphorus absorption in the anoxic section; at the same time, the post-aeration section can remove the residual phosphorus and make the PHA in the body of the DPAOs to consume completely, so as to create the conditions for the next anaerobic stage to synthesize and renew the PHA[15]. Dephanox process can maximize the advantages of denitrification to remove phosphorus, while saving carbon source and aeration energy consumption, nitrifying bacteria and DPAOs are in their optimal growth environments, which solves the problem of differences in the age of the bacterial sludge.

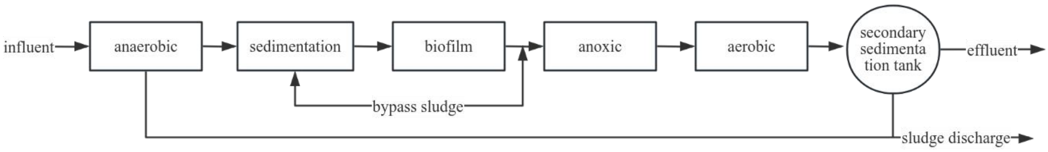

Figure 2 Dephanox Process Flow Chart

3.2.2SHARON-ANAMMOX Joint process

Sharon process is a high nitrogen removal technology formed on the basis of the principle of short-range nitrification denitrification, which has the characteristics of effective, low energy consumption, low reaction time, no need to add foreign carbon and no secondary pollution. The difference between this principle and the traditional denitrification is that Shraon can control the ammonia nitrogen oxidation in the nitrosation stage by controlling certain conditions such as temperature and dissolved oxygen content, and at the same time denitrify it directly.

The Sharon-Anammox combined process is the process of removing ammonia and nitrogen from the effluent after a series of reactions by introducing the effluent from the preliminary formation of the Sharon process directly into the Anammox reactor[16].

3.2.3BCFs

The BCFs process was developed by the Delft University of Technology in the Netherlands based on the principles of Pasveersloot and UCT during relevant experiments. This new process has a wide range of applications and can make full use of the efficient denitrification and phosphorus removal carried out by denitrifying phosphorus removing bacteria under anoxic conditions. In this process, up to 50% of the phosphorus is removed by this feature, and the treatment effect is very high.

The BCFs process consists of 5 reactors(anaerobic, selective, anoxic, anoxic/aerobic, and aerobic), each with a relatively specialized function. The processing flowchart of BCFs is shown in Figure 3 below.The survival environment of bacteria in each reactor can be optimized by controlling the 3 cycles. In this process reaction, the effect of nitrogen and phosphorus removal is improved, and the complete removal of phosphorus and the optimal removal of nitrogen are realized[17]. Since phosphorus bacteria have an affinity for phosphate, phosphorus-rich supernatant can be drawn from the end of the anaerobic tank to recover the phosphorus therein, improving resource utilization and maximizing environmental and economic benefits.

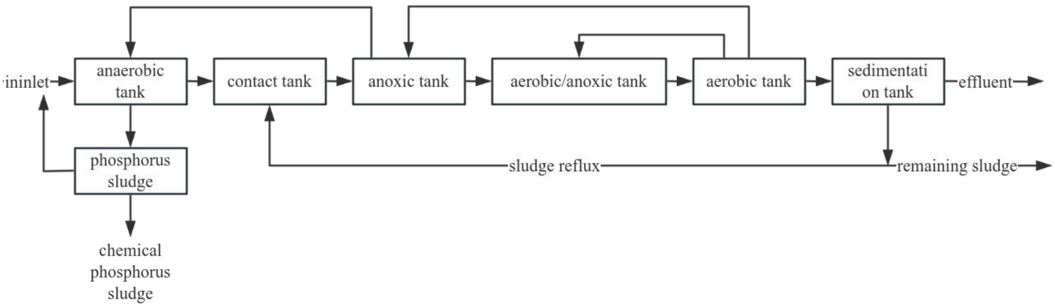

Figure 3 BCFs Process Flow Chart

4 COMPARISON OF NITROGEN REMOVAL AND PHOSPHORUS REMOVAL TECHNOLOGY

At present, the advantages and disadvantages between the new wastewater biological nitrogen and phosphorus removal technology comparison (Table 1 below). As can be seen from the table, on the whole, the different technologies can reduce the carbon source, sludge production, faster reaction rate, and then in the treatment of low C/N sewage process has a certain adaptability, and in all kinds of operating conditions, including pH, temperature, sludge age, aeration, etc., also reflects a strong tolerance, to meet the requirements of stable operation. Several technical advantages proposed in the article can be very good to improve the effect of urban wastewater denitrification and phosphorus removal treatment, although the existing research also has certain limitations, and the actual engineering application conditions are not mature enough, but in the future development of these new technologies are put into use, and many of the problems will be solved naturally. Comprehensive analysis of these new wastewater biological denitrification and removal of phosphorus technology to achieve the principle is not difficult to find, strengthen the control of the advantage of microbial flora has become an important premise to ensure the effectiveness of the process and the basis, but due to the control of the conditions required for more,hindering the new technology to further promote the application of practice.

Table 1 Advantages and Disadvantages of Nitrogen and Phosphorus Removal Technologies

Technical approach	Advantages	Disadvantages
Traditional biological method	Easy to achieve the application, the overall stability is good, the technology is basically mature	The effect did not meet the expectation, the carbon source requirements, can not apply special water quality
Anaerobic ammonia oxidation	Sludge has a small yield, high nitrogen removal efficiency, fast reaction speed, small carbon source demand, and good effect in low C / N sewage	The slow growth rate, the cell yield, the reaction process is easily affected by environmental factors and difficult to control
Synchronous nitrification and denitrification	Integrated nitrogen removal and phosphorus removal can treat low C/N sewage, reduce the demand for carbon source and sludge production	Dissolved oxygen is difficult to control due to different biological reactions within one reactor
Short-range nitration and denitrification	It can save the consumption of oxygen, carbon source and alkalinity, reduce the sludge production; and reduce the faster denitrification rate, and reduce the HRT of the system	High requirements for bacteria, the need for seed enrichment, and has high requirements for oxygen environment
Redenitrification and phosphorus removal	The realization of "one carbon dual use" can save aeration and carbon source, reduce sludge production, and realize the reduction of energy consumption	Bacteria must be enriched to achieve, and subsequent sludge production is small but difficult to treat, increasing additional costs

5 SUMMARIZE

Traditional biological denitrification and phosphorus removal technology has been unable to meet the needs of modern urban sewage purification and environmental characteristics, coupled with the high standard of nitrogen and phosphorus emission requirements put forward by the state,forcing major cities in the sewage treatment process must improve the level of technology to ensure the sustainable development of sewage treatment.Through the article on the sewage treatment process of nitrogen, phosphorus removal of new technology research and comparative analysis is not difficult to find that these new wastewater biological denitrification and phosphorus removal technology(synchronous nitrification denitrification, denitrification phosphorus, anaerobic ammonia oxidation, short-range nitrification denitrification) are based on the principle of the traditional biological nitrogen removal and phosphorus removal process on the basis of further research and development of new technologies, in order to improve the economy, high efficiency, low-consumption sustainable development and the formation of new biological denitrification and phosphorus removal technologies. In order to improve the economy, high efficiency, low consumption and sustainable development and the formation of a new biological denitrification and phosphorus removal technology. It can be applied to sewage treatment to further improve the biological denitrification and phosphorus removal process and promote urban construction and development.

The future urban wastewater treatment process for biological nitrogen and phosphorus removal should deeply integrate biotechnological innovation, digital empowerment, and the concept of resource recycling to promote the transformation of sewage treatment into a sustainable development model characterized by "low-carbon efficiency and intelligent collaboration." It is essential to continue focusing on low-consumption processes such as shortcut nitrification, anaerobic ammonium oxidation, and denitrifying phosphorus removal, while combining innovative technologies from various fields to specifically enhance the activity of functional microbial communities. Overcoming issues such as carbon source limitations and sludge production bottlenecks, continuous innovation of new biological nitrogen and phosphorus removal processes should be pursued to achieve deep removal of nitrogen and phosphorus.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] Jordi P, Ferran R, Albert B, et al. Enhancement of biological nutrient removal process with advanced process control tools in full-scale wastewater treatment plant. Water Research, 2021, 200:117212-117212.
[2] Kamonwan K, Heewon J, Rahul K, et al. Bioelectrochemical system for nitrogen removal: Fundamentals, current status, trends, and challenges. Chemosphere, 2023, 339:139776-139776.
[3] Gan R, Zhang K. Enhanced nitrogen and phosphorus removal by iron-manganese mediated autotrophic denitrification in electrochemical system and the underlying mechanisms. Process Safety and Environmental Protection, 2024, 190(PA):545-559.
[4] Jianmin L, Wei Z, Hong L, et al. Achieving deep autotrophic nitrogen removal in aerated biofilter driven by sponge iron: Performance and mechanism. Environmental Research, 2022, 213:113653-113653.
[5] Tanwar P, Nandy T, Khan R, et al. Intermittent cyclic process for enhanced biological nutrient removal treating combined chemical laboratory wastewater. Bioresource Technology, 2006, 98(13):2473-2478.
[6] Wang Y, Tang T, Wu J, et al. Succession of nitrogen and phosphorus removal functions of sludge and biofilm in low-temperature sewage treatment. Journal of Water Process Engineering, 2024, 58:104836.
[7] Peng W, Xingxing Z, Yuguang W, et al. Development of a novel denitrifying phosphorus removal and partial denitrification anammox (DPR + PDA) process for advanced nitrogen and phosphorus removal from domestic and nitrate wastewaters. Bioresource Technology, 2021, 327:124795-124795.
[8] Xiu-Zhen G, De-Shuang Y, Meng-Fei Y, et al. Denitrification and Phosphorus Removal from Low C/N Urban Sewage Based on a Post-Partial Denitrification AOA-SBR Process. Huanjing Kexue, 2019, 40(1):360-368.
[9] Ronghua X, Fuqiang F, Qining L, et al. Overlooked Ecological Roles of Influent Wastewater Microflora in Improving Biological Phosphorus Removal in an Anoxic/Aerobic MBR Process. Environmental Science & Technology, 2021, 55(9).
[10] Drawbridge M, Huo Y, Fanning E, et al. Growth, productivity and nutrient removal rates of sea lettuce (Ulva lactuca) in a land-based IMTA system with white seabass (Atractoscion nobilis) in Southern California. Aquaculture, 2024, 587:740836.
[11] Wei Q, Lv D, Huang H M, et al. Research on Treatment of Domestic Sewage with Aerobic Denitrifying Bacteria Immobilized by Carbon Fiber. Applied Mechanics and Materials, 2014, 3547(675-677):627-632.
[12] Weiqing J, Yunguang M, Zebing N, et al. Improving nitrogen and phosphorus removal and sludge reduction in new integrated sewage treatment facility by adjusting biomass concentration. Journal of Water Process Engineering, 2022, 50.
[13] Chuansheng Y, Yongzhen P, Jiantao J, et al. Advanced nitrogen and phosphorus removal from municipal wastewater via simultaneous enhanced biological phosphorus removal and semi-nitritation (EBPR-SN) combined with anammox. Bioprocess and Biosystems Engineering, 2020, 43(11):1-14.
[14] Du S, Yu D, Zhao J, et al. Achieving deep-level nutrient removal via combined denitrifying phosphorus removal and simultaneous partial nitrification-endogenous denitrification process in a single-sludge sequencing batch reactor. Bioresource Technology, 2019, 289:121690.
[15] Peng C, Junkang W, Xiwu L, et al. Denitrifying phosphorus removal and microbial community characteristics of two-sludge DEPHANOX system: Effects of COD/TP ratio. Biochemical Engineering Journal, 2021:108059.
[16] Zhuwu J, Zhongjian Z, Mengfan W, et al. Full-scale operation of an integrated aerated biofilter–denitrification shallow biofilter system for simultaneous nitrogen and phosphorus removal from low-carbon domestic sewage: Influencing parameters, microbial community and mechanism. Chemical Engineering Journal, 2023, 471.
[17] Xiao H, Kai Y, Jianghua Y, et al. Nitrogen removal performance and microbial characteristics during simultaneous chemical phosphorus removal process using Fe3. Bioresource Technology, 2022, 363:127972-127972.